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Cinnamon as a Potential Feed Additive: Beneficial Effects on Poultry Health and Production Performances – An Update

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ABSTRACT

According to the Food and Agricultural Organization, global poultry output increased from approximately 115 million tons in 2016 to around 136 million tons in 2023. Poultry production has increased significantly with the dramatic uptick in meat and egg demand. Feed accounts for between 65 and 70 percent of total production costs, making it the largest chicken industry expense. This is why it's important to maximize the transformation of poultry feed into feed with a high biological value while taking as many steps as possible to protect feed quality and reduce feed costs. The use of feed additives in poultry feed has recently gained popularity and has been essential to increase feed efficiency and growth rate, which typically leads to reduced costs. The meat's texture, consistency, and nutritional content are all improved, and its shelf life is lengthened as a bonus. Feed additives are a fantastic tool for boosting a

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Gut microbiota

poultry farm's bottom line. For example, cinnamon (*Cinnamomum verum*) is often used as a traditional feed supplement. Rather than antibiotics, the poultry industry could benefit from using cinnamon as a natural antibiotic replacement, which would benefit animal welfare, consumer health, and the bottom line. The performance index, feed intake, FCE performance, and weight growth of poultry can all be improved by including cinnamon in the feed at varied concentrations. The digestive health and intestinal microbial population of hens are enhanced by a diet containing bioactive components of cinnamon. Cinnamon essential oils' popularity stems from their many valuable features, such as their ability to increase gastric enzyme synthesis and other biofunctional benefits. This review focuses on the possible advantages of cinnamon as a natural feed supplement for chickens, particularly about their intestinal microbiota, blood chemistry, nutrient absorption, gene expression, and immunology.

1 Introduction

Improvements in chicken farming have come a long way in recent decades. The Food and Agriculture Organization reported that the global poultry output increased from 115 million tons to around 136 million tons in 2022. This trend is being driven in high-income nations by the increasing popularity of white meats as a healthier and more convenient alternative to red meat (Buttar et al. 2022; Mitra et al. 2022). Lower pricing for poultry meat relative to other meats contributes to the increased trend in low and middle-income countries. For instance, the average annual rate of increase in India's poultry meat consumption (in 1000 metric tons) from 2013 to 2022 is depicted in Figure 1. Chicken will be the most common source of protein among meats, accounting for 47% of total consumption. The Economic Survey 2021-22 reported that India's domestic egg production increased from 91 eggs per year per capita in 2020 to 122.11 billion eggs in 2022, making India the third-largest producer of eggs and the eighth-largest producer of meat globally. The feed cost is the primary barrier to the profitable production of broilers (Hashemi et al. 2010). In India, 58% of the feed market is devoted to poultry. The current demand for chicken feed in India is around 22 million tons (Habib et al. 2021; Chandran et al. 2022). Maintaining feed quality while cutting feed costs to achieve optimal conversion of animal feed into feed of high biological value is a top priority (Thirumalaisamy et al. 2008; Chandran 2021; Rajan et al. 2023).

Feed efficiency and growth rate can be improved, and therefore savings on feed can be expected when nutritional supplements are incorporated into chicken feed (Abd El-Hack and Alagawany

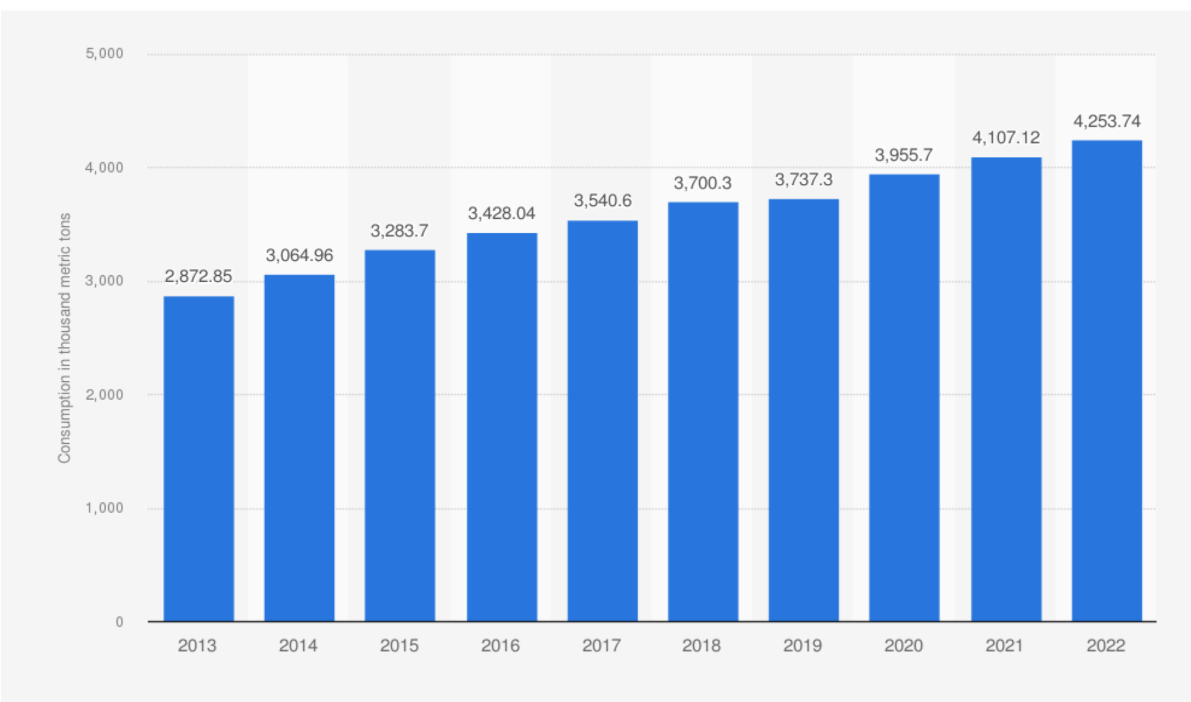

Figure 1 Average annual rate of increase in India's poultry meat consumption (in 1000 metric tons) from 2013 to 2022 (adopted, modified and updated from: Statista Research Department)

2022). Moreover, it enhances the meat's flavour, tenderness, shelf life, and nutritional value. Profit margins for the chicken industry have been greatly helped by the widespread availability of nutritional supplements (Rajan et al. 2022; Rajan et al. 2023). Research on the efficacy of traditional and potential herbal remedies in maximizing livestock and poultry production is being conducted in many countries. Phytochemicals and bioactive ingredients in plants and medicinal herbs have revealed multiple beneficial applications in promoting animal and poultry health and enhancing production performances, as well as found promising for safeguarding human health (Dhama et al. 2015a; Abdelli et al., 2021; Hartady et al. 2021; Seidavi et al. 2022; El-Sabrout et al. 2023; Zebeaman et al. 2023). These provide vital nutrients, act as potent immunomodulatory regimens, and possess antioxidants, antimicrobial and other activities, also suggested as alternatives to antibiotics and play supportive / ādjunctive roles in the current scenario of emerging antimicrobial and drug resistance (Dhama et al. 2014; Dhama et al. 2015b; Yadav et al. 2016; Dhama et al. 2018; Tiwari et al. 2018; Kuralkar and Kuralkar 2021; Uddin et al. 2021; Parham et al. 2020).

Antibiotics are commonly used to speed up the growth of chickens and other fowl (Ali et al. 2021; Habiba et al. 2021). However, antibiotic use is not generally promoted because of the detrimental implications of these residues in products; thus, the creation of a reliable and efficient antibiotic alternative is necessary, as reported by Hashemi et al. (2010) and Farag et al. (2021). Thus, natural ingredients have been investigated as potential replacements for synthetic substances in producing safe and healthy human meals. Spices and other herbs have been used to incorporate alternative medicines into animal feed (Habiba et al. 2021). Traditional fish meals, bone meals, and other plant-derived items like peanut or soybean meal, used in poultry diets, have become prohibitively expensive in developing countries. Rising raw material costs and increased human competition mean that even though these food ingredients are readily available, they are not nearly enough. Finding alternative feed sources to reduce feed prices has become critical (Swain et al. 2014; Prakash et al. 2022; Rajan et al. 2022).

Antibiotic growth promoters (AGPs) are used as a common practice for treating gut infections and mitigating the negative effects of stress on chicken digestion. However, as public awareness grows about antibiotics' negative impact on human health, as does the prevalence of bacterial resistance, and as concerns grow about food safety, measures have been taken to limit antibiotic incorporation in poultry production (Alagawany et al. 2020; Abd El-Hack and Alagawany 2022). To combat this problem, scientists and businesses are looking at feasible

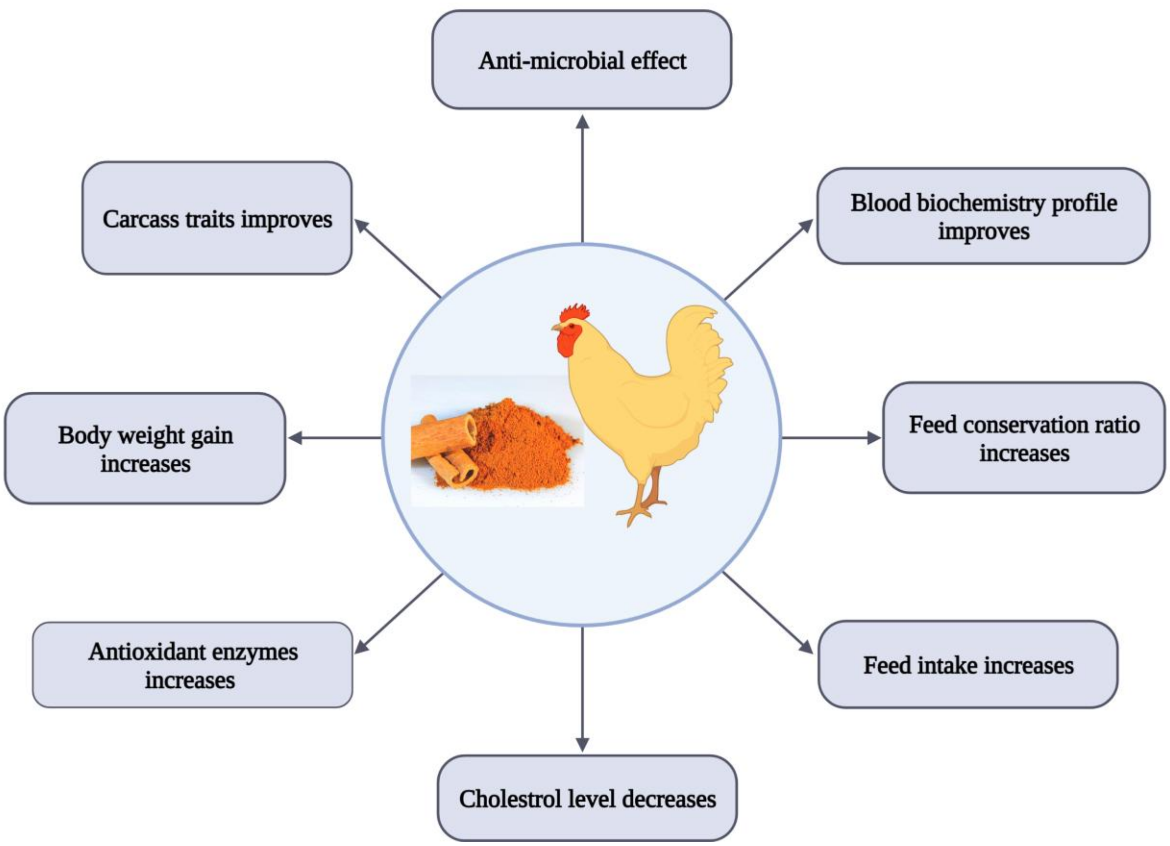

Figure 2 Positive health and nutrition impact of cinnamon as a feed additive in poultry

alternatives to AGPs, such as dietary therapies that boost the microbiome and general health of chickens without resorting to antibiotics. Potentially replacing AGPs, phytogenic feed additives (PFAs) have entered the market and show significant promise in the poultry sector. The immune system, health performance, and stress response are all boosted in chickens exposed to heat stress, for instance (Ali et al. 2021; Prakash et al. 2022; Rajan et al. 2022; Rajan et al. 2023).

Additionally, there has been a rise in the demand for leaner poultry, which has prompted scientists to focus on developing safe growth promotions and carcass modifiers. To that end, PFAs have been investigated as potential replacements for AGPs and growth modifiers in producing healthy and safe food. Several PFAs contain natural antioxidants that increase poultry products' longevity, quality, and marketability. With their therapeutic characteristics, phytochemicals found in herbs and spices have gained attention as potential replacements for AGPs. The poultry industry was pleased with their availability, natural safety, and lack of chemical residue. Natural plant compounds have been shown to have therapeutic benefits in animals, including an aperitif, an increase in digestive enzyme secretion, immunity stimulation, killing bacteria and viruses, and acting as an antioxidant. Potentially beneficial to poultry, cinnamon is one of the most potent PFAs (Prakash et al. 2021a; Prakash et al. 2021b; Kumar et al. 2022; Kumari et al. 2022).

Ceylon cinnamon, or cinnamon (*Cinnamomum verum*), is a spice derived from the bark of a tree in the Lauraceae family (Jakhetia et al. 2010; Arain et al. 2018). It's a staple seasoning in kitchens throughout the globe. In the agricultural sector, cinnamon has the potential to replace antibiotics, boosting health, food security, and the bottom line for commercial chicken operations. Adding cinnamon to broiler feed, even in small amounts, positively affects the birds' growth, supplement consumption, and feed conversion efficiency (FCE) (Chowlu et al. 2019). Therapeutic potential in cinnamon includes its ability to aid digestion and stimulate hunger (Taback et al. 1999), kill bacteria (Chang et al. 2001), neutralize free radicals (Singh et al. 2007), and reduce inflammation and acid reflux (Singh et al. 2007; Jakhetia et al. 2010). The potential benefits of cinnamon's addition to chicken feed in terms of health and nutrition are shown in Figure 2.

This review focuses on the possible advantages of cinnamon as a natural feed supplement for chickens regarding intestinal microbiota, blood chemistry, nutrient absorption, gene expression, and immunology.

2 Chemical composition and bioactive compounds in cinnamon

Many resinous substances, such as cinnamaldehyde, cinnamate, cinnamic acid, and other essential oils, make up cinnamon (Senanayake et al. 1978; Alagawany et al. 2016). The chemical composition of different parts of cinnamon is presented in Table 1; key bioactive compounds responsible for the functional characteristics of cinnamon are shown in Figure 3. Cinnamaldehyde, created by oxygen absorption, gives the food its pungent smell and taste. Cinnamon's colour darkens over time, and the amount of the resinous ingredient likewise rises (Singh et al. 2007). Cinnamon contains a variety of essential oils, including trans-cinnamaldehyde, cinnamyl acetate, eugenol, L-borneol, L-acetate-bornyl, beta-caryophylene, E-nerolidol, alpha-cubebene, alpha-terpineol, caryophyllene oxide, terpinolene, and alpha-thujene, (Tung et al. 2008; Farag et al. 2016). Procyanidins and catechins are present in cinnamon bark (Nonaka et al. 1983). The primary chemical components responsible for the aroma and other biological functions include cinnamaldehyde, trans-cinnamaldehyde (Cin), and eugenol (Chang et al. 2001). According to Marongiu et al. (2007), cinnamic aldehyde from *C. zeylanicum* has anti-tyrosinase activity. According to recent studies, cinnamaldehyde and cinnamon powder, alone or

Table 1 Important bioactive compounds present in different parts of cinnamon

Part of the plant	Bioactive compound	References
Leaves	Cinnamaldehyde: 1.00 to 5.00% Eugenol: 70.00 to 95.00%	Saeed et al. (2010); Abd El-Hack et al. (2020); Ali et al. (2021)
Bark	Cinnamaldehyde: 65.00 to 80.00% Eugenol: 5.00 to 10.00%	Saeed et al. (2010); Abd El-Hack et al. (2020)
Root bark	Camphor: 60.00%	Saeed et al. (2010); Abd El-Hack et al. (2020)
Fruit	*trans*-Cinnamyl acetate: 42.00 to 54.00% and caryophyllene: 9.00 to 14.00%	Saeed et al. (2010); Ali et al. (2021)
Buds	Terpene hydrocarbons: 78.00% *alpha*-Bergamotene: 27.38% *alpha*-Copaene: 23.05% Oxygenated terpenoids: 9.00%	Saeed et al. (2010); Habib et al. 2021; Ali et al. (2021)
Flowers	(E)-Cinnamyl acetate: 41.98% *Trans-alpha*-Bergamotene: 7.97% Caryophyllene oxide: 7.20%	Rao et al. (2014); Abd El-Hack et al. (2020)

Source: Jayaprakasha et al. (2002); Vangalapati et al. (2012); Saeed et al. (2018)

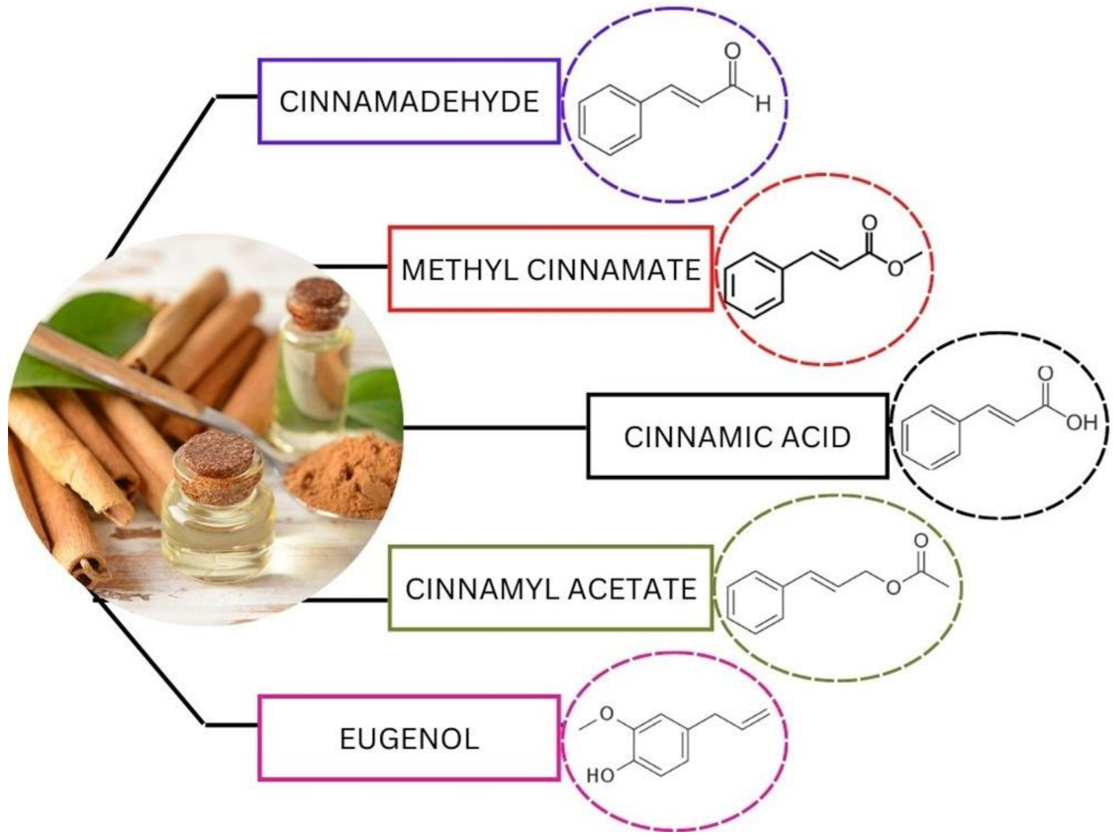

Figure 3 Key bioactive ingredients in cinnamon that contribute to its beneficial effects

in combination with other essential oils, have a variety of advantageous benefits on chickens. Among these results is a rise in feed consumption (Al-Kassie 2009), more excellent growth rates and meat of higher quality (Sang-Oh et al. 2013), increased output and effectiveness of feed (Kamel 2001; Al-Kassie 2009; Isabel and Santos 2009), elevated intestinal and pancreatic lipase activity (Kim et al. 2010), increased production of breast flesh (Isabel and Santos 2009), increased state of health (Kamel 2001; Al-Kassie 2009), protection against *Escherichia coli*, *Enterococcus faecalis*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, epidermal Staphylococcus, Salmonella sp., *Helicobacter pylori* and *Vibrio parahemolyticus* (Taback et al. 1999; Chang et al. 2001; Chang et al. 2008) are reported.

3 Impact of cinnamon on digestion and absorption of nutrients

Cinnamon is now legal to use as a PFA in poultry feed. To improve the health, growth, carcass quality and carcass features of chickens, including bioactive chemicals such as essential oils, cinnamaldehyde, and phenolic compounds in chicken food is necessary (Ali et al. 2021). Studies have shown that the bioactive compounds present in extract of cinnamon are efficient enough to slow the process of digestion in the small intestine to augment the efficiency of utilization of nutrients (Baskara et al. 2021). Cinnamon's bioactive components have potent antimicrobial, antioxidant, anti-inflammatory, and free radical scavenging effects and inhibit NF-κB activity to minimize NO production. Broiler chicken research shows that cinnamon and its essential oils are antimicrobial and antioxidant (Zhu et al. 2020). In addition, cinnamon oil is effective as an anti-inflammatory, anti-fungal, anti-pain, and antioxidant. Concurrently, the bioactive chemicals in cinnamon can inhibit the growth of pathogenic germs in the intestines of chickens while encouraging the expansion of commensal bacteria (Lin et al. 2003).

When fed properly, broiler chickens benefit from a higher feed efficiency (FCR), greater body weight growth (BWG), and better health. Feed utilization can be enhanced, and growth-restricting metabolic and digestive disorders can be mainly avoided by stabilizing the gut microbial environment and stimulating the release of digestive enzymes (Bento et al. 2013). Cinnamon oil may influence intestinal mucosa and pancreas digesting enzyme release, according to chicken research (Bento et al. 2013; Zhu et al. 2020). Furthermore, cinnamon's bioactive components influence lipid metabolism via mediating fatty acid transport in broilers' intestines. Cinnamon oil aids digestion by stimulating the production of digestive enzymes and facilitating nutrient absorption (Garcia et al. 2007).

Additionally, the gut morphology and integrity protection provided by cinnamon oil may increase nutrient absorption. One study found that the cinnamon-fed group absorbed more nutrients than the control group (Devi et al. 2008). Cinnamon oil supplementation in the broiler diet increased duodenal and jejunal villus height (VH), villus surface area, and nutrient absorption and digesting efficiency. In addition, increased mucosal digesting enzyme activity is associated with a higher VH, leading to better nutrient absorption. Cinnamon oil's antioxidant properties are responsible for improving VH (Mehdi et al. 2018; Zhai et al. 2018). Digestion generates reactive oxygen species (ROS), which act on the intestinal mucosa and shorten intestinal villi but are bound by antioxidant enzymes (Windisch et al. 2008). One manner in which cinnamon oil safeguards the intestinal villi from oxidative damage is by elevating the activity of these antioxidant enzymes. The antimicrobial properties of cinnamon oil enhance intestinal morphology (Chowdhury et al. 2018).

Poultry benefit from cinnamaldehyde because it stimulates their digestive function. Cinnamaldehyde helped broiler chickens break down their food more efficiently by stimulating saliva production. This, in turn, stimulated the production of digestive enzymes in the pancreas and intestines. Cinnamon tannins have been found to improve poultry health and nutrition by precipitating proteins in the intestine (Zeng et al. 2015; Kumar et al. 2022). Groups given cinnamaldehyde supplements saw dramatic increases in their nutritional, amino acid, and crude fat digestibility. Cinnamon oil supplementation in broiler diets enhanced protein digestion by stimulating gastric production of hydrochloric acid (HCl) and pepsin (Platel and Srinivasan 2004; Redondo et al. 2014).

On the other hand, broiler chicks fed 200 ppm of an essential oil extract containing oregano, pepper, and cinnamon did not exhibit any changes in nutritional digestibility (Hernandez et al. 2004). Improvements in nutrient absorption and a return to a more normal state of gut ecology have been observed in hens treated with cinnamon oil (Jamroz et al. 2003; Mountzouris et al. 2011), which may be due to the terpenoids in cinnamon. Phytobiotic growth promoters that remained active throughout the digestive tract enhanced nutrient uptake changed intestinal histomorphology, reduced microbial load, and raised host immunity. Since it encourages the production of digestive enzymes and bile acid, it makes food and fat seem easier to break down. It also affects the digestive process by mediating interactions between feed and digestive enzymes (Zhai et al. 2018). The impact of cinnamon on nutrient digestion and absorption is summarized in Figure 4.

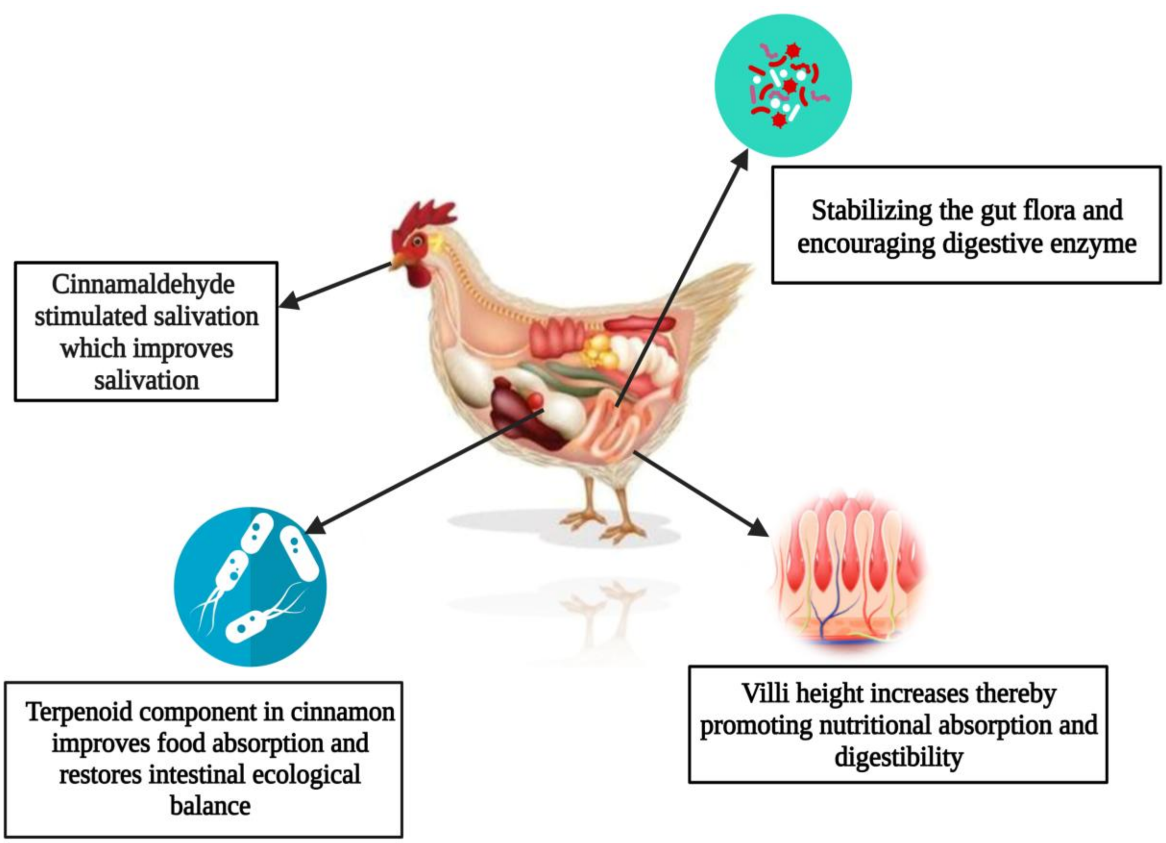

Figure 4 Potential impact of cinnamon on nutrient digestibility and absorption

4 Impact of cinnamon on body weight gain

It has been the subject of numerous scientific investigations into the effect of cinnamon and its derivatives on poultry diets. Researchers found that adding cinnamon essential oil to broiler feed led to a greater weight increase than giving the feed to broilers without any added cinnamon (Al-Kassie 2009). Consumption of cinnamon products at the rate of 2g/kg similarly enhanced the weight of chicks (Toghyani et al. 2011; Shirzadegan 2014). It has been shown by another group of researchers (Lee et al. 2003) that female broilers who consume cinnamon oil and its byproducts don't gain weight, but they do drink less water. Adding cinnamon products at a rate of 0.5-2 g/kg, as shown in the study of Koochaksaraie et al. (2011), did not affect body weight or broiler growth. The body weight of broilers does not change during the sale period when they consume 0.5 to 1 mL/kg (Symeon et al. 2014). Alternate strategies have concentrated on improving health and immune system function by decreasing the number of pathogenic bacteria and modifying the gut microbiota composition to increase output. Essential oils improve feed efficiency and growth performance by influencing immune function, regulating intestinal microflora, stimulating the production of gastric enzymes, and promoting antimicrobial and antioxidant properties. Though the inclusion of cinnamon in poultry diets has been shown to have no direct effect on body weight, few researchers reported that cinnamon has a positive impact on the birds' overall health and wellbeing, particularly their intestinal health and immunity, both of which contribute to increased growth and production (Saeed et al. 2018; Abo-Ghanima et al. 2020). In broiler chickens under heat stress conditions, it has been found that there is a significant improvement in the gain of body weight by feeding cinnamon powder (Khan et al. 2022).

5 Impact of Cinnamon on feed conversion efficiency and feed intake

Cinnamon oil has improved poultry immune systems, reduced feed consumption, and improved feed conversion efficiency; however, studies have reached conflicting conclusions. Three studies have confirmed this effect (Mehdipour et al. 2013; Sim sek et al. 2015; Torki et al. 2015). Poultry fed a meal containing 200 ppm of an essential oil blend of thyme and cinnamon performed better in terms of feed efficiency and feed intake, as reported by Al-Kassie (2009). Broilers fed a diet containing 500 ppm of essential cinnamon oil outperform antibiotic-treated groups in terms of feed conversion efficiency, according to Ciftci et al. (2009). However, it was reported that using cinnamon oil in the diet decreased the feed conversion rate (Sim sek et al. 2015). Torki et al. (2015) found that layers fed a diet containing zinc and cinnamon oil had a worse feed conversion rate when exposed to chilly stress. Antibiotics can be reinstated with organic acid and essential oil, as shown by the fact that the feed control rate increased after two weeks when poultry were given either enramycin at 125 ppm or a mixture of cinnamaldehyde (500mg/kg) and calcium formate. Broilers fed 200 ppm of an essential oil extract containing oregano, pepper, and cinnamon did not exhibit any changes in feed conversion efficiency during weeks 2 and 3, as reported by Hernandez et al. (2004). In broilers under heat stress conditions, it has been found that there is a significant improvement in the intake of feed and feed conversion ratio by feeding cinnamon powder (Khan et al. 2022).

6 Impact of Cinnamon on gene expression profiling

Gene expression profiling is one of the most cutting-edge methods for understanding the genetics behind complicated features like residual feed intake (RFI) in chickens and other animals (Izadnia et al. 2019). The genes and processes that contribute to complex traits in chickens have been categorized using RNA sequencing and next-generation sequencing technologies, which have been widely used to study molecular genetic pathways (Erfan and Marouf 2019). For example, by manipulating gene expression in chickens for up- and down-regulations, 121 and 279 previously identified genes were revealed to be involved with RFI and growth rate, respectively (Izadnia et al. 2019). Quantitative trait loci (QTL) analysis revealed the down-regulation of genes involved in feed efficiency features (Ali et al. 2021). In a study conducted by Tabatabaei et al. (2015), a chicken who received *E. coli* injections in addition to dietary cinnamon extracts (100-200 mg) showed significantly lower expression levels of nuclear factor beta (NF-β) and tumour necrosis factor-alpha (TNF-α). Another study found an upregulation of gene expressions of cationic and neutral amino acid transporters in birds fed with encapsulated cinnamaldehyde (Yang et al. 2021).

7 Impact of Cinnamon on Immunomodulation

The delicate balance of diet, bacteria, and mucus necessary to maintain the gut's immune system properly functioning is not easy. The phenolic components in cinnamon have free radical-scavenging properties; therefore, eating cinnamon can help keep your skin looking young. Multiple studies (Ciftci et al. 2010; Simsek et al. 2013; Alves-Santos et al. 2020) support this notion. Consuming cinnamon regularly increases the beneficial bacteria in the gut, which protects against disease and offers essential nutrients. As a result of their bacteriostatic properties, short-chain fatty acids inhibit the growth of pathogen-causing bacteria, increase the colon's absorption surface by stimulating cell division, and attempt to halt the production of new bile byproducts. Cinnamonaldehyde has been found to reduce the production of inflammatory cytokines in cells stimulated with lipopolysaccharide (Habiba et al. 2021). The expression of critically important mRNA in epithelial cell inflammation is also suppressed in response to these cytokines. Chickens' resistance to disease is improved by cinnamonaldehyde, which contains antiinflammatory effects (Dawson et al. 2003; Pannee et al. 2014). The antigen and immune response pathways are involved in cinnamon's immune regulatory actions (Lillehoj et al. 2011). Improvements in intestinal immunocompetence and an increase in IgA content in chickens fed cinnamon essential oil were reported by Kettunen et al. (2006). Increased serum immunoglobulin was seen in broilers fed a cinnamon diet (Sang-Oh et al. 2013). The serum immunoglobulin M (IgM) concentration increased in hens after being fed cinnamon essential oil for 42 days (Yang et al. 2019), and the MDA concentration dropped after just 21 days.

8 Impact of Cinnamon on blood biochemistry profile

Blood biochemistry is a useful diagnostic tool in both human and veterinary medicine for determining the effects of the environment, diet, and treatment. The positive effect of cinnamon oil in reducing the level of sugar in the body is evident. Both the albumin-to-globulin (A/G) ratio and total cholesterol levels were affected by the cinnamon-derived PFAs. PFAs derived from cinnamon could lower cholesterol levels in consumers' favourite meat, increasing its appeal (Chandran 2021; Krauze et al. 2021; Kumari et al. 2022). The effects of cinnamon on chicken blood biochemistry, however, are inconsistent. There is a notable impact on blood biochemistry from using cinnamon essential oil, cinnamon powder, cinnamaldehyde, or any combination of these, as chicken feed additives. Total protein content, hemoglobin, RBCs and WBCs increased in chickens given 200 ppm of cinnamon essential oil as supplemental feed (Al-Kassie 2009). The heterophils/lymphocytes ratio and cholesterol concentration both decreased. Cholesterol and malondialdehyde (MDA), total saturated fatty acid, and alanine aminotransferase activity were all found to be decreased in chickens fed 1000 ppm cinnamon essential oil, while unsaturated fatty acids, omega-6 fatty acids, catalase activities and blood phagocytic activity were all found to be increased (Ciftci et al. 2010; Prakash et al. 2021a, b). Superoxide dismutase (SOD) activity, antioxidant capacity, catalase, and corticosteroid levels were all enhanced after 42 days of supplementation with cinnamon powder in chickens (Mehdipour and Afsharmanesh 2018). Blood levels of uric acid, malondialdehyde, and lactate dehydrogenase were all lower in heat-stressed Ross 300 broiler chicks fed cinnamon powder (Kanani et al. 2016). Poultry fed a diet containing 7.5g of cinnamon powder per kilogram of body weight experienced a reduction in the heterophil/lymphocyte ratio, suggesting that the spice may have a calming effect (Naderi et al. 2014). These results were accomplished because cinnamaldehyde is an antioxidant that prevents ROS from damaging the liver. Figure 5 shows how cinnamon changes the biochemistry of poultry blood.

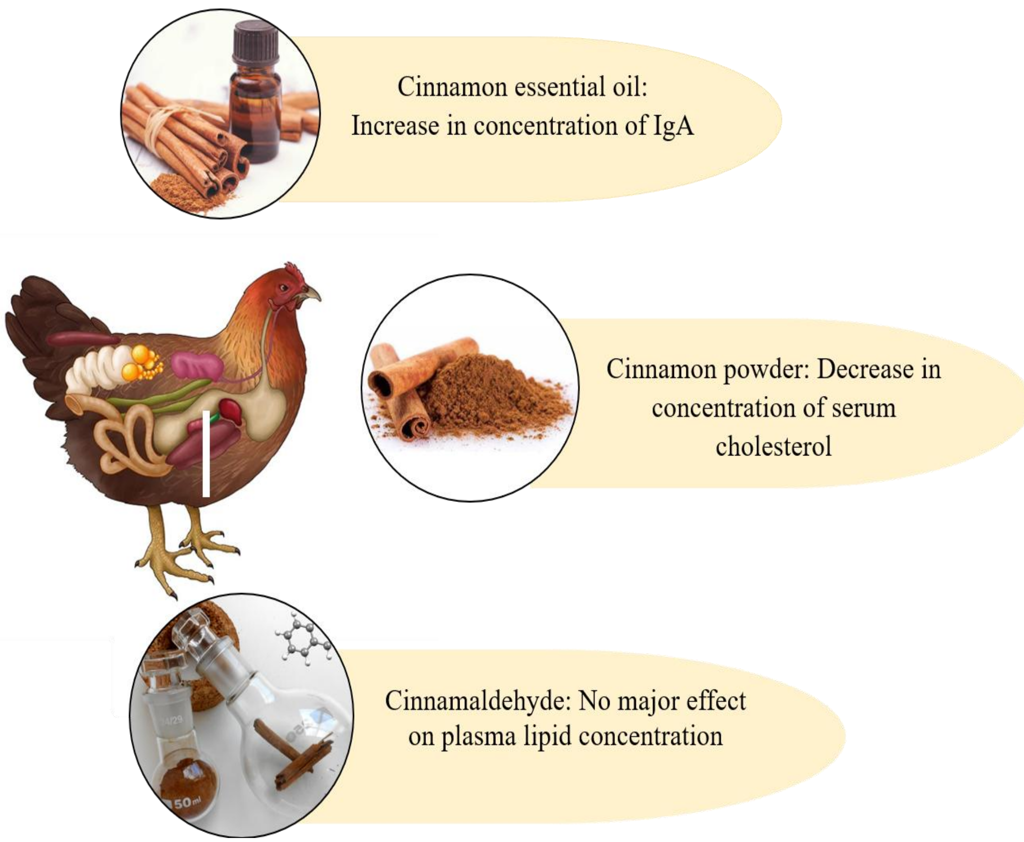

Figure 5 Potential impact of cinnamon on blood biochemistry profile of poultry

Adding cinnamon essential oil to broiler feed increased HDL cholesterol and decreased triglycerides and LDL cholesterol (Faghani et al. 2014). When added to chicken feed at a dosage of 0.8%, cinnamon has been shown to decrease total protein, low-density lipoprotein (LDL) cholesterol, plasma cholesterol, and blood glucose concentrations in birds (Najafi and Taherpour 2014; Kumari et al. 2022). Blood sugar levels were lowered and the proportion of antibody-positive controls increased when cinnamon powder at a concentration of 1.0% was added to the chicken feed (Hossain et al. 2014). Torki et al. (2015) found that adding cinnamon and zinc to the diets of broilers exposed to cold stress reduced the animals' triglyceride and blood glucose levels. A lower blood cholesterol concentration was observed when ground cinnamon was added to the food of broiler chickens at 250 and 500 ppm (Gopi et al. 2012). The plasma lipid concentrations of broilers were not noticeably affected by the addition of cinnamaldehyde to their diet (Lee et al. 2017). The use of the medium and highest doses of cinnamon (0.1 and 0. 25 ml/l) resulted in a beneficial increase in the concentration of low-density lipoprotein receptor-related protein 1 and acetylcholinesterase as well as a decrease in the level of cholesterol and hyperphosphorylated Tau protein (Krauze et al. 2023).

9 Impact of cinnamon on gut microbiota and overall gut health

Eliminating infectious pathogens and promoting great intestinal health in chickens depend on the proper development of meal digestion and absorption, the immune system, and the gut's balance of water and electrolytes. The content of the diet, the presence or absence of feed additives (such as prebiotics, probiotics, phytobiotics, etc.), heat stress, genetic profile and chicken farm feeding practices all affect the gut microbial ecology. Chickens' health and the composition of their gut microbiota are profoundly impacted by these factors (Nawab et al. 2018). It is well known that a healthy poultry intestine with enough microbiota to perform its necessary functions is essential for peak performance. This is because all of these factors—energy balance, sustained inflammatory balance, tissue metabolism, and correct gut physiological function—are intertwined with structural consistency and antibody production. Chicken health is affected by the composition and activity of the gut microbiome (Diaz Carrasco et al. 2019).

A wide variety of bacteria make up the microbiota of a chicken's digestive tract. There are hundreds of different types of bacteria in the intestinal microbiota of chickens, including actinomycetes, bacteroides, firmicutes, fusobacteria, and proteobacteria (Iqbal et al. 2020). The feed efficiency of broilers is increased, increasing the growth rate and productivity of poultry (Bedford 2000). The parasite 5 infects the eggs of laying hens because it resides in the intestines of these birds and then spreads to other organs, including the fallopian tubes. Including trans-cinnamaldehyde in laying hens' diets has improved their health by reducing the spread of infections from *Salmonella enteritidis* eggs (Upadhyaya et al. 2015). Iqbal et al. (2020) estimate that anywhere from 500 to 1100 distinct bacterial species are present in the GIT, each accounting for 100 trillion individual cells. Protozoa, bacteria, and fungi all have roles in the avian digestive system. Poultry had varying microbial concentrations throughout the intestine, with the highest levels towards the tail end. To ward off microbial invasion and play a role in cell signalling, intestinal epithelial cells form tight interactions with one another. Oxidative stress, which is the result of interactions between pathogenic bacteria and their toxins and the mucosa, is known to cause damage to the intestinal mucosa, the intestinal epithelial barrier, tight junctions, and lipid peroxidation, as shown in many studies (Gopi et al. 2012; Upadhyaya et al. 2015; Habiba et al. 2021).

Broilers are designed to gain the most weight quickly to satisfy the ever-growing demand for chicken meat (Lee et al. 2017). Antioxidant compounds added to meals reduce free radicals and protect the intestinal lining (Mandal et al. 2015). Thus, the poultry industry needs to figure out how to implement this finding. The high expense of testing and the need for a final sampling of a large number of birds to capture stomach contents have limited the application of this technique, even in commercial settings. The health, longevity, and antioxidative capacity of chickens can be improved by adding bioactive components to their diet. Essential oils and phenolics are two of cinnamon's active components that have been shown to have antiinflammatory and antimicrobial benefits in animal studies. Modifying the intestinal microbiota and its activity with dietary adjustments can counteract cinnamon's potential effect on the microbiome (Mandal et al. 2015; Lee et al. 2017).

To this end, PFAs are being tested in poultry feed as a non-toxic and safe way to improve the birds' health by fostering a more diverse and stable gut microbiota. In order to improve nutritional absorption through the intestinal walls of chickens, phytobiotics are utilized to alter their gastrointestinal systems (Mueller et al. 2012). This is accomplished by promoting antibacterial, antiinflammatory, and antioxidant responses. The caecal organism's aid in the host's nitrogen metabolism is associated with food's positive health effects (Oakley et al. 2014). Although the small intestine is where most digestion and absorption of nutrients occurs, the bacteria found in the cecum ferment any food that was only partially digested in the ileum (Lee et al. 2017).

The ileum of the intestine is dominated by aerobic bacteria (Enterococcus spp. and Lactobacillus spp.), whereas the cecum is dominated by pathogenic obligate anaerobic bacteria (Campylobacter spp. and Enterococcus spp.) (Yin et al. 2010; Boguslawska-Tryk et al. 2015). It has been hypothesized that a chicken's digestive tract's health directly affects its productivity.

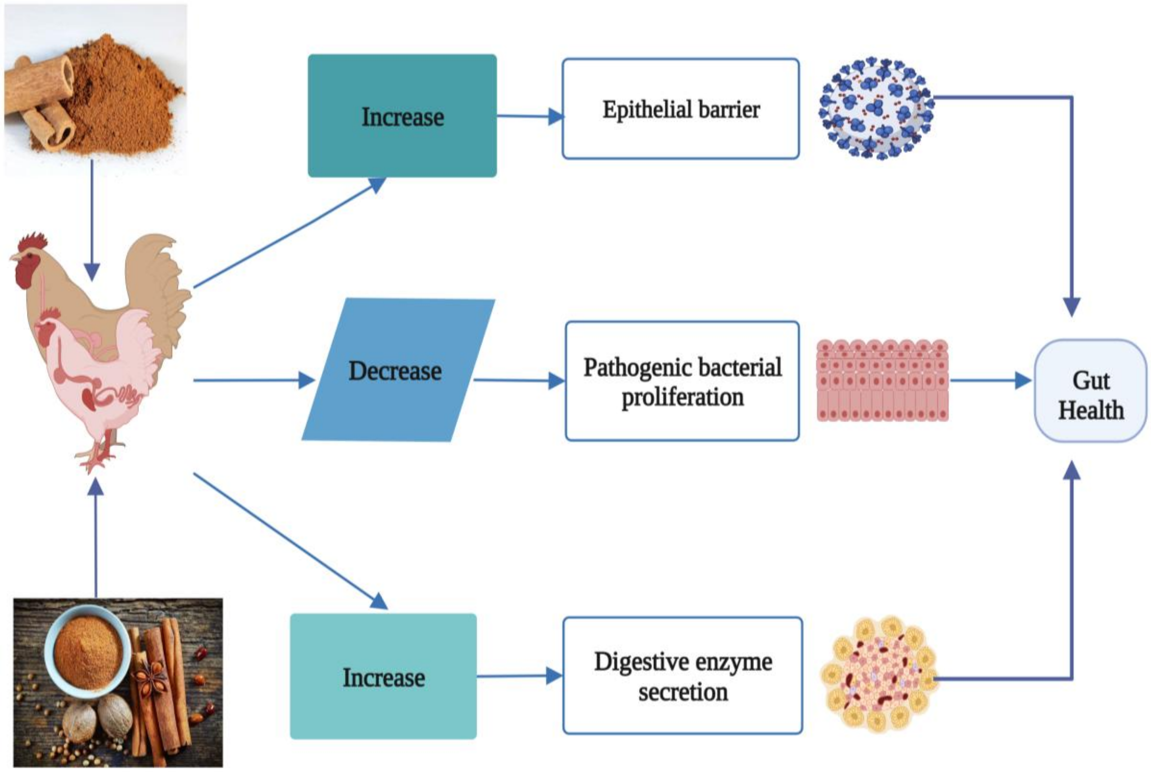

Figure 6 Potential impact of cinnamon on poultry gut health

Including cinnamon in a chicken's food has been shown to improve intestinal microbiota and digestive health (Mehdi et al. 2018). The gut ecology functioned better after consuming a cinnamon-based diet, as beneficial bacteria proliferated and detrimental bacteria decreased (Rashid et al. 2020). The cinnamon diet promoted the growth of Lactobacillus spp. in chickens ileum and caecum while dramatically inhibiting Campylobacter spp., *E. coli*, and other microorganisms. There are bioactive components in cinnamon that kill bacteria, such as Enterococcus spp. and *Pseudomonas aeruginosa* (Chang et al. 2001).

Volatile components such as cinnamaldehyde, eugenol, and carvacrol make up the bulk of cinnamon essential oils. Compared to cinnamon extract, cinnamon oil was more effective against bacteria. Further research showed that cinnamon essential oil has a bactericide minimum bactericidal concentration (MBC) of 125–250 g/mL and a minimum inhibitory concentration (MIC) of 25–100 g/mL (Pathak et al. 2017). It is important to note that cinnamaldehyde in encapsulated form may not prove toxic to the birds (Zaefarian et al. 2019). Combining thymol and cinnamaldehyde has been recommended in several studies for its potential to reduce disease transmission and give animals better stomach wellbeing (Ouwehand et al. 2010; Tiihonen et al. 2010). Cinnamaldehyde, capsaicin, carvacrol, and other compounds in cinnamon have been shown to reduce the number of *E. coli* and increase the number of Lactobacillus in the intestines of broilers (Jamroz et al. 2005). The ability of cinnamon oil to disrupt bacterial cell membranes may explain why it helps reduce *E. coli* populations. Again, cinnamaldehyde (encapsulated) alone or in combination with citral has been found to cause a reduction in the cases of necrotic enteritis (Yang et al. 2020). Poultry with a higher antioxidant status, immunity, and antimicrobial activity can benefit by including cinnamon essential oil as a feed element in poultry feed (Tiihonen et al. 2010). As Solanki et al. (2022) reported, Cinnamon oil can be used as a substitute for chemical growth enhancers in the chicken business. Caecal *E. coli*, *Salmonella*, total yeast, mold, and total microbial count were reduced in chickens fed cinnamon oil, but the total microbial count was identical to that of antibiotic-treated chickens. Broiler chickens can benefit from a diet supplemented with cinnamon oil instead of antibiotic growth enhancers at doses of 10 mg/kg avilamycin, 500 mg/kg, 1000 mg/kg, and 1500 mg/kg, respectively (Saied et al. 2022). The potential impact of curcumin on poultry gut health is illustrated in Figure 6.

Conclusion and future prospects

Using cinnamon as a feed additive improved a variety of characteristics in poultry, including their ability to digest and use nutrients, their rate of growth, their body weight gain, their appetite, their feed conversion efficiency, the traits of their carcasses, the quality of their meat, their blood chemistry, the expression of their genes, the composition of their gut microbiota, and their immune function. Increased demand for broilers resulted in the stress-reducing effects of cinnamon on their feed, which reduces the heterophil to lymphocyte ratio. As a result, cinnamon has the potential to replace antibiotics, as it protects against food poisoning, lessens exposure to harmful chemicals in feed, and promotes environmental health. Incorporating cinnamon into poultry feed has been demonstrated to have positive effects. In addition to boosting the immune system and lowering illness prevalence, cinnamon has been shown in certain tests to increase broiler chickens' growth rate and feed efficiency. Cinnamon may also have positive effects on human health and the environment, and it is also a safe and natural feed ingredient that can replace synthetic additives. A rising number of people are concerned about the environmental effects of the poultry business and are working to increase the efficiency of poultry farming. Improved poultry health and growth with less reliance on antibiotics and other synthetic chemicals might be possible with cinnamon's inclusion in poultry feed. Demand for natural and organic poultry products is also rising, thanks to increasing consumer awareness of the negative effects of conventional poultry agriculture on the environment and human health. Cinnamon's timely inclusion as a feed additive could help farmers gain a competitive edge and higher prices for their wares. Overall, cinnamon's potential as a feed additive for poultry is encouraging, and more study in this area is expected to provide additional insights and benefits in the future. While cinnamon has shown promise as a feed additive, its efficacy may vary based on individual chicken farms' environmental factors and management techniques; experiments should be conducted and performance closely monitored.

Using PFAs like cinnamon can make poultry production more cost-effective, risk-free, and healthy without negatively impacting the productivity of the birds. Even yet, further investigation is needed to elucidate the fundamental link of these PFAs with enhanced gut microbiota. Heat stress, in particular, has a major effect on the health and productivity of chickens and may be mitigated by applying cinnamon oil. There has been a rise in interest in using cinnamon oil for its immunomodulatory characteristics in poultry production, although this area still lacks sufficient study. To monitor the metabolites and fate of cinnamon's bioactive components in the chicken intestine, it is necessary to establish methodologies for the analytical analysis of these compounds. The effectiveness of the poultry industry's use of cinnamon or cinnamon oil depends on our having a more solid understanding of the biological activities of cinnamon and related components. More research is needed into the relationship between cinnamon's chemical composition and its Influence on poultry health and productivity.

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