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Review Article

Synergistic Effects of Phytogenics, Prebiotics and Organic Acids on Gut Health and Performance in Poultry

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Abstract: The poultry industry is moving toward the use of antibiotic-free production systems in response to concerns regarding antimicrobial resistance, regulatory restrictions on antibiotic growth promoters (AGPs), and increasing consumer demand for sustainable poultry products. This change has highlighted the importance of gut health as a major factor affecting nutrient utilization, immune competence, disease resistance and growth performance. A healthy GI tract supports effective digestion and absorption of nutrients, a balanced microbial ecosystem and intestinal barrier function. Phytogenics feed additives, prebiotics and organic acids are among the nutritional alternatives to AGPs that have been well studied. These feed additives act through different but complementary mechanisms to improve gut resilience. Phytogenic compounds have antimicrobial, antioxidant, and anti-inflammatory effects. Prebiotics selectively stimulate beneficial intestinal microorganisms and stimulate the production of SCFAs. Organic acids act by decreasing intestinal pH, inhibiting pathogenic bacteria, improving the digestibility of nutrients and promoting intestinal integrity. Research shows that often the greatest benefits are achieved with a combination of these additives. They act synergistically targeting microbial modulation, epithelial barrier function, immune responses, oxidative status, and digestive efficiency leading to improved gut resilience and productive performance. These integrated strategies are associated with enhanced body weight gain, enhanced FCR, improved nutrient utilization and reduced disease susceptibility in poultry. This review summarizes the current understanding of the mechanisms, functional benefits and practical application of Phytogenics, prebiotics, and organic acids in poultry nutrition. It also emphasizes new opportunities in precision nutrition, microbiome guided feeding, and multi-functional feed additive strategies that may support sustainable poultry production in the post-antibiotic era.

Keywords: Poultry nutrition, Phytogenic feed additives, Prebiotics, Organic acids, Gut microbiota, Fructo-oligosaccharides, Cinnamaldehyde, Carvacrol, Antibiotic alternatives, Broiler performance.

Introduction

Modern poultry industry production is expected to supply affordable animal protein while simultaneously reducing the use of antibiotic growth promoters and minimizing environmental impacts. These expectations have shifted industry focus towards nutritional strategies that are capable of supporting intestinal health, productivity and disease resilience through natural mechanisms [1]. For over 70 years, poultry farmers have used antibiotic growth promoters (AGPs), to improve the poultry growth performance and feed efficiency [2,3]. However, regions such as Europe and USA have banned or restricted the use of AGPs in animal feed because of the increase in antibiotic resistance which has increased the susceptibility to enteric diseases, gut dysbiosis and stress–related conditions such as heat stress and necrotic enteritis [4]. These conditions impact negatively on nutrient-absorption, growth rates and overall health of the poultry which in turn leads to economic losses and reduced production efficiency.

Increasing restrictions on and bans of AGPs, have encouraged the development of natural feed additives that are known to improve the productivity of animals without compromising food safety [3]. These additives including phytogenic compounds, prebiotics, and organic acids have become essential tools for improving nutrient uptake, intestinal morphology, modulating gut microbiota and enhancing immune responses [3]. Recent studies on gut health explain that gut microbiota plays a critical role in growth, feed utilization and disease resistance. This is mainly due to its ability to perform normal physiological functions, maintain homeostasis and withstand infectious and non-infectious stressors [5]. Therefore, maintaining intestinal microbial balance through dietary additives has become an essential strategy in sustainable and safe poultry production.

Numerous reviews have independently focused on phytogenic feed additives, prebiotics, and organic acids as alternatives to AGPs. However, gut health is regulated by a complex network of microbial, nutritional, immunological and physiological interactions. Consequently, the benefits of these additives are increasingly associated with their complementary and synergistic actions rather than their individual effect alone [6]. This review provides a systemic synthesis of current knowledge, based on a comprehensive search of electronic databases (e.g., PubMed, Web of Science, Scopus) covering literature from 2000 to 2026. Inclusion criteria prioritized peer-reviews studies investigating the integrated mechanism through which Phytogenics, prebiotics and organic acids collectively influence intestinal health, microbial ecology, immune competence and productive performance in poultry.

Poultry Gut Health and Microbiome

The gut microbiome of poultry is a complex and dynamic ecosystem comprising diverse microbial populations that are critical for maintaining intestinal homeostasis and overall poultry health. Lactobacillus, Bifidobacteria, Clostridium and other members of the phyla Firmicutes and Bacteroidetes have been identified as dominant bacterial genera in the poultry GIT [7]. However, the composition and relative abundance of communities are dynamic, significantly influenced by factors such as the bird's age and specific composition of dietary additives. These microbes are involved in digestion of nutrients, fermentation of indigestible components of feed and the production of metabolites such as SCFAs (short-chain fatty acids) which are energy sources for enterocytes and modulate immune responses. A balanced gut microbiota competitively excludes pathogenic bacteria by occupying ecological niches and secreting antimicrobial substances, thus reducing the risk of infection [8].

The gastrointestinal tract (GIT) of poultry is complex and has an important role in digestion, absorption of nutrients, metabolism and immune protection. GIT converts ingested feeds into nutrients which are essential for maintenance, growth and reproduction activities. It also helps in signaling immune response against the pathogens and microorganisms that the bird encounters [9]. The GIT of the poultry comprises a complex and diverse microbial ecosystem including bacteria, viruses, archaea and fungi. These microorganisms attach to the epithelial wall and trigger the immune system's maturation which include the mucus layer, epithelial monolayer and immune cells mediates this immune maturation [7,10]. These microorganisms are involved in the production of vitamins, organic acids and SCFAs that support intestinal integrity, nutrient metabolism and immune function. A stable and well-balanced gut microbiota is therefore essential to achieve optimal growth, feed efficiency and poultry health. Beneficial microorganisms can improve intestinal barrier function and can inhibit pathogens such as Salmonella, Escherichia coli and Clostridium perfringens [8]. Natural growth promoters significantly improving intestinal morphology by increasing the villus height and the villus to crypt depth ratio. This improvement directly expands the surface area for nutrient absorption from feed and feed utilization efficiency [11,12].

However, the factors including poor diet quality, environmental stress, pathogenic infections, heat stress and excessive use of antibiotics can disrupt intestinal microbial balance [9,10]. This disruption has a negative effect on nutrient digestion, weakens immune responses, damages intestinal integrity and increases the susceptibility to enteric diseases which then reduces the growth and production efficiency in poultry [10]. Therefore, stabilization of the gut microbiota by nutrient intervention can be the better approach in sustainable poultry production [7]. Figure 1 summarizes the major mechanisms through which phytogenic feed additives, prebiotics, and organic acids contribute to gut health improvement in poultry.

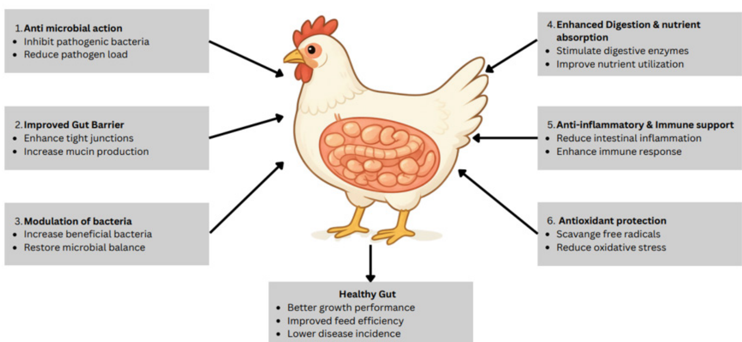

Figure 1: Mechanisms of gut health improvement in poultry.

The figure illustrates the key mechanisms through which Phytogenics, prebiotics and organic acids improve gut microbiota, intestinal integrity, immune function and nutrient utilization in poultry.

A balanced gut microbiota should not be viewed solely as a microbial population but as a functional metabolic organ engaging in critical activities such as SCFA production and bile acid metabolism that directly influences nutrient utilization, immune competence and resistance to enteric disorders. Therefore, nutritional interventions are required to support microbial stability which can have broader implications for productivity than strategies focused exclusively on growth promotion.

Phytogenic Feed Additives in Poultry

Phytogenic feed additives (PFAs) also termed photobiotic, are plant-derived bioactive compounds, incorporated into poultry diets to improve health productivity and overall performance [2,3]. These additives are extracted from herbs, spices, essential oils, and plant extracts and are increasingly used as natural alternatives to AGPs because of their antimicrobial, antioxidant, anti-inflammatory and immunomodulatory properties [2,13,14]. Commercial phytogenic products are typically composed of plant-derived bioactive compounds obtained from herbs, spices, essential oils and botanical extracts [13,15]. Although individual phytogenic compounds differ in chemical structure, they share overlapping biological activities which enhance digestive support, microbial balance, immune function and oxidative status in poultry. Unlike traditional antibiotics that are directed mainly against microorganisms, phytogenic compounds act through multiple interrelated pathways that support intestinal health and overall physiological function [13,14,16].

One of the important advantages of phytogenic compounds is their ability to modulate a balanced intestinal microbiota. Poultry gut is a complex microbial ecosystem and plays an important role in nutrient utilization, immune development and disease resistance [10,17]. Several plant-derived bioactive compounds exhibit natural antimicrobial activity to inhibit pathogenic microorganisms such as Salmonella, Escherichia coli (E. coli), Clostridium perfringens (C. perfringens), while promoting the establishment of beneficial microbial population [18]. Studies on compounds derived from essential-oil have demonstrated reductions in intestinal pathogen colonization and improvement in microbial balance, contributing to better intestinal stability and health [19]. Phytogenic compounds, in addition to microbial regulation have been shown to improve the efficiency of digestion by stimulating the secretions of digestive enzymes and enhancing the breakdown of nutrients in the GIT [15]. Plant bioactive may enhance the activity of digestive enzymes and stimulate bile secretions, thus improving the digestion of proteins, lipids and carbohydrates [14,16]. Supplementation of phytogenic compounds in broiler chickens has been shown to improve feed conversion ratio (FCR), nutrient utilization and growth performance due to enhanced nutrient digestion and absorption [20]. Feed conversion ratio (FCR) measures the amount of feed required to produce a unit of body weight which is one of the most important indicators of production efficiency in poultry.

Another important property of phytogenic compounds is their antioxidant activity. Environmental and physiological stressors such as heat stress, transportation, vaccination and high stocking densities are often present in commercial poultry production. Such conditions are favorable to produce reactive oxygen species (ROS) which can damage cellular structures and reduce productivity. Polyphenols and other antioxidant compounds of plant origin are beneficial to neutralize ROS and stimulate endogenous antioxidant defense systems thus protecting intestinal tissues and supporting physiological resilience [12,21]. Improved antioxidant status has been associated with better intestinal integrity, enhanced physiological resilience and improved product quality in poultry production systems [12,22]. Phytogenic compounds are also involved in the regulation of immune functions by modulating inflammatory pathways and enhancing immune responsiveness. Excessive inflammation can disrupt growth by diverting nutrients from productive processes into immune processes. Several phytogenic bio actives have been reported to modulate cytokine production, reduce inflammatory stress and enhance immune competence leading to improved response of birds to disease challenges and minimizing unnecessary inflammatory damage [15,23,24]. Such immunomodulatory effects are crucial under commercial production conditions where birds are frequently exposed to multiple environmental and infectious stressors [23]. As a result, phytogenic compounds can improve intestinal morphology and epithelial integrity. Studies evaluating various plant-derived bio actives have shown an increase in villus height, improved villus-to-crypt ratios which enhanced epithelial structure and better nutrient absorption capacity, all of which improve gut functionality and productive performance [12,25]. Maintenance of intestinal barrier function is widely accepted as a critical factor linking gut health with feed efficiency and disease resistance [13,26].

The table summarizes the primary mechanism and beneficial effects of Phytogenics, feed additives on gut microbiota, intestinal health, immunity, antioxidant activity and poultry performance.

Table 1: Major mechanisms through which Phytogenic feed additives improve Poultry gut health.

Biological Mechanism	Mode of Action	Physiological Outcome	References
Antimicrobial activity	Suppresses pathogenic bacteria	Improved microbial balance	[16,17]
Antioxidant activity	Neutralizes reactive oxygen species	Reduced oxidative stress	[21,22]
Digestive stimulation	Enhance digestive enzyme secretion	Improved nutrient utilization	[20]
Immune regulation	Modulates inflammatory pathways	Improved disease resistance	[23,24]
Intestinal barrier support	Maintains epithelial integrity	Better nutrient absorption	[26,27]

Together these biological actives result in improved intestinal integrity, increased nutrient utilization, better growth performance and increased resilience to environmental and pathogenic stressors. Therefore, phytogenic feed additives are currently considered important components of AGP-free poultry production systems [15,25]. Although the benefits of phytogenic feed additives have been widely reported, responses are not always consistent across studies [15]. Variations in plant sources, extraction methods, bioactive composition, dosage, bird genotype and environmental conditions can influence the magnitude of the observed effects [13,15]. Differences in diet formulation and management practices further complicate direct comparisons between studies. These factors highlight the need for greater standardization in the evaluation of phytogenic products under commercial production conditions. The major mechanism through which phytogenic compounds improve poultry gut health are summarized in Table 1.

Major outcomes of Phytogenic Feed Additives

Together, the mechanism summarized in Table 1 suggests that phytogenic feed additives influence digestion, microbial ecology, oxidative stress, and immune signaling through multiple interaction pathways. Improvements in villus height architecture, digestive secretions, pathogen suppression and antioxidant protection have been associated with better nutrient utilization, feed efficiency and growth performance. However, the magnitude of responses varies according to phytogenic source, bioactive composition, inclusion level, diet formulation, bird's genotype and production environment [20,23].

Prebiotics in Poultry Nutrition

Prebiotics are non-digestible feed components that target and boost growth and activity of essential gut microbes which in turn improves gut health and performance in poultry [7]. Poultry diets often include prebiotics like fructooligosaccharides (FOS), mannan-oligosaccharides (MOS), galactooligosaccharides (GOS), inulin and resistant starch [28]. With AGPs under heavy restrictions, prebiotics stand out as a sustainable way to support gut microbial balance, immune function and better nutrient use, all without the problem of antimicrobial resistance [3,8].

The poultry gut consists of a complex community of microbes. These microorganisms play a central role in digestion, nutrient metabolism, immune development and pathogen resistance [5,28]. When a stable population of beneficial bacteria is maintained in the gut it competes with harmful ones for nutrients and attachment sites, limiting colonization by harmful bacteria and improving intestinal stability [17,28]. Unlike phytogenic compounds, prebiotics do not directly affect pathogens or host tissues instead, they serve as selective substrates for beneficial intestinal microorganisms [7]. Because prebiotics escape digestion in the upper GIT, they reach the lower intestine where they are fermented by resident microbiota. This fermentation process generates short-chain fatty acids (SCFAs) including acetate, propionate and butyrate [7,8,28]. These SCFAs provide energy to the intestinal cells while helping to preserve the strength of gut barrier [28,29]. When SCFA production intensifies, the intestinal pH lowers thereby reducing the ability of pathogens like Salmonella and C. perfringens species to colonize [28].

Prebiotics also help maintain the structural development of the intestine. An increase in villus height and villus-to-crypt ratio increase the absorptive surface area available for uptake of nutrient which improve digestion efficiency and feed utilization [8]. Better absorption of nutrients leads to better growth performance and feed conversion efficiency most particularly under conditions of physiological stress and disease challenges [3].

The table highlights the mechanism by which prebiotics promote beneficial microbial population, enhance intestinal health, improve immune responses and support productive performance in poultry.

Table 2: Functional benefits of prebiotic feed additives in poultry.

Functional Benefits	Mechanism of Action	Outcome in Poultry
Promotion of beneficial microbiota	Selective stimulation of beneficial bacteria	Improved microbial balance [17,28]
SCFA production	Microbial fermentation of prebiotic substrates	Improved intestinal health and energy supply [7,8]
Pathogen suppression	Competitive exclusion and lower gut pH	Reduced pathogen colonization [3,17,28]
Improved gut morphology	Enhanced villus development	Better nutrient absorption [8]
Immune support	Modulation of mucosal immunity	Improved disease resistance [3,7]
Growth promotion	Combined gut health effects	Improved BWG and FCR [8,17]

Prebiotics affect immune function other than their effects on digestion, through interactions between intestinal microbes and the host immune system. Prebiotics stimulate beneficial bacteria that can improve mucosal immunity, strengthen gut-associated lymphoid tissue (GALT), and regulate inflammatory responses, allowing birds maintain health without excessive immune activation [7,10]. With the shift in poultry production towards antibiotic-free systems, prebiotics have become valuable nutritional tools to support microbial balance, intestinal integrity, nutrient utilization and immune competence while contributing to sustainable production practices [30]. Despite the positive effects frequently associated with prebiotic supplementation, considerable variability exists regarding the type of prebiotic used, inclusion levels, duration of feeding and the existing microbial composition of the GIT [28]. Since the efficacy of prebiotics largely depends on the resident microbiota, responses may differ among production systems and geographical regions. Additional research is required to establish optimal application strategies and improve the predictability of responses under commercial conditions. The principal functional benefits in poultry are summarized in Table 2.

Major outcomes of Prebiotic Supplementation

The mechanism summarized in Table 2 demonstrates that prebiotics primarily support poultry gut health through selective stimulation of beneficial microorganisms and increase production of SCFAs [28]. These effects improve intestinal morphology, enhanced barrier integrity, reduced pathogen colonization and more efficient nutrient utilization [3,28]. Simultaneously, improved immune responsiveness reduces the physiological burden associated with disease challenges and environmental stressors [7,29]. Therefore, prebiotics supplementation is often linked to improved gut health, nutrient digestibility, stronger immunity and better production performance in commercial poultry systems [3,8].

Organic Acids in Poultry Nutrition

Organic acids have become more common in poultry nutrition, serving as natural alternatives to AGPs. Organic acids are naturally occurring weak acids that have been widely used in poultry nutrition to improve intestinal stability, control pathogenic microorganisms and enhance productive performance [31]. The organic acids most used in poultry feeds are lactic acid, formic acid, citric acid, propionic acid and butyric acid which are used either singly or in combination formulations [31,32]. The primary action of organic acids is to bring down the pH inside the GIT making it unsuitable for harmful bacteria like Salmonella, Escherichia coli, and Clostridium perfringens [31].

The antimicrobial effects of organic acids are mostly from the undissociated forms of these acids. These molecules enter bacterial cell membranes and disrupt intracellular metabolic processes and pH balance [31]. This reduction in pathogen load allows beneficial gut bacteria to thrive promoting a healthy microbial balance [32]. Organic acids also improve the structure of the intestine, increase the activity of digestive enzymes and boost nutrient absorption which together mean better nutrient utilization and digestibility [31]. Improved gut integrity further supports immune function by reducing the movement of pathogens and toxins across the intestinal barrier, helping to lower inflammatory stress and allowing nutrients to be directed toward growth and production [33]. As a result, the addition of organic acids to poultry diets consistently leads to better body weight gain, improved FCR, stronger immune responses and overall enhanced performance in poultry [30,31].

The table represents the key roles of organic acids in intestinal acidification, pathogen control, nutrient digestibility, gut stability and overall poultry productivity.

Table 3: Major functional benefits of organic acids in poultry.

Functional Benefits	Mechanism of Action	Outcome in Poultry
Intestinal acidification	Lowers gastrointestinal pH	Reduced pathogen survival and colonization [32]
Antimicrobial activity	Inhibits pathogenic bacterial growth	Improved microbial balance and gut stability [31,34]
Improved digestion	Enhances enzyme activity and nutrient solubility	Better nutrient utilization and feed efficiency [34,35]
Intestinal morphology support	Improves villus structure and epithelial health	Enhanced nutrient absorption and intestinal functionality [33]
Immune support	Reduces intestinal inflammation and immune stress	Improved health and resilience and disease resistance [31,33]
Growth promotion	Combined effects on gut health and digestion	Improved Body Weight Gain and FCR [34,35]

The effectiveness of organic acids may vary depending on acid type, inclusion rate, buffering capacity of the diet and the microbial status of the birds [31,32]. While numerous studies report improvements in gut health and performance, inconsistent responses are occasionally observed under different production environments. Greater understanding of the interactions between organic acids, dietary composition and intestinal microbiota would support more precise and effective application in poultry. The major functional benefits of organic acids are summarized in Table 3.

Major outcomes of Organic Acid Supplementation

The evidence summarized in Table 3 indicates that organic acids improve gut health mainly through intestinal acidification and suppression of pathogenic microorganisms [31,32]. Additional benefits include enhanced nutrient digestibility, improved intestinal morphology and support of a favorable microbial environment [27,31,32,33].

Synergistic Effects of Combined Feed Additives

Although Phytogenics, prebiotics, and organic acids individually have the potential to improve poultry health and productivity, the increasing evidence suggests that more benefits can be obtained from the use of these additives in combination because they target different but interconnected aspects of GI function [11,36]. Because microbial composition, intestinal integrity, immunity and digestion interact, interventions that influence multiple pathways may produce consistent responses compared with single target additives. Therefore, strategies that affect multiple pathways simultaneously are more likely to result in consistent improvements in performance under commercial production conditions (Figure 2) [5,10,29].

1. Phytogenics + Prebiotics

The combination of Phytogenics and prebiotics enables the selective proliferation of beneficial commensal bacteria while preventing the survival of harmful pathogens such as ESBL- producing E. coli [28,36]. The synbiotic-phytogenic combination supports improved metabolic activity and colonization resistance in the crop and caecum by promoting a dominant Lactobacillus population that is rarely achieved with the single compound feeding [36]. In commercial settings, the prebiotic feed additive acts as a fermentable substrate, which stimulates the growth of protective bacterial population. Phytogenic compounds strengthen the gut barrier through the upregulation of tight junction proteins and antioxidant defenses [37]. This synergistic combination decreases oxidative stress in the intestinal mucosa thereby enhancing structural integrity and systemic immune responses [38]. Therefore, this combinational approach improves nutrient digestibility and intestinal villus morphology, resulting in superior weight gain and feed efficiency in broiler chickens [3,30].

2. Phytogenics + Organic Acids

The combination of Phytogenics and organic acid additives enhances the antimicrobial effect by reducing the pH of the luminal environment which significantly inhibits the growth of acid-intolerant pathogenic bacteria such as Salmonella and Campylobacter [3]. Taken together, the lipophilic nature of essential oils in Phytogenics damages the bacterial membrane, while organic acids cause intracellular acidification, which reduces the metabolic expense of pathogen resistance [39]. This synergistic mechanism stabilizes the intestinal environment, thus optimizing the digestive physiology and nutrient absorption capacities of the birds [30]. Another advantage is that the ability of organic acids to lower the luminal pH can increase the solubility of phytogenic molecules improving their bioavailability and ensuring a more effective modulation of the intestinal microbiota [16]. Such combination thus improves digestibility of dry matter and crude protein, providing a direct physiological basis for an observed improvement of broiler growth performance [11].

3. Triple Combination Systems

These three classes of additives together provide a holistic multi-tiered defense system that addresses physiological, microbial, and immunological stressors at the same time. The tripartite system is highly effective in reducing the mortality rates and increasing the immune resilience by modulating the intestinal environment via pH reduction, selective prebiotic fermentation, and direct disruption of pathogens cell walls [12]. As a result, this combined supplementation has been shown to improve FCR and total bodyweight gain through the optimization of intestinal histomorphometry and boosting systemic immune responses [39].

Organic acids are primarily responsible for acidification by lowering the gut pH making it a challenge for acid-sensitive pathogens like Salmonella and E.coli to survive while helping beneficial microbes thrive [39]. Meanwhile, Phytogenics disrupt bacterial membranes which allows organic acids to enter pathogens more readily reducing the energy bacteria typically used for defense [32,35,39]. Prebiotics intervene by providing fermentable substrates like fructooligosaccharides which boost the production of SCFAs and significantly enhance the integrity of the intestinal lining [33].

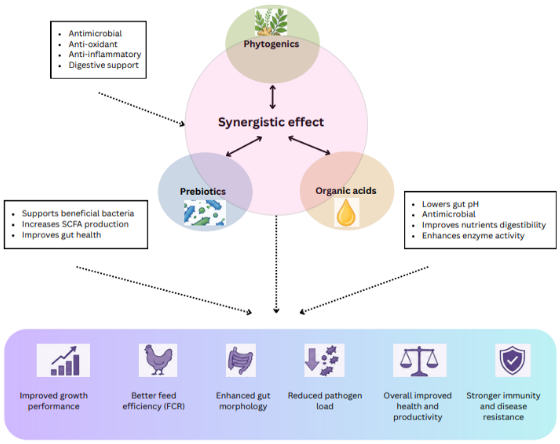

Figure 2: Synergistic interaction among Phytogenics, Prebiotics and Organic acids.

The figure depicts the complementary and synergistic interaction of Phytogenics, prebiotics and organic acids in enhancing gut health, disease resistance and productive performance in poultry.

When these additives act together, they gently steer the ileal microbiome towards a positive outcome which increases the number of beneficial Lactobacillus species and decreases harmful Enterobacteriaceae [10,36]. This improved gut ecosystem results in reduced energy loss due to inflammation and thereby increases nutrient absorption from the feed which promotes more effective growth performance. The combination of these three additives in the feed enhances the gut barrier, boosting essential antimicrobial peptides along with tight junction proteins such as claudin-1 and zonula occludens-1 which aids in preventing pathogens from entering the bloodstream [39]. This multidimensional strategy may reproduce some performance related effects historically associated with AGPs improving intestinal morphology and microbial stability. Further optimization of intestinal function is achieved by strategic modulation of cecal metabolic pathways, especially stimulation of SCFAs synthesis.

The concurrent administration of these additives increases the antimicrobial effect by 2-fold: organic acids reduce the luminal pH, which disrupts pathogen cell membranes, facilitating the ability of phytochemicals to neutralize bacteria such as Salmonella and C. perfringens [15,35]. This mechanism promotes the secretion of endogenous digestive enzymes and greatly enhances the utilization of protein and minerals [34]. Moreover, this strategy favors a strong GIT that results in stable growth performance and decreased shedding of pathogens in intensive production systems [23,40]. This intervention has been associated with a more stable cecal environment and increased SCFAs production in some studies [5,12,25]. Lastly, protected delivery systems, including microencapsulated formulations, optimize the release of essential oils and organic acids in the distal small intestine, significantly improving villus height and barrier function [34,35].

Performance Outcomes

Phytogenic feed additives, prebiotics and organic acids are highly effective at improving intestinal health, nutrient utilization, microbial balance and immune function, which in turn improve poultry performance [17,29]. Each additive has a specific physiological pathway, but the combination of additives has a synergistic effect, including modulating the gut microbiota, improving the integrity of the intestinal barrier, reducing oxidative stress and improving digestive efficiency and disease resistance, thereby enhancing growth performance and feed efficiency [3,30].

Phytogenic compounds such as cinnamaldehyde, carvacrol, curcumin, etc., have antimicrobial, antioxidant, digestive stimulant and anti-inflammatory properties.

Such bio actives enhance intestinal morphology, nutrient digestibility, pathogen suppression and FCR [12,14,16,25]. Prebiotics, particularly FOS, can selectively stimulate growth of beneficial bacteria such as Lactobacillus and Bifidobacterium leading to enhanced SCFA production, improved gut integrity and heightened immune response. The main organic acids are lactic acid which lowers the pH of the intestine, inhibits pathogenic bacteria and improves nutrient digestibility and mineral absorption [7,28,31,32].

The table provides comparative overview of the effects of Phytogenics, prebiotics, organic acids and their combined application on growth performance, feed efficiency, gut health, immunity and production outcomes in poultry. Legends: ↑ = improvement; ↑↑ = moderate improvement; ↑↑↑ = substantial improvement; ↔ = neutral to slight improvement.

Table 4: Summary of performance parameters improved by functional feed additives.

Performance Indicator	Phytogenics	Prebiotics	Organic Acids	Triple Combination	Key References
Body Weight Gain	↑	↑	↑	↑↑↑	[3,11,39]
Feed Conversion Ratio	↑	↑	↑	↑↑↑	[35]
Feed Intake	↑	↔/↑	↔	↑	[16,14]
Nutrient Digestibility	↑↑	↑	↑↑	↑↑↑	[20,33]
Villus Height	↑	↑↑	↑	↑↑↑	[13]
SCFA Production	↔	↑↑↑	↑	↑↑↑	[28,7]
Beneficial Bacteria	↑	↑↑↑	↑	↑↑↑	[36]
Pathogen Reduction	↑↑	↑	↑↑	↑↑↑	[32,34,35]
Immune Response	↑↑	↑	↑	↑↑↑	[24,39]
Oxidative Stress Reduction	↑↑↑	↑	↑	↑↑↑	[21,24]
Mortality Reduction	↑	↑	↑	↑↑↑	[33,35,39]

The major phytogenic prebiotics and organic acid compounds discussed in this review and their effects on gut health and poultry performance are summarized in Table 4. The increasing interest in multifunctional feed additive systems is mainly due to their ability to provide synergistic effects beyond the level of individual additives. The combined use of Phytogenics, prebiotics and organic acids has complementary mechanisms that enhance the microbial balance, intestinal morphology, nutrient digestibility, immune response and oxidative stability [39]. The synergistic effects are especially relevant in antibiotic-free poultry production systems, where gut health is essential for sustainable productivity.

Table 4 shows comparative data that indicates that Phytogenics, prebiotics and organic acids all play different but complementary functions in poultry gut health. Phytogenics are particularly associated with antimicrobial activity, antioxidant protection and immune modulation through their bioactive compounds [16,23,24]. Prebiotics mainly promotes the beneficial microbial populations and SCFAs production, thus maintaining gut microbial balance and gut health [7,28]. Organic acids mainly contribute to a more favorable GI environment through intestinal acidification, pathogen control and improved nutrient digestibility [3,30].

Across most measures of performance, combined supplementation strategies generally produce greater responses than individual additives. In studies evaluating combination of Phytogenics, prebiotics and organic acids, improvements in growth performance, feed efficacy, intestinal morphology a disease resistance have been reported under both normal and disease challenge conditions [33,34,35,39]. These benefits are likely due to the simultaneous modulation of microbial population, digestive process, epithelial integrity and host immune responses [3,12,14,30,36]. Overall these results support the use of integrated feed additive programs as a practical strategy to maintain gut health and productivity [40]. Further studies should focus on identifying optimal combinations, dose-response relationships and mechanisms of interaction under commercial production. Such information will be essential for developing precision feeding strategies which will maximize both biological and economic returns.

Practical Application in Commercial Poultry Production

Phytogenics, prebiotics, and organic acids are biologically functional and practical in modern poultry production systems as these additives directly address several major challenges [3,30]. They have the ability to promote a healthier gut environment, maintain microbial balance and enhance physiological resilience, which makes them especially useful under commercial conditions where birds are exposed to multiple environmental and disease-related stressors [5,29].

1. Heat Stress Management

Heat stress is one of the major constraints to poultry productivity worldwide and is associated with oxidative stress, intestinal barrier dysfunction, immune suppression and reduced growth [29]. Phytogenic compounds can help to neutralize ROS and promote the endogenous antioxidant defense systems to reduce cellular damage under heat stress, owing to their high natural antioxidant activity [21,24]. High environmental temperatures can disrupt intestinal integrity and microbial stability, which are often maintained by prebiotics and organic acids [7,32].

2. Coccidiosis and Enteric Diseases

Enteric disease such as coccidiosis and necrotic enteritis, still results in considerable economic loss to poultry production through reduced growth, impaired nutrient absorption and increased mortality [37,38]. Nutritional additives that enhance gut resilience may help reduce the severity of gut damage associated with these diseases. An improved microbial balance strengthened epithelial integrity and more robust immune responses enhance the resistance to pathogen colonization and disease-associated dysbiosis [10,38,39].

3. Support for Antibiotic-free Production Systems

The global reduction of AGP usage has accelerated the implementation of nutritional strategies that can sustain productivity with reduced dependence on antibiotics [2,3]. Phytogenics, prebiotics, and organic acids have become an essential part of antibiotic-free production programs as they improve gut functionality through several complementary mechanisms beyond direct antimicrobial action [13,30]. Incorporation into feeding programs supports animal health and consumer interest in sustainable poultry products [40].

4. Economic benefits for Commercial Producers

Feed accounts for approximately 80-70% of total poultry production costs, improving feed efficiency one of the most important determinants of farm profitability [1]. From the production perspective, improvements in feed efficiency often have a greater economic impact than improvements in growth rate alone because feed represents the largest operating cost in poultry production [1]. These feed additives may improve FCR, body weight gain, mortality rate and production efficiency by enhancing nutrient utilization, decreasing losses due to diseases and improving intestinal functionality [3,11,35]. Multifunctional feed additives are thus increasingly viewed as economically viable tools to improve profitability in modern poultry enterprises [40].

While practical application of these additives continues to expand, economic considerations and variability in field responses remain important challenges. For example, Mincheva et al.,(2024) observed that diets performance was enhanced by diets supplemented with some herbs and their essential oils, with good economic return. Similar findings have been reported for phytogenic and organic acid-based feeding strategies, where improved profitability was linked to enhanced feed conversion and improved flock health [39]. The cost-effectiveness of feed additive programs may vary among production systems, ingredient prices, disease pressure and management conditions. Therefore, further large-scale commercial studies are needed to validate research findings and establish economically optimized feeding strategies for different poultry production environments.

Future Perspectives

Despite the significant progress in understanding the role of feed additives in poultry gut health, there are still significant knowledge gaps in relation to optimal combination, long term effects, microbiome interactions and responses under different commercial conditions. Addressing these limitations will require a multidisciplinary approach that combines nutrition, microbiology, immunology, molecular biology, and data-driven technologies to improve the precision and consistency of feed additive application.

The research on feed additives promoting gut health is fast evolving and future developments are expected to focus on precision-based nutritional approaches optimizing intestinal function based on the specific needs of individual production systems [10,29]. The progress in microbiome science is leading to a better understanding of host-microbial interactions and allowing for more specific dietary interventions [28]. A promising approach is the design of microbiome-driven feeding strategies, where feed formulations are tailored according to the microbial composition and functional characteristics of poultry [10]. Such approaches may improve the consistency and predictability of responses to feed additives under different production conditions.

Encapsulation technologies are also an important area of innovation since they can protect sensitive bioactive compounds from degradation during feed processing and ensure their targeted release in specific regions of the GIT [35]. Improved delivery systems of phytogenic compounds, and organic acids can lead to better efficacy and reduced inclusion levels for desired responses. Further investigation will likely also be on advanced multifunctional formulations combining Phytogenics, prebiotics and organic acids within a single nutritional approach [39]. Synbiotic-phytogenic systems may provide broader biological benefits by simultaneously promoting microbial balance, immune competence, oxidative stability and nutrient utilization.

The use of multi-omics technologies (genomics, transcriptomics, metabolomics and microbiomics) will improve understanding of the effects of feed additives on host physiology and microbial ecosystems at the molecular level [10]. These technologies may be useful in identification of biomarkers associated with gut health and production efficiency, enabling a more precise evaluation of nutritional interventions. Such innovations are expected to play an increasing role in the future development of sustainable, efficient and antibiotic-free poultry production systems.

Conclusion

The poultry industry is undergoing a significant transition toward antibiotic-free production systems driven by concerns over antimicrobial resistance, regulatory restrictions and increasing consumer demand for safe and sustainable poultry products. In this changing production landscape, gut health has become one of the most important factors influencing bird performance, health welfare and profitability. GIT health is crucial not only for optimal digestion and absorption of nutrients but also for immune competence, physiological resilience and a critical line of defense against pathogens.

The evidence presented in this paper suggests that phytogenic feed additives, prebiotics, and organic acids each have a role in gut health through different but complementary mechanisms. Phytogenic compounds possess antimicrobial, antioxidant, anti-inflammatory and digestive-supporting properties. Prebiotics promote the growth of beneficial microorganisms in a selective manner and increase the production of SCFAs. Organic acids acidify the gut and suppress pathogens and promote healthy intestinal conditions by supporting nutrient utilization and gut integrity. Each additive alone can improve the performance of poultry, but their greatest value appears to come from their combined use, when several biological pathways are targeted at the same time.

One of the key themes that is emerging from current research is that gut health is no longer the result of a single nutritional intervention. Rather, it results from the complex interplay between the intestinal microbiota, epithelial barrier function, immune responses, digestive processes and oxidative status. Feed additives that act via several of these systems in parallel are more likely to provide consistent and sustainable improvements under commercial production conditions. Several studies have reported improved growth performance, intestinal morphology and disease resistance when Phytogenics, prebiotics and organic acids were used in combination rather than individually [35,39].

These multifunctional feed additives provide valuable tools from a practical point of view to help address many of the challenges faced by today's poultry producers including enteric diseases, environmental stress, reduced antibiotic use and increased pressure to improve production efficiency. Ultimately improvements in FCR, nutrient utilization, intestinal integrity, immune competence and disease resistance result in better economic returns and more sustainable production practices.

In general, successful replacement of AGPs will depend on a gut health strategy combining complementary nutritional interventions, rather than on a single alternative. Phytogenics, prebiotics, and organic acids are a promising basis to improve poultry health, productivity and sustainability in the coming years, as they simultaneously support microbial balance, intestinal integrity, immune function and nutrient utilization. Future poultry feeding strategies will likely depend on integrated gut-health programs that combine complementary nutritional technologies rather than relying on a single additive approach. The strategic use of multifunctional feed additive systems therefore represents a practical pathway toward sustainable, resilient and economically viable poultry production.

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Conflict of Interest

Several authors are affiliated with Becarre Speciality Ingredients Pvt Ltd, a company engaged in the development of nutraceutical and feed additive products, including products related to the subject matter discussed in this review. The authors declare that this affiliation did not influence the selection, interpretation, or presentation of the literature reviewed. The authors declare no other conflict of interest.

Author Contributions

Conceptualization, P.B. and C.P.S.; Literature search, data curation and writing original draft preparation, R.C.M.; critical review, scientific editing and manuscript refinement, C.P.S, P.P.; veterinary and technical expertise. B.E.; supervision, project administration and overall coordination, P.B.; All authors critically reviewed the manuscript, approved the final version and agreed to the published version of the manuscript.

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