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Prebiotics in poultry production: mechanisms of action, gut microbiota modulation, health benefits, and potential alternatives to antibiotic growth promoters

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A B S T R A C T

The poultry industry is increasingly challenged by antimicrobial resistance, rising feed costs, and the growing demand for sustainable production systems, accelerating the search for effective alternatives to antibiotic growth promoters (AGPs). This narrative review synthesizes current evidence on the classification, mechanisms of action, and practical applications of prebiotics in poultry nutrition. Relevant literature published in peer-reviewed journals was systematically identified through major scientific databases using predefined search terms, with studies selected based on their relevance to poultry production, gut health, immune function, and growth performance. Prebiotics, including fructans (inulin and fructooligosaccharides), galacto-oligosaccharides, mannan-oligosaccharides, resistant starch, lactulose, and other functional oligosaccharides, have demonstrated considerable potential to beneficially modulate intestinal microbiota and improve host physiology. Their beneficial effects are primarily mediated through the selective stimulation of beneficial microorganisms, enhanced short-chain fatty acid production, improved intestinal barrier integrity, immune modulation, and increased nutrient digestibility. These mechanisms contribute to improved growth performance, feed efficiency, disease resistance, and overall poultry health. However, inconsistent responses among studies indicate that the efficacy of prebiotics is influenced by multiple factors, including prebiotic type and dosage, bird genotype and age, dietary composition, management practices, and environmental conditions. This review critically evaluates these variations, identifies current knowledge gaps, and highlights emerging opportunities for precision prebiotic supplementation and microbiome-based nutritional strategies. Overall, prebiotics represent promising functional feed additives for reducing antibiotic dependency and supporting sustainable poultry production, although further well-designed studies under commercial production conditions are required to optimize their practical application.

Keywords: feed additives, growth performance, intestinal micro-biota, poultry, prebiotics

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1. INTRODUCTION

Poultry production has become one of the fastest-growing sectors of animal agriculture due to its high efficiency in converting feed into high-quality animal protein. Poultry meat is widely consumed because of its favorable nutritional profile, including lower levels of saturated fat compared with many red meats, affordability, and availability (Jilo & Hasan, 2022). However, the rapid expansion of the poultry industry has created several challenges, including maintaining productivity, controlling intestinal disorders, reducing production costs, and ensuring food safety (Efremova, 2018).

For many decades, AGPs have been used in poultry production to enhance growth performance, improve feed efficiency, and reduce bacterial challenges. However, the extensive and prolonged use of antibiotics has contributed to the emergence of antimicrobial-resistant microorganisms, which represents a major concern for animal production, public health, and environmental sustainability (Reznichenko et al., 2021). Therefore, global efforts have focused on identifying safe and effective alternatives to AGPs that can maintain productivity while minimizing antimicrobial resistance risks (Solis-Cruz et al., 2019).

Among various functional feed additives, prebiotics have received increasing attention due to their ability to regulate intestinal microbial ecosystems and improve host health. Prebiotics are non-digestible compounds that are selectively utilized by beneficial microorganisms in the gastrointestinal tract, resulting in the production of bioactive metabolites, particularly short-chain fatty acids (SCFAs) (Gibson et al., 2017; Bevilacqua et al., 2024). These metabolites contribute to intestinal homeostasis by influencing microbial composition, intestinal barrier integrity, nutrient utilization, and immune regulation (Xia et al., 2024).

A wide range of prebiotic compounds, including fructans (inulin and fructooligosaccharides), galacto-oligosaccharides (GOS), mannan-oligosaccharides (MOS), resistant starch, lactulose, and pectic oligosaccharides, have been investigated in poultry nutrition. Previous studies have demonstrated that dietary prebiotics can enhance beneficial microbial populations, increase SCFA production, improve intestinal morphology, and support immune function in poultry (Abd El-Hack et al., 2022; Ali et al., 2023). For example, mannan-oligosaccharides and β-glucans have been associated with improved growth performance and immune responses, particularly under environmental stress conditions such as heat stress (Sayed et al., 2023).

Despite the increasing number of studies investigating prebiotics in poultry, their effectiveness is not always consistent. Differences in outcomes may be related to prebiotic type, chemical structure, inclusion level, bird species, age, dietary composition, and environmental conditions (Johnson et al., 2025). Moreover, although several studies have evaluated individual prebiotic compounds, a comprehensive understanding of their mechanisms of action, comparative effectiveness, and practical application in commercial poultry production remains limited.

Therefore, this review aims to provide an updated overview of prebiotics in poultry nutrition, focusing on their classification, biological mechanisms, effects on gut microbiota, nutrient utilization, immune function, production performance, and their potential role as alternatives to antibiotic growth promoters.

2. METHODOLOGY

This review was conducted as a narrative review to evaluate the current knowledge regarding the application, mechanisms, and effects of prebiotics in poultry production. A comprehensive literature search was performed using major scientific databases, including PubMed, ScienceDirect, Scopus, Web of Science, and Google Scholar, to identify relevant studies related to dietary prebiotics and their effects on poultry health and productivity. The literature search was conducted using combinations of the following keywords and Boolean operators: different types of prebiotics and

poultry growth performance, gut microbiota intestinal health, immune response and antibiotic alternatives.

Studies were selected based on predefined inclusion criteria, including: (1) research conducted on poultry species, (2) evaluation of dietary prebiotic supplementation, (3) investigation of outcomes related to growth performance, intestinal microbiota, nutrient utilization, immune responses, disease resistance, or product quality, and (4) publication in peer-reviewed scientific journals. Recent studies published mainly between 2015 and 2026 were prioritized to incorporate current advances in prebiotic research.

Studies were excluded when they focused exclusively on non-poultry species, human nutrition, non-dietary applications of prebiotics, or lacked sufficient information regarding prebiotic type, dosage, or biological outcomes. Relevant information, including prebiotic source, supplementation level, bird species, experimental duration, and reported effects, was extracted and systematically organized. Finally, the collected information was qualitatively analyzed to identify major trends, biological mechanisms, research limitations, and future opportunities regarding the use of prebiotics as functional feed additives and alternatives to antibiotic growth promoters in sustainable poultry production.

3. Classification and Sources of Prebiotics Used in Poultry Nutrition

Prebiotics are non-digestible functional feed ingredients that are selectively utilized by beneficial intestinal microorganisms, resulting in improved microbial balance, enhanced intestinal function, and better physiological responses in poultry. Based on their chemical structure and biological activity, prebiotics used in poultry nutrition are mainly classified into fructans (inulin and fructooligosaccharides, FOS), galacto-oligosaccharides (GOS), mannan-oligosaccharides (MOS), xylo-oligosaccharides (XOS), isomalto-oligosaccharides (IMO), resistant starch (RS), lactulose, pectic oligosaccharides (POS), β-glucans, and other non-digestible oligosaccharides (Gibson et al., 2017; Abd El-Hack et al., 2022).

Fructans, including inulin and fructooligosaccharides, are among the most extensively studied prebiotics in poultry nutrition. These carbohydrate compounds are fermented by intestinal microorganisms and promote the production of short-chain fatty acids (SCFAs), which contribute to intestinal microbial balance and improved gut function (Franco-Robles & López, 2015; Hernández & Plou, 2023). Supplementation of fructan-based prebiotics has been associated with improved intestinal microbiota composition and enhanced nutrient utilization in poultry (Ferrocino et al., 2023).

Galacto-oligosaccharides (GOS) are another important group of prebiotics produced through enzymatic conversion of lactose. GOS selectively stimulate beneficial bacteria and contribute to improved intestinal barrier function and microbial stability (Vera et al., 2016; Ambrogi et al., 2023). Recent studies have indicated that GOS supplementation can support intestinal health and increase SCFA production in poultry (Mei et al., 2022).

Mannan-oligosaccharides (MOS), mainly derived from yeast cell walls, are widely used as functional feed additives in poultry production. MOS can modulate intestinal microbial populations, reduce pathogen colonization, and improve growth performance and immune responses. Previous studies have demonstrated beneficial effects of MOS supplementation on broiler performance and intestinal health (Ali et al., 2023; Nawaz et al., 2024).

Resistant starch (RS) is considered an important prebiotic substrate because it escapes digestion in the upper gastrointestinal tract and reaches the hindgut, where it is fermented by microorganisms into SCFAs, particularly butyrate. In poultry, resistant starch has been associated with improved gut microbial activity, intestinal health, and metabolic regulation (Tan et al., 2021; Hussain et al., 2025).

Other prebiotic compounds, including xylo-oligosaccharides (XOS), isomalto-oligosaccharides (IMO), lactulose, pectic oligosaccharides (POS), and β-glucans, have also received increasing

attention in poultry nutrition. XOS and IMO influence beneficial microbial populations and intestinal fermentation, whereas lactulose contributes to microbial balance and digestive health (Morgan et al., 2022; Mookiah et al., 2014; Sizova et al., 2025). Pectic oligosaccharides derived from plant materials represent emerging prebiotic compounds with potential roles in regulating intestinal microorganisms and supporting immune responses (Singh et al., 2020; Tang et al., 2025). β-glucans, often obtained from yeast sources, have demonstrated immunomodulatory and microbiota-regulating properties in poultry (Sayed et al., 2023).

Although different prebiotic classes vary in their chemical structures and biological functions, their effectiveness in poultry depends on several factors, including molecular characteristics, supplementation level, bird species, age, dietary composition, and environmental conditions. Therefore, understanding the specific properties of each prebiotic category is essential for optimizing their application in sustainable poultry production.

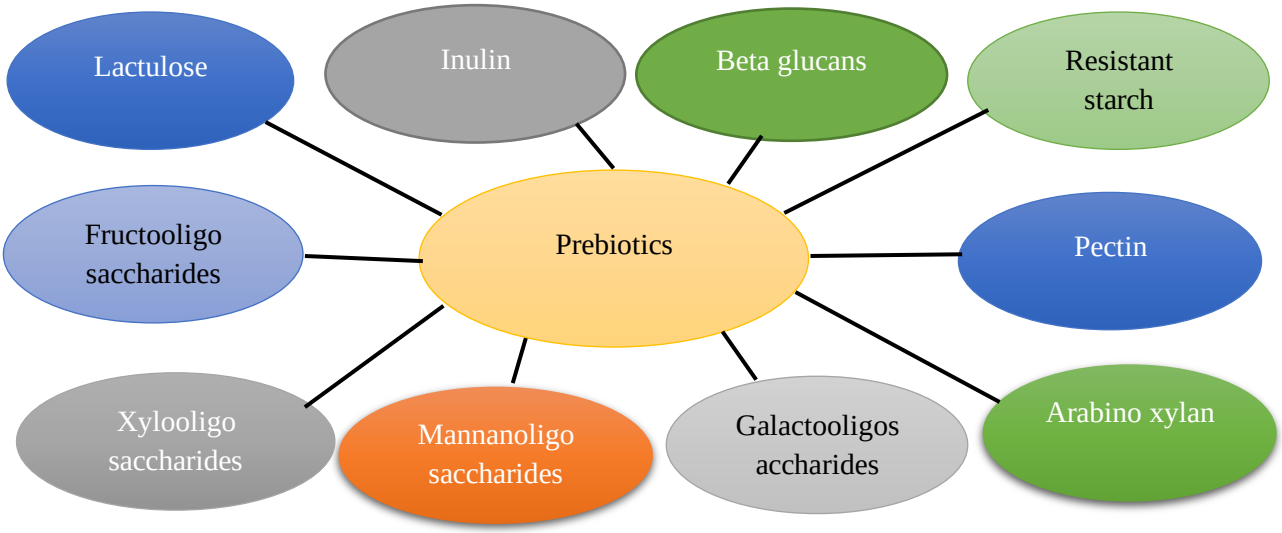


Figure 1. Different types of prebiotics (Obayomi et al., 2024).

4. Mechanisms of Action of Prebiotics in Poultry

Prebiotics exert their beneficial effects in poultry through multiple interconnected mechanisms, primarily involving the regulation of intestinal microbiota, production of microbial metabolites, enhancement of intestinal barrier function, modulation of immune responses, and inhibition of pathogenic microorganisms. The biological responses induced by prebiotics depend largely on their chemical structure, fermentation characteristics, and interaction with the gastrointestinal microbiome.

4.1. Modulation of Intestinal Microbiota

One of the primary mechanisms of prebiotics is the selective stimulation of beneficial intestinal microorganisms, particularly *Lactobacillus* and *Bifidobacterium*, while limiting the proliferation of harmful bacteria. Because poultry cannot enzymatically digest most prebiotic compounds, these substrates reach the lower gastrointestinal tract, where they are selectively fermented by resident microorganisms. This microbial regulation contributes to improved intestinal microbial balance and enhanced gut ecosystem stability (Gibson et al., 2017; Xia et al., 2024).

Supplementation of prebiotics such as fructooligosaccharides, mannan-oligosaccharides, and galacto-oligosaccharides has been reported to increase beneficial bacterial populations and reduce pathogenic microorganisms, including *Salmonella* and *Escherichia coli*, in poultry (Pourabedin & Zhao, 2015; Micciche et al., 2018). The ability of prebiotics to promote favorable microbial communities represents a key mechanism underlying their role as alternatives to antibiotic growth promoters. The application of prebiotics in poultry production represents a scientifically robust strategy to address the global imperative of reducing antibiotic growth promoters (AGPs) while maintaining animal

health, performance, and food safety. Their multifaceted mechanisms of action are not isolated effects but interconnected biological processes that collectively enhance gut ecosystem homeostasis. The primary mechanism begins with the selective modulation of the intestinal microbiota. Prebiotics, defined as non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of beneficial bacteria in the colon, serve as a substrate for specific commensal microbes such as *Bifidobacterium* and *Lactobacillus* species (Yue et al., 2025).

4.2. Production of Short-Chain Fatty Acids and Regulation of Intestinal Environment

The fermentation of prebiotics by intestinal microorganisms produces short-chain fatty acids (SCFAs), including acetate, propionate, and butyrate. These metabolites play important roles in maintaining intestinal health by lowering intestinal pH, enhancing epithelial cell energy supply, and creating unfavorable conditions for pathogenic bacterial growth (Morgan, 2023). Butyrate, in particular, serves as an important energy source for intestinal epithelial cells and contributes to maintaining intestinal integrity. Increased SCFA production following prebiotic supplementation has been associated with improved gut function and reduced pathogen colonization in poultry (Tan et al., 2021; Al-baadani et al., 2025). Second, and perhaps more importantly, SCFAs act as key signaling molecules and energy sources for the host. Butyrate, in particular, is the preferred energy source for colonocytes, the cells lining the intestinal tract. Its provision is essential for maintaining the health, proliferation, and functional integrity of these epithelial cells (Ducatelle et al., 2023)6. Furthermore, SCFAs like butyrate and propionate can modulate host gene expression through mechanisms such as histone deacetylase (HDAC) inhibition and activation of G-protein-coupled receptors (GPCRs), influencing a wide array of cellular processes from metabolism to inflammation (Oke et al., 2025)7.

4.3. Improvement of Intestinal Barrier Integrity and Morphology

Prebiotics improve intestinal structure by influencing villus development, crypt depth, and epithelial integrity. Enhanced villus height and increased villus height-to-crypt depth ratio indicate improved absorptive capacity and nutrient utilization. These structural improvements facilitate better digestion and absorption of nutrients while strengthening protection against intestinal challenges (Rehman et al., 2020; Ali et al., 2023). Furthermore, prebiotic-induced changes in microbial metabolites can enhance intestinal barrier function by supporting tight junction integrity and reducing intestinal inflammation. These effects contribute to improved nutrient availability and overall poultry performance. This metabolic support directly translates into the improvement of intestinal barrier integrity and morphology. A healthy, well-nourished epithelium forms a tight, impermeable barrier against the translocation of harmful bacteria, toxins, and undigested antigens—a condition often referred to as "leaky gut" when compromised (Sayed et al., 2023). Prebiotic supplementation has been consistently shown to enhance key morphological features of the gut, including increased villi height and a higher villi height-to-crypt depth ratio in the small intestine (Yaqoob et al., 2021). These structural improvements significantly expand the absorptive surface area of the gut, which is fundamental for efficient nutrient uptake. Concurrently, prebiotics strengthen the barrier at a molecular level by upregulating the expression of tight junction proteins (e.g., claudins, occludin, ZO-1) that seal the paracellular spaces between epithelial cells, thereby reinforcing the physical barrier (Teng & Kim, 2018).

4.4. Immune Modulation

Prebiotics influence both innate and adaptive immune responses through interactions between intestinal microorganisms and host immune cells. By promoting beneficial bacteria and increasing microbial metabolites, prebiotics enhance immune system development and improve resistance against environmental and pathogenic challenges. Dietary supplementation with MOS, β-glucans, and other oligosaccharides has been associated with increased immunoglobulin production, improved immune organ development, and enhanced disease resistance in poultry (Sayed et al., 2023; Bayat et al., 2025). These immunomodulatory effects make prebiotics valuable components of antibiotic-free

poultry production systems. The immune system is profoundly intertwined with gut health, and prebiotics exert significant immunomodulatory effects. They do not simply stimulate the immune system in a non-specific manner; rather, they help calibrate it towards a state of balanced responsiveness. By promoting a healthy microbiota and providing SCFAs, prebiotics support the development and function of regulatory T cells (Tregs), which are crucial for maintaining immune tolerance to commensal bacteria and dietary antigens while preventing excessive inflammatory responses (Swaggerty et al., 2022). This is achieved through SCFA-mediated signaling that promotes an anti-inflammatory milieu in the gut-associated lymphoid tissue (GALT). Additionally, prebiotics can enhance the production of secretory immunoglobulin A (sIgA), a key antibody that provides immune exclusion by trapping pathogens and toxins in the mucus layer, preventing their attachment to the epithelium (Tellez-Isaias et al., 2024). This refined immune status makes birds more resilient to infections and environmental stressors, such as heat stress, which can otherwise lead to immunosuppression (Sayed et al., 2023).

4.5. Inhibition of Pathogenic Microorganisms

Prebiotics can reduce pathogenic bacterial colonization through several mechanisms, including competitive exclusion, alteration of intestinal pH, increased SCFA production, and enhancement of mucosal defense. Certain prebiotics, particularly MOS, can bind bacterial surface structures and reduce attachment of pathogens to intestinal epithelial cells. Studies have demonstrated that prebiotic supplementation can decrease intestinal *Salmonella* populations and improve microbial safety in poultry products (Micciche et al., 2018; Abd El-Hack et al., 2022). Therefore, prebiotics provide a multifaceted approach for controlling intestinal pathogens without contributing to antimicrobial resistance. The inhibition of pathogenic microorganisms is a synergistic outcome of several aforementioned mechanisms. The lowered pH from SCFA production creates a direct chemical barrier. The competitive exclusion by a thriving population of beneficial bacteria limits the ecological niche available for pathogens. Moreover, some beneficial bacteria stimulated by prebiotics can produce their own antimicrobial substances, such as bacteriocins, which directly kill or inhibit competing pathogenic strains (Ashfaq et al., 2020). This multi-pronged approach makes it significantly harder for pathogens like *Salmonella* to establish a foothold and proliferate within the avian gastrointestinal tract, thereby reducing the risk of both clinical disease in the bird and the potential for foodborne pathogen contamination in the final product (Abd El-Hack et al., 2022).

4.6. Enhancement of Nutrient Utilization and Metabolism

By improving intestinal morphology, microbial balance, and digestive processes, prebiotics contribute to enhanced nutrient utilization. Increased populations of beneficial microorganisms support nutrient metabolism and improve the availability of minerals and other dietary components. Previous studies have reported that prebiotics such as MOS, β-glucans, and inulin improve nutrient digestibility, nitrogen utilization, and metabolic efficiency in poultry (Leone & Ferrante, 2023; Ferrocino et al., 2023). Finally, the enhancement of nutrient utilization and metabolism is the ultimate driver of improved growth performance, which is the primary economic goal in poultry production. The improved gut morphology (taller villi, greater surface area) directly facilitates more efficient digestion and absorption of nutrients from the feed (Yaqoob et al., 2021). A stable, healthy gut environment also reduces the energetic cost associated with chronic low-grade inflammation and immune activation, allowing more dietary energy to be directed towards growth and muscle deposition (Yadav & Jha, 2019). Furthermore, a balanced microbiota contributes to the host's metabolic capacity by synthesizing certain vitamins (e.g., B vitamins, vitamin K) and aiding in the breakdown of complex dietary components that the host enzymes cannot fully digest on their own (Fathima et al., 2022). Together, these mechanisms allow prebiotic-fed birds to achieve feed conversion ratios and weight gains that can rival those previously obtained with AGPs, making them a viable and sustainable cornerstone of modern, antibiotic-free poultry production systems (Adhikari & Kim, 2017; Yang et al., 2025).

5. Effects of Prebiotics on Poultry Production

Prebiotics have gained increasing attention in poultry nutrition because of their ability to improve production efficiency, maintain intestinal health, and support disease resistance without contributing to antimicrobial resistance. Their beneficial effects are mainly associated with modulation of intestinal microbiota, increased production of microbial metabolites, improved nutrient utilization, and regulation of immune responses. However, the effectiveness of prebiotics depends on factors such as prebiotic type, inclusion level, bird species, age, dietary composition, and environmental conditions (Abd El-Hack et al., 2022; Bevilacqua et al., 2024).

5.1. Improvement of Growth Performance and Feed Efficiency

Growth performance and feed efficiency are among the most important indicators for evaluating the effectiveness of functional feed additives in poultry production. Several studies have demonstrated that prebiotic supplementation can improve body weight gain (BWG) and feed conversion ratio (FCR) by creating a favorable intestinal environment and enhancing nutrient utilization. Mannan-oligosaccharides (MOS), fructooligosaccharides (FOS), and other oligosaccharides have been reported to improve broiler growth performance through stimulation of beneficial microorganisms and reduction of intestinal microbial disturbances (Ali et al., 2023; Nawaz et al., 2024). MOS supplementation has shown positive effects on body weight gain and feed efficiency, with responses comparable to antibiotic growth promoters, indicating its potential as a natural alternative to AGPs (Ali et al., 2023). Furthermore, prebiotic supplementation may improve performance under environmental stress conditions. Dietary administration of MOS and β-glucans in heat-stressed broilers enhanced growth rate, maintained beneficial microbial populations, and improved immune responses, suggesting that prebiotics can support production stability under challenging conditions (Sayed et al., 2023). Similarly, prebiotic supplementation during heat stress has been associated with improved growth performance and feed utilization efficiency (Awad et al., 2020).

5.2. Enhancement of Nutrient Digestibility and Utilization

Prebiotics improve nutrient utilization by modifying intestinal microbial activity, enhancing intestinal morphology, and increasing the efficiency of nutrient absorption. The fermentation products generated by beneficial bacteria contribute to improved digestive processes and nutrient availability. Supplementation with MOS and β-glucans has been shown to enhance ileal nutrient digestion and nitrogen utilization by improving intestinal structure and microbial activity (Leone & Ferrante, 2023). Inulin supplementation has also been reported to increase intestinal microbial functional capacity, which may contribute to improved nutrient uptake and gut health in broilers (Ferrocino et al., 2023).

In addition, prebiotics may influence mineral utilization. Wheat-derived prebiotic compounds have been associated with improved iron status through changes in intestinal conditions and enhanced mineral availability (Tako et al., 2014). Similarly, prebiotic supplementation has been reported to increase copper utilization in poultry (Leblebicier & Aydoğan, 2018).

5.3. Improvement of Gut Health and Intestinal Microbial Balance

The gastrointestinal tract plays a central role in poultry productivity, and maintaining microbial balance is essential for efficient digestion, nutrient absorption, and disease prevention. Prebiotics regulate intestinal microbiota by selectively promoting beneficial bacteria and suppressing harmful microorganisms. Dietary supplementation with FOS, MOS, and other oligosaccharides increases beneficial bacterial populations, particularly *Lactobacillus* and *Bifidobacterium*, while reducing pathogenic bacteria. These microbial changes enhance SCFA production, decrease intestinal pH, and create unfavorable conditions for pathogen growth (Pourabedin & Zhao, 2015; Morgan, 2023). Prebiotics also improve intestinal morphology by increasing villus height and enhancing the villus height-to-crypt depth ratio, which contributes to greater absorptive capacity and intestinal integrity (Rehman et al., 2020; Ali et al., 2023). These structural improvements support better nutrient utilization and overall production performance.

5.4. Enhancement of Immune Function and Disease Resistance

Prebiotics influence poultry immunity through interactions between intestinal microorganisms and host immune systems. By improving microbial balance and increasing beneficial microbial metabolites, prebiotics enhance both intestinal and systemic immune responses. Supplementation with MOS, β-glucans, and other prebiotic compounds has been associated with increased immunoglobulin levels, improved immune organ development, and enhanced resistance against infectious challenges in poultry (Sayed et al., 2023; Bayat et al., 2025). These effects demonstrate the potential of prebiotics to strengthen natural defense mechanisms in antibiotic-free production systems.

5.5. Reduction of Antibiotic Dependency

The global increase in antimicrobial resistance has accelerated the search for alternatives to antibiotic growth promoters in poultry production. Prebiotics provide a promising strategy because they improve intestinal health through ecological regulation rather than direct bacterial elimination. Unlike antibiotics, prebiotics selectively stimulate beneficial microorganisms and enhance intestinal conditions that limit pathogen development. This mechanism reduces pathogen pressure while maintaining microbial diversity within the gastrointestinal tract (Ricke, 2018; Solis-Cruz et al., 2019). Previous studies have reported that prebiotic supplementation can improve productivity and disease resistance while reducing the need for antibiotics in poultry production systems (Andrew Selaledi et al., 2020). Furthermore, agricultural and industrial by-product-derived prebiotics have been proposed as sustainable solutions for improving animal health and reducing dependence on antimicrobial agents (Ravanal et al., 2025).

5.6. Effects on Poultry Product Quality

In addition to improving growth and health parameters, prebiotics may influence poultry product quality through their effects on nutrient metabolism, intestinal function, and lipid regulation. Dietary inulin supplementation has been reported to maintain favorable meat physicochemical properties while providing a potential alternative to antibiotic growth promoters (Guaragni et al., 2020). Moreover, improvements in intestinal health and nutrient utilization associated with prebiotic supplementation may contribute indirectly to enhanced carcass characteristics and production quality (Tavaniello et al., 2018).

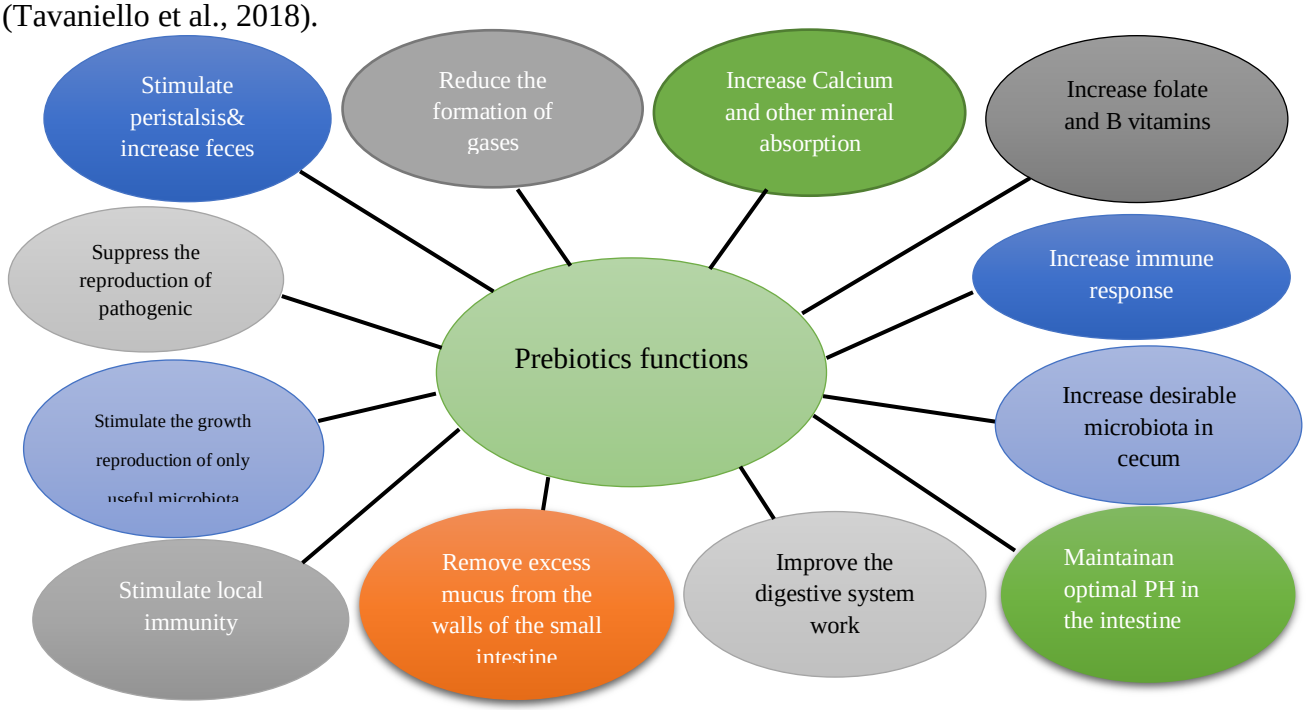


Figure 2. The main functions of prebiotics in poultry.

Table 1 Effects of dietary supplementation with different types of prebiotics on poultry gut microbiota and SCFAs concentrations.

Effect	Name of Prebiotics	Amount (mg/kg)	Species	Age	Reference
Feeding 10,000 mg/kg FOS led to a reduction in the viable count of *Salmonella enteritidis.*	Fructo oligosaccharides	0,5000,10000 (mg/kg) of feed	Layer White Leghorn hens	60–65to weeks	Adhikari et al.,2018
Feeding 2,000 mg/kg resulted in increased ileal protein digestibility	Xylo-oligosaccharides	0, 50, 2000 (mg/kg)	Layer	39–47 weeks	Morgan et al.,2022
Increased acetate with 3500 mg/kg SBO.	Soybean oligosaccharides	3500,5000 (mg/kg)	Broiler	0–42days	Liu et al.,2021
Reduced pH of ileal and cecal, especially at the highest dose, without changing their concentration.	Fructo oligosaccharides	2000 (mg/kg)	Turkeys	0-56days	Juśkiewicz et al.,2006
Increased caecal *lactobacilli* and *bifidobacteria*, reduced *E. coli*, and elevated caecal VFA and non-VFA concentrations	isomalto-oligosaccharides +Probiotics+ Symbiotics	5000 IMO (mg/kg)	Broiler-(Ross 308)	0–42days	Mookiah et al.,2014
Increased *Lactobacillus* levels accompanied by reduced total coliforms and pH, along with improved ileum morphology.	Nutrition yeast (NY)	2000 (mg/kg)	Broiler-(Ross 308)	0–42days	Bayat et al.,2025
Enhanced propionic acid production with XOS	Xylo-oligosaccharides	0.250	Broiler- Ross	0–21days	Craig et al.,2020

6. Current Challenges and Research Gaps

Although prebiotics have demonstrated promising effects in poultry production, several challenges remain regarding their consistent application under commercial conditions. Variations in experimental outcomes among studies indicate that the effectiveness of prebiotics is influenced by multiple factors, including chemical structure, molecular size, degree of polymerization, inclusion level, bird genotype, age, diet composition, and environmental conditions (Gibson et al., 2017; Abd El-Hack et al., 2022).

One of the major challenges is the variation in responses among different prebiotic sources. Different prebiotic compounds do not produce identical biological effects because their fermentation characteristics and interactions with intestinal microorganisms vary. For example, MOS, FOS, GOS, and resistant starch may influence microbial populations through different pathways, making it difficult to establish universal recommendations regarding the most effective prebiotic type or dosage for specific poultry production systems (Pourabedin & Zhao, 2015; Bevilacqua et al., 2024).

Another important limitation is the lack of standardized dosage recommendations. Although many studies have reported beneficial effects of prebiotics, supplementation levels differ considerably among experiments. Excessive or insufficient inclusion rates may reduce their effectiveness or fail to produce measurable improvements in poultry performance. Therefore, dose–response studies under

commercial production conditions are required to determine optimal inclusion levels for different poultry categories (Nawaz et al., 2024; Ali et al., 2023).

The complex interaction between prebiotics and intestinal microbiota represents another research challenge. The response of poultry to prebiotic supplementation depends on the existing microbial community, environmental conditions, and host factors. Advances in microbiome analysis have improved understanding of these interactions; however, further research is needed to identify specific microbial populations responsible for beneficial responses and to develop precision-based prebiotic strategies (Ferrocino et al., 2023; Xia et al., 2024).

The economic feasibility and practical application of prebiotics also require further investigation. Although prebiotics can improve poultry health and productivity, production costs, availability of raw materials, processing methods, and stability during feed manufacturing may affect their commercial adoption. The development of cost-effective prebiotic sources from agricultural and industrial by-products may provide sustainable solutions for large-scale poultry production (Ravanal et al., 2025).

Furthermore, limited information is available regarding the long-term effects of continuous prebiotic supplementation on poultry health, microbiome stability, and product quality. Most current studies focus on short-term experimental periods, whereas commercial poultry production requires evaluation throughout the entire production cycle. Long-term investigations are necessary to confirm safety, consistency, and economic benefits.

Finally, future studies should focus on precision nutrition approaches, including the integration of prebiotics with microbiome-based technologies, probiotics, enzymes, and other functional feed additives. Such approaches may improve predictability and maximize the benefits of prebiotics as sustainable alternatives to antibiotic growth promoters in poultry production systems (Sayed et al., 2023; Ravanal et al., 2025).

7. Future Perspectives and Research Directions

The increasing demand for sustainable poultry production systems and the global movement toward reducing antibiotic use have created new opportunities for the application of prebiotics as functional feed additives. Although prebiotics have demonstrated beneficial effects on poultry performance, intestinal health, and immunity, future research should focus on improving their predictability, efficiency, and practical application under commercial production conditions.

One important research direction is the development of precision prebiotic strategies. Since different prebiotic compounds produce variable responses depending on their chemical structure, fermentation characteristics, and interaction with intestinal microorganisms, future studies should identify specific prebiotics that target particular microbial populations and production objectives. The integration of microbiome sequencing and advanced bioinformatics approaches may help determine the most effective prebiotic–microbiota interactions and support personalized nutritional strategies for different poultry categories (Ferrocino et al., 2023; Xia et al., 2024).

Another promising area is the investigation of combined applications of prebiotics with other functional feed additives, including probiotics, enzymes, phytogenic compounds, and organic acids. These combinations may produce synergistic effects by simultaneously improving microbial balance, nutrient utilization, and immune responses. However, further research is required to determine optimal combinations, inclusion levels, and practical benefits under field conditions (Sayed et al., 2023; Ravanal et al., 2025).

Future studies should also emphasize the development of cost-effective and sustainable prebiotic sources. Agricultural residues and industrial by-products may represent valuable sources of novel prebiotic compounds; however, their extraction methods, consistency, safety, and biological effectiveness require further evaluation before large-scale application in poultry feed production (Ravanal et al., 2025).

The use of advanced analytical technologies, including metagenomics, metabolomics, and molecular approaches, will provide deeper insights into the mechanisms through which prebiotics influence host–microbiota interactions. These approaches may facilitate the identification of microbial biomarkers associated with improved growth performance, disease resistance, and feed efficiency.

Furthermore, future research should evaluate the long-term effects of prebiotic supplementation throughout the complete production cycle, including impacts on growth, reproductive performance, product quality, microbiome stability, and economic efficiency. Large-scale commercial trials are necessary to validate experimental findings and determine the feasibility of prebiotics under diverse production systems.

Overall, future advances in prebiotic research should move from general supplementation approaches toward targeted, microbiome-driven nutritional strategies. Such developments will strengthen the role of prebiotics as sustainable alternatives to antibiotic growth promoters and contribute to the advancement of environmentally responsible poultry production systems.

8. CONCLUSION

Prebiotics represent promising functional feed additives for improving the sustainability and efficiency of poultry production systems. Their ability to selectively stimulate beneficial intestinal microorganisms contributes to improved microbial balance, enhanced intestinal function, and better host responses. Different prebiotic classes, including fructans, galacto-oligosaccharides, mannan-oligosaccharides, resistant starch, lactulose, and other oligosaccharides, have demonstrated beneficial effects on poultry performance, nutrient utilization, intestinal integrity, and immune regulation. The beneficial effects of prebiotics are mainly associated with modulation of gut microbiota, increased production of short-chain fatty acids, reduction of intestinal pH, improvement of intestinal morphology, and limitation of pathogenic bacterial colonization. These mechanisms support their potential as alternatives to antibiotic growth promoters by enhancing natural disease resistance and maintaining productivity without increasing antimicrobial resistance risks (Ricke, 2018; Solis-Cruz et al., 2019). However, variations in responses among studies indicate that the effectiveness of prebiotics depends on factors such as compound type, dosage, bird characteristics, dietary composition, and environmental conditions. Therefore, future research should focus on precision-based prebiotic applications, microbiome-driven approaches, long-term safety evaluations, and cost-effective strategies for commercial poultry production. Overall, prebiotics provide a valuable approach for developing antibiotic-free and sustainable poultry production systems. Their integration with advanced nutritional technologies and evidence-based feeding strategies may further enhance their role in improving poultry health, productivity, and environmental sustainability.

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Conflict of Interest
The authors declare no conflict of interest.

Artificial Intelligence (AI) Use Statement
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