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RESEARCH ARTICLE

Targeted Prebiotics in the Control of *Eimeria* spp. to Reduce Concurrent Parasitic Zoonotic Animal Diseases in Poultry

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Abstract

Avian coccidiosis, caused by protozoan parasites of the genus *Eimeria* remains one of the most economically devastating diseases in poultry production worldwide. Traditional methods of control are mostly based on the use of anticoccidial medication and vaccines; nevertheless, the growing development of drug-resistant strains of the parasites and governmental limitations on the usage of chemotherapeutics have initiated the development of alternative methods of control. Because of the rising concern of antimicrobial resistance, there is a need to develop alternative control strategies. There is an emergence of targeted prebiotics as promising functional feed additives that can be used to regulate the microbiota in the intestine, improve the strength of the mucosal immune system, and improve the integrity of the gut barrier. Prebiotics help to increase intestinal homeostasis and coccidial protection through selective stimulation of positive microbial populations. Moreover, because of better gut health, there could be reduced vulnerability to concomitant parasitic zoonotic pathogens, including *Toxoplasma gondii*, *Cryptosporidium parvum*, and *Giardia duodenalis*. This review investigates the application of targeted prebiotics such as fructo-oligosaccharides, mannan-oligosaccharides, inulin and β-glucans in the reduction of *Eimeria* infections, poultry performance, and in sustainable poultry production and poultry food safety.

Keywords: *Eimeria*, prebiotics, poultry nutrition, coccidiosis, control, gut microbiota, zoonotic parasites

INTRODUCTION

The world poultry business has become very important in supplying the increasing demands of animal protein [1]. Poultry meat and eggs are a major source of inexpensive human foodstuffs for a developing human population [2]. Nonetheless, infectious diseases remain a major impediment to the health, production, and financial viability of poultry [3]. One of the most common and costly diseases affecting poultry in the world is avian coccidiosis, which is caused by protozoan parasites of genus *Eimeria* [4]. Coccidiosis is an intestinal infection caused by ingesting sporulated oocysts in litter, feed, or water contamination [5]. After being consumed, the parasite has several developmental stages which occur inside the epithelial cells that form the intestinal tract [6]. Some species of poultry, such as *Eimeria tenella, Eimeria maxima* and *Eimeria acervulina,* all of which attack particular parts of the intestine [7]. The consequences of infection include the destruction of epithelial cells, haemorrhage, malabsorption, a decrease in growth performance, and an enhanced susceptibility to secondary infection [8]. Coccidiosis may result in severe mortality cases, especially in young birds in severe cases [9].

The economic cost of avian coccidiosis is high and includes dwindling productivity, an upsurge in the ratios, death rates, and the expenditure on control [10]. The poultry industry has over the decades been majorly depending on anticoccidial drugs and vaccines to control the disease [11]. The chemical anticoccidials and ionophores have been extensively used in poultry feed to deter or restrict the reproductive ability of parasites [12]. Nevertheless, persistent and extensive use of such compounds has led to the development of *Eimeria* strains resistant to drugs and drug residue problems [13]. Moreover, the demand of consumers towards the antibiotic-free poultry products and the development of more stringent regulatory measures in most countries have restricted the use of chemotherapeutic agents in animal production systems [14, 15]. The challenges have prompted the need to seek alternative methods for the control of coccidiosis that are safe and sustainable [16]. The alternative control strategies include use of botanical compounds, nanoparticles, probiotics, prebiotics, peptides, immunoglobulins, vaccines, vitamins and many more that can be used in avian coccidiosis and multiple other parasitic, bacterial, and viral diseases [17-19]. The effectiveness of a functional feed additive to enhance the condition of the gut and host resistance against pathogenic organisms is one such promising strategy [20,21]. The prebiotics are one of them, which have acquired significant coverage in the scientific community as they possess the capacity to selectively activate health-promoting microorganisms in the gut and enhance the function of the intestine [22].

Prebiotics can be described as non-digestible dietary factors that have health advantages to the host through their selective stimulatory effects on desirable microorganisms in the gastrointestinal tract [23]. Fructo-oligosaccharides, mannan-oligosaccharides, inulin and β-glucans are most commonly used as prebiotics in poultry [24]. These are substances that are not degraded by host enzymes but fermented by beneficial microbes along the intestine, leading to the generation of short-chain fatty acids and other metabolites, which increase the health of the gut [25]. In the intestinal microbiota, the main role is to ensure the efficiency of digestion, immune functions, and defence against infectious agents [8]. A healthy microbial environment can prevent the settlement of pathogens by competitive exclusion, generation of antimicrobial compounds, and activation of host defences [26]. On the other hand, intestinal dysbiosis may make birds susceptible to illness and undermine overall productivity [27]. *Eimeria* infection impairs intestinal integrity and changes the composition of the gut microbiota, establishing advantageous conditions in the intestine for opportunistic agents and secondary infections [28]. A promising approach to alleviate the effects of coccidiosis is the enhancement of the intestinal microbial balance by dietary interventions (e.g., specific prebiotics) [29]. Prebiotics can improve the mucosal immune system, improve the efficiency of the epithelial barrier, and slow the growth of parasites by selectively boosting the beneficial microbial populations, including Lactobacillus and Bifidobacterium [30]. Besides controlling *Eimeria* infection, there is also the possibility that better gut health reduces the chances of concomitant parasitic zoonotic infections in poultry [31].

The poultry production systems are related to various parasites of zoonotic significance: in particular, *Cryptosporidium parvum* has been identified as a major foodborne zoonotic disease [32]. They may contaminate the environment and products of poultry and threaten human well-being [33]. Dietary interventions in enhancing the intestinal defence system of poultry could lower the shedding of pathogens and contamination of the environment, and thus, result in better food safety [34]. The most recent studies have shown that specific prebiotics can tune the host immunity, alleviate gut microflora balance, and enhance resistance to illness in poultry [35]. In addition, the compounds can be used in combination with other alternative strategies, including probiotics, phytogenic additives, and vaccines to increase the overall disease control [36,37]. The recent development of interest in microbiome-based strategies is indicative of a wider adoption of sustainable and antibiotic-free systems of poultry production [38]. Although there is a growing amount of evidence supporting the effectiveness of prebiotics, but their mechanisms need to be evaluated for effective use [39]. More studies are needed to clarify the interaction of dietary ingredients and intestinal microbiota, host immune response, and the development of parasites [40]. The objective of this review is to provide a comprehensive overview of the role of targeted prebiotics in controlling *Eimeria* infections in poultry.

Gut Health as a Central Component of Disease Resistance

Not only is the gastrointestinal tract of poultry the major place where digestive processes and the absorption occur, it is also an essential barrier against pathogenic microorganisms [41]. Healthy intestinal environment is the primary basis for keeping the overall health of poultry health, improving its growth performance, and preventing infectious diseases [8,42]. Gut health can be defined as structural integrity of intestinal epithelium, intestinal microbiota, balance and mucosal immune system efficiency [43]. The intestinal epithelium is the initial barrier to pathogenic invasion [44]. The tight junction proteins bind epithelial cells together and ensure that harmful microorganisms and toxins are not translocated into the systemic circulation [45]. The loss of intestinal integrity allows the entry of pathogens into the epithelial barrier, which causes inflammatory reactions and leads to decreased nutrient absorption rates [46]. *Eimeria* infection is a severe disorder, which leads to severe alterations in the intestinal structure by causing the death of epithelial cells throughout the intracellular parasite life cycle [47]. The effect of this damage is haemorrhage, retarded uptake of nutrients, and decreased feed efficiency [48].

Besides structural protection, the gut microbiota is critical in the protection of the host against pathogenic organisms [49]. Various microbial communities also live in the poultry intestinal tract and play a role in digestion, vitamin production, and immunity [8]. The useful microorganisms like Lactobacillus and Bifidobacterium generate organic acids and antimicrobial substances that suppress the development of detrimental microorganisms [50]. Competitive exclusion is also a process where these microbes and pathogens compete for nutrients and points of attachment to intestinal epithelial surfaces [51]. Another necessary element of disease resistance is the interaction of gut microbiota and host immune system [52]. The microbial metabolites in the short-chain fatty acids promote the proliferation of the intestinal immune tissues and control inflammation [53]. Normal immune responses enable the host to destroy pathogens and cause minimal damage on the tissues [54]. Nevertheless, an imbalance of microorganisms, which is also known as dysbiosis, may impair immunity and predispose to infections [55].

Avian coccidiosis has been shown to significantly alter the composition of the intestinal microbiota [56]. The lysis of the epithelial cells and cellular contents provides a good environment for opportunistic pathogens [57]. Such a microbial imbalance has the potential to worsen intestinal inflammation and increasing the severity of the disease [46]. Moreover, altered gut integrity can augment the danger of colonization by other pathogens, such as zoonotic parasites [58]. Intestinal homeostasis is thus an important aspect in proper disease management in poultry production systems [8]. Nutritional therapies to promote gut health have become more popular as an alternative to conventional antimicrobial agents [59,60]. Dietary prebiotic supplementation is one such strategy, and it has proven to be promising in tuning the gut microbiota and improve host defence programs [61].

Prebiotics facilitate the growth of beneficial microorganisms and enhance the generation of metabolites that enhance the functioning of the intestinal barrier [35]. A better microbial diversity can help to restore the intestinal balance after pathogen-induced imbalance [62]. Moreover, the better mucosal immunity enables birds to get a better response against the infection by parasites [63]. Incorporation of gut health management into poultry nutrition is one of the basic elements of sustainable disease control measures [64]. Increasing the intestinal ecosystem allows chicken farmers to decrease the occurrence and severity of such infections as coccidiosis and enhances productivity and animal welfare at the same time [13].

Prebiotics as Functional Feed Additives

Prebiotics are non-digestible food substances that choose to stimulate the growth and metabolic activity of favourable microorganisms in the gastrointestinal tract [23]. Contrary to probiotics, which insert live microorganisms into the host, prebiotics act as food that helps to promote the growth of already existing favourable microorganisms in the gut ecosystem *(Fig. 1)* [65]. Prebiotics are being considered as a functional feed additive in the poultry nutrition field with the aim of improving the gut health, immune system, and resistance against infectious diseases [66,67]. Fructo-oligosaccharides, mannan-oligosaccharides, inulin, and β-glucans are common prebiotic compounds used in the diets of poultry [24]. These substances are not digested by the host enzymes in the upper gastrointestinal tract and appear in the lower intestine intact, where they undergo fermentation by useful microbial populations [68]. The end product of fermentation is short-chain fatty acids like acetate, propionate, and butyrate, which have significant functions in ensuring intestinal integrity as well as immunological responses [69].

The protective effects of prebiotics might include the development of microbial communities that prevent the colonization of pathogens, the reinforcement of intestinal tone, and the improvement of the immune response of the mucosa [70]. All these effects have the potential to decrease the severity of *Eimeria*-induced infections and enhance the overall performance of poultry [71].

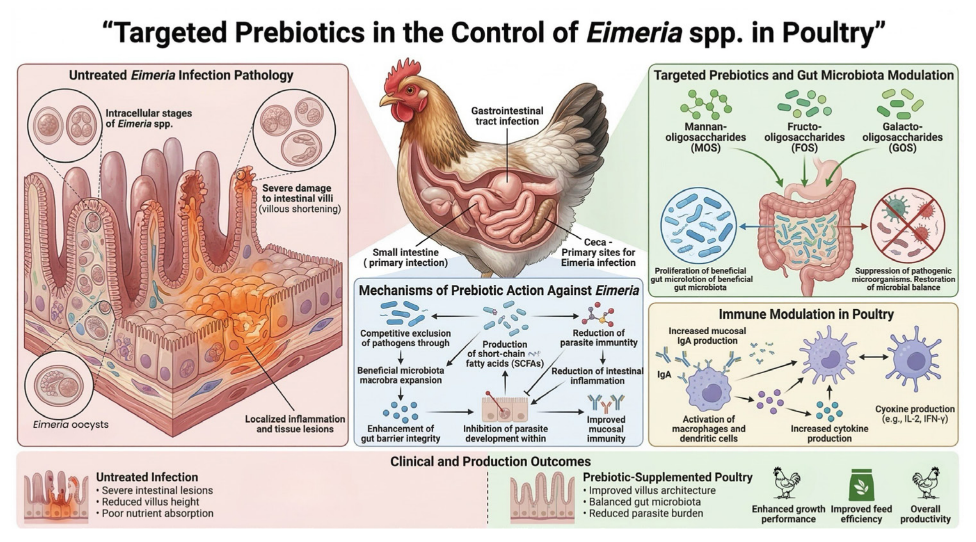

Fig 1. Targeted prebiotics in control of *Eimeria* spp. in poultry

Fructo-Oligosaccharides

Fructo-oligosaccharides (FOS) are a short chain fructose polymers, which are usually obtained by the use of plants like chicory, onion, and garlic [72,73]. The prebiotic properties of these compounds make them a popular choice as feed additives in the poultry feed industry for the selection of beneficial intestinal microorganisms [74]. Because of their resistance to digestion by the host enzymes in the proximal gastrointestinal tract, FOS are transported to the lower intestine unfermented to be used by the microbes [68]. In chickens, FOS supplementation has been shown to stimulate the growth of good bacteria, especially Lactobacillus and Bifidobacterium [75]. FOS fermentation by these bacteria leads to short-chain fatty acids, of acetate, propionate, and butyrate [76]. These metabolites are important in intestinal homeostasis because they reduce intestinal pH, prevent proliferation of pathogenic microorganisms, and enhance the integrity of epithelial cells [43]. Low intestinal pH will lead to an unfriendly condition for pathogenic microbes and indirectly restrict the growth of parasites like *Eimeria* [77].

Immunomodulatory effects, which also have anticoccidial effects, are also exerted by FOS [78]. Research has shown that FOS supplementation may cause an improvement in mucosal immunity by increasing the generation of immunoglobulin A [79] and controlling the response of cytokines in the intestinal mucosa. Improved immune reactions make the recognition and killing of the stages of intracellular parasites easier [58]. Also, FOS can enhance intestinal barrier operation by inducing cell regeneration of epithelial cells and preserving tight junction integrity, which restricts the invasion of parasites and tissue injury [43].

Another important mechanism of FOS is the control of intestinal microbiota composition [80]. FOS play a role in the competitive exclusion mechanism by supporting the growth of advantageous microorganisms in the small intestine, which compete with pathogens in the intestinal environment to obtain nutrients and points of attachment, which inhibits opportunistic infections commonly related to coccidiosis [51]. Enhanced microbial balance can also decrease secondary infections which intensify the intestinal inflammation in cases of coccidiosis outbreak [81]. In combination, microbiota regulation, immune-stimulation, and increased intestinal barrier integrity FOS have the potential to be a valuable nutritional solution to prevent coccidiosis in poultry and intestinal health improvement [82].

Mannan-Oligosaccharides

Mannan-oligosaccharides (MOS) are prebiotic compounds derived primarily from the cell walls of yeast species such as Saccharomyces cerevisiae [83]. These oligosaccharides consist mainly of mannose residues that possess unique biological properties beneficial for intestinal health and disease resistance in poultry [84]. One of the most important anticoccidial mechanisms of MOS involves pathogen binding and competitive exclusion [39]. Many pathogenic microorganisms possess mannose-specific lectins on their surface that enable them to attach to intestinal epithelial cells [85]. MOS molecules mimic these binding sites and act as decoy receptors, preventing pathogens from attaching to the intestinal mucosa [86]. Although *Eimeria* parasites invade epithelial cells through complex host–parasite interactions, MOS supplementation may reduce the severity of infection by limiting the colonization of secondary bacterial pathogens that exacerbate intestinal damage during coccidiosis caused by Eimeria [29]. MOS also stimulates the development of beneficial gut microbial populations, including Lactobacillus species [87]. Increased populations of beneficial microbes enhance fermentation processes that generate short-chain fatty acids, improving intestinal epithelial health and promoting mucosal immunity [87]. Improved intestinal microbial balance reduces inflammation and supports faster recovery from epithelial damage induced by coccidiosis [28].

Another important mechanism of MOS involves immunomodulation [88]. Research has demonstrated that MOS supplementation can stimulate both innate and adaptive immune responses in poultry [75]. Activation of macrophages, increased production of cytokines, and enhanced antibody responses contribute to improved resistance against parasitic infections [89]. Additionally, MOS may stimulate the development of gut-associated lymphoid tissues, strengthening mucosal immune defences [90]. MOS have also been associated with improvements in intestinal morphology [91]. Increased villus height and enhanced absorptive surface area contribute to improved nutrient uptake and faster recovery of intestinal tissues following coccidial damage [92]. By promoting intestinal integrity and immune competence, MOS supplementation may significantly reduce the clinical severity and production losses associated with coccidiosis in poultry [93].

The integration of prebiotics into poultry feeding programs therefore represents a promising approach for enhancing productivity while simultaneously supporting animal welfare and sustainable production practices [94].

Inulin

Inulin is a polysaccharide that occurs naturally and is mainly composed of β-(2→1) linked fructose units with a glucose residue at its end [95]. It is often isolated out of plants like chicory root and Jerusalem artichoke and is commonly known to have prebiotic effects in the nutrition of animals [96]. Since inulin is not digested by upper gastrointestinal tract enzymes, it will come to the large intestine where it is fermented by the good population of microbes [97]. In birds, intestinal inulin in the diet enhances the development of desirable intestinal microbes like Bifidobacterium and Lactobacillus [35]. Inulin fermentation results in the generation of short-chain fatty acids, which help to keep the intestinal pH at the optimum level and epithelial cell health [98]. One of the major products of fermentation is butyrate, which is a key source of energy to intestinal epithelial cells and is essential in the preservation of mucosal integrity [43].

It is presumed that the anticoccidial activity of inulin is triggered by a number of complementary mechanisms [12]. Inulin helps in competitive mechanisms of exclusion that prevent colonization by pathogenic microorganisms because it enhances the presence of advantageous microbial communities [51]. This microbial balance decreases gut inflammation, and it also contributes to a stable gut condition in *Eimeria*-induced infection [47].

The fermentation product of inulin improves intestinal barrier performance by increasing the growth rate of epithelial cells and strengthening tight junction proteins [98]. Inulin has been demonstrated to mediate the effects of the immune system by enhancing the activities of immune cells in the intestinal mucosa [99]. The increased production of cytokines and the improvement of secretory IgA levels augment the host's resistance to invading pathogens [100]. Besides exerting a direct effect on gut microbiota and immunity, inulin supplementation can also have an anti-oxidative stress and anti-inflammatory effect on intestinal infections [101]. Enhanced antioxidant status helps in tissue repair and healing after the damage of epithelial cells by parasitic infections [102]. These mechanisms will lead to better intestinal health, and inulin may be an effective dietary intervention during the prevention of the effects of coccidiosis in poultry production systems [5].

β-Glucans

β-Glucans are polysaccharides made of glucose molecules connected mostly by β-(1→3) and β-(1→6) glycosidic bonds [103]. They are usually originated through yeast, fungus, cereal, and some bacteria, and have been well known in the immunomodulatory effects on animal nutrition [104]. The use of β-glucans in poultry has also been widely explored as a means of boosting immune function and resistance of the animal to infectious diseases [105]. The main action by which the β -glucans have an anticoccidial effect is through the activation of the host immune system, where the β -glucans bind to the pattern recognition receptors (DRRs) like Dectin-1 and complement receptor 3 on the immune cells like the macrophages and dendritic cells [106]. Interaction of b-glucans to these receptors causes a cascade effect of immune response that improves the host capacity to identify and exclude the invading pathogens [105]. This immune stimulation can enhance immunity against such parasites as *Eimeria* [39].

β-Glucans also provoke the synthesis of cytokines that manage inflammatory reactions and facilitating communication among the immune system cells [107]. There is better clearance of infected epithelial cells and parasite stages with increased activation of macrophages and natural killer cells in coccidiosis [39]. In addition, the β-glucans have been demonstrated to boost antibody and the growth of gut-associated lymphoid tissue [108]. The other positive impact of β-glucans is that it enhances the intestinal barrier integrity [109]. B-glucans stimulate growth of epithelial cells and facilitate processes of tissue repair that restore the intestinal architecture after being destroyed by parasitic invasion [5]. Mucosal integrity is improved, which minimizes the occurrence of secondary infections and increases the recovery of intestinal functions [44].

β-Glucans can also modify intestinal microbiota composition and make beneficial microbial populations, promoting overall gut health [110]. Immune stimulation, intestinal healing, and microbiota regulation have their combined effects that render β-glucans good nutritional interventions to curb coccidiosis in poultry production systems. MOS and β-Glucans can be used for direct immune boosting and pathogen blocking, while FOS and Inulin can be used to build a strong, parasite-resistant gut microbiome.

Impact of Prebiotics on Poultry Performance

The addition of prebiotics to poultry diets has been largely correlated with an increase in growth performance, feed efficiency, and overall health condition [35]. It is mostly credited to improved gut health, nutrient utilization, and resistance to infectious diseases [8]. Among the most significant benefits of prebiotic supplementation, the increased feed ratio should be mentioned [111]. Prebiotics promote the growth of positive intestinal microorganisms, including *Lactobacillus,* to enhance the digestion process and the breakdown of complex nutrients into absorbable forms [112]. Prebiotic compounds are fermented to form short-chain fatty acids that trigger the growth of the intestinal epithelial and improve gut absorptive capacity [113].

Another factor that is significant in determining improved poultry performance is improved intestinal morphology [114]. Research has shown that birds fed prebiotic supplements tend to have a higher villus height and lesser depth of the crypt in the intestinal mucosa [115, 116]. These enhancement measures raise the amount of surface area used in nutrient taking leading to high growth rates and high feed utilization [117]. Prebiotics can also work to lessen the adverse effects of intestinal pathogens on poultry

Table 1. *Summary of experimental studies evaluating the effects of dietary prebiotics on poultry gut health, immune responses, growth performance, and control of coccidiosis caused by Eimeria species*

Sr. No.	Prebiotic	Source	Poultry Type	Experimental Design	Dose / Inclusion	Duration	Target Condition	Parameters Evaluated	Mechanism	Results	Ref.
1	Mannan-oligosaccharides (MOS)	Yeast cell wall from *Saccharomyces cerevisiae*	Broiler chickens	Experimental infection with coccidia	MOS supplemented diet	3-4 weeks	Infection with *Eimeria tenella*	Oocyst shedding, caecal lesion score	Enhanced immune response and gut protection	Reduced number of schizonts in infected birds	[127]
2	MOS + probiotic synbiotic	Yeast-derived MOS + bacterial culture	Hubbard broilers	Controlled feeding experiment (250 chicks)	Prebiotic supplementation with probiotic combination	Starter to finisher phase	Growth performance & immunity	BW gain, FCR, antibody titers, intestinal morphology	Gut microbiota modulation and immune activation	Improved bodyweight gain, villus height, and antibody levels	[128]
3	MOS and FOS	Yeast-derived MOS and plant FOS	Broiler chickens	Feeding trial (240 chicks)	0.1-0.2% in diet	6 weeks	Growth and meat quality	Carcass traits, lipid oxidation, cholesterol content	Improved nutrient absorption and microbial balance	Improved carcass yield and antioxidant stability	[129]
4	Fructo-oligosaccharides	Plant-derived oligosaccharides	Cobb 500 broilers	Two production cycles feeding experiment	5 g/kg feed	5 weeks	Immune response & microbial profile	Immune cell response, microbial counts	Lower intestinal pH and stimulation of beneficial microbes	Higher cellular immune response and reduced pathogenic bacteria	[130]
5	MOS prebiotic	Yeast cell wall polysaccharide	Commercial broilers	Controlled feeding trial	Dietary MOS supplementation	42 days	Growth and gut histology	BW gain, FCR, gut morphology	Enhanced villus height and nutrient absorption	Improved intestinal morphology and performance	[131]
6	MOS, FOS, and inulin	Multiple prebiotic sources	Ross 308 broilers	Randomized feeding experiment	Dietary supplementation	42 days	Metabolism & gut microbiota	Protein digestibility, gut microbial composition	Fermentation producing beneficial SCFA	Improved gut microbial diversity and nutrient metabolism	[132]
7	FOS and MOS	Plant and yeast oligosaccharides	Broiler chickens	Controlled feeding experiment	5g/kg each	5 weeks	Microbial balance	LAB count, pathogenic bacteria count	Competitive exclusion and acidic gut environment	Reduced *E. coli* and improved microbial balance	[133]
8	Glucomannan (prebiotic fiber)	Plant tuber (*Amorphophallus muelleri*)	Broiler chickens	Feeding experiment	0.25% diet	Broiler growth cycle	Gut microbiota & growth performance	BW gain, FCR, microbiome sequencing	Promotion of beneficial microbes such as *Lactobacillus* spp.	Improved microbial diversity and feed efficiency	[134]
9	MOS + FOS	Prebiotic mixture	Broilers	Comparative study vs antibiotic growth promoters	0.1-0.2% diet	42 days	Meat quality & antioxidant status	Lipid oxidation, meat cholesterol	Improved antioxidant status and microbiota	Reduced cholesterol and oxidative damage	[129]
10	Prebiotic supplementation under stress	MOS-based prebiotic	Broiler chickens	Heat-stress experimental trial	Dietary supplementation	Several weeks	Heat stress and immune suppression	BW, mortality, WBC count	Improved gut microbiome and immune defence	Improved feed intake and reduced mortality	[122]

production [118]. *Eimeria* infections may dramatically affect growth performance because of intestinal damage, decreased feeding levels, and decreased nutrient uptake [119]. Prebiotics can make coccidiosis milder and help the intestinal tissues to recover faster by improving intestinal microbial balance and improving immune responses [120].

Besides strengthening the resistance to coccidiosis, gut health can improve the resistance to other pathogens that affect the productivity of poultry [93]. Enhanced mucosal immunity and the balance of microbes are useful for a stable intestinal environment, preventing the colonization of pathogens [121]. Consequently, the mortality rate and the general health of the flock are significantly improved in birds that were supplemented with prebiotics *(Table 1)* [122]. Prebiotics can also lead to a higher quality carcass and safety of the product [123]. Improved intestinal health results in less shedding of pathogens and the contamination of the environment in poultry production systems [124]. This can reduce the risk of zoonotic pathogen contamination, like that of *Toxoplasma gondii* and *Cryptosporidium parvum* hence enhancing food safety and ensuring the health of the people [125,126].

Future Prospects

The rising research in microbiome-based disease control approaches has presented novel prospects for the field of creating specific prebiotic interventions in poultry production. The current development of high-throughput sequencing tools and microbial ecology allows gaining more information about the intricate interplay of dietary ingredients, gut microbiota, host immunity, and parasitic infection. Such technologies can help identify certain groups of microbes that lead to resilience to *Eimeria*-induced infections. Future studies can involve the development of precision prebiotics that can specifically target populations of microbes that help to boost the immunity of the host and inhibit the growth of pathogenic microbes. Although these nutritional techniques can improve disease control and poultry performance, combining prebiotics with other nutritional measures like probiotics, phytogenic compounds, and vaccines could enhance the results of this effort. The alternative potential research area is the study of synbiotic preparations involving the combination of prebiotics and useful microorganisms. Such solutions can be found to have a synergistic effect to enhance intestinal health and resistance to infectious diseases. Also, long-term field experiments are required to check the efficacy of these strategies under commercial conditions of poultry production. Further investigation of microbiome-based nutrition interventions can eventually lead to poultry production systems that are sustainable and free of antibiotics.

Conclusion

Avian coccidiosis has continued to be one of the greatest problems in poultry production, mainly because of infections by protozoan parasites of *Eimeria* genus. Conventional methods of control involving anticoccidial medication and vaccination have been effective in the management of the disease over many years but the development of drug-resistant strains of parasites and increasing limitation on the use of antimicrobial agents have led to the need to seek alternative control methods. Specific prebiotics are a novel nutritional solution to enhance intestinal condition and increase coccidiosis resistance. Fructo-oligosaccharides, mannan-oligosaccharides, inulin, and β-glucans have a positive influence through various mechanisms that include the regulation of gut microbiota, an increase in mucosal immunity, and an increase in intestinal barrier integrity. These effects lower the severity of coccidiosis but also lead to an increase in growth performance and feed efficiency in poultry. Moreover, better gut health can lead to an increased resistance to concomitant parasite zoonotic pathogens (including *Toxoplasma gondii* and *Cryptosporidium parvum*), which can improve food safety and the health of the population. Further studies on microbiome-specifically oriented nutritional interventions can offer useful options for the management of poultry diseases and the design of production systems without antibiotics.

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