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REVIEW ARTICLE

Prebiotics in Prevention of *Salmonella* shedding in Layer Hens

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Abstract

Salmonella infection in laying hens is one of the biggest challenges to poultry production and food safety because of its role in contaminating eggs and being transmitted to humans as a zoonotic infection. The use of antibiotics in control strategies was well established until there has been growing interest in searching alternative control strategies due to the growing concerns with antimicrobial resistance. Prebiotics which are defined as non-digestible feeds components which selectively stimulates desirable intestinal microbiota have been found promising as functional feed additives in the diet of poultry. Fructo-oligosaccharides, mannan-oligosaccharides, inulin and β-glucans have the ability to influence the gut microbiosis, improve mucosal immunity and decrease intestinal colonization of pathogenic microorganisms such as *Salmonella*. Prebiotics aid competitive exclusion and the production of short-chain fatty acids and an improved intestine barrier through the stimulation of the growth of beneficial bacteria like *Lactobacillus* and *Bifidobacterium*. All these mechanisms are associated with the reduction of cecal colonization and fecal shedding of Salmonella in layer hens. This review is a summary of the epidemiology of *Salmonella* in poultry, the biological importance of major prebiotics, their mechanisms of action, and effect on poultry performance, which clearly point at them as a sustainable instrument in the enhancement of poultry health and food safety.

Keywords: *Salmonella*, prebiotics, poultry nutrition, salmonellosis, control, gut microbiota, zoonotic bacteria

INTRODUCTION

Poultry-related food borne pathogens are a major public health issue in the world today [1]. Of these pathogens, *Salmonella* spp. still are a significant part of the most significant zoonotic agents associated with poultry and egg-related human infections [2]. Poultry products represent significant reservoirs of a number of *Salmonella* serovars especially *Salmonella* Enteritidis and *Salmonella* Typhimurium capable of colonizing the intestinal tract of birds without causing serious clinical effects but can contaminate eggs, meat and the surrounding environment [3]. This is an asymptomatic carrier that complicates the management of *Salmonella* especially in large poultry enterprises [4]. The poultry business in the world has been growing very fast over the past few decades to satisfy the growing need of animal protein at low cost [5]. As the growth has occurred, management of foodborne pathogens is now of high priority among producers, regulating agencies and government agencies that deal with health [6]. *Salmonella* infection in laying hens can cause horizontal infection by feces contamination and vertical infection by an infected reproductive organ, both of which can cause egg contamination before its shell develops [7]. It is therefore possible that infected layer flocks provide the consumer with a possible source of infection [8]. Historically, antibiotics were commonly applied in the poultry production to prevent diseases, treat them, and enhance the growth [9]. Nevertheless, the high usage of antimicrobial agents in animal production has led to the development and spread of antimicrobial resistant bacteria [10]. The growing cases of antibiotic resistance have brought serious concerns about safety and sustainability of antibiotics use on livestock [11]. To counter this, the use of antibiotic growth promoters in the production of poultry in many countries is limited or banned. Such regulatory developments have triggered a lot of research on alternative measures that can keep poultry healthy and productive with minimum dependence on antibiotics. Multiple alternative control strategies are in use to control different bacterial, viral, fungal, and parasitic diseases of poultry and other animals [12,13]. Among all alternative control strategies, probiotics are considered as most effective because of their diverse medicinal and biological activities [14,15].

The use of effective feed additives to improve gut health and boost the natural resistance of birds to pathogens is one of the promising directions [16]. However, prebiotics have attracted significant amount of attention among these additives because of their capacity of regulating the intestinal microbiota and enhancing the beneficial microbial populations which results in lowering the antimicrobial resistance [17]. Prebiotics are generally non-digestible carbohydrates that cannot be digested in the upper tract and get to the lower intestine where they are fermented by benevolent bacteria [18]. The most typical ones are fructo-oligosaccharides, mannan-oligosaccharides, galacto-oligosaccharides and inulin [19]. The intestinal microbiota is at the centre of the gut health and pathogen colonization prevention [20]. A healthy microbial community is able to inhibit pathogenic bacteria by the help of competition exclusion, antimicrobial metabolites production and the activation of host immune systems [21]. Prebiotics serve the selective proliferation of positive microorganisms that incline to thrive in the poultry food when added to chicken diets *(Lactobacillus* and *Bifidobacterium)* [22]. During fermentation, these microorganisms synthesize short chain fatty acids (SCFAs) which include acetate, propionate and butyrate out of prebiotic substrates [23]. The benefits of SCFAs include decreasing the intestinal PH, inhibiting the growth of pathogens, and enhancing the intestinal epithelial integrity [24]. Some studies have shown that dietary supplementation of prebiotics has the power of decreasing colonization and shedding of *Salmonella* in poultry [25]. Indicatively, fructo-oligosaccharides have been found to reduce cecal loads of *Salmonella* Enteritidis in laying hens and fecal shedding concomitantly with increased mucosal immune responses [26]. It has been linked to these effects, including the increased number of helpful bacteria and increased intestinal immunoglobulin A (IgA), which is a significant part of mucosal immunity [27].

Besides microbiota modulation, prebiotics also have the ability to regulate the host immune functions [28]. Most prebiotic compounds stimulate innate and adaptive immune responses by promoting the activation of immune cells, such as macrophages, dendritic cells, and lymphocytes [29]. Certain prebiotics have also been shown to enhance the structure of the intestinal epithelium, with respect to the height of villus and nutrient uptake [30]. Better gut morphology helps in the enhancement of nutrient usage and the general performance of poultry [31]. Prebiotics have one more benefit since they do not interfere with other means of controlling diseases [32]. Probiotics may be administered as synbiotics together with prebiotics to increase the gut microbial homeostasis and resistance to pathogens [33]. These combined strategies are being seen more and more as powerful parts of overall systems of poultry health management [34]. Full knowledge of the complexes of how various prebiotics can affect gut microbiota and pathogen settlement is needed to maximize them in poultry systems of production [35].

There are some extensive reviews of the effectiveness of prebiotics in colonizing reduction of *Salmonella* in poultry, but most of them include a strong emphasis on broiler chickens. The physiology and production of laying hens is fundamentally different. They have much longer production cycles, high calcium requirements for eggshell development, have special physiological stresses like moult and pose a special public health risk through the vertical transmission of *Salmonella* through eggs. Thus, an important knowledge need is the mechanism of action of prebiotics in the special physiological conditions of the layer hen. This article will focus on laying hens and is not a broad review as in previous articles. Critically reviews current literature on prebiotic interventions (fructo-oligosaccharides, mannan-oligosaccharides, inulin, and β-glucans), as well as their mechanisms of action with regard to the stressors present during different stages of egg production and their effectiveness in reducing intestinal colonization and fecal shedding of *Salmonella* to prevent egg contamination.

Literature Search Strategy

A structured search strategy was used to identify texts adequately and objectively for evaluation. Peer-reviewed articles published in the English language between 2020 to 2026 were searched in the databases PubMed, Scopus and Google Scholar. The main search string used was a Boolean combination of words: ("prebiotic" OR "fructo-oligosaccharide" OR "mannan-oligosaccharide" OR "inulin" OR "beta-glucan") AND ("*Salmonella*") AND ("layer hen" OR "laying hen" OR "pullet"). Studies that were only performed on broiler chickens and studies that have been conducted on the non-*Salmonella* pathogens were excluded from this review unless specifically needed to compare physiological mechanisms between the two types of chicken. For prebiotic mechanisms, *Salmonella* colonization, fecal shedding, mucosal immunity, and layer hen performance, articles were chosen on the basis of their relevance to the topics. Also existing systematic reviews were consulted in order to avoid duplication of scientific questions in this narrative review.

Epidemiology of *Salmonella* in Layer Hens

The *Salmonella* infections are still considered as the most prominent issues in the production of poultry as they are widely distributed and may lead to foodborne illness in humans [2]. Many *Salmonella* serovars have been identified in poultry since *Salmonella* Enteritidis and *Salmonella* Typhimurium are the most commonly identified with egg-borne and poultry outbreaks [36]. They can colonize the intestinal tract of chickens and stay in the ceca over long periods without overt clinical disease [37]. *Salmonella* epidemiology of layer hens is multidimensional and multi-source of transmission [38]. Horizontal transmission is by consuming infected feed, water, littering or fecal matter of infected birds [39]. After being introduced to a flock, the pathogen may propagate quickly because of the high stocking density and contamination of the environment [40]. Cecum is a major reservoir where *Salmonella* may proliferate and survive giving rise to unremitting fecal shedding [41]. Vertical transmission is also a very important factor in the epidemiology of *Salmonella* in laying hens [42]. Contaminated hens can develop bacteria in their reproductive tract specifically the ovary and oviduct. This may cause the eggs to be contaminated during formation in the reproductive tract [43]. Internally contaminated eggs have a high food safety risk as the bacteria might withstand the normal provision of food and therefore cause an infection to the consumers [4].

The persistence of the environment also makes the task of control harder [44]. *Salmonella* is able to endure long periods in poultry houses, litter, dust and equipment. Rats, insects and wild birds might also act as reservoirs and vectors of the pathogen and enable the introduction of the pathogen into the poultry birds [45]. Moreover, infected feed materials are found to be the possible causes of infection [46]. The intestinal microbiota of chicken is very essential in determining the susceptibility to *Salmonella* colonization [47]. Laying hens have a more delicate 'ecological niche' due to the regular extreme physiological changes that occur during the onset of lay and induced molting, increasing the susceptibility of the bird for colonization at this time compared to broilers. Stable intestinal microbiota can also be considered a natural defence mechanism against these diseases in healthy birds that are naturally balanced [48]. This can be accomplished by the presence of favourable microorganisms in ecological niches in the gut and compete with pathogens over nutrients and attaching sites [21]. Such a disturbance of this microbial balance is referred to as dysbiosis that may predispose to infection and colonization by pathogens [49]. There are various management aspects that determine the prevalence of *Salmonella* in layer flocks [50]. The introduction and spread of the pathogen may be caused by poor biosecurity, insufficient sanitation, and poor handling of feed [51]. Moulting, transportation, high stocking density and other stress conditions also have the potential to increase an individual to infection due to the weakening of the immune system and changes in gut microbial composition [52].

The poultry industry has also practiced several control strategies such as vaccination, better biosecurity exercises, and surveillance programs within the industry over the last few years to curb the prevalence of *Salmonella* [53]. Nonetheless, these measures are not likely to eradicate the pathogen in the poultry production systems fully [9]. Therefore, nutritional treatment, i.e., the prebiotic and probiotic use, have increasingly become the focus of interest as an adjunctive approach to counteract intestinal colonization and fecal shedding of *Salmonella* [54].

Prebiotics as Functional Feed Additives

Prebiotics are considered to be non-digestible food substances which selectively induce growth or action of the healthy microorganisms in the gastrointestinal tract [55]. These substances are usually complex carbohydrates like oligosaccharides which are not fermented in the upper tract of the digestive system and are fermented by the intestinal microbes of the lower tract *(Fig. 1)* [56]. Prebiotics increase intestinal microbial balance through fermentation that supports the growth of positive bacteria such as *Lactobacillus* and *Bifidobacterium* [57]. Prebiotics are also being considered as an important functional feed additive because of their gut health benefits, nutrient absorption, and their ability to decrease pathogen colonization in poultry nutrition [58]. Prebiotics may inhibit the growth of pathogenic microorganisms by promoting the growth of the beneficial microorganisms by competitive exclusion, generation of antimicrobial metabolites, and lowering of the pH of the intestinal environment [33]. All these effects lead to a better intestinal barrier integrity and increased immune responses in chickens [59]. Some forms of prebiotics have been studied in poultry production and these include fructo-oligosaccharides, mannan-oligosaccharides, inulin, and β-glucans [60]. The individual unique structural properties and modes of action of each of these compounds affect the gut microbiota and host physiology *(Table 1)* [61]. It has been found that these prebiotics can greatly decrease the colonization of such pathogens as *Salmonella* through enhancing the mucosal immunity and improving the microbial balance [25].

Fructo-oligosaccharides

Fructo-oligosaccharides (FOS) are short fructose polymers that are obtained as a result of chicory, onions, garlic, and bananas [62]. The compounds cannot be digested by the host enzymes in the upper gastrointestinal tract and pass on to the large intestine where they can be fermented by the beneficial bacteria [63]. In chickens, supplementation with FOS has been identified to have a considerable effect on the intestinal microflora and the gut condition [64]. Selective stimulation of beneficial bacterial populations is one of the main methods according to which FOS work [65]. The fermentation of FOS by *Lactobacillus* and *Bifidobacterium* species also increases the short-chain fatty acid generation such as acetate, propionate and butyrate [23]. These organic acids reduce the pH in the intestine and provide an unfavourable habitat to the pathogenic bacteria including

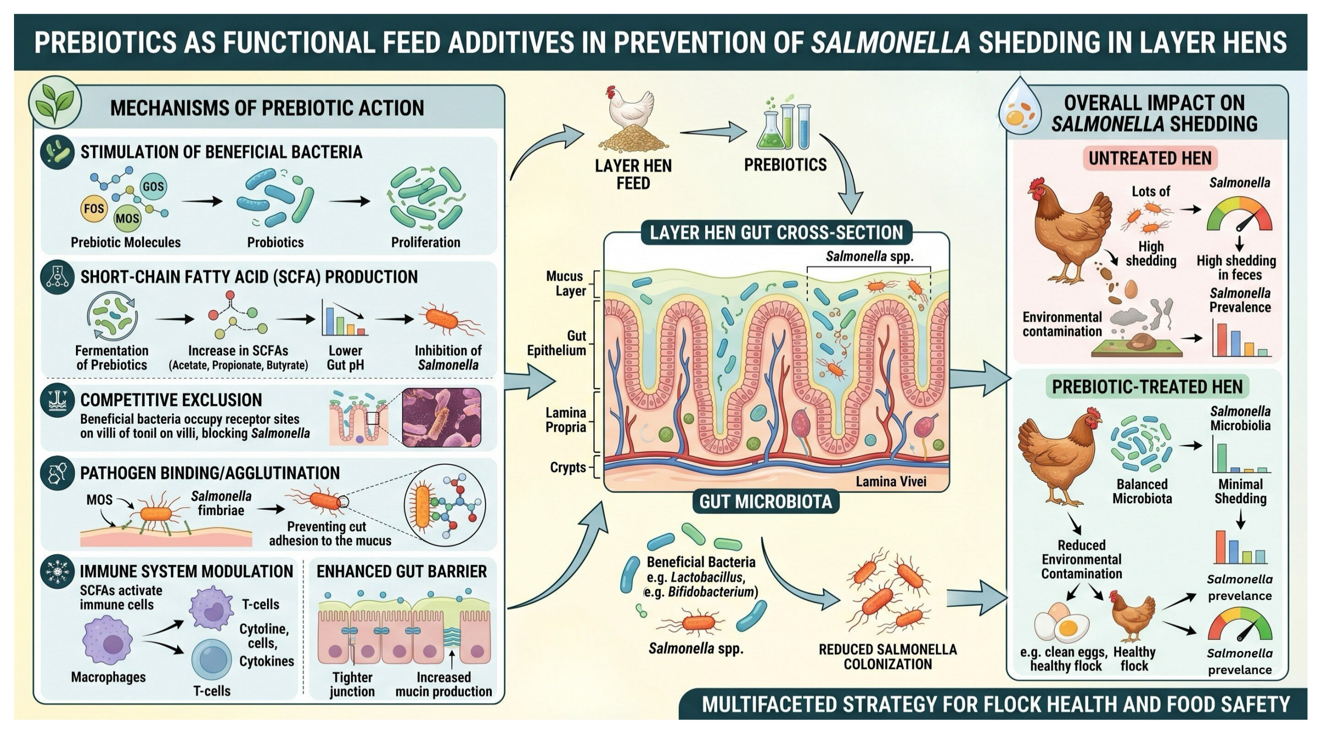

Fig 1. Prebiotics as functional feed additives in prevention of *Salmonella* shedding in layer hens

Salmonella [66]. Moreover, SCFAs are an energy source of intestinal epithelial cells and help to increase intestinal integrity [24]. The laying hen experimental studies have shown that food supplementation of FOS can greatly reduce cecal colonization and shedding of *Salmonella* Enteritidis of the feces [67]. However, the strength of this evidence varies significantly depending on the age of the flock and the challenge dose. While FOS is highly effective in early-lay hens, its efficacy often diminishes during late-stage production or forced molting, suggesting that age-related dysbiosis may overpower prebiotic interventions if dosages are not properly adjusted. Due to FOS supplemented diets, infected birds had lower pathogen loads and improved mucosal immune responses such as increased IgA-producing cells in the intestinal lamina propria [68].

FOS also have an effect on host immune response by stimulating the innate and adaptive immune response [69]. The compounds have the potential to alter the expression of immune related genes including Toll-like receptors and cytokines, which are vital in the pathogen recognition and immune signalling [70]. There are boosted immunity and resistance to intestinal pathogens [71]. The other mechanism is competitive exclusion [72]. The beneficial bacteria, which are stimulated by FOS, occupy the sites of attachment in the intestinal epithelium and prevent infection by the pathogenic microorganisms [73]. Such microbial rivalry prevents the possibility of *Salmonella* to be attached to intestinal cells and become an infection [74]. Their capacity to regulate the intestinal microorganisms, augment immune responses, and prevent the proliferation of pathogens make them useful feed supplements towards the advancement of the wellbeing of chickens and the decrease of *Salmonella* shedding in layer hens [75].

Mannan-oligosaccharides

Mannan-oligosaccharides (MOS) [18] are a group of products, mainly derived by the cell wall of the yeast *Saccharomyces cerevisiae*, and are also used as prebiotic feed supplements in poultry feed [76]. MOS are polysaccharide mannose polymer with exceptional biological characteristics being in a position to regulate intestinal microbiota and enhance immunity [77]. Inhibition of bacterial adhesion to epithelial cells of the intestine is amongst the most significant mechanisms through which MOS inhibit pathogen colonization [78]. *Salmonella* has type-1 fimbriae which are used to attach to mannose residues in host cells, and this is common in many pathogenic bacteria [79]. MOS serve as molecular decoys as they present alternative binding sites to such fimbriae [80]. Consequently, the pathogens bind to MOS molecules instead of to the intestinal epithelial cell, which prevents the colonization process and allows the pathogen to be eliminated in the gastrointestinal tract [78]. However, a major restriction of the existing MOS literature is that the data is often extrapolated from a model developed for broilers. Many of the studies do not include the high calcium diets and long gut transit times common to laying hens which could potentially affect the binding affinity of MOS and efficacy in laying hens.

Table 1. Effects of dietary prebiotics on intestinal microbiota, immune responses, and Salmonella colonization or shedding in layer hens

Sr. No.	Prebiotic Type	Source	*Salmonella* Serovar Studied	Inclusion Level in Diet	Experimental Design	Results	Effects on Performance	Ref.
1	Fructo-oligosaccharides	Chicory root derived oligosaccharide	*Salmonella* Enteritidis	0.375-0.75% of diet	*In vivo* layer challenge (Molt-induction)	Reduced cecal colonization and liver/ovary infection in multiple trials	Maintained post-molt production performance	[132]
2	Fructo-oligosaccharides	Plant-derived oligosaccharide	*Salmonella* Enteritidis	0.5-1% dietary supplementation	*In vivo* challenge	Significant reduction in fecal shedding and cecal load	No negative effect on growth or egg production	[133]
3	Fructo-oligosaccharides	Plant fructans	*Salmonella* Enteritidis	Variable (synbiotic formulation)	*In vivo* synbiotic layer challenge	Reduced cecal *Salmonella* load during infection	Maintained egg production	[134]
4	Mannan-oligosaccharides	Yeast cell wall (*Saccharomyces cerevisiae*)	*Salmonella* Enteritidis	0.1-0.5%	*In vivo* layer field trial	Reduced intestinal pathogen colonization	Improved feed conversion and egg production	[135]
5	Mannan-oligosaccharides	Yeast-derived	*Salmonella* Enteritidis	Commercial feed additive	*In vivo* layer challenge	Reduced intestinal and ovarian infection	Improved intestinal health	[136]
6	MOS + Bacillus probiotic (Synbiotic)	Yeast MOS + *Bacillus* spp.	*Salmonella* Enteritidis	Commercial synbiotic formulation	*In vivo* synbiotic layer challenge	Reduced intestinal colonization and egg contamination risk	Maintained production	[137]
7	Inulin	Chicory root fructan	*Salmonella* spp.	0.5-1% dietary inclusion	*In vivo* layer field trial	Reduced intestinal pathogen populations	Improved gut morphology	[133]
8	Inulin + Postbiotic	Chicory fructan + LAB metabolites	*Salmonella enterica*	Experimental formulation	*In vitro* and *in vivo* layer evaluation	Antimicrobial activity against *Salmonella*	Improved intestinal mucosal architecture	[133]
9	β-Glucans	Yeast or fungal polysaccharides	*Salmonella* Typhimurium	0.05-0.1%	*In vivo* layer field trial	Reduced pathogen colonization	Improved disease resistance	[138]
10	Mixed Prebiotics	Various oligosaccharides	*Salmonella* spp.	Variable	Meta-analysis of multiple studies	Overall reduction in fecal and cloacal shedding	No negative effects on productivity	[54]

MOS, likewise, enhance the development of the beneficial bacteria like *Lactobacillus* and *Bifidobacterium,* which lead to the competition of the pathogenic microorganisms [81]. These useful bacteria break down foods to generate short chain fatty acids which reduce the pH of the intestines and prevent the growth of pathogens [82]. The increased microbial balance leads to increased intestinal health and lower pathogen burden. Besides their microbiota-modulating properties, MOS have been revealed to induce immunity in poultry [83]. MOS supplementation enhances the production of antibodies as well as the growth of lymphoid organs which are vital constituents of avian immune system [84]. The benefits of having improved immune responses is that birds have a better chance of withstanding infections as well as being healthy [85].

The MOS supplementation has been linked to better absorption of nutrients and enhanced digestion [86]. MOS help to enhance the morphology of the intestines and nutrient absorption through the promotion of the beneficial microbial populations and the reduction of the number of the pathogenic bacteria [87]. This eventually enhances the performance and productivity of poultry [88].

Inulin

Inulin is a naturally occurring fructan polysaccharide that is present in most plants such as chicory root, Jerusalem artichoke, garlic, and also onions [89]. Similar to other prebiotic substances, inulin is indigestible in the proximal gastrointestinal tract and gets into the lower intestine where it is fermented by useful microorganisms [90]. The inulin fermentation by intestinal bacteria leads to the generation of short chain fatty acids that are very essential in the intestinal health [82]. SCFAs reduce the level of intestinal pH, prevent the proliferation of pathogenic bacteria, and supply energy to the epithelial cells [91]. This increases the integrity of barriers of the intestine and decreases the chances of invasion of pathogens [92]. Inulin supplementation in chickens has also been reported to have a large effect on gut microbial composition by raising the count of profitable microbes including *Lactobacillus* and *Bifidobacterium* [93]. These bacteria can cause competitive exclusion by holding ecological niche in the gut and compete with pathogens in the nutrients and attachment sites [94]. Consequently, the intestinal tube becomes less colonized by the pathogenic bacteria like *Salmonella* [95].

Inulin is also significant in the regulation of immune system [96]. It has been established that the inulin supplementation may be used to boost the synthesis of immunoglobulins and the activation of immune cells contributing to the defence against the pathogens [97]. Better immune responses are also a contributing factor to high resistance to intestinal infections [98]. Also, inulin enhances the intestinal morphology by raising the length of the villus and the surface area in the small intestine [99]. These structural improvements increase the absorption of nutrients and digestion [100]. Enhanced nutrient use leads to enhanced growth performance and aggregate productivity in poultry [101]. Inulin is also an effective prebiotic ingredient that can be used to reduce the colonization of pathogens and improve the health of the gut in poultry through its individual effect on gut microbiota, immune system and intestinal morphology [22].

β-Glucans

β-Glucans are a group of polysaccharides that are typically obtained in yeast, fungi, cereal and some of the algae [102]. These are compounds that are made of glucose molecules, which are connected through β-glycosidic bonds and are commonly known to possess immunomodulatory effects [103]. The application of β-glucans as functional feed additives in the poultry nutrition is becoming more common to boost the immune response and disease resistance [104]. Stimulation of the innate immune system is one of the main mechanisms of β-glucans actions because they are perceived by particular receptors on the macrophages, dendritic cells, and heterophils [105]. Interaction of β-glucans to the receptors triggers signalling pathways that increase phagocytosis, cytokine generation, and clearance of pathogens [106]. Dietary supplementation of poultry with β-glucans has been demonstrated to increase both cellular and humoral immune response [107]. The increased production of antibodies and the augmented functioning of immune cells lead to heightened resistance against bacterial infections and β-glucans can also regulate the inflammatory reactions, which may avoid over-protection of tissue damage during the stage of infection [108]. β-glucans also lead to the modification of gut microbiota composition [109]. Beneficial bacteria can ferment these polysaccharides and thus grow and be active [110]. Higher population of good microorganisms has been associated with competitive elimination of pathogenic bacteria as well as better microbial balance in the intestines [111].

Moreover, β-glucans enhance the intestinal barrier activity through the increase of epithelial integrity and the mucosal immunity [112]. Enhanced gut barrier operation decreases the capacity of the pathogen to invade the intestinal lining and initiate infection by *Salmonella* [47]. Studies have established that β-glucans supplementation has the potential of enhancing growth performance, immune functions, and environmental stress resistance in short-term poultry trails [113]. However, it is important to remember that the strongest of these immune responses has been seen in fast growing broilers. There is limited evidence to demonstrate the efficacy of β-glucan throughout an entire commercial laying cycle, and it is not conclusive. This represents a significant research gap.

Impact of Prebiotics on Poultry Performance

Besides having antimicrobial and immunomodulatory qualities, prebiotics have great impact on poultry productivity and performance [114]. Healthy gut and superior microbial balance will lead to higher levels of digestion, nutrient absorption and immunity that will ultimately lead to high growth and egg development in laying hens [115]. The regulation of intestinal microbiota is one of the main ways in which prebiotics can affect the performance of poultry [25]. Prebiotics induce the growth of desirable microorganisms *(Lactobacillus* and *Bifidobacterium)* in the gastrointestinal system, which form a stable ecosystem [116]. The beneficial bacteria outcompete the pathogenic microorganisms on nutrients and attached space, which minimizes the colonization of the pathogen and intestinal inflammation [117]. The short-chain fatty acids are also produced by prebiotic fermentation and are used to provide energy to the intestinal epithelial cells [118]. These metabolites regulate the intestinal health by improving the integrity of the epithelia and inducing cell growth in the intestinal mucosa [119]. A better morphology of the intestine with a higher height and surface area of the villus height will result in more efficient nutrient absorption [120]. Increased nutrient absorption results in increased feed efficiency and growth performance of poultry [121]. Multiple researches have also indicated that prebiotic oligosaccharides supplementation has the potential to increase feed ratio, egg production, and egg mass in laying hens [122]. The difficulty of interpreting these performance metrics, however, cannot be ignored. Many of the trials have short supplementation periods (e.g. 4-8 weeks) and small numbers of birds and do not adequately reflect the long duration of a commercial laying cycle under the rigorous physiological and metabolic demands of the commercial layer. As an illustration, MOS supplementation has been found to enhance egg production and feed efficiency via the regulation of gut microbiota and a better provision of nutrients [86]. The prebiotics too affect the parameters of egg quality [123]. Certain investigations have indicated the increase of the eggshell thickness, albumen quality and yolk composition after supplementation with some oligosaccharides [124]. Eggshell quality is also of great value in diminishing microbial contamination and enhancing egg safety [125]. The other notable advantage of prebiotics is that they boost flagella and lessen death rates in chicken flocks [126]. Prebiotic supplementation of birds is also associated with better immune parameters with increased antibody and improved resistance to infectious diseases [127]. Enhanced immune response lowers disease occurrence and leads to a high flock productivity [128]. Besides enhancing the health and productivity of the birds, prebiotics can also assist the birds to survive stressful environmental conditions like heat stress [129]. It has been shown that prebiotic supplementation is able to stabilize gut microbiota, enhance immune reaction when facing a stressor situation, thus ensuring performance stability and diminishing the adverse physiological outcomes [130]. Prebiotic addition to the poultry feed is a promising policy of optimizing performance, disease resistance and ensuring sustainable production of poultry [131].

Future Prospects

The growing market interest in nutritional solutions to improve gut health and disease resistance has been driven by the growing demand of producing poultry free of antibiotics. Prebiotics are the potential category of feed supplements that can be used to enhance the intestinal microbial status and the decrease of colonization with pathogens in poultry. The future studies will be directed towards the discovery of new prebiotic compounds that have improved functional properties. Recent developments in microbiome studies and molecular biology are also allowing researchers to gain a clearer insight into the interplay between the various elements of diet, intestinal microbiota, and immune responses by the host. These findings can be used to develop specific prebiotic preparations that can be used selectively to stimulate the growth of favourable microbial communities that will outcompete pathogens like *Salmonella*. The other research opportunity is the development of synbiotic formulations which are a combination of pre and probiotics. These combinations have the ability to offer synergistic effects which at once introduces useful microorganisms as well as offers substrates that are conducive to the growth of these microorganisms. Precision nutrition strategies also could be very helpful in the optimization of prebiotic supplementation. The effect of prebiotics is strongly dependent on the age of the birds, genetic strain and environmental factors, making it important to make layer trials over the full production cycle, rather than using extrapolated broiler data. Adapting existing prebiotic formulations to the specific physiological needs and longevity of commercial layer systems to maximize effectiveness and predictability of prebiotics in these systems will be essential for future prebiotic formulations.

Conclusion

Controlling *Salmonella* infection in poultry is an important issue to the poultry industry and health in general. Since the issues of antimicrobial resistance are still evolving, the need to find efficient alternatives to antibiotics has become the focus of higher significance as well. Prebiotics have become promising functional feed supplements that could be used to enhance the gut health and decrease pathogen colonization in poultry. Fructo-oligosaccharides, mannan-oligosaccharides, inulin, and β-glucans possess beneficial effects which occur in a variety of ways. They are modulation of intestinal microbiota, stimulation of the beneficial bacterial population, the production of short-chain fatty acids, mucosal immune enhancement, and pathogen adhesion inhibition in the intestinal epithelial cells. These processes make prebiotics play a role in less colonization and fecal shedding of *Salmonella* in hens in the layer. Prebiotics can also be used to improve poultry performance by improving nutrient digestibility, feed conversion and egg production besides increasing disease resistance. The fact that they can enhance immune response and stabilize gut microbiota also helps them to be more resilient to environmental stress and infectious diseases. Prebiotics are a viable and long-term solution to enhancing the health of poultry and preventing the transmission of foodborne pathogens. The future study and the refined use of prebiotics in the nutrition of poultry will be important in aiding safe and efficient poultry production systems.

Declarations

Availability of Data and Materials: All the data generated are included in the manuscript

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