Review

The Promising Future of Resistant Starch as a Prebiotic for Enhancing Gut Health and Organic Meat Production in the Poultry Industry

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Abstract | Resistant starches (RS) constitute a category of functional dietary fibers that exert prebiotic effects in the hindgut and can modulate gut health. In contrast to conventional starch, RS is not absorbed in the small intestine and is fermented in the ceca into beneficial short-chain fatty acids (SCFAs), such as butyrate. These metabolites improved gut integrity, modulate the microbiota, and suppress pathogenic bacteria, which may contribute to better nutrient absorption and immunity. Recent research has explored the role of RS in reducing feed costs and promoting sustainable poultry production by enhancing growth rates and feed efficiency. Incorporating RS into poultry diets offers a natural, cost-effective, and environmentally friendly strategy to improve bird health and productivity. Previously published studies have demonstrated that supplementation with RS significantly impacts avian intestinal health, growth performance, weight gain, feed efficiency, and villus height in the small intestine. Incorporating RS into broiler chicken diets has been shown to improve gut health by increasing beneficial microbial populations such as *Bifidobacteria*, *Lactobacilli*, and *Roseburia*; while simultaneously reducing populations of harmful bacteria. According to research on RS in poultry feeds, supplementing diets with 1% RS can improve gut health indicators such as SCFAs synthesis and cecal pH balance without negatively impacting growth. By modulating SCFA levels in the ileum and influencing nutrient digestion, RS may positively affect both digestive health and the growth performance of broiler chickens. This review has examined the effects of RS on gut microbiota, its synergistic potential with prebiotics and probiotics, and its promise as a replacement for antibiotic growth promoters. While numerous studies across various animal and human models have reported beneficial outcomes, there remains a significant gap in research specifically focused on poultry. Therefore, this review aims to encourage future investigations into the mechanisms of RS action and to determine its optimal inclusion level in poultry nutrition.

Received | August 11, 2025; **Accepted** | September 22, 2025; **Published** | September 27, 2025
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Citation | Saeed, M. and G. Liu. 2025. The promising future of resistant starch as a prebiotic for enhancing gut health and organic meat production in the poultry industry. *Advances in Agriculture and Animal Sciences,* 41(1): 28-39.
DOI | https://dx.doi.org/10.17582/journal.aaas/2025/41.1.28.39
Keywords | Resistant starch, Natural feed additive, Gut microbes, Production performance, Broiler

Introduction

Intestinal health problems in poultry are common and remain a persistent challenge. The use of antibiotic growth promoters (AGPs) has historically played a significant role in broiler production by reducing gastrointestinal issues and improving feed conversion efficiency. However, the misuse of antibiotics has contributed to the rise of antimicrobial resistance (AMR) and the presence of antibiotic residues in meat. Around two decades ago, the use of antibiotics and antimicrobials in animal feed to enhance performance began to face increasing public scrutiny and political debate (Vondruskova *et al*., 2010).

In response, extensive research over the past 20 years has focused on developing alternatives to in-feed antibiotics to maintain animal health and performance (Zimmermann *et al*., 2001; Erickson and Hubbard, 2000; Hayhoe *et al*., 2022). The growing need for antibiotic-free broiler production has driven scientists to explore viable substitutes (Zhu *et al*., 2021; Cervantes, 2015; Haque *et al*., 2020). In alignment with market demand and efforts to combat AMR, many poultry farmers are shifting toward antibiotic-free production. They are reducing or eliminating antimicrobial feed additives while seeking ways to improve feed efficiency, growth performance, and gut health. Probiotics and phytobiotics have emerged as promising alternatives to AGPs (Fonseca *et al*., 2024).

The increasing demand for natural and functional feed additives in the poultry industry has led to innovations targeting gut health and growth promotion without the use of antibiotics (Ayalew *et al*., 2022). Among these, resistant starch (RS) has garnered attention for its ability to support a healthy gut microbiota, improve nutrient absorption, and enhance overall animal performance (Zhu *et al*., 2021). Consumer demand for high-quality products with health-promoting attributes has also fueled advancements in feed formulation and modern food processing techniques (Bolek, 2021; Khaneghah, 2021).

To support gut health, several dietary strategies have been employed, including the use of enzymes, probiotics, prebiotics, amino acids, and other bioactive compounds. Functional starches, such as RS, represent another promising approach (Dobranowski and Stintzi, 2021). RS, a type of starch that resists digestion in the small intestine, acts as a prebiotic by being fermented by microbiota in the large intestine (Landon *et al*., 2012; Slavin, 2013; Davani-Davari *et al*., 2019). As a functional dietary fiber, RS helps regulate gut health by promoting beneficial microbial activity in the hindgut.

Gut health is characterized by efficient digestion and nutrient absorption, a balanced intestinal microbiota, a strong immune response, and overall animal well-being (Bischoff, 2011). RS has shown the ability to influence intestinal health and support the growth of beneficial microbial populations (Qin *et al*., 2023). Because it bypasses digestion in the upper gastrointestinal tract, RS reaches the ceca, where it is fermented to produce short-chain fatty acids (SCFAs), such as acetate, propionate, and butyrate (Landon *et al*., 2012). These SCFAs play vital roles in enhancing gut barrier function, nutrient absorption, and immune response (Macfarlane and Macfarlane, 2003).

Of the three main SCFAs, butyrate is considered the most beneficial for gut health and is strongly influenced by RS intake (Fuentes-Zaragoza *et al*., 2010; Demartino and Cockburn, 2020). For instance, supplementing the diet of Cherry Valley ducks with 120 g/kg of raw potato starch (RPS) for 35 days increased cecal concentrations of acetate, propionate, and butyrate (Qin *et al*., 2019). RS also lowers the pH in the ceca, creating a hostile environment for pathogenic bacteria and regulating SCFA production (Roy *et al*., 2006; Regassa and Nyachoti, 2018).

Resistant starch is classified into four types (Wang *et al*., 2023a): RS1, which is found in whole or coarsely ground grains and legumes; RS2, present in raw potatoes and unripe bananas; RS3, which forms when starchy foods such as rice or potatoes are cooked and then cooled; and RS4, which consists of chemically modified starches. While RS has demonstrated health benefits, some studies have also reported potential drawbacks. For instance, Zhang *et al*. (2020b) found that RS might affect intestinal morphology by activating the Notch pathway and suppressing goblet cell proliferation, resulting in decreased mucin production and tight junction gene expression.

Nonetheless, RS-rich diets have been associated with various health benefits, including reduced postprandial glycemia and insulinemia, improved mineral absorption, enhanced satiety, and better intestinal function (Sajilata *et al*., 2006; da Silva *et al*., 2012). SCFAs also modulate the metabolism of enterocytes and colonocytes, influencing intestinal muscle tone and blood flow. RS intake has been linked to improved gut barrier integrity, lower blood glucose and cholesterol levels, and reduced inflammation and risk of colon cancer in both animal and human studies (Bojarczuk *et al*., 2022).

In poultry, Ariza-Nieto *et al.* (2012) reported that pigeons fed RPS showed improved gut morphology, with higher villus-to-crypt ratios in the duodenum and jejunum compared to control groups, indicating potential benefits for intestinal structure and nutrient absorption.

Although numerous studies across various species have highlighted the benefits of RS, research specifically focused on poultry remains limited. This review aims to underscore the importance of addressing consumer demand for natural and health-promoting approaches in poultry nutrition. Emphasizing alternatives like RS can support a more sustainable and health-conscious future for poultry production systems.

Different types of resistant starches

The term "resistant starch" was first used to describe the part of starch that cooled down in cooked foods but α-amylase couldn't break down. Then, this meaning was expanded to include starch and the parts of it that break down in the large intestine and become food for microbes to ferment (Englyst *et al.*, 1982; Englyst *et al.*, 1996). Later, RS was named as a similar carbohydrate that should be thought of as nutritional fiber (Champ, 2004).

RS type 1 (RS1) starches are inaccessible to the body in cereal and pulse diets. Amylolytic enzymes cannot access starches contained within intact plant cells or uncooked grains. Native resistant starch crystals (RS2) are present in raw potatoes and green bananas. They readily transform into gelatin when combined with water at 60°C. High amylose cornstarch is another type of RS 2 that doesn't turn into gelatin at temperatures above 120°C. Retrograded starches (RS type 3) happen when starchy foods like bread and potatoes are cooked and turn into gelatinize. When they are cooled, they return to their original shape. Chemical changes are made to RS type 4 (RS4) carbs to stop amylase from working. For this, chemical bonds are made by dextrinization, etherification, esterification, oxidation, and cross-linking with chemicals (Champ, 2004; Birkett and Brown, 2008; Miao and Hamaker, 2021). Table 1 exhibited different kinds of resistance starches.

Different sources of resistant starches

RS is present in nearly all starchy foods, albeit in varying quantities. The quantity of starch is contingent upon the starch's structural formation during biosynthesis and the methods of food preparation, processing, and storage, applicable in both domestic and industrial contexts (Rahman *et al.*, 2007). Starch is present in plant tissues including leaves, tubers, fruits, and seeds. RS exists in both processed and unprocessed food items. Instances of this phenomenon include bananas and mangos, which, in their unripe state, contain high levels of RS, approximately 70–80% in mangos and 40–50% in bananas, while having minimal amounts of simple carbohydrates such as glucose, fructose, and sucrose (Sandhu and Lim, 2008). Additionally, legumes and cereal grains are also recognized as natural sources of RS, as shown in Table 2.

Table 1: *Different types of resistant starches.*

Kind of RS	Explanation of RS	Examples	Reference
RS1	Resistant starch that is physically inaccessible	Whole-kernel grains or Coarsely ground	Englyst *et al.*, 1992
RS 2	It is granular starch that has the B- or C-polymorph.	Raw potato, corn starch with a lot of amyloses, banana starch	Englyst *et al.*, 1992; Trachsel *et al.*, 2019
RS3	Naturally occurring retrograded starch during food processing	Cooled down cooked starchy foods, wheat, rice	Woo and Seib, 2002; Giuberti *et al.*, 2012
RS 4	Changes made to starches chemically	Starch with cross-links and octenyl succinate	Han and BeMiller, 2007

Table 2: *Legumes and cereal grains as natural RS sources (g/100 g as eaten).*

Different sources	Total dietary fiber	Total starch	Resistant starch
Legumes			
Black-eyed peas	32.8	53.9	17.7
Red kidney beans	36.8	42.6	24.6
Lentils	33.1	53.3	25.4
Flours			
Wheat	12.1	68.8	1.7
Potato	2.1	81.0	1.7
Corn	2.8	84.3	11.0
Cereal grains			
Oats	37.7	43.4	7.2
Barley	17.0	52.2	18.2
White rice	1.5	95.1	14.1
Cereal products			
White bread	n/a	46.7	1.9
Cooked spaghetti	n/a	n/a	2.9
Puffed wheat cereal	n/a	67.0	1.2
Potato products			
Chips	n/a	29.5	4.8
Mashed potatoes	n/a	n/a	2.4
Boiled potatoes	n/a	n/a	2.0

Adapted from Lunn and Buttriss (2007); n/a: it mean not available.

Prebiotic effect of resistant starch

Resistant starch, a recognized prebiotic, has been incorporated into fiber-rich foods to modulate the gut microbiome and support overall health. Beneficial gut bacteria can selectively ferment RS, inhibiting the growth of potentially harmful microorganisms and thereby contributing to a balanced and healthy gut microbiome (Davis *et al*., 2011; Fuentes-Zaragoza *et al*., 2011). Prebiotics like RS are known to promote the proliferation of beneficial microbial populations, including *Akkermansia*, *Eubacterium*, *Propionibacterium*, *Roseburia*, and *Faecalibacterium*, in addition to the well-established probiotic genera *Lactobacillus* and *Bifidobacterium* (Rezende *et al*., 2021; Włodarczyk and Śliżewska, 2021).

A group of prebiotics known as RS is distinguished by the fact that it is starch that is able to avoid being digested in the small intestine and instead makes its way to the large intestine (Keenan *et al*., 2015; Nugent, 2005). According to a review of studies that looked at how RS could specifically boost the growth and activity of good gut bacteria, type II RS was discovered to encourage the growth of *Bifdobacterium* and *Bacteroidetes* in mice (Sybille *et al*., 2013). According to (Purwani *et al*., 2012), the use of type III RS *in vitro* improved SCFA synthesis and aided *Bifdobacterium* proliferation. Although *in vitro* applications, type IV RS altered the characteristics of bacterial populations; in a clinical investigation, it also raised the synthesis of SCFA and lowered colonic pH (Erickson *et al*., 2018; Upadhyaya *et al*., 2016). The available evidence suggests that RS may have prebiotic properties; hence, there is a great deal of interest in the area of contemporary animal and human health related to the change of microbiota by means of RS. The caecal barrier function, intestinal shape, microbiota composition, inflammatory indicators, and barrier marker expression were all enhanced in ducks given meals containing 12% RPS. In comparison to the control diet, the 24% RPS diet had considerably greater levels of *Lactobacillus* and *Bifidobacterium* (Qin *et al*., 2020). The fermentation of RS promotes the proliferation of beneficial gut bacteria such as *Bifidobacterium* and *Lactobacillus*, supporting its classification as a potential prebiotic (Tekin and Dincer, 2023). Microbiota analyses have shown that broilers fed diets containing 8% and 12% RS exhibited a 23.08% and 20.47% reduction in cecal *Firmicutes*, respectively, along with a corresponding 24.33% and 21.92% increase in *Bacteroidetes*, compared to the negative control group ($P < 0.05$) (Zhang *et al*., 2020a).

Beneficial impacts of RS on Gut health

Resistant starch has the potential to enhance gut health and function by altering and stabilizing the gut microbial ecology and by augmenting the host's immune condition (Regassa and Nyachoti, 2018). It can also change the expression in the gut of genes that control the immune system, which in turn affects gut health. Among SCFA, butyrate, which is made by RS fermentation, is the main source of energy for colonocytes and is thought to affect the operation of the intestinal barrier and immunity (Peng *et al*., 2009; Leonel and Alvarez-Leite, 2012). RS has been demonstrated to induce gastrointestinal motility, minimize the transit time of intestinal contents, and boost feces volume; consequently, it helps prevent constipation occurrence (Qian *et al*., 2013; Wang *et al*., 2014). Dietary RS reduced ileum permeability and upregulated Mucin-2 and tight junction protein expression in ducks. Metabolomics demonstrated that RS diet treatment group metabolites were mostly connected with amino acid and lipid metabolism, vitamin metabolism pathway, and intestinal inflammation, helping explain how RS promotes intestinal health (Qin *et al*., 2023). Randomized controlled research showed that the RS diet changes gut flora using phylogenetic chip and quantitative PCR analysis, yet the diet only partially explained microbiota composition, much less than individual variability. This study shows that individual microbial flora respond differently to the diet, which is essential when assessing the impact of RS on intestinal integrity (Salonen *et al*., 2014). The most significant microbial activity transpires in the cecum and proximal colon of pigs; yet, considerable microbial activity also occurs in the distal portion of the small intestine (Knudsen *et al*., 1991; Jensen and Jørgensen, 1994). A meta-analysis of 24 research articles demonstrated that augmenting RS type 2 to a minimum dietary level of 10% in pigs decreased pH and enhanced the presence of *Lactobacilli* and *Bifidobacteria* in feces, hence potentially inhibiting the proliferation of pathogenic bacteria in the hindgut (Metzler-Zebeli *et al*., 2019). Altering the metabolism of enterocytes and colonocytes is one of the ways that SCFAs contribute to the proper functioning of the lower digestive tract. This has an effect on the muscles and blood vessels in the intestines. In both humans as well as mice, the consumption of RS has been linked to numerous health advantages, including prebiotic properties, reductions in cholesterol and blood glucose levels, enhanced gut barrier integrity, and a decreased risk of inflammation and colon cancer (Bojarczuk *et al*., 2022). In addition, studies conducted on pigs and rats demonstrated that the health of the animals was enhanced against infections and that the intestinal shape was transformed (Bhandari *et al*., 2009; Kleessen *et al*., 1997). The cecum is the only place where RS is broken down. This changes the microbiota makeup of the cecum and increases the amount of SCFAs in both (Bhandari *et al*., 2009). Supplementation with RS may have augmented the tibial mass of meat ducks. Supplementation with 12% raw potato starch inhibited inflammation and modified gut microbiota and SCFAs production. Consequently, the reduction of inflammatory cytokine-mediated bone resorption resulted in an augmentation of bone mass (Zhang *et al*., 2022).

The aforementioned literature highlights the positive effects of RS on gut health and offers practical guidance for further research into its potential as an alternative to in-feed antibiotics. It also emphasizes the need for more targeted approaches to identify specific types of RS or other dietary fibers that effectively promote gut health.

Effects of resistant starches on growth performance

The ability of butyrate to suppress the growth of common pathogenic organisms in chicken has been examined through a variety of trials. In a study that investigated the capacity of butyrate to mitigate the adverse effects of coccidian, it was shown that birds that were given butyric acid before to the challenge saw higher rates of growth compared to those that were given non-medicated diet (Leeson *et al*., 2005). The better gut health brought about by butyrate medication helps to explain this better development performance. In young hens, similarly, coated butyric acid greatly reduced cecal *Salmonella Enteritidis* colonization at 3 days post-infection in comparison with control poultry birds (Van Immerseel *et al*., 2005) and butyrate-based additives demonstrated a noteworthy decrease in *Salmonella Enteritidis* infection in broiler chicks aged 1 day following 27 days of feeding throughout a 42-day experiment (Fernández-Rubio *et al*., 2009). Additionally, RS may lessen the production of toxic nitrogenous metabolites that result from consuming meals high in crude protein (Mu *et al*., 2016). According to the findings of the study, feeding broilers diets that had greater levels of RS was detrimental to the development of their small intestine. Because of this, it appeared as though the hens did not absorb as many nutrients, which resulted in a decrease in body weight gain (BWG), feed efficiency, and adverse carcass quality (Liu *et al*., 2020). Figure 1 illustrates the roles of RS in improving carcass quality, enhancing gut health and function, modulating and maintaining gut microbiota, and optimizing energy metabolism and growth performance in pigs and poultry (Regassa and Nyachoti, 2018).

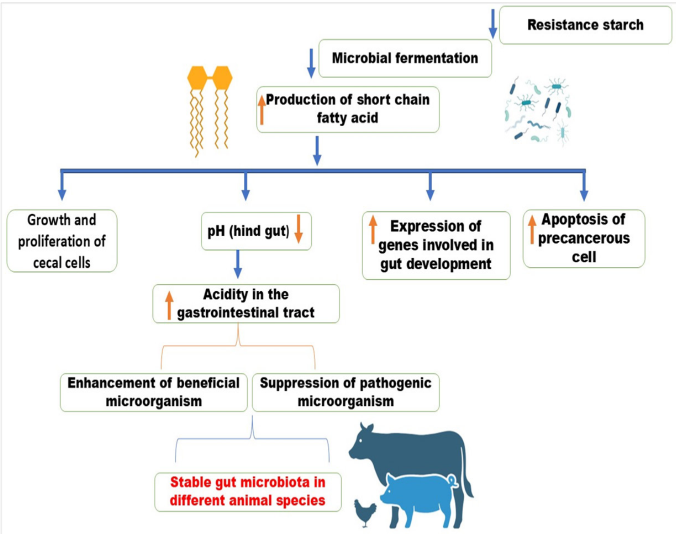

Figure 1: *Graphical representation illustrating the effects of resistant starch on gut health and growth performance across various animal species.*

Promising effects of resistant starch in poultry nutrition

Consumer concern and the ban of antibiotic feed additives in some countries have compelled the quest for feed components that can promote poultry development and gut health (Vondruskova *et al*., 2010). Consequently, feed additives such RS can enhance beneficial bacterial proliferation and inhibit pathogen growth, resulting in altered intestinal architecture that influences growth performance in poultry nutrition (Yang *et al*., 2009). Resistant starch has the ability to enhance gut health and function by changing and stabilizing the gut microbial ecology and boosting the host's immune condition in poultry nutrition (Regassa and Nyachoti, 2018). According to 16S rRNA sequence analysis, the diet with 12% raw potato starch (RPS) had more *Firmicutes*. *Lactobacillus* and *Bifidobacterium* considerably increased in the 24% RPS diet compared to the control diet. In conclusion, that the dietary supplementation of RS enhanced caecal barrier function by improving intestinal shape and altering microbial composition and as well as improved the growth performance of ducks (Qin *et al*., 2020). Dietary resistant potato starch enhanced growth performance and feather development in Pekin ducks on a low phosphorus diet (Xu *et al*., 2021). Resistant starch comes in 5 types discussed in details by (Ashwar *et al*., 2016; Lockyer and Nugent, 2017) and SCFAs are one of the byproducts of fermenting RS. They can stop pathogens from growing (Topping *et al*., 2003). Resistant starch is advocated as a factor for intestinal health that can alter the microbiota composition of the digestive tract (Raigond *et al*., 2015). In another study by Lotfi *et al*., (2019) evaluated the effects of RS on performance and ileal morphology in broilers. They compared the effects of RS to those of fructooligosaccharide (FOS) and zinc bacitracin (ZnB). When compared to the group that was given FOS, the overall growth performance of the RS groups was much higher. The changed ileum morphology, which is characterized by increased villus height and decreased crypt depth, can be attributed to the enhanced growth performance of broilers that were given RS. An investigation conducted by M'Sadeq *et al*. (2015) assessed the effects of acetylated and butyralated high-amylose maize starch on broilers, revealing that acetylated high-amylose maize starch diminished luminal pH and augmented SCFAs, consequently enhancing intestinal health and growth performance in broilers subjected to *Eimeria* and *C. perfringens* challenges. Huff *et al*. (2015) tested three types of RS (HI Maize 260, unmodified potato starch, and fresh raw russet potato) in broilers and found that *E. coli*-challenged broilers fed unmodified potato starch under cold stress had a higher body weight than that of the other groups. Retrograded RS (*S. Tuberosum* and *S. Phureja*) and mannanoligosaccharide did not affect daily body weight increase in broilers compared to the control group, according to (Ariza-Nieto *et al*., 2012). However, broilers ingesting RS and fructooligosaccharide had better growth due to improved innate immunological function and higher SCFA synthesis, which may be absorbed through the hindgut and used as tissue energy, and results suggested that potato resistant starch is a potential prebiotic (Adhikari and Kim, 2017). Dietary RS modifies the microbial makeup and diversity, and influences the metabolic pathways of microbial metabolism in the caecum of broilers, that potentially impacting nutrient consumption and hindgut health of the host (Zhang *et al*., 2020c). This result was consistent with previous reports, which suggested that Japanese quails fed a diet rich in amylose yielded lower carcass weights. In addition, the results showed that hens fed a diet high in RS produced less semi-eviscerated and eviscerated meat than the control group, implying that a diet high in RS may indirectly increase the birds' maintenance needs by shifting resources away from the carcass and toward the visceral organs (Cardoso *et al*., 2011). This review article had examined the contemporary comprehension of RS and its applications within the poultry business, investigating its mechanism of action, the evidence substantiating its advantages, and the ramifications for the future of sustainable chicken production (Figure 2). The summary of various beneficial effects of resistant starch studies in poultry has been summarized in Table 3.

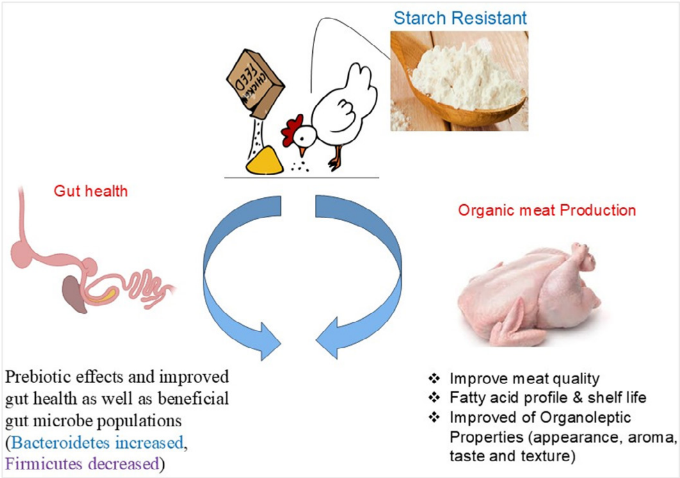

Figure 2: *Promising effects of starch resistant on gut health and meat quality in poultry.*

Conclusion

Support the idea that resistant starch could be used as a natural and long-lasting feed addition to help chickens' gut health and growth. Bring up the need for more research and what it means for lowering the use of antibiotics and making the poultry business more environmentally friendly. Research finding revealed that RS can be included at 4%, 8%, and 12% levels in corn-soybean diets. These dose-dependent levels enhanced jejunal lymphocytes and IgA-producing cells, improving gut health. At 21 days, 8% RS improved gut immune activity. In constructing diets with resistant starch, it is essential to consider both the level and the growing period of poultry, as well as the total diet composition, to optimize gut health advantages and prevent growth deficits. More research is required to go deeper into the mechanisms of RS digestion and its degree of inclusion.

Table 3: *Summarized the various beneficial effects of resistant starch studies in poultry.*

Different types of resistant starches	Effects	References
Dietary resistant starch	Dietary Resistant Starch increased the final body weight gain and effectively reduced lipid levels in broiler plasma and liver, likely due to alterations in bile acid production and reabsorption capacity.	Wang *et al*., 2023b
Potato-resistant starch	Birds fed with retrograded resistant starch had the highest villus: crypt ratio (12.34μm) compared to mannan-oligosaccharides (MOS) (8.25μm). The findings imply potato-resistant starch may be a prebiotic.	Ariza-Nieto *et al*., 2012
Raw potato starch	In meat ducks, resistant starch improved intestinal barrier function and increased caecal barrier function.	Qin *et al*., 2020
Corn resistant starch	Feeding broilers with diets containing higher concentrations of RS may inhibit the growth of the small intestine.	Liu *et al*., 2020
Resistant starches	Resistant starch may affect broiler chicken gut health and growth by modulating cecal SCFA and nutrient digestion.	Oluseyifunmi *et al*., 2024
Corn resistant starch	Cecal concentrations of acetic and butyric acid in broilers were elevated when fed 40, 80, and 120 g/kg of corn RS.	Zhang *et al*., 2020a
Slowly digestible starch	The findings indicated that broiler chickens exhibited a superior performance on diets with a small quantity of slowly digestible starch.	Weurding *et al*., 2003
Dietary resistant potato starch	Dietary resistant potato starch enhances feather development and performance of growth in Pekin ducks.	Xu *et al*., 2021
Dietary starch to lipid ratios	In finishing broiler chickens, starch has been linked to both meat quality and growth performance.	Khoddami *et al*., 2018
Resistant corn starch	The utilization of resistant corn starch for the development of low-fat meat products with health benefits in the broiler meat sector appears promising.	Wang *et al*., 2019

Acknowledgments

This research was funded by the Donkey Innovation Team of the Shandong Modern Agricultural Industry Technology System (SDAIT-27), the Shandong Provincial Natural Science Foundation (ZR2022QC242), the Science and Technology SMEs Innovation Ability Improvement Project of Shandong Province (2023TSGC0377), the Science and Technology Help SMEs Climb Plan of Liaocheng (2023PDJH22), the Key Research and Development Plan of Liaocheng (2023YD82), the Open Project of Liaocheng University Animal Husbandry Discipline (319312101-08, 319462207-14, 319312105-14), and the Research Foundation of Liaocheng University (318052122, K22LD04, K23LD64).

Novelty Statement

This review highlights the underexplored potential of resistant starch as a natural alternative to antibiotic growth promoters in poultry nutrition. By synthesizing current findings on RS's prebiotic effects, its impact on gut microbiota, and growth performance, this article identifies critical research gaps and offers new insights into sustainable and health-promoting feed strategies for the poultry industry.

Author's Contribution

All authors were equal contributors in writing this review article.

Ethics approval
Not applicable.

Generative AI and AI-assisted technology statement
No AI-assisted tool was used in this study.

Conflicts of interest
The authors have declared no conflict of interest.

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