

## Efficacy of Microbial Metabolites in Poultry for Better Health and Immunity

Sajjad Ur Rahman<sup>1</sup>, Dur E Nayyab<sup>2</sup>, Farwa Farooq<sup>3\*</sup> and Muhammad Mukarrarm Bashir<sup>4</sup>

<sup>1</sup>Institute of Microbiology, Faculty of Veterinary Sciences, University of Agriculture, Faisalabad, Pakistan

<sup>2</sup>Bioaugmentation Research Laboratory Jaranwala Road Faisalabad, Pakistan

<sup>3</sup>Institute of Microbiology, Faculty of Life Sciences, Government College University Faisalabad, Pakistan

<sup>4</sup>DairyLac Private Limited, Faisalabad, Pakistan

### \*Corresponding Author

Farwa Farooq, Institute of Microbiology, Faculty of Life Sciences, Government College University Faisalabad, Pakistan.

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### Abstract

Poultry farming remains a crucial part of the global food supply, offering affordable, nutrient-rich protein. In intensive broiler farming, enteric infections are serious. Several types of these diseases can kill chickens, slow weight gain, raise medical costs, and lower feed conversion ratios. From 2015 to 2021, broiler meat production increased by 35%, global egg production rose by 10%, the laying hen population expanded by 30%, and breeder stock grew by approximately 25%, early chick mortality rates (up to 1.8%) and enteric infections such as necrotic enteritis, which impacts 40% of flocks and has a clinical mortality rate ranging from 10% to 50%, pose significant challenges. The frequent use of antibiotic growth promoters (AGPs) has raised concerns, mainly due to the prevalence of disease outbreaks and the development of antimicrobial resistance (AMR). In response, microbial metabolites such as short-chain fatty acids (SCFAs), bacteriocins, organic acids, and other bioactive compounds, are gaining attention as sustainable alternatives. These substances postbiotics help to maintain gut health, strengthen immune defenses, and inhibit harmful pathogens. As butyrate supports gut lining repair and regulates immune signaling, while bacteriocins directly target disease-causing bacteria. Microbial metabolites in poultry feed improve efficiency, growth performance, and survival rates, while decreasing pathogen shedding and dependency on antibiotics. YCM, a metabolite-rich postbiotic supplement, illustrates the potential of such innovations in improving poultry health. The study emphasizes the effective use of microbial metabolites as bioactive compounds that enhance avian immune systems and promote safe production against global antibiotic limitations.

### 1. Introduction

Poultry, including chickens, ducks, turkeys and geese play a crucial and versatile part in global food systems. Its significance incorporates nutrition, food security, sustainability, poverty alleviation and economic development. Poultry eggs and meats are among the most important sources of premium animal protein worldwide [1]. Poultry meat often has a higher proportion of beneficial monounsaturated fats compared to most pork and beef, while also retaining lower fat content, particularly harmful fats [2]. Eggs offer highly digestible protein and serve as a year-round source of sustenance, especially for vulnerable populations such as

children, elders and pregnant women [3]. In low-income regions, substantial data demonstrates that increased chicken intake helps fight child malnutrition and nutritional deficiencies. The poultry sector, encompassing farming, processing, feed production and retail, represent a significant driver of economic activity, sustaining millions of livelihoods worldwide along its value chain [4]. The global chicken industry has significantly expanded during the past decade, particularly in the production of grilled meat. In 2011, global production of grilled meat reached over 80 million metric tons. By 2021, the figure had increased to over 121 million metric tons, reflecting a growth rate above 50% over a decade. This

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rise is attributed to advancements in breeding techniques, disease management, and feed enhancement, with an escalating need for affordable protein. Significantly, Asia and Africa have had the most rapid growth. Over the past two decades, grill production in Asia has increased by 132%, whilst in Africa; it has risen by 161%. Annually, around 119 billion broilers are raised and slaughtered globally. This results from the expansion of commercial poultry farms and the increasing global demand for chicken meat [5]. In rural areas, it is essential as it provides smallholder farmers with financial resources and jobs, as well as a kind of house insurance during calamities. Poultry farming is often a low-investment, high-return enterprise, readily accessible to novice and small-scale farmers.

Poultry farming is recognized as one of the fastest-growing agricultural sub-sectors, especially in emerging economies. Poultry species have less usage of feed, production cycles and space compared to larger livestock and exhibit rapid growth. Poultry eggs and meat are readily accessible sources of animal protein for many populations, since this efficiency results in lower production costs and more affordable products. As the global population nears 10 billion, food security relies on a consistent supply of protein-rich food, partially guaranteed by the scalability and reliability of chicken production. Poultry production has a relatively negligible environmental effect in comparison to other livestock. Reduced water, land and feed requirements result in few greenhouse gas emission [6]. Advancements in agricultural management, breeding and nutrition have further enhanced productivity and sustainability. Additionally, byproducts such as chicken litter, which may be employed as fertilizers or converted into biogas, contribute to circular economy concepts in agriculture. In some areas, chicken is currently more in demand than beef; moreover, poultry is projected to be the most consumed animal protein globally. The demand for chicken continues to rise due to its health benefits, affordability and widespread acceptability [7].

Egg production has been increasing rapidly, both in the quantity of eggs produced and the population of layer hens. From 2011 to 2021, worldwide egg production increased from around 65.5 million tons to 86.4 million tons, reflecting a 31.9% growth over a decade. This swift increase is mostly attributable to heightened urban demand, improved genetics for layer hens, and enhanced feeding practices. In 2021, the global population of laying hens exceeded 1.4 billion, supplying eggs to a market that continues to expand at an annual pace of 2–3%. Moreover, worldwide egg consumption is anticipated to increase as awareness grows about eggs as a source of economical, high-quality protein and their significance in nutritional security for at-risk groups. The health and performance of laying hens, particularly through gut-targeted feed solutions such as microbial metabolites and postbiotics, is becoming an increasingly critical area of emphasis [8].

Poultry populations are very prone to infections and can disseminate rapidly due to their high animal density and demanding farming practices [9]. Newcastle disease, avian influenza, salmonellosis and

infectious bronchitis are the primary diseases affecting chickens. Avian influenza, commonly referred to as bird flu, greatly impacts the economy and presents zoonotic risks to humans. Newcastle disease is prevalent in several regions, posing a significant threat to both domestic and commercial poultry, particularly in areas with weak vaccine coverage. The international trade in live poultry products, accompanied by biosecurity violations, facilitates the rapid transmission of infections across borders [10].

Increasing concerns around antimicrobial resistance (AMR) and disease outbreaks are fostering considerable interest in alternatives like prebiotics, probiotics and microbial metabolites within the poultry industry [11]. Probiotics, including *Lactobacillus* and *Bacillus* species, enhance gut health by stabilizing intestinal bacteria, augmenting nutritional absorption and fortifying the immune system. These results improved overall poultry performance and reduced colonization by harmful illnesses [12]. In contrast, prebiotics are nondigestible food elements such as mannan-oligosaccharides and fructo-oligosaccharides that particularly promote the proliferation of beneficial gut bacteria, hence improving gut integrity and disease resistance [13]. Microbial metabolites, including bacteriocins, short-chain fatty acids and enzymes, are crucial for maintaining gut health; these metabolites supply energy to intestinal cells, lower gut pH to inhibit infections and facilitate digestion. The rising focus on these replacements is mostly attributed to global restrictions on antibiotic growth promoters, consumer demand for antibiotic-free poultry, and campaigning for more sustainable agricultural practices [14]. These natural replacements, while utilized collectively, offer effective methods to enhance chicken health and productivity while addressing the significant issue of antimicrobial resistance (AMR), hence serving as essential components of modern poultry farming systems.

YCM (Yeast Culture Metabolites) is a postbiotic supplement developed by DairyLac which is formulated by *saccharomyces cerevisiae*, containing different microbial metabolites such as peptides, phospholipids, oligosaccharides and some of bioactive enzymes. This investigation is aimed at demonstrating the roles of microbial metabolites in enhancing disease resistance and immunity, as well as to delineate the primary types of microbial metabolites produced by the poultry gut microbiota. In poultry, microbial metabolites such as short-chain fatty acids (SCFAs) which include propionate, butyrate and acetate have been studied for their immune-modulating properties [15]. SCFAs, mostly produced through the fermentation process of dietary fibers by beneficial bacteria such *Firmicutes* and *Bacteroids*, play a crucial role in regulating inflammation, enhancing immune cell activity, particularly that of macrophages and T cells and promoting the production of immunological components that facilitate pathogen clearance [16]. Butyrate has been shown to regulate antiviral pathways in avian respiratory cells and enhance the expression of interferon-simulated genes, hence augmenting resistance to viral infections. Moreover, metabolites such as spermidine are linked to improved immune gene expression and energy metabolism in

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chicken, hence fostering higher productivity and health. These microbial metabolites together inhibit pathogenic microorganism and modulate the host's immune system, therefore enhancing both gut and systemic immunity. Understanding and using these metabolites offers intriguing methods to naturally strengthen disease resistance in poultry reduce antibiotic dependence and improve overall flock health [17].

The past decade has a distinct trend of accelerated growth in broilers, layers, and breeders. Broilers have had the most rapid increase in production due to their abbreviated lifecycles and high feed efficiency. Simultaneously, innovative feed formulations and disease control strategies have benefited egg layers, resulting in increased laying rates and extended lifespans. Breeder populations have expanded to suit this need; however their precise figures are not consistently recorded globally. Consequently, the poultry industry has emerged as one of the most vertically integrated and biologically efficient methods of food production globally. The simultaneous increase in the population of birds, the quantity of meat, and the number of eggs underscores the significance of feed additives. These additions enhance avian growth and productivity while stabilizing the microbiota and improving immunological function, similar to postbiotic interventions. The global chicken meat output from 2012 to 2025, reached around 103.7 million metric tons, with a projected growth to over 105.8 million metric tons by 2025 [18].

## 2. Type and Sources of Microbial Metabolites

Microbial metabolites are bioactive compounds primarily produced by gut flora through fermentation process of food elements and microbial metabolic activities within the poultry gastrointestinal tract. The maintenance of intestinal health, enhancement of disease defense in poultry and regulating of immune responses are contingent upon these metabolites [19]. SCFAs, organic acids, enzymes, bacteriocins, secondary metabolites such as peptides and phenolic constitute the primary categories of microbial metabolites. Beneficial bacteria such as *Clostridium*, *Lactobacillus* and *Bifidobacterium* species metabolize dietary fibers to produce short chain fatty acids, particularly butyrate and acetate. SCFAs serve as a vital role of energy for gut epithelial cells, regulate cytokine production, exhibit significant anti-inflammatory effects and promote mucosal integrity, hence promoting immunological homeostasis. These metabolites also lower gut pH, rendering dangerous microbes less hospitable, hence promoting systemic immune efficacy and gut health. Bacteriocins, produced by probiotic strains such as *Bacillus* and *Lactobacillus*, are antimicrobial peptides that inhibit the proliferation of pathogenic bacteria, including *Clostridium* and *Salmonella*, hence maintaining microbial equilibrium and preventing infections [20]. Formic and propionic acids, along with other organic acids, regulate stomach by functioning as bacteriostatic agents that inhibit pathogenic bacteria or enhance nutrient digestion [21]. Microbial enzymes and exopolysaccharides exert immunomodulating effects by activating cytokine production, lymphocyte proliferation and antioxidant activity, hence enhancing the immune response of host. Secondary

metabolites modulate pathogens and signal by modifying host defense mechanisms and reducing oxidative stress [22].

Microbial metabolites originate from resident gut bacteria, fermented feed items and probiotic strains. Their mechanisms of action include competitively driving out of pathogens through niche occupation, strengthening of tight junctions to enhance mucosal barrier integrity, the production of anti-inflammatory and antioxidant properties and decrease of gut pH to regulate harmful bacteria [23]. Additionally, microbial metabolites stimulate immune-related genes, hence enhancing adaptive as well as innate immune responses, which are essential for disease resistance in poultry [24].

The global poultry business has experienced significant growth over the past decade across all sectors, including meat, eggs, layers, and breeders. Between 2015 and 2021, the production of grill meat increased by 35%, rising from over 90 million tonnes to almost 121.5 million tonnes. Simultaneously, global egg production increased by 9%–10%, rising from around 80 million tonnes in 2017 to over 87 million tonnes by 2021–2022. In response to the increasing demand for eggs, the population of laying hens expanded over 30%, exceeding 1.4 billion by 2021. Despite the infrequent documentation of breeding flock data, poultry research indicates that the population of breeder stocks has increased by around 25% throughout the same timeframe, ensuring a sufficient supply of parent stock for broilers and layers [25].

The findings highlight an immediate necessity for gut- and immunity-enhancing interventions in poultry production. Microbial metabolites, such as short-chain fatty acids, organic acids, enzymes, vitamins, and immunomodulatory chemicals, enhance intestinal fortitude, facilitate food absorption, and reduce susceptibility to illness. Targeted postbiotic formulations such as YCM comprise over 600 active metabolites. They enhance feed conversion ratios, growth rates, egg production, and overall flock health by fostering beneficial bacteria and inhibiting infections. This is a significant factor in the continuous increase of output.

## 3. Immunological Aspects: Types of Immunity and Impact of Microbial Metabolites

### 3.1 Innate (Non-Specific) Immunity

Similar to other vertebrates, the avian immune system comprised of a highly specialized innate immune system which is composed of effector cells that provide rapid, broad-spectrum responses encoded by germline genes, together with various physiological obstacles. The avian innate immune system comprises many functionally distinct effector cells such as natural killer cells, macrophages, innate-like T-cells and heterophils [26].

Avian monocytes, originally produced from bone marrow stem cell, are an important phagocytic element in blood and it can differentiate into macrophages that inhabit diverse organs. In compared to mammals, the avian respiratory macrophages; lung lavages from healthy birds seldom yield immune cells. Essential elements in

avian pulmonary defense appear to be highly phagocytic free avian respiratory macrophages with potent antibacterial activity [27]. Subsequent an intra-tracheal immunization with a virulent *Pasteurella multocida*, free avian respiratory macrophages rapidly migrates to the lung, resulting in a significant increase in the lung macrophages population. The difficulty posed by *Salmonella* and *E. coli* is also evident. Intra-tracheal administration of *P. multocida* Chloral vaccine strain in poultry provides protection against *E. coli* air-sac exposure occurring 7 hours later, with evidence indicating that macrophage recruitment induces non-specific protection. This defense is attributed to macrophage migration to the infection site and the activation of innate immunological memory [28].

The phagocytic purpose of avian macrophages is well classified, with Fc-U and enrich receptors for C3 and IgY interacting while targets are opsonized, indicating the crucial role of receptors in this process [29]. Additionally, activated macrophages include pattern recognition receptors (PRRs) that detect pathogens-associated molecular patterns (PAMPs), such as lipopolysaccharides, exogenous nucleic acids and flagellin, hence triggering a signaling or physiological response. The most extensively studied family of PRRs is toll-like receptors (TLRs), which upon activation; initiate the type-1 interferon pathways together with inflammatory cytokines and chemokine. 13 TLRs have been identified in mammalian species; moreover four more TLRs have been revealed in chickens [30].

### 3.2 Adaptive Immunity

The avian adaptive immune system is more targeted and connected to the production of immunological memory, in contrast to the low specificity of innate immune system. The avian adaptive immunity is often divided into two reactions: humoral immune responses that target cell-mediated responses and external infections that focus on eliminating intracellular pathogens. T cells that propagate in avian species in a manner comparable to mammals fundamentally coordinate cell-mediated responses. Before moving to the periphery, these T-cells which were initially occupied by mesodermal hematopoietic cells throughout embryonic development go through rearrangement and differentiation of the T-cell receptor (TCR) gene. TCR $\alpha\beta$  is a heterodimeric surface domain that facilitates antigen recognition. These domains collaborate to produce TCR $\alpha\beta$  heterodimers. The distinct types of  $\alpha V\beta 1$  and  $\alpha V\beta 2$  chains can be used to distinguish two T-cell lineages seen in chicken. T cells expressing  $\alpha V\beta 1$  chains from vaccinated or infected chickens, but not naïve birds, recognize peptides from avian viruses in association with conventional MHC molecules. Adaptive immunity, therefore, comprises T cells that express  $\alpha V\beta 1$  chains. It remains uncertain whether T cells with  $\alpha V\beta 2$  chains contribute to adaptive immunity, given no specific antigen recognized by this TCR has been identified.

Additionally present in chickens and permitting further classification are the CD4 and CD8 co-receptors, which interact with major histocompatibility complex (MHC) I and MHC II, respectively [31]. B lymphocytes facilitate humoral responses in chickens,

similarly to their function in humans. However, as B cells proliferate in the bursa of Fabricius, their genesis is unique to avian species. Similar to T cells, the bursa is populated by lymphoid precursors throughout embryonic development prior to their migration to the periphery. B cells require a diverse antibody repertoire to generate antibodies specific to various pathogenic threats. Although this phenomenon persists in avian, the predominant mechanism of diversity in mammals is achieved by immunoglobulin (Ig) gene rearrangement; this often occurs from somatic gene conversion occurs solely during embryonic development in avian species, but immunoglobulin gene rearrangement persists continuously inside the bone marrow of mammals [32]. Subsequently, chicken B cells may differentiate into plasma cells, facilitating the release of immunoglobulin that can opsonize extracellular infections. This facilitates the establishment of enduring protective responses post-immunization and enhances Ig production after a secondary assault [33].

### 4. Early Chick Mortality and Enteric Diseases

Early chick mortality poses a significant challenge to poultry production, frequently attributable to germs, fungi, and viruses. A necropsy study including 2,346 broiler chicks less than two weeks of age revealed a death rate of 1.7%, comprising 1.6% in the first week and 1.8% in the second week. Colibacillosis (2.01%), salmonellosis (1.9%), aspergillosis (0.9%), and visceral gout (0.6%) were the predominant causes. Colibacillosis remained the predominant cause of mortality, but there was a little increase in fatalities from conditions such as salmonellosis and gout in the latter period. Histopathological findings revealed that kidney tissues exhibited congestion, inflammatory infiltrates, granulomas, and urate deposits [34].

In intensive broiler farming, enteric infections are serious. Several types of these diseases can kill chickens, slow weight gain, raise medical costs, and lower feed conversion ratios. Thus, poultry gastrointestinal diseases affect farmers' profits. Preventing disease spread is essential for poultry business survival. Enteric infections can be caused by bacteria, viruses, and parasites, other microorganisms, or non-infectious factors including nutrition, management, and environment. However, determining if a gastrointestinal ailment is infectious is difficult. The intensive poultry system's environmental conditions and large animal population may also spread certain gastrointestinal diseases. Clostridia are the most common pathogens that cause avian gastrointestinal illness. This pathogen can produce several symptoms.

Necrotic enteritis, a prominent clostridial enteric illness in chickens, is caused by *C. perfringens* spores in every poultry farm litter. Younger animals are more susceptible to enteric illnesses. The main symptoms include anorexia, increased warmth seeking, lethargy, and diarrhea. Subclinical infections greatly affect poultry performance. Coccidiosis, caused by Eimeridae protozoa, is common and can cause gastrointestinal issues in chicken. Most chicken farms have *Eimeria* coccidia, which affects avian

intestines. Due to poor hygiene, poor environmental conditions, and high bird density, many parasites may survive in poultry operations for long periods and spread quickly. Due to reduced production and preventive and treatment expenses, coccidiosis costs the global economy almost \$3 billion USD yearly. Necrotic enteritis outbreaks on broiler farms cost the world economy \$2 billion yearly [35].

## 5. Health Benefits in Poultry

### 5.1 Improved Feed Conversion Ratio (FCR)

The feed conversion ratio is a vital measure for evaluating chicken production efficiency, reflecting the quantity of feed necessary to obtain a unit increase in body weight. Short chain fatty acids (SCFAs), including acetate and butyrate, function as microbial byproducts that improve the digestive environment by triggering the growth of beneficial gut bacteria and facilitating in food digestion. Birds require reduced feed to maintain the same or greater growth owing to their improved gastrointestinal efficiency in nutrition assimilation. Given that feed is the most significant cost in chicken production, farmers may therefore, reduce feed costs while preserving or improving productivity especially, if farmers have succeeded in maintaining or increasing output. This efficiency significantly enhances environmentally sustainable chicken production practices [36].

Feed efficiency may be quantified in several ways, including feed conversion (FCR) and residual feed intake (RFI). A number of scholars have undertaken comprehensive research on FE, yielding significant new insights. RFI may be influenced by several genes linked to the absorptive capacity and production of intestinal villi. A total of 41 uniquely expressed genes are associated with FRI. These significant genes are crucial for metabolism, digestion, energy equilibrium and stress responses, resulting in varying RFI performances. A collection of significant genes and pathways connected with RFI, identified by bioinformatics analysis. Despite extensive study on feed efficiency, RFI has attracted comparatively less consideration. FCR is one of the most often employed feed efficiency measurement tools for layer hens [37].

### 5.2 Enhanced Growth Rates

The complex interaction of gut health, microbiome composition, immune control and nutrient absorption facilitates increased growth rates in chickens significantly influenced by microbial metabolites and probiotics interventions. Recent research indicate that probiotics, including Bifidobacterium and Lactobacillus species, are crucial for improving the intestinal environment, therefore promoting beneficial gut bacteria and diminishing pathogens, all of which directly influence growth performance [38].

One of the primary mechanisms by which these bacteria enhance growth is by production of SCFAs, such as propionate, acetate and butyrate. SCFAs, produced by gut bacteria through the fermentation of dietary fibers, serve as an essential energy source for gut epithelial cells. The renewal and maintenance of gut lining, facilitated by the vitality, result in enhanced nutritional utilization and absorption. In addition to strengthening gut health and

facilitating efficient food conversion, SCFAs lower intestinal pH, creating an environment less conducive to dangerous microbes [39]. Lysine is a crucial amino acid that contributes to protein synthesis, tissue repair, enzymatic function, and immune system development in avian species. It is crucial for muscle deposition and development as it is directly involved in the synthesis of body proteins and structural components such as collagen and elastin. Lysine aids in the synthesis of antibodies and immunological signaling molecules, enhancing the body's resistance against diseases. YCM (Xtra Pure Metabolites) is a postbiotic supplement developed by DairyLac which contains methionine, a crucial amino acid in is biofortified with both lysine and methionine, donates methyl groups to cells and is vital for cellular metabolism, antioxidant defense (via glutathione synthesis), and hepatic fat metabolism. The sulfur in methionine's structure contributes to feather formation and detoxification. Lysine and methionine collaborate to provide optimal growth rate, feed efficiency, and reproductive success. Probiotics supplementation in broilers has significantly enhanced average body weight and daily gain. The incorporation of Lactobacillus and Bacillus in chicken diets enhances body weight gain, improves feed conversion ratios to control or antibiotic-fed group and increases feed intake. In addition to enhanced nutritional digestibility, these advancements stem prevalence of pathogenic species such as *C. perfringens* and *Salmonella* [40]. Moreover, immunomodulating probiotics and their metabolites enhance the levels of immunoglobulin (IgM, IgA, and IgG) and cytokines (IL-4, IL-6 and IL-10), hence activating T-cells. This leads to a more effective immune system, reducing the energy birds use in combating infections and reallocating resources towards growth. Additionally, some bacteria such as *B. subtilis* and *Lactobacillus* are associated with less stress and improved wellbeing, hence facilitating optimal developmental conditions. Precision biotic supplementation, aimed targeting specific microbiome metabolic pathways, has been shown to improve pathways associated with protein metabolism in the gut, hence promoting growth. Many researches indicate that the advantages associated with enhance SCFAs production and an optimized microbiome protein metabolism index can lead to a 3% increase in body weight growth and an improvement in corrected feed conversion ratios of up to 3.7% [41].

## 6. Reduced Mortality and Morbidity

Major risks to avian health and productivity include disease epidemics and subclinical conditions. A healthy gut flora, microbial metabolites and a natural defense mechanism all contribute to decreased morbidity of flock and mortality rate [42]. Probiotics and their metabolites, including organic acids and bacteriocins, limit the intestinal colonization dissemination of pathogens such as *E. coli*, *C. perfringens* and *Salmonella* by producing antimicrobial substances and lowering gut pH. These medications effectively enhance the immune response by modulating cytokine production, therefore stimulating both innate and adaptive immunity [43]. As a result, birds require reduced antibiotic treatment, exhibit accelerated recovery and demonstrate increased resistance to infections, so addressing concerns related to antimicrobial resistance. A less infection burden leads to cleaner flocks, improved welfare and

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more uniform product output [44].

### **7. Better Gut Morphology (Villi Height, Crypt Depth)**

A fundamental component that influences digestive efficiency and overall health in poultry is the morphology of the gut. In the small intestine, the villi and crypts are the two most important structural components. Slender, finger-like projections known as villi penetrate the small intestine and significantly augmenting the surface area available for nutrient absorption. The greater the height of villi, the most surface area is available for the absorption of amino acids, carbohydrates, fatty acids, vitamins and minerals from digested diet this result in enhanced growth rates and feed efficiency for poultry [45]. In contrast, crypts are tabular invaginations located toward the base of villi. New intestinal epithelial cells are generated in these areas. The regular regeneration of the gut lining relied on cryptic depth; however, excessively deep crypts typically indicate rapid cell turnover due to inflammation, tissue damage or infection. Shallower crypts often indicate a healthy and stable intestinal environment characterized by less inflammation and diminished cellular repair requirements [46].

Butyrate is the primary energy source for the cells that line colon and it facilitates intestinal cell proliferation and differentiation. Increased villi height results from this, enhancing the intestine absorptive capacity [47]. SCFAs synergistically reduce intestinal inflammation and enhance tissue repair through anti-inflammatory signaling pathways, hence decreasing crypt death. A lowered crypt depths signifies less stress and injury to the gut, resulting in a decreased necessary for new cells to replace the injured ones. This indicates a stronger and resilient intestinal lining. The effective intestinal barrier is a consequence of increased villi and reduced crypt depth together [48]. In addition to improving nutritional absorption, this barrier prevents the transfer of pathogens and toxins from the stomach into the bloodstream, hence reducing the risk of systemic disorders. Consequently, enhanced gut morphology is closely associated with improved nutritional utilization, fortified immunological responses and overall increased productivity and poultry populations. Various studies indicate that dietary supplementation, including as probiotics, prebiotics and their metabolites, can significantly enhance villus height and reduce crypt depth in broiler and laying hens. The rise in body weight, enhanced feed conversion ratio and reduced occurrence of enteric diseases are associated with these advancements [49].

### **8. Decreased Pathogen Shedding**

In poultry, pathogens shedding involves to the expulsion of infectious germs such as *E. coli*, *Campylobacter*, *C. perfringens* from feces and *Salmonella* spp., hence presenting significant risks for disease transmission within flocks and environmental damage, feed and water sources. The potential zoonotic diseases associated with this shedding pose concerns to public health and food safety, as well as endangering poultry health. Effective biosecurity and sustainable poultry production rely on the regulation of disease dissemination [50]. A diverse healthy gut microbiome, facilitated

by microbial metabolites, is crucial for reducing pathogen by creating a competitive environment that obstructs bacterial colonization and dissemination throughout the GIT. Probiotics and prebiotic supplements utilize resources that would otherwise be available to pathogenic bacteria, therefore challenging them through a mechanism known as competitive exclusion. Probiotics produce organic acids such as acetic acid and lactic acid, which lower gut pH and provide unfavorable conditions for numerous infections, as well as bacteriocins. These systems collaborate to inhibit the survival and proliferation of detrimental microbes in GIT [51].

Moreover, the enhancement of mucin and antimicrobial peptide production improves intestinal barrier integrity and inflammatory responses. Microbial metabolites, particularly SCFAs like butyrate, contribute to improve host's immune defenses. An improved gut environment and a more effective immune system reduce pathogen load and limit the extent of shedding [52]. The study indicates that probiotics and prebiotic supplements significantly decrease fecal shedding of major foodborne pathogens *Campylobacter* and *Salmonella* spp. in birds [53]. Reducing shedding diminishes horizontal transmission among birds and contamination during processing, hence improving food safety for consumers. Furthermore, reduced pathogen shedding diminishes the use for antibiotics; aligning with global efforts to combat antimicrobial biosecurity and advance public health objectives in poultry production is the alteration of the gut microbiome through microbial metabolites and beneficial bacteria [54].

### **9. Comparison with Antibiotic Growth Promoters**

For decades, poultry farming has extensively utilized antibiotic growth promoters (AGPs) to enhance feed efficiency and growth rates. Their utilization is however, associated with significant harmful impacts:

#### **9.1 Limitations and Resistance Issues with AGPs**

Low dosages of antibiotics constantly expose gut bacteria to low levels of antibiotics constantly expose gut bacteria to low levels of antibiotics which select resistant strains like carbapenem-resistant *E. coli* and *Enterobacteriaceae* generating extended-spectrum beta-lactamase (ESBL). Unchecked, these resistant bacteria might cause up to 10 million fatalities yearly 2025; moreover, these bacteria can be transferred to people via the food chain or environmental pollution, so aggravating the global AMR epidemic [55]. The way AGPs disturb the gut flora is another main disadvantage. Broad-spectrum antibiotics reduce microbial diversity and cause the loss of helpful commensals that are essential for digestion, immunological development and pathogen exculsion by not discriminating between hazardous and good bacteria. This disturbance produces ecological niches that opportunistic bacteria like *C. perfringens* and *salmonella* can be used, hence raising the risk of gut inflammation and infections. Furthermore, AGPs delayed maturity of the intestinal flora compromises the immune system of the host, thus increasing the susceptibility of poultry to illness and so lowering the general flock health.

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Many nations, notably members of European Union and Indonesia, have responded to these problems by imposing bans or limit on AGP usage. Previously under control by AGNPs, these regulatory changes have sometimes aligned with difficulties in poultry production including higher FCR, disease outbreaks (such as, coccidiosis and enteritis) and higher mortality rates. Regardless these difficulties, some areas continue to use AGPs because of their low cost and high efficacy [56].

## 9.2 Microbial Metabolites as Safer, Sustainable Alternatives

Effectively dealing with many of the challenges related with AGP use, microbial metabolites like SCFAs, organic acids and bacteriocins have emerged as potential and safer substitutes for AGP in chicken production [57]. Lack of contribution to AMR among microbial metabolites is one of their most important benefits. Microbial metabolites tend to act more selectively than AGPs, which typically show broad spectrum antimicrobial effects and support selection of resistant bacterial strains. For example, bacteriocins are antimicrobial peptides produced by some helpful bacteria that especially target harmful bacteria without affecting the commensal flora [58]. SCFAs like acetate and butyrate improve gut barrier integrity and control immune responses without upsetting the delicate equilibrium of the gut microbial population [59]. This targeted approach protects the helpful gut flora necessary for immune function and nutrient absorption and lowers the possibility of resistance development.

Apart from their safety profile, microbial metabolites also greatly help to maximize intestinal condition. Promoting the synthesis of these metabolites, probiotics and prebiotics hasten the maturation of the gut microbiota, hence enhancing microbial diversity and stability. Probiotic-supplement broilers display better microbial networks marked by an abundance of beneficial bacteria including *Lactobacillus* species. Associated with gut inflammation and infection, these helpful bacteria strongly fight harmful infections.

YCM is formulated using *Saccharomyces cerevisiae* utilizing microbial metabolite technology. It is derived via a specialized multi-step fermentation and microencapsulation process that stabilizes and concentrates over 600 functional metabolites, including short-chain fatty acids (SCFAs) such as propionate, bioactive peptides, organic acids, vitamins (A, D, B-complex), selenium-methionine, and lysine. YCM has significantly enhanced animal health by optimizing rumen function, feed digestibility, and immune response. The encapsulated version enables targeted administration to particular locations while maintaining steady pH levels, akin to its function in avian intestines. YCM has demonstrated the ability to enhance milk yield and promote intestinal health in cattle. This indicates that microbial metabolite products may enhance poultry performance and decrease the need on antibiotics.

## 10. Challenges and Limitations

To completely realize their potential as alternatives to AGPs, microbial metabolites and probiotic-based treatments in poultry

farming must face several challenges and limitations.

The variability in outcomes is a significant challenge, often arising from differences in microbial strains employed, environmental conditions and dosage levels. Diverse probiotic strains or metabolite-producing bacteria may exert varying effects on gut health and immune modulation, making it difficult to predict uniform outcomes across several poultry farms [60]. The efficiency of these medications is additionally affected by environmental factors like as management practices, feed consumption and housing circumstances. The age, health status and production goals of the bird will influence the optimal dose required to achieve the intended benefits; hence, precise formulation and administration techniques to enhance efficacy.

The absence of standardized regulations and comprehensive regulatory frameworks relating to production, quality assurance and application of microbial metabolites and probiotics in poultry is a significant limitation. This regulatory inconsistency may lead to the promotion of substandard or unverified items, so undermining producer confidence and limiting widespread acceptance [61]. Guaranteeing product safety, efficacy, and reproducibility necessitates well defined policies, uniform testing methodologies, and sanctioned processes. The economic implications of using microbial metabolites and probiotics in commercial settings involve cost considerations that may influence their adoption by poultry producers. Despite the long-term benefits of these alternatives, such as improved health and reduced antibiotic consumption, the initial costs associated with product development, quality assurance, and consistent supply may exceed those of traditional AGPs. Additionally, performance fluctuations may impact return on investment, especially in big firms with slim profit margins. Nonetheless, advancements in manufacturing technology and economies of scale are expected to enhance the economic viability of microbial metabolites as consumer demand for antibiotic-free poultry products increases and regulatory pressures mount [62].

## 11. Future Prospects

Microbial metabolites in poultry production provide significant promise for enhancing avian health and promoting industrial sustainability. The advancement of symbiotic formulations, which encompass provide prebiotics, probiotics and microbial metabolites inside a single product, represents a significant area of growth [63]. These combined effects aim to enhance gut health, nutritional absorption and immunological function by simultaneously providing helpful microbes, their growth substrates and health-promoting metabolites, thereby improving the gut environment. In comparison to a single-component solution, these formulations are expected to deliver more consistent and robust performance improvements. Utilizing next-generation (NGS) technology to elucidate the complex interactions among poultry microbiota, microbial metabolites and host immunity offers an intriguing opportunity [64]. Through comprehensive study of gut microorganisms and their functional genes, NGS enables researchers to identify specific microbial signatures and metabolite

pathways associated with enhanced immunity, disease resistance and growth. Targeted medicines and precision feeding strategies tailored to the specific needs of individual flocks or production systems will be created based on this molecular understanding.

A unique approach to enhance the efficacy of microbial therapies involves the creation of probiotic strains that produce metabolites. Advancements in synthetic biology and genetic engineering have made it possible to develop probiotic strains that can produce specific SCFAs, immune-modulating molecules, thereby enhancing the levels or varieties of beneficial metabolites. Next-generation probiotics may provide tailored therapies to address specific health issues or production objectives in poultry farming. Ultimately, accurate poultry nutrition and sustainable agriculture are anticipated to rely significantly on microbial metabolites and advanced microbiome management. Nutritionists may formulate meals that precisely promote optimal gut health, development, and disease resistance by utilizing comprehensive microbiome and metabolite data, hence reducing the necessity for antibiotics and synthetic additives [65]. This method aims to reduce environmental impact, improve animal welfare, and meet consumer demand for safe, high-quality chicken products, aligning with the principles of sustainable agriculture [66]. Ultimately, the integration of symbiotic products, advanced sequencing, engineered probiotics, and precision feeding signifies a new era in poultry farming—characterized by data-driven approaches, sustainable practices, and the optimization of production and animal health.

## 12. Conclusion

Microbial metabolites such as short-chain fatty acids (SCFAs), bacteriocins, organic acids, and secondary metabolites are becoming significant factors in enhancing poultry health, immunity, and production. Produced by beneficial gut bacteria or enhanced by probiotics and fermented meals, these compounds have many effects: such bacteria enhance gut barrier integrity, modulate immune responses, eliminate pathogenic bacteria, and optimize nutrient absorption. Although bacteriocins directly combat infections such as *Salmonella* and *Clostridium*, short-chain fatty acids (SCFAs) like butyrate enhance mucosal immunity by promoting regulatory T-cell differentiation and reducing inflammation. Their immunomodulatory capacity—specifically, their ability to modulate gut microbiota and enhance both innate and adaptive immunity—renders them crucial in modern poultry health initiatives.

The persuasive efficacy of microbial metabolites strongly supports their integration into antibiotic-free poultry production methods. These metabolites provide a prolonged, concentrated approach to disease prevention and performance enhancement, in contrast to traditional antibiotic growth promoters (AGPs), which exacerbate antimicrobial resistance (AMR) and disrupt microbial equilibrium. Microbial metabolites address the essential challenges of AGP-free systems by enhancing feed efficiency, reducing pathogen shedding, and decreasing mortality rates, therefore aligning with global demands for safer, ethically produced food.

Ultimately, microbial metabolites provide a scientifically validated and economically viable approach to advancing sustainability in chicken production. Their adoption safeguards public and animal health while facilitating the development of robust, high-performing flocks in a post-antibiotic era.

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