



# Bioaugmentation of Gut Microbiota in Animals Using Microbial Functional Metabolites-A Transmuting Approach



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Submission: January 27, 2026, Published: April 14, 2026

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## Abstract

Over the past decades, the global human population has had an average annual growth rate of 1.16%. On the contrary, the global cattle population is growing at an average annual rate of 0.43%. Despite the relatively slower increase in cattle numbers, global milk production reflects an average annual growth rate of 2.0%. The widening gap between human population growth and livestock expansion, particularly in cattle, underscores the urgent need for more efficient, sustainable, and innovative strategies in livestock production. To ensure food and nutritional security, functional metabolites, or postbiotics, are obtained from bacteria, yeast and algae having variable potential in improving animal health and productivity. However, metabolites derived from yeast fermentation have an important role in stabilizing rumen pH and providing essential micronutrients for useful gut microbiota. These yeast culture metabolites have been reported in several animal studies to improve growth performance, selected immune parameters, and reproductive outcomes. This review highlights the importance of microbial functional metabolites in the betterment of animal health and performance. Moreover, this review summarizes the evidence on their production, mechanisms of action, and application across animal species and discusses safety and regulatory challenges.

**Keywords:** Functional metabolites; Fermentation; Animal nutrition; *S. cerevisiae*; Antibiotic

## Introduction

The global human population has experienced steady and substantial growth over the past two decades, increasing from 6.58 billion in 2005 to 8.23 billion in 2024, an average annual growth rate of approximately 1.16% [1]. This demographic trend has placed increasing pressure on global food systems, especially the livestock sector, to meet the rising demand for animal-derived food products. Among these, milk plays a critical role in ensuring food and nutritional security due to its high biological value and richness in essential nutrients such as proteins, fats, vitamins, and minerals. To support this growing demand, the livestock industry has had to enhance production efficiency. However, the global cattle population, a primary source of milk, has not kept pace with human population growth. From 2005 to 2024, the cattle population increased only marginally from 1.43 billion to 1.56 billion, corresponding to an average annual growth rate of 0.43%.

In contrast, global milk production grew from 665 million tons to a projected 979 million tons by 2025, with an average annual increase of 2.0% [2]. This disparity indicates that significant gain in milk productivity has been achieved per animal, largely due to advancements in animal nutrition, health management, genetic improvement, and farm practices. Bridging the gap between increasing human nutritional needs and limited livestock population growth requires a multidimensional approach rooted in animal nutrition and sustainable agricultural practices.

Postbiotics or metabolites are cell free biological products, which are released by microbes, and are combination of high-value metabolic products that, when supplemented in feed, may provide synergy to promote useful microbiota, including a proportionate balance of protozoa, bacteria, and fungi in the animal gut [3]. Previously, live yeast and probiotics in combination

with prebiotics had been used extensively in livestock, poultry, and aqua feed, which could not provide useful outcomes due to the fact that these probiotics and live yeast were unable to proliferate to such a useful extent to provide a beneficial impact. The major challenges faced by the live yeast and probiotics include the unstable pH of the rumen and gut due to the variable quality of drinking water and seasonal variation in fodder type and quantity along with seasonal changes in temperature and humidity, which may lead to disruption the bioavailability of essential metabolites in the gut for the growth and proliferation of natural microbiota [4]. These optimized microbial metabolites exhibit diversified biological functions [5]. Yeast culture metabolites (YCM) potentially influencing various immune-regulatory, antioxidant and anti-inflammatory pathways [6].

Application of metabolites as diet component has proven beneficiary effects in animals. In dairy cattle, an increase in milk yield has been observed [7], and a similar pattern was observed in camel as well [8]. Supplementation of postbiotics also enhanced the growth rate in growing minks [9]. Moreover, functional metabolites can be replaced by antibiotics [10] and could reduce the antibiotic use as growth promoters in animal feed [11]. One more possible role of postbiotics, as a viable path to increase biological preservation and food safety has also been studied [12]. Some bacterial metabolites in the form of bacteriocins, etc. may be utilized specifically against pathogens that increased the shelf life of food and reduced the risk of antimicrobial resistance (AMR). It has become clear that the key emphasis of the research investigation is on the search for alternative approaches to improve development and health standards [13]. With the increase in the global population and the transition towards diets higher in animal protein, it is imperative to raise food animals safely and effectively [14]. This review emphasizes the concept of postbiotics and their characterization, types, function, and application in animal health

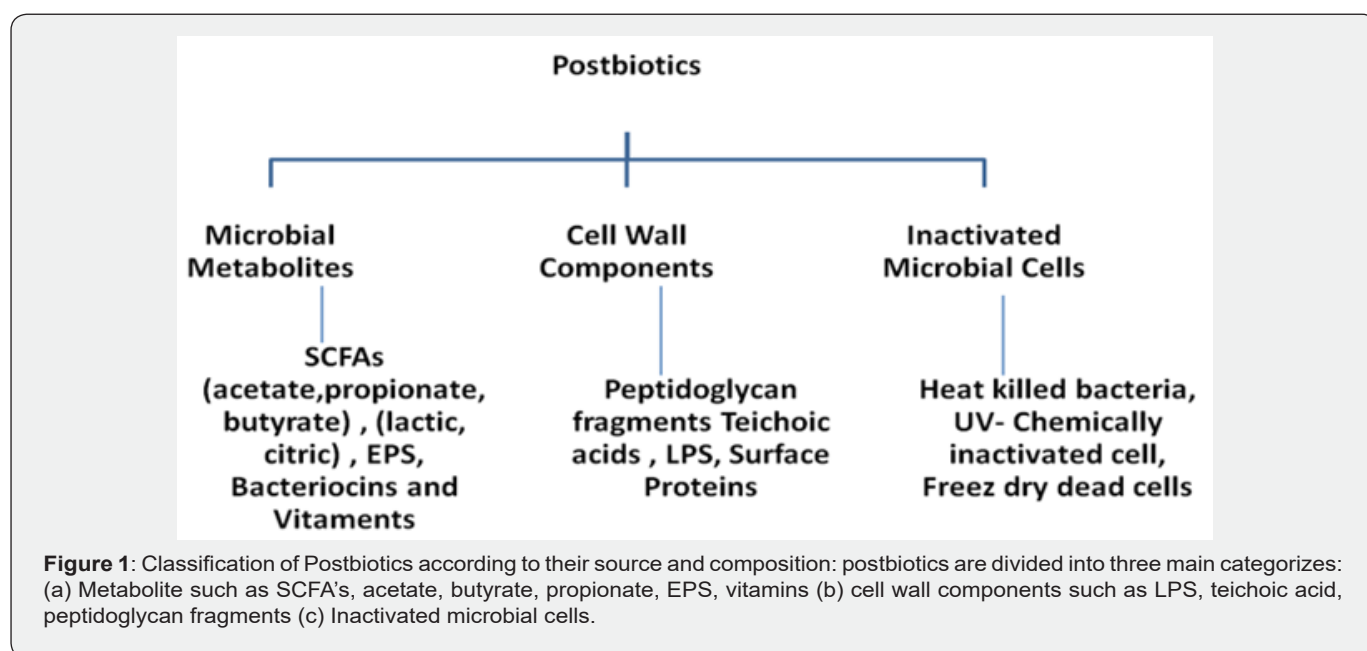
and growth. Furthermore, this review highlights the interaction of gut microbiota and postbiotics and also aims to summarize some possible future research perspectives.

### Definition and classification of Functional metabolites

It is believed that trillions of microorganisms reside in the gastrointestinal tract [15]. The gut microbiome consists of beneficial as well as harmful bacteria. A fragile equilibrium occurs between both of them, and dysbiosis adversely affects the gastrointestinal system and impairs the activities of other organs [4]. Numerous studies have shown that this equilibrium may be restored with the use of postbiotics, which provide a lower risk [16]. Postbiotics are microbial products with structural and metabolic components, including cell-free supernatants, microbial lysates, teichoic acid, cell wall fragments, short-chain fatty acids, enzymes, vitamins, exopolysaccharides, different amino acids, and peptides [17].

### Production processes and product characterization

Naturally, probiotics produce postbiotic components as they break down [Figure 1]. In the laboratory settings, postbiotics might also be created by radiation, heating, pressure, sonication, and chemicals. Heating is the predominant technique used to manufacture functional metabolites; however, other procedures such as radiation, tantalization, sonication, and chemical treatments are also applicable. The cellular makeup and biological activity vary according to the inactivation mechanism [18]. Current research has shifted toward postbiotics because of safety and health benefits [18]. Postbiotics serve as an effective substitute and have minimal effects on the food matrix, providing little risk of creating antibiotic resistance genes [20]. Research on laboratory models showed that non-viable cells preserve the biological characteristics of living cells, reduce inflammation, and modify host physiology [21].



## Types of functional metabolites

### Yeast Culture metabolites (YCM)

Yeasts are categorized according to cellular shape, metabolic routes, modes of proliferation, and environments [22]. In anaerobic settings, such as the gastrointestinal system or surroundings which are designed for alcoholic beverage production, yeasts partially lose viability to digest carbohydrates into ethanol and CO<sub>2</sub> [23]. Although some yeast species may be detrimental, most of them are non-infectious. Indeed, yeasts have shown beneficial health effects [24]. The renowned probiotic *S. cerevisiae* and its postbiotic released after fermentation are widely used in commercially available nutrition supplements. Yeast products are increasingly used as a viable substitute for antibiotics in contemporary agricultural production due to their advantageous effects on gastrointestinal health and general immunity [25].

Necrotic enteritis induced by *Clostridium perfringens* results in a substantial economic decrease in poultry farming, and one study indicated that feed intake of cell wall components of yeast cells can be utilized as a substitute to antibiotics in managing necrotic enteritis in poultry [26]. Yeast culture comprises a complicated amalgamation of viable and nonviable yeast and its metabolites, together with their polysaccharide cell wall components, making exact definition difficult. *S. cerevisiae* fermentation products, a prominent instance of YCM production including residual yeast cells, biological active by-products, and cell wall fragments are extensively used in animal feed manufacturing, especially within the dairy sector [27]. Long-term use of yeast in its viable and autoclaved form in the rumen indicated that both live and autoclaved *S. boulardii* enhanced metabolism in the rumen and activated good bacterial species, proving the addition of postbiotic in the rumen [28]. Research examining the effects of viable, autoclaved, and gamma rays treated *S. cerevisiae* on the ruminal microbial communities revealed that the use of autoclave can eliminate the majority of the stimulatory activity, but gamma ray treated cells preserved around 50% of the activity of viability [28].

These investigations demonstrate that activity status of yeast cells is contingent upon the different treatment approaches. Original live microbe and the techniques used in postbiotic development have significantly affected its efficiency. Although laboratory studies cannot meet the environmental conditions of the rumen, that undertakes fast modifications in both internal and external pressures. Moreover, the unique mix of elements in animal feed calls for greater research to evaluate the compositional modifications occurring from the production to the gastrointestinal tract. The exact methods by which YCs enhance the overall health of hosts remain anonymous. They might include immunomodulation, metabolic effects, change of the gut flora, and oxygen elimination [30]. Yeast auto-lysates, which include lysed yeast, including internal and external components. Regarding functional metabolites, it is now essential to firmly follow the postbiotics theory. More research is needed to clarify the question,

such as how yeast postbiotics are produced and what the benefits of different postbiotics are in every field of science and technology [31].

### Bacteria derived metabolites

Lactic acid producing bacteria (LAB) are the major species that serve as probiotics and only a few have pathogenic properties [32]. LABs are distinguished by their capacity to ferment glucose into diverse isomers of lactic acid. Fermented foods are rich with these probiotic bacterial species. These biologically potent bacteria can be used in various feed sectors [33]. LABs are recognized for their capacity to generate diverse metabolites, such as exopolysaccharides, short-chain fatty acids, fructo-oligosaccharides, linoleic acids, seleno-proteins, and bacteriocins [34]. These metabolites exhibit significant health advantages, including antioxidant capabilities, immunomodulation, and strengthening of the epithelial membrane. LAB species include a minimum of 60 different types of bacteria. In food production, these probiotic bacteria have been utilized for decades. There are various commercially available pro- and postbiotics, which exhibit proven beneficial effects in various fields. For example, in a rat model, a lipolytic postbiotic derived from *Lactobacillus paracasei* may cure metabolic syndrome [35]. Lactococcus is a genus of bacterium often used in the process of fermentation, especially within the dairy sector. These microbes are spherical or oval and can thrive in both aerobic and anaerobic environments. Additional postbiotics derived from *Pediococcus spp.* are used in the dairy industry [36]. Leuconostoc served crucial functions in industrial food production, such as processed meat, dairy, and several industrial uses. The metabolites produced by Leuconostoc may serve as postbiotics for the management of fungal pathogen infections [37]. The consumption of antibiotics as feed additives in cattle has facilitated the dissemination of AMR across the food chain into the humans. The use of postbiotics lowers the risk of AMR spread [38].

Bifidobacterium is another gram-positive bacterium that can ferment glucose into lactic and acetic acids and are essential for sustaining gut health, comprising an estimated 3%–7% of the intestinal microbiota [38]. Specific strains of Bifidobacterium are known probiotics that produce organic acids and other antimicrobial compounds, including exo-polysaccharides (EPS), linoleic acid, and bacteriocins, and have the ability to modulate immune responses [40]. Furthermore, postbiotics originating from Bifidobacteria have shown suppression effects on pathogen development and proliferation, along with prospective advantages in mitigating fat deposition and regulating obesity [41]. *Akkermansia muciniphila* is a Gram-negative, oval-shaped, strictly anaerobic, non-spore-forming and non-motile eubacterium often present in feces, comprising roughly 1%–4 % of the gut microbiota in adults [42]. Comprehensive studies have shown that postbiotics from *A. muciniphila* may modulate host metabolism, including glucose and lipid metabolism. In murine models, non-

living cells and extracellular vesicles may influence the gut-adipose liver axis to control the metabolic activities and prevent obesity [43]. Moreover, pasteurized *A. muciniphila* may serve as an effective therapy for infections caused by some organisms, such as Salmonella Typhimurium [44]. However, the postbiotics of yeast origin were recently promoted because of their proven application in growth development, feed efficiency, decrease of pathogens, and sustainable animal production.

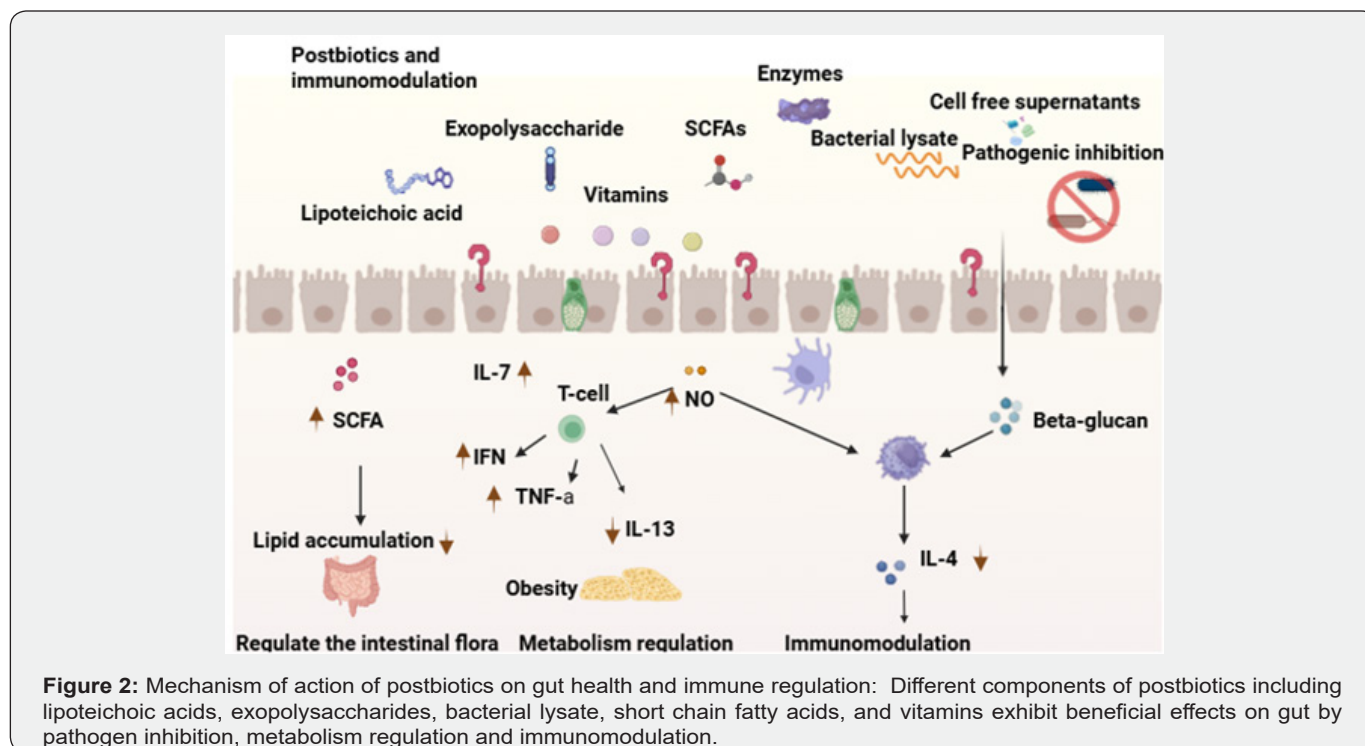
**Mechanism of action of functional metabolites**

Growing data indicates that functional metabolites can interact with the immune system of the gut and exhibit potential immunomodulatory and therapeutic properties [45]. Pattern recognition receptors, including Toll-like receptors (TLRs), C-Type lectin-like receptors (CTLRs), G-protein-coupled receptors (GPCRs) and nucleotide-binding oligomerization domain-like receptors (NLRs), in the gastrointestinal tract, can identify components

in postbiotics and subsequently activate downstream signaling pathways that confer advantageous effects on the host organism [46]. Toll-like receptor 2 (TLR-2) is linked to the inflammatory response elicited by gram-positive bacteria. Particular bacterial constituents, including lipoproteins, lipoteichoic acid (LTA), and peptidoglycan, can stimulate TLR-2 [47]. Whereas, TLR-4 identifies LPS found in Gram-negative bacterial species, potentially resulting in infections [48]. Short-chain fatty acids may activate immunological activities via GPCRs, such as GPR41, GPR43, and GPR109A, with potential therapeutic effects [48]. The cell wall components of yeast consist of carbohydrates, mostly β-glucan and mannan, with small quantities of chitin. In both human and animal digestive tracts, oligosaccharides present in *S. cerevisiae* cell walls have been shown to impact interactions between hosts- pathogen and the immune system [50]. Table 1 present the classification and potential functions of postbiotics.

**Table 1:** Classification and potential function of postbiotics

Category	Common Microbial Sources	Example	Potential Functions
Microbial Metabolites	Bifidobacterium, Lactobacillus, Bacillus	Bacteriocins, SCFAs, lactic acid, citric acid, vitamins, EPS	Antimicrobial activity, Gut microbiota modulation, and energy source
Yeast-Derived Compounds	Saccharomyces cerevisiae, Kluyveromyces marxianus	mannan oligosaccharides, β-glucans,	Immune enhancement, reduce pathogen binding, and antioxidant defense
Inactivated Microbial Cells (Paraprobiotics)	Lactobacillus, Bifidobacterium, Saccharomyces	Heat-killed Lactobacillus, UV-treated Bifidobacterium,	Immune stimulation, competitive pathogen inhibition, safe alternative to probiotics
Cell Wall Components	yeasts and bacteria,	Peptidoglycan fragments, teichoic acids, LPS, surface glycoproteins	Immunomodulation, gut barrier reinforcement, and anti-inflammatory effects,
Fungal-Derived Compounds	Penicillium, Aspergillus,	Polysaccharides, Bioactive peptides, enzymes,	improved gut function, immunomodulation, and antimicrobial activity,



**Figure 2:** Mechanism of action of postbiotics on gut health and immune regulation: Different components of postbiotics including lipoteichoic acids, exopolysaccharides, bacterial lysate, short chain fatty acids, and vitamins exhibit beneficial effects on gut by pathogen inhibition, metabolism regulation and immunomodulation.

$\beta$ -glucan, a well-examined component of the cell wall of *S. cerevisiae*, offers structural support and activates immunological responses [51]. Mannan can strengthen the gut environment by modulating the equilibrium of intestinal microecology. Furthermore, it elicits immunological responses inside the host gut [52]. Specific postbiotics originating from LAB demonstrate analogous effects. In an in-vivo research, post-weaning lambs administered the postbiotic of *Lactobacillus plantarum* bacterium exhibited lower blood neutrophils, leukocytes, lymphocytes, basophils, and platelets. Furthermore, there was an elevation of expression of IL-6 mRNA, accompanied by reductions in IL-10, IL-1 $\beta$ , and TNF- $\alpha$  [53]. Heat-inactivated probiotics have demonstrated an immunoregulatory effect in the gastrointestinal tract, like to that of living bacteria [54]. A previous work has shown that heat-inactivated *L. paracase*, has stimulated the IL-12 release, hence augmenting innate immunity in rats [55]. Furthermore, *L. paracasei* live cells and postbiotic components demonstrated antifungal efficacy on planktonic cells and biofilms of *Candida auris*. The protective effect had been found and complemented by an improvement in immunological response. These results demonstrate a dual role of postbiotics derived from *L. paracasei* in influencing host immune reactions. Figure 2 represents the immunoregulatory effect of different postbiotics.

### Applications of functional metabolites

#### Ruminants

Postbiotic treatment can enhance the bodyweight, feed intake, nutrient digestion, and total dietary intake. Izuddin et al. have demonstrated that the use of postbiotics can elevate the level of ruminal butyrate and ammonia-N, and overall volatile fatty acids (VFA) and pH remained unchanged [53]. Blood levels of nitrogen, glucose, and total protein were elevated with administered postbiotics. Postbiotic therapy resulted in a reduction in rumen methanogens and protozoa while enhancing fiber-degrading bacterial species. Postbiotics demonstrate several advantageous impacts on the health of animals by enhancing immunity, maintaining the gut microbiota, and reducing colonization and proliferation of harmful microorganisms in the gut. These positive attributes enable postbiotics to be environmentally sustainable elements that enhance the performance of animals and ensure the safety of final goods, such as meat and eggs [56]. In the dairy industry, *S. cerevisiae* fermentation products (SCFP) demonstrated a remarkable impact on calves' performance, immunological function, post-weaning weight increase, and bovine disease control. The immunomodulation of SCFP may regulate the occurrence of bovine respiratory tract infections in newborn calves, hence reducing the death rate in neonates [57]. Short-chain fatty acids produced by fermentation of yeast are commonly utilized as feed additives in the livestock nutrition sector and have demonstrated beneficial effects on the health and performance of dairy cows. Studies examining the addition of SCFPs in calves consistently demonstrate advantageous results,

including elevated overall dry matter intake, increased average per day growth and boosted weight gain [58].

These yeast-derived extra-pure metabolites enhanced the milk production, fortified overall immunity, diminished infections such as mastitis, fostered beneficial microflora, and elevated VFAs [58]. Supplementing the diet of lactating goats using *S. cerevisiae* fermentation-derived postbiotic products enhanced fiber digestibility and propionate levels in the rumen, consequently improving the energy effectiveness of the production of milk and decreasing emissions of CH<sub>4</sub> [60]. Weaning stress remains a significant challenge to young animals; nevertheless, research indicates that metabolites generated by *L. plantarum* may mitigate its detrimental consequences. Supplementation with 0.3% postbiotics derived from *L. plantarum* may enhance developmental outcomes and immunological functions and alter the gut bacterial composition in developing minks [61].

#### Monogastric

Postbiotics may serve as feed additives to enhance growth performance and health in monogastric animals (Poultry and swine) [62]. Postbiotics, including *L. plantarum* have antioxidative properties in fowl during heat stress [63]. Furthermore, these metabolites enhanced egg quality and decreased levels of cholesterol in both yolk and plasma of laying hens [64]. Incorporating postbiotics with inulin into the diet of broiler chickens enhanced the efficiency of feed and overall body weight while also maintaining mRNA expression of growth hormone receptors, growth factor 1, and gut mucosal architecture [65]. Postbiotics from Lactobacilli markedly ameliorated the disease condition, promoted growth performance, augmented immunological response, improved the bursa-to-body weight ratio, and decreased coliform counts in the intestines of challenged hens relative to untreated birds [66]. The fermentation product of *S. cerevisiae* and the probiotic *Bacillus subtilis* may serve as an effective alternative to antibiotics in chicken production, given their positive effects on broilers consuming an antibiotic-free meal [67]. The incorporation of a postbiotic derived from *S. cerevisiae* is linked to a reduced burden of *Salmonella enterica* in chickens. Postbiotic additives to feed may facilitate the decrease of foodborne pathogens [68]. The addition of postbiotics to the regular meal of pigs may foster the development and regulate the immunity. Postbiotics suppress the proliferation of pathogens responsible for diarrhea and restore microbial equilibrium in the digestive system. Postbiotics also strengthen the gut barrier. This may lead to improved gut health and less vulnerable to intestinal diseases. For instance, including short chain fatty acids (SCFA) in the daily diet helps mitigate weaning stress in pigs by influencing the gut microbiome and enhancing the effectiveness of barriers [68]. Deactivating *Lactobacillus rhamnosus* can improve the development rate and feed effectiveness, decrease diarrhea, and improve immunity in young pigs [70]. A blend of postbiotics from yeast cell walls might mitigate the effects of dietary exposure

to several mycotoxins, particularly deoxynivalenol, on the growth development of weaned pigs [71]. The incorporation of *Saccharomyces* postbiotics in diets diminished diarrhea during the initial week post-weaning and safeguarded the jejunal villi by augmenting the immune system reaction of infant pigs, fostering crypt proliferation of cells, and decreasing the level of expression of genes linked to apoptosis [72]. Furthermore, the addition of yeast postbiotics into the diets of gestating sows, nursery pigs, nursing sows, and growing pigs improved reproductive success and the development. Yeast postbiotics were most effective at 0.27 to 0.32 g/kg of feed [73].

### Aquaculture

The use of postbiotics in aquaculture is still in the initial developmental stages. Initial investigation providing the groundbreaking evidence that use of postbiotics significantly improve the growth parameters in common carps [74]. Apart from growth enhancer in aquaculture [75], postbiotics may also improve the yield and quality of aquaculture [76]. For instance, application of postbiotics from *S. cerevisiae* not only improves the growth rate in shrimps but also reduce the *Vibrio parahaemolyticus* infection [77]. These improvements in quality are essential to meeting the market's need for high-grade aquaculture goods. Furthermore, postbiotics also exhibit several beneficial effects on the health of aquatic animals by modulating the gut microflora [78]. Application of postbiotics in aquaculture can also augment the production efficacy by lowering the disease risk, such as, yeast derived postbiotics enhanced the intestinal health, lowering the hepatic damage and modulated the immune response, which ultimately increase the product quality and yield in hybrid *Epinephelus* [78].

### Companion animals

Senior dogs often have chronic illnesses, partially due to immunity decline, which is marked by a decrease in blood helper T cells and an increase in the cytotoxic T cells. Research in adult canines indicated that the supplementation of short-chain fructooligosaccharides (scFOS) or YCM may enhance the immunological response. Therefore, including YCM and scFOS into the diet may help dogs with T-cell immune senescence by preventing some of its symptoms [80]. The addition of postbiotics enhanced the relative number of helpful bacteria, including *Bacillus* and *Lactobacillus*, in the feces, while decreasing the overall number of undesirable bacteria, such as *Anaerobiospirillum* and *Fusobacterium*. The research indicates that including postbiotics into the diet may enhance gut health of canines [81]. Dietary postbiotics, such as fatty acids, affect circulation metabolites via being absorbed and integrated into fatty acid-containing particles, like the fatty acid components of glycerol in felines. Dietary postbiotics reduced circulation levels of dimethyl glycine, betaine, and sarcosine [82]. Horses may benefit from prophylactic administration with a postbiotic generated from yeast before being subjected to stress. When comparing horses given SCFP to control, less change in their functional profile and microbial diversity was found. It makes sense that a more resilient and stable microbiome would

reduce the likelihood of pathogen colonization and improve health maintenance. Postbiotics have shown favorable benefits across several species, necessitating greater investigation into the mechanisms behind these advantages [83].

### Safety and regulatory consideration

The European Food Safety Authority (EFSA) governs food requirements and regularly updates them based on food safety assessments across Europe. The regulatory frameworks of the FDA and EFSA for probiotics, which rely on the generally recognized as safe (GRAS) and qualified presumption of safety (QPS) lists, are inapplicable to postbiotic preparations since they do not include live bacteria. The Food and Drug Administration (FDA) in the United States has not issued any explicit declarations about postbiotics. The FDA will likely regulate postbiotics based on the precise regulatory category chosen for a product under development, since postbiotics may be produced under many regulatory classifications. The product must comply with the standards of the applicable regulatory category for its intended use, safety, and effectiveness [84]. Postbiotics are not subject to these regulations. Consequently, a regulatory void seems to exist, permitting more latitude in the development and commercialization of postbiotic treatments than guarantees the safety of the postbiotic chemicals themselves. Until the FDA and EFSA establish a regulatory framework for postbiotics, research is necessary to ascertain appropriate safety and regulatory requirements for postbiotic preparations [85].

### Climate sustainability

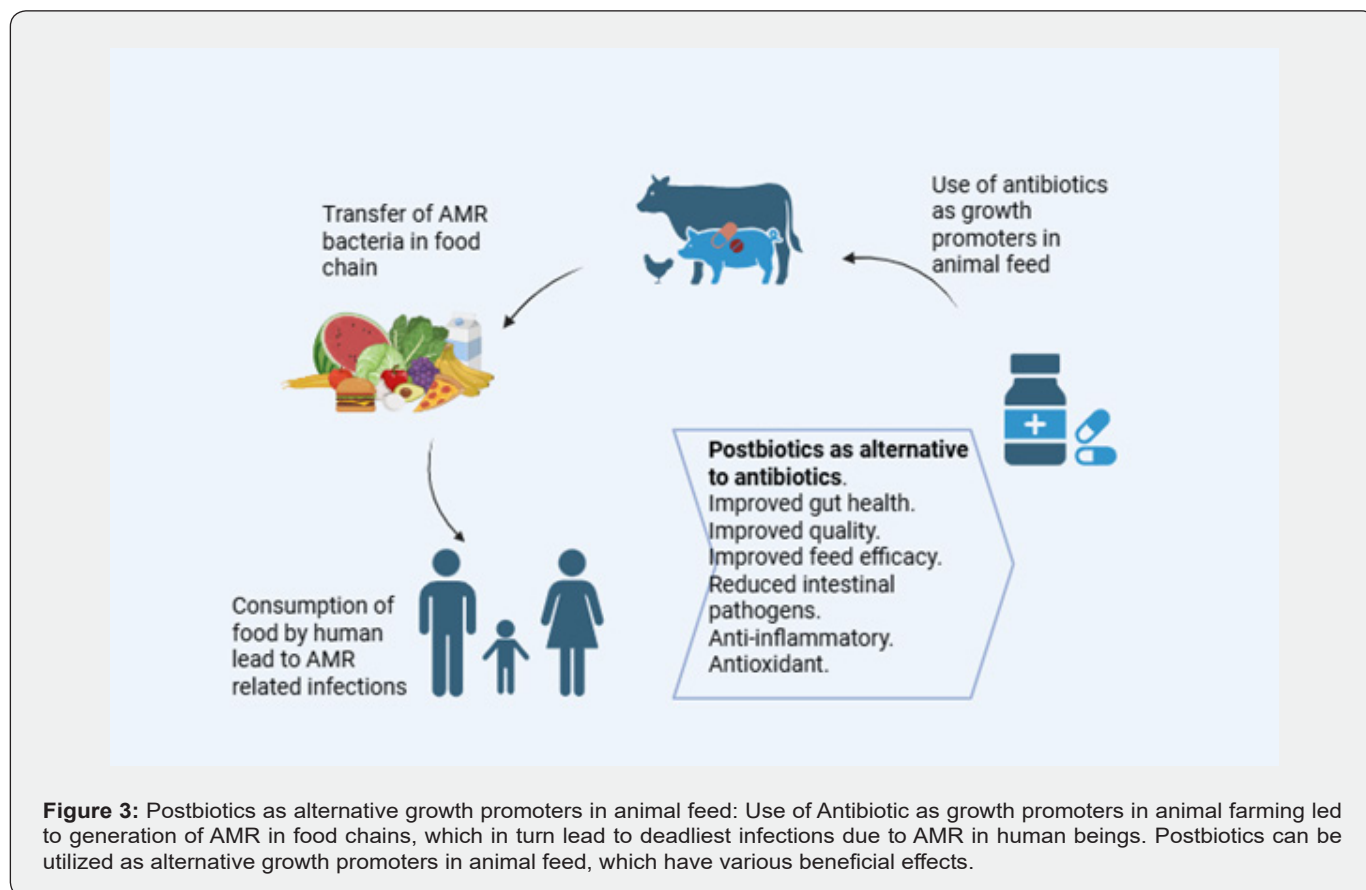
Mitigating the effects of climate change on the production of premium feedstuffs is essential for promoting cattle thermal well-being, maintaining high productivity, decreasing greenhouse gas emissions, and improving system sustainability [86]. The fermentation process in animal intestines generates considerable greenhouse gases, especially methane, which significantly contributes to climate change. A variety of additions, including probiotics, organic acids, plant metabolites, exogenous enzymes, fodder trees, and other bacteria, reduce methane emissions [87]. Yeasts generate beta-glucans, antioxidants, and ergosterol that bolster immune activities and mitigate oxidative cell death [88]. YCM mitigate carbon emissions from manure, thereby supporting climate sustainability and promoting animal health organically [4]. This aids in reducing greenhouse gas emissions linked to ruminant farming.

### Mitigation of antibiotic resistance

The misuse of antibiotics has produced resistance to the various antibiotics [Figure 3] [88]. Postbiotic supplementation served as a substitute for antibiotics due to their positive effects on gut health, growth performance, bacterial colonization, mucin synthesis, and immune regulation [90]. Beneficial impacts of LABs and their metabolites on the well-being of livestock have been seen. The restrictions on antibiotics in agriculture positively impact the environment and subsequently diminish the prevalence

of resistance in pathogenic microbes [91]. Supplementation of yeast-derived postbiotics mitigates the adverse effects linked to infection induced by *Escherichia coli*. These postbiotics reduce the quantity of gram-negative bacteria, decreasing the pro-inflammatory cytokine secretion in the jejunal mucosa, and improving absorption. *Saccharomyces*-derived metabolites

alleviate the detrimental effects associated with infection by an intestinal pathogen [92]. The introduction of postbiotics as a feed additive can promote the bird's health and a comprehensive management strategy for food safety. Yeast metabolites reduce the *Salmonella* infection in the ceca of poultry birds when given as antibiotic alternative growth promoters [93].



**Figure 3:** Postbiotics as alternative growth promoters in animal feed: Use of Antibiotic as growth promoters in animal farming led to generation of AMR in food chains, which in turn lead to deadliest infections due to AMR in human beings. Postbiotics can be utilized as alternative growth promoters in animal feed, which have various beneficial effects.

Olson et al. have used a chicken cecal lab model to examine the effect of feed additives of postbiotic supplements from yeast fermentation on lowering Multidrug resistance (MDR) *Salmonella*. The findings indicated a significant decrease in *Salmonella* species [94]. Furthermore, the supplementation of yeast-based postbiotics and whole yeast cells during the gestation period of sows may enhance lactating productivity and reduce mortality and antibiotic use in piglets. The results are notably significant, specifically for contemporary farming of pigs, given the rising costs of raw materials, demand for higher-performing livestock, and the associated requirement to reduce antibiotic usage [96]. The nutritional treatment of sheep with yeast based postbiotics abundant in beta-glucans, mannan and selenium increased the milk production and reduced pro-inflammatory effects [97]. The postbiotics from yeast origin were recently promoted because of their proven application in growth development, feed efficiency, decrease of pathogens, and sustainable animal production. Feed quality has a significant impact on the animal body's energy

efficiency; conversely, the heat increases the cellular defense for oxidative stress [98]. The nutritional effects on an animal's thermoregulation and the repercussions of heat stress for their health and production are essential for climate-smart practices [98].

### Limitation of postbiotics

Although postbiotics are becoming increasingly common as viable antibiotic substitutes for animal feed, a number of restrictions prevent their broad use in animal nutrition. The high manufacturing costs brought on by intricate fermentation, filtration, and stabilization procedures are one of the main obstacles [100]. Also, the fact that different strains of microbes might have different metabolic profile and biological activity, makes it hard to get the same level of effectiveness across different production system and animal species [101]. Since regulatory bodies continue to define postbiotics differently across locations, the absence of unified regulatory definitions and procedures

further restricts their commercialization and integration in feed formulations [102]. Furthermore, mechanistic knowledge is still lacking, especially with regard to how postbiotic components interact with the immune system, gut microbiota, and metabolic processes in various animal species [103]. Lastly, to confirm safety, ideal doses, and economic viability under real-world farm settings, extensive, long-term in vivo research is required. To convert postbiotic research into dependable and affordable applications for sustainable animal production, these research gaps must be filled by multidisciplinary studies and well-defined regulatory frameworks.

## Future Perspective

Rising concerns, including AMR, food safety, and environmental sustainability, are driving growing pressure on the livestock sector to cut antibiotic use [104]. In this regard, functional metabolites have imparted health advantages to the livestock and offer a prospective substitute for traditional growth promoters and therapies [105]. Antimicrobial characteristics of postbiotics help to control harmful bacteria while supporting the growth of good bacteria. Their use helps to promote worldwide AMR reduction programs by lowering dependence on antibiotic growth promoters (AGPs). By changing the gut microbiota and enhancing intestinal barrier performance, postbiotics help to increase nutrient digestion and absorption [106]. Compounds like lactate and butyrate have been shown to enhance epithelial integrity and the immune system, therefore lowering gastrointestinal diseases and raising feed efficiency. Better growth rates, feed conversion ratios, and general animal performance have been connected to consistent postbiotic inclusion in feed [107]. Furthermore, postbiotic help to increase animal well-being by lowering mortality rate and pathogen load. Postbiotics are rather stable and fit for pelleted or extruded feed, unlike probiotics, which depend on exact storage conditions or viability during processing and digestion. For big-scale cattle enterprises, this improves their practicality and economy. With increasing attention from industrial settings and scientists, the regulatory environment is progressively changing to suit postbiotics. These postbiotics are projected to become a mainstay of precision livestock farming and integrated animal health management systems as additional evidence on effectiveness and safety mounts [108]. Future research should concentrate on the identification of strain-specific postbiotic chemicals, mechanisms of action, and optimization of delivery methods. Moreover, future prospective should also base on concept of biofortification of postbiotics with essential minerals, to fulfill the malnutrition issue in humans and domesticated animals [109]. Overall, combining postbiotics with other bio-based products, including phytochemicals and prebiotics, can improve their cooperative effects even further.

## Conclusion

Microbial functional metabolites impact the proliferation of

natural microflora in animals. These metabolites offer a sustainable means of enhancing animal health and yield by increasing gut flora, boosting the immune system, and lowering the frequency of pathogenic organisms. Bioaugmentation of these metabolites with supplementary elements provides a two-fold advantage for both cattle sectors and worldwide initiatives to counteract climate change by improving animal performance while reducing environmental impact. The use of yeast culture metabolites in sustainable animal farming would ensure global food safety and security. Functional metabolites provide viable climate-smart feed supplies and, contingent upon cost, provide the benefit of fast protein synthesis in regulated conditions, using little land and water resources, and resulting in minimal environmental effect. **Moreover, postbiotics can replace the antibiotics use as growth promoters.** To fully realize its possibilities across various agricultural systems, future studies should concentrate on improving strains, production techniques, and application strategies.

## Acknowledgement

The authors acknowledge Bioaugment research laboratory, DairyLac private limited, Jaranwala road Faisalabad, Pakistan, for the research and technical support.

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DOI:10.19080/JDVS.2026.18.555983

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