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Review Article

Impact of Postbiotics on Ruminant Health and Productivity

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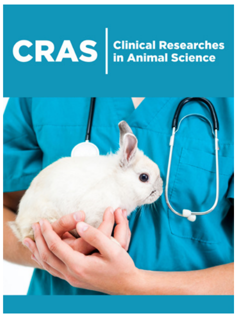

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Abstract

The increasing global demand for sustainable livestock production necessitates alternatives to antibiotic growth promoters, with postbiotics emerging as a viable solution due to their stability, safety and bioactive properties. This review synthesizes research on postbiotics-non-viable microbial components or metabolites, such as those derived from *Saccharomyces Cerevisiae* Fermentation Products (SCFP), *Aspergillus oryzae* and *Lactobacillus spp.* and their effects on ruminant health and productivity. Findings indicate that postbiotics enhance rumen fermentation by stabilizing pH, increasing volatile fatty acid production and modulating microbial populations, particularly fibrolytic bacteria such as *Ruminococcaceae* and *Lachnospiraceae*. Immunomodulatory benefits include reduced inflammatory markers (e.g., IL-6, TNF-α) and improved gut barrier function, achieved through the upregulation of tight junction proteins. Species- and dose-dependent responses are evident, with dairy cows showing improved nutrient digestibility and immunity, while beef cattle exhibit variable outcomes in rumen fermentation. Postbiotics also demonstrate antimicrobial effects, reducing pathogens like *Salmonella* and *Staphylococcus aureus*. Despite promising results, efficacy depends on the formulation, dosage and the animal's physiological stage. This review highlights postbiotics as a strategic tool to enhance ruminant performance while aligning with One Health principles, though further research is needed to optimize their application across production systems.

Keywords: Postbiotics; Ruminant nutrition; *Saccharomyces cerevisiae*; Rumen fermentation; Immunomodulation; Antimicrobial resistance; Gut health; Feed additives; Sustainable agriculture

Introduction

The global livestock sector is under increasing pressure to meet the rising demand for animal-derived protein while addressing critical challenges related to Antimicrobial Resistance (AMR), feed efficiency and environmental sustainability [1-3]. Historically, antibiotics have been widely used in animal production not only for disease control but also as growth promoters [4-6]. However, the emergence of antimicrobial-resistant pathogens has led to stringent regulatory restrictions, including the European Union's ban on antibiotic growth promoters in 2006 [7,8] and the U.S. FDA's Veterinary Feed Directive in 2017 [9]. These measures highlight the urgent need for sustainable alternatives that enhance animal health and productivity without contributing to AMR.

One of the major challenges in modern ruminant production is the disruption of gut microbiota due to high-concentrate diets, which can lead to Subacute Ruminal Acidosis (SARA), liver abscesses and systemic inflammation [10]. Such conditions not only impair animal performance but also increase susceptibility to pathogens such as Salmonella and Fusobacterium [1,9,11,12]. In this context, postbiotics are gaining significant attention as a novel category of "biotics," offering a promising alternative to traditional antibiotics in livestock production, particularly for ruminants. The International Scientific Association of Probiotics and Prebiotics (ISAPP) defines postbiotics as "a preparation of inanimate microorganisms and/or their components that confers a health benefit on the host" [13]. Postbiotics are generated through the fermentation of probiotics, where these probiotics produce bioactive compounds during anaerobic fermentation [14]. Extraction methods include centrifugation, ultrafiltration, chromatography and mass spectrometry [15]. This means they are non-living products, often derived from microbial fermentations, comprising cellular components, metabolites and fermentation end products [13,16]. Unlike live probiotics, postbiotics are more stable and safer, as they do not contain live microorganisms, thereby reducing the risk of gut-to-blood bacterial translocation or the acquisition of antibiotic-resistant genes [17,18]. They also have a longer shelf life and are not inactivated by chemicals or drugs [6], making them particularly suitable for inclusion in animal feed [1,19].

The multifaceted chemical composition of postbiotics highlights their profound biological relevance in ruminant nutrition and gut health [20]. Postbiotics encompass a wide range of bioactive compounds and metabolites, each contributing distinct functional attributes that influence host physiology, microbial ecology and immune modulation [21,22]. The strategic application of postbiotics in ruminant diets hinges on a nuanced understanding of their chemical constituents and mechanistic pathways. Short-Chain Fatty Acids (SCFAs), particularly acetate, propionate and butyrate (Figure 1), serve as essential energy substrates for enterocytes and exhibit systemic anti-inflammatory effects, thereby enhancing intestinal barrier integrity-a critical factor in mitigating metabolic stress in high-producing ruminants [21,23-25]. Organic acids, including lactic and phenylacetic acids, exert a bacteriostatic effect by modulating luminal pH, thus selectively inhibiting pathogenic colonization while fostering commensal microbiota proliferation [26,27]. Exopolysaccharides (EPS) and bacteriocins further exemplify the dual role of postbiotics in pathogen exclusion and immune priming. EPS such as β-glucans enhance mucosal immunity through receptor-mediated signalling [28,29], while bacteriocins, such as nisin, provide targeted antimicrobial activity without disrupting symbiotic microbial consortia [2,30,31]. The presence of B vitamins and antioxidant enzymes within postbiotic matrices (Figure 1) also suggests a synergistic role in ameliorating oxidative stress, a common constraint in intensive production systems [28,32,33].

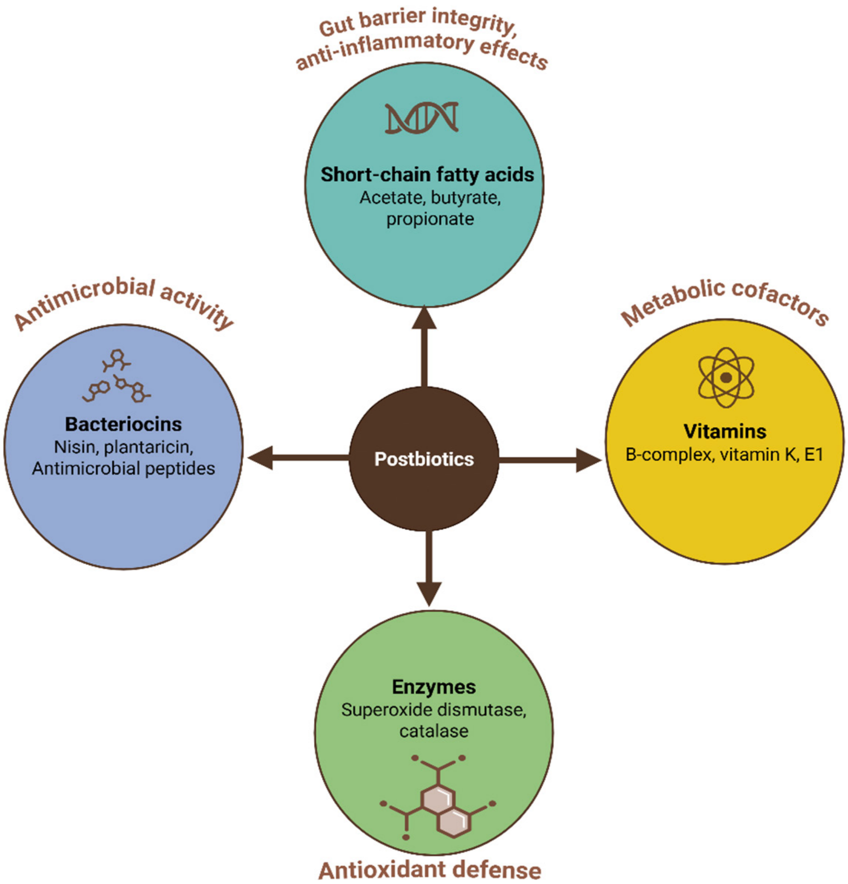

Figure 1: The diverse and complex chemical composition of postbiotics underpins their wide range of biological activities.

The efficacy of postbiotics depends on their source and compositional profile [11]. For instance, *Saccharomyces Cerevisiae* Fermentation Products (SCFP) have been extensively validated in dairy cattle, where their metabolite-rich composition improves fibre digestibility, enhances feed efficiency, reduces lactic acid accumulation, and promotes beneficial microbial populations in the rumen [34,35] and lactation performance [36-39]. Similarly, Lactobacillus plantarum RG14 metabolites demonstrate significant benefits in young ruminants by improving nutrient digestibility and inhibiting pathogenic bacteria through lowered intestinal pH and the formation of protective biofilms [22], highlighting the strain-specific nature of postbiotic effects [22]. Recent research has expanded our understanding of postbiotic applications across different ruminant species and production stages [1,5,17,40]. In dairy cows, SCFP supplementation has been shown to mitigate SARA by stabilizing ruminal pH and enhancing Volatile Fatty Acid (VFA) production [41,42]. In calves, postbiotics improve immune function and reduce diarrhea incidence [5,43-45], while in beef cattle, they enhance feed efficiency and liver health [46]. Additionally, postbiotics exhibit immunomodulatory properties, reducing systemic inflammation and oxidative stress markers such as Serum Amyloid A (SAA) and Lipopolysaccharide-Binding Protein (LBP) [17,32,39,47-52]. Although significant progress has been made, there are still gaps in optimizing postbiotic formulations for various production systems and in understanding their long-term effects on rumen microbiome dynamics. The primary objective of this review is to synthesize existing knowledge on postbiotic applications in ruminant nutrition, focusing on their impact on rumen fermentation and animal health. This work aims to contribute to the development of sustainable strategies that enhance animal health, productivity, and food safety while aligning with the "One Health" paradigm.

Effects of postbiotics on rumen fermentation and animal health

The efficacy of *Saccharomyces cerevisiae* fermentation products in stabilizing ruminal pH during dietary stress is well-documented (Table 1). In lactating Holstein cows subjected to SARA challenges, SCFP supplementation (14-38g/d) consistently mitigated pH fluctuations and lactate accumulation, while enriching fibrolytic taxa *(Ruminococcaceae, Lachnospiraceae)* essential for fibre degradation [34,42,53,54]. This microbial shift correlated with increased acetate production and reduced proteolytic activity, enhancing nitrogen utilization efficiency. SCFP's benefits were dose-dependent; for example, higher doses (38g/d of SCFPb-2X) amplified rumen resilience during high-starch feeding by attenuating propionate metabolism and stabilizing the Firmicutes: Bacteroidetes ratio [34,42]. On the other hand, steers receiving a combination of liquid (11mL/100kg BW) and dry SCFP (12g/d) showed a 28.8% decrease in ruminal NH_3-N, accompanied by an increase in valerate, indicating enhanced peptide metabolism [41,52]. Such findings accentuate SCFP's role in optimizing fermentation stoichiometry, though responses vary with delivery method and basal diet composition [55-59].

Table 1: Effects of postbiotics on rumen fermentation parameters.

Category	Summary of Results	References
pH Stabilization	SCFP stabilized ruminal pH and attenuated SARA-induced pH drops in lactating dairy cows. *Saccharomyces cerevisiae* increased rumen pH (6.12 vs. 5.72) and reduced lactate (1.33 vs. 7.72mM). Buffalo calves showed ↑ pH (6.58 vs. 6.47) with yeast supplementation.	[23,34,44,55]
Volatile Fatty Acid Production	↑ Propionate (6.08 vs. 5.01mM/L) and ↓ Acetate: Propionate ratio (3.41 vs. 4.79). SCFP increased total VFA (151.2 vs. 133.3mM) and reduced lactate in steers. Yeast cultures reduced lactate accumulation and acetate-to-propionate ratio. Postbiotics enhanced SCFA production (acetate, propionate, butyrate).	[21,35,37,41]
Nutrient Digestibility	↑ Digestibility of DM (73.44% vs. 64.00%), OM (74.68% vs. 65.90%) and NDF (71.65% vs. 57.67%) with PR. Inactive yeast ↑ DM and NDF digestibility in Jersey cows. *Saccharomyces cerevisiae* improved DM (4.6%) and NDF (10.3%) degradability.	[56-58]
Microbial Population Modulation	SCFP promoted microbial diversity and beneficial bacteria (*Ruminococcaceae, Lachnospiraceae, Prevotellaceae*). MOS+beta-glucans ↑ beneficial bacteria, ↓ pathogens. Yeast culture enhanced fibrolytic bacteria growth. SCFP increased Lactobacillales and altered microbial enzymes (↑ gluconokinase, xylanase).	[23,34,42,51,53]
Ammonia & Lactic Acid Reduction	Buffalo calves ↓ lactic acid (150.0 vs. 168.7mg/L) and NH_3-N (142.7 vs. 167.7mg/L) with yeast. Brewers' spent yeast ↓ ammonia-N levels in dairy sheep. SCFP reduced NH_3-N (4.86 vs. 6.83mg/dL) in steers.	[41,44,59]

SARA=Subacute Ruminal Acidosis, SCFP=*Saccharomyces Cerevisiae* Fermentation Product, MOS=Mannan Oligosaccharides, DM=Dry Matter, OM=Organic Matter, NDF=Neutral Detergent Fiber, PR=Probiotic, VFA=Volatile Fatty Acids, SCFA=Short-Chain Fatty Acids and NH_3-N=Ammonia Nitrogen. ↑ Indicates an increase, ↓ Represents a decrease, % Denotes percentage, mM=millimolar, mM/L=millimolar per litre, mg/L=milligrams per litre, mg/dL=milligrams per decilitre.

Immunomodulatory and anti-inflammatory mechanisms

Beyond rumen modulation, SCFP exerts systemic immunoregulatory effects (Table 2). Transition cows supplemented pre-and postpartum (19g/d) exhibited reduced Serum Amyloid A (SAA) and LPS-binding protein, suggesting mitigation of endotoxin translocation [60]. This aligns with Guo et al. [34], who found that SCFPb-2X (38g/d) downregulated pro-inflammatory cytokines (IL-6, TNF-α) by 25-30% during SARA, while elevating the anti-inflammatory cytokine IL-10. The mechanistic link involves enhanced gut barrier integrity, as evidenced by the upregulation of tight junction proteins (occludin, claudin-1) in mid-lactation cows [51]. Similarly, Aspergillus oryzae fermentation extract (3-6g/d) reduced plasma LBP and IL-6 in lactating Holsteins, corroborating the anti-inflammatory potential of fungal metabolites [32]. Intriguingly, Ferguson et al. [61] reported a reduced incidence of mastitis with SCFP, while Thomas et al. [62] observed no such effect-A discrepancy potentially attributable to herd health status or basal diet differences (Table 2).

Table 2: Effects of postbiotics on animal health and immune function.

Category	Postbiotic Source	Summary of Results	Reference
Antimicrobial & Anti-Virulence Effects	*Lactobacillus sakei* postbiotics	Antibacterial and antibiofilm activity against Staphylococcus aureus (mastitis pathogen)	[63]
	Lactobacillus-derived postbiotics (e.g., 2-undecanone)	Suppressed virulence of pathogens by inhibiting biofilm formation and yeast-to-hyphal transitions	[64]
	Enterococcus durans ED 26E/7 postbiotics	Broad-spectrum antimicrobial effects (inhibited Enterococcus hirae, Staphylococci and some *E. coli* strains)	[65]
	Bacteriocins from *Lactococcus lactis*	Suppressed growth of enterococci/staphylococci by disrupting cytoplasmic membranes	[31]
	Saccharomyces cerevisiae-based (XPC™/NutriTek™)	Reduced *Salmonella enterica* prevalence in lymph nodes of cull dairy cattle	[1]
Reduced Inflammation & Oxidative Stress	*Lactobacillus plantarum* metabolites	Improved antioxidant capacity (↑ catalase activity)	[66]
	SCFP	Reduced IL-1β, NEFA, ceruloplasmin and haptoglobin	[17]
	SCFP	Reduced inflammatory markers (SAA, LPS-binding protein)	[60]
	Cell-free supernatant of *Lactobacillus plantarum* RG14	Increased serum/ruminal GPX activity; decreased oxidative stress marker TBARS (MDA).	[67]
	SCFP (e.g., NutriTek)	Reduced somatic cell counts, maintained milk quality below subclinical mastitis threshold. Reduced LPS/inflammatory markers, improved gut barrier function in mid-lactation cows. Improved metabolic health.	[34,39,51]
	Intravaginal LAB	Modulated local/systemic immune responses; lowered uterine infections	[68]
	LAB mixture	Reduced purulent vaginal discharge	[68]
	Saccharomyces cerevisiae culture	Reduced plasma haptoglobin (28%). Increased glucose (63.8 vs. 62.1mg/dL).	[23]
	Lactobacillus plantarum KLDS 1.0344	Protective effects against LPS-induced mastitis	[61,69]
Enhanced Immune Responses	*Saccharomyces cerevisiae*-based postbiotics	Stimulated immune cell function and reduced pathogen survival	[70]
	SCFP	Enhanced immune preparedness; rapid IL-1β/IL-6 response during digital dermatitis (suggests "trained immunity")	[71]
Udder Health	Bacteriocin from *L. lactis* CJNU 3001	Inhibited *Staphylococcus aureus*, improving udder health and milk quality	[72]

LAB=Lactic Acid Bacteria, SCFP=*Saccharomyces Cerevisiae* Fermentation Products, CFS=Cell-Free Supernatant, GPX=Glutathione Peroxidase, TBARS=Thio barbituric Acid Reactive Substances, MDA=Malondialdehyde, NEFA=Non-Esterified Fatty Acids, SAA=Serum Amyloid A, *IL-1β*=Interleukin-1 Beta, *IL-6*=Interleukin-6, LPS=Lipopolysaccharide. ↑=increased, mg/dL=Milligrams per decilitre

Interaction between postbiotics and the rumen microbiome

Postbiotics are gaining significant attention as a novel category of "biotics," offering a promising alternative to traditional antibiotics in livestock production, particularly for ruminants [63-66]. The interaction between postbiotics and the rumen microbiome has been the topic of several studies due to their potential to enhance ruminant productivity while mitigating environmental impacts [67]. Recent studies demonstrate that postbiotics exert species-and stage-specific effects on rumen fermentation and microbial ecology. In goats, yeast-derived postbiotics (Probisan Ruminants) administered at 3.75g/d during late lactation increased propionate production by 21% and improved the acetate-to-propionate ratio, suggesting enhanced energy utilization [37,68,69]. Similarly, lambs supplemented with Lactobacillus plantarum RG14 postbiotics exhibited a selective reduction in Enterobacteriaceae without disrupting total bacterial populations, indicating targeted antimicrobial activity against potential pathogens [22,70-72]. These findings highlight the capacity of postbiotics to modulate microbial communities in a manner that supports host health and metabolic efficiency. In young ruminants, postbiotic supplementation has shown promise in boosting immune defences. Calves receiving *Saccharomyces Cerevisiae* Fermentation Products (SCFP) at 1-2g/d demonstrated improved resistance to respiratory and enteric pathogens, with notable reductions in Salmonella-induced diarrhea and lung pathology [73,74]. However, responses vary with the dietary context, as evidenced by beef heifers on high-grain diets showing improved fermentation profiles with SCFP, whereas mid-fattening Angus steers exhibited no significant changes in rumen parameters [75,76].

This highlights the importance of dosage, dietary composition and physiological stage in determining the efficacy of postbiotics. Beyond immediate performance benefits, postbiotics influence rumen microbial ecology in ways that enhance long-term feed efficiency [20,23,77]. Studies in newly weaned lambs have revealed that postbiotics increase weight gain, nutrient digestibility, and populations of fibrolytic bacteria, while reducing protozoa and methanogens [22]. *In vitro* work further supports these observations, demonstrating that postbiotics from *L. plantarum* RG14 enhance organic matter digestibility and volatile fatty acid production without compromising rumen pH [78]. Such improvements in fermentation efficiency are critical for optimizing feed conversion in production systems. A particularly compelling aspect of postbiotic supplementation is its potential to reduce methane emissions. By suppressing methanogen populations, postbiotics directly lower methane output [22]. Additionally, *Saccharomyces cerevisiae* postbiotics promote microbial stability, fostering lactate-utilizing and fibrolytic bacteria while mitigating subacute ruminal acidosis [42]. This stabilization of rumen microbiota not only improves animal health but also redirects metabolic hydrogen toward propionate synthesis rather than methanogenesis [77,79]. The resulting shift in fermentation pathways aligns with broader goals of sustainable livestock production. The mechanisms underlying these effects involve intricate microbial interactions. Postbiotics modulate the rumen microbiome's composition and functional dynamics, enhancing fermentation efficiency while reducing environmental pollutants [80]. As research progresses, a deeper understanding of these interactions will enable more targeted applications, ensuring that postbiotics are utilized optimally across different production systems. For farmers and nutritionists, these findings offer practical strategies to improve both animal performance and environmental sustainability.

Conclusion

The growing body of research stresses the potential of postbiotics as a viable alternative to antibiotics in ruminant nutrition, offering benefits in rumen fermentation, immune modulation and overall animal health. Postbiotics, particularly those derived from *Saccharomyces cerevisiae* and *Lactobacillus spp.*, demonstrate consistent improvements in rumen pH stability, volatile fatty acid production, and nutrient digestibility, while mitigating subacute ruminal acidosis and reducing pathogenic bacterial loads. Their immunomodulatory effects, including reduced inflammatory markers and enhanced gut barrier function, further support their role in promoting animal health without the risks associated with live probiotics or antimicrobial resistance. However, the efficacy of postbiotics varies depending on factors such as dosage, animal species and physiological stage, highlighting the need for standardized protocols. While current findings are promising, further large-scale, long-term studies are necessary to validate these effects across diverse production systems. The integration of postbiotics into ruminant diets aligns with sustainable livestock production goals, offering a science-backed strategy to enhance productivity while addressing global concerns over antimicrobial resistance.

Future directions and research gaps

Despite the demonstrated benefits, critical gaps remain in postbiotic research, particularly regarding optimal dosing, species-specific responses and long-term metabolic impacts. Future studies should prioritize *in vivo* trials evaluating postbiotic efficacy in methane mitigation, feed efficiency and immune function under varying dietary conditions. Additionally, the economic feasibility of large-scale postbiotic production must be assessed to facilitate industry adoption. Mechanistic insights into rumen-microbe-postbiotic interactions, particularly in relation to methanogen suppression and volatile fatty acid dynamics, warrant deeper investigation. Standardized methodologies for postbiotic characterization and application will be essential to maximize their potential in sustainable ruminant production systems.

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