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Original Article**Postbiotics: Mechanisms, Production and Therapeutic Applications****Prasad Patil*, Madhav Patil, Sneha Shende, and Gajanan Narnaware***College of Dairy Technology, Warud (Pusad)-445204, MAFSU, Nagpur***Corresponding Author: prasadpatil@mafsu.ac.in**Received: 02/10/2026**Accepted on: 08/10/2026***ABSTRACT**

Postbiotics are formally defined as inanimate microorganisms and their components that confer health benefits on the host, shifting the paradigm of microbiome therapeutics away from a strict reliance on live cultures. This review article synthesises current literature on postbiotics, categorising them into cell-containing structures (like peptidoglycans and teichoic acids) and cell-free components (such as short-chain fatty acids and enzymes). Their production relies on precision upstream fermentation followed by controlled thermal, UV, or acoustic inactivation and downstream spray-drying to ensure stability. Mechanistically, they drive host immunomodulation via Toll-like receptors, inhibit pathogens and biofilms, and strengthen the epithelial gut barrier. Compared to live probiotics, postbiotics offer unmatched clinical safety for immunocompromised individuals, superior industrial shelf-life without a cold chain, and versatile delivery configurations. These unique attributes have accelerated their commercial application in infant formulas, shelf-stable functional foods, and cancer immunotherapy adjuvants. Ultimately, future research must prioritise clinical standardisation, exact dosage metrics, and large-scale human trials to safely bridge the gap between traditional biology and precision pharmacy.

INTRODUCTION

Postbiotics are defined as "preparations of inanimate microorganisms and/or their components that confer a health benefit on the host" (ISAPP). Unlike live probiotics, postbiotics achieve therapeutic effects through inactivated microbial biomass, disrupted cell wall fractions, and functional metabolic byproducts. This review synthesises current literature regarding the classification, production, physiological mechanisms, and clinical advantages of postbiotics over traditional biotics.

1. Classification and Chemical Composition

Postbiotics comprise a diverse array of non-viable components. They are broadly divided into two major categories:

- **Cell-Containing Postbiotics:** These include structurally inactivated whole cells, cell lysates, and cellular surface fragments such as peptidoglycans, teichoic acids, and lipoteichoic acids (LTAs).

- **Cell-Free Postbiotics:** These consist of cell-free supernatants (CFS) and metabolic byproducts secreted during fermentation.

Key bioactive fractions identified in postbiotic matrices include:

Component Category	Specific Bioactive Molecules	Primary Biological Effect
Short-Chain Fatty Acids (SCFAs)	Acetate, propionate, butyrate	Intestinal barrier maintenance, epigenetic modulation
Enzymes & Proteins	Superoxide dismutase, catalase, bacteriocins	Pathogen inhibition, oxidative stress reduction
Polysaccharides	Exopolysaccharides (EPS)	Immunomodulation, gut microbiota cross-feeding
Structural Fragments	Muropeptides, teichoic acids	Toll-like receptor (TLR) signaling interaction
Micronutrients	B-group vitamins, Vitamin K2	Systemic homeostasis regulation

2. Preparation and Production Methods

The production of high-quality postbiotics requires deliberate cultivation and processing steps to guarantee consistency and functionality:

- Upstream Culturing:** Standard probiotic strains, such as *Lactic acid bacteria* (LAB) or *Bifidobacterium*, are fermented in specialized media (e.g., MRS broth or dairy by-products).
- Inactivation Step:** The live cells are rendered inanimate using physical methods such as **thermal processing (heat-killing)**, ultraviolet (UV) irradiation, or sonication. This process breaks or stabilizes the cellular structure without destroying key surface antigens.
- Downstream Processing:** The mixture undergoes separation via centrifugation or ultrafiltration. The resulting fractions are preserved through lyophilisation (freeze-drying) or spray-drying to produce a stable, powder-form agent.

3. Mechanisms of Action

Postbiotics exert multiple protective pathways within the host organism, functioning as targeted "magic bullets" for cellular pathways:

Immunomodulation

Inactivated cells and cell wall fractions interact directly with host immune cells via Toll-like receptors (TLRs). This signaling triggers regulatory T-cell (Treg) induction and balances cytokine production, which effectively moderates inflammatory cascades.

Antimicrobial and Anti-biofilm Action

Postbiotics lower luminal pH through organic acid content and release bacteriocins that disrupt pathogen membranes. This makes them useful for eliminating dangerous bacterial biofilms in medical and industrial settings.

Epithelial Barrier Enhancement

Metabolites like butyrate serve as primary energy substrates for colonocytes, strengthening tight junction proteins. This prevents intestinal permeability and helps prevent systemic metabolic syndromes.

4. Key Clinical Advantages Over Probiotics

According to evaluations published in *Frontiers in Microbiology*, postbiotics offer several critical advantages over live probiotics:

- **Enhanced Safety Profile:** Because they lack live microbial replication, postbiotics pose no risk of bacterial translocation or antibiotic resistance gene transfer. This makes them safe for immunocompromised individuals or vulnerable infants.
- **Superior Industrial Stability:** Postbiotics do not require cold-chain transport or refrigeration. They resist thermal processing, allowing them to remain stable throughout long-term storage.
- **Diverse Delivery Sites:** They can target anatomical sites where live microbes struggle to persist, such as the oral cavity, skin, nasopharynx, and urogenital tract.

5. Commercial and Industry Applications

The physical and chemical stability of postbiotics has accelerated their integration into multiple market sectors:

- **Early Life Nutrition:** Postbiotics are increasingly added to infant formulas to reduce the symptoms of infant colic, atopic dermatitis, and acute diarrhea.
- **Functional Foods and Beverages:** They are incorporated into shelf-stable dairy, plant-based matrices, and functional beverages (such as commercial kombucha adaptations) without losing efficacy over time.
- **Therapeutic Adjuvants:** Recent clinical trials highlight their ability to re-stimulate immune responses, boosting tumor-killing efficiency alongside modern cancer immunotherapies.

6. CONCLUSION

Postbiotics represent a significant shift in microbiome therapeutics. Postbiotics prove that the benefits of the microbial world are not tied to life itself, but to a complex language of chemical intelligence. By moving from live cultures to stable, non-viable components, we open up a safer, highly customizable frontier in precision medicine. The immediate focus must now shift toward standardizing processing methods and conducting large-scale human clinical trials to decode exactly how different bacterial matrices interact with our genetics. As we master these molecular pathways, postbiotics will bridge the gap between traditional biology and modern pharmacy, removing the

logistical hurdles of the cold chain entirely. Ultimately, the future of microbiome science isn't just about keeping bacteria alive it's about capturing and refining the lasting biological legacy they leave behind. Future research must prioritize clinical standardization, dosage metrics, and resolving strain-specific metabolic profiles.

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