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(Review Article)

Microbiome dynamics: Defenses against foodborne threats

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Abstract

The gut microbiome is a diverse ecosystem of microorganisms inhabiting the human gastrointestinal tract, playing a crucial role in health and disease. This review examines inter-individual variability in gut microbiota composition and the impact of diet, genetics, and environmental factors on microbial diversity. It explores how probiotics and bacteriocins can serve as therapeutic agents against foodborne pathogens, offering alternatives or synergists to traditional antibiotics. The mechanisms through which probiotics interact with pathogens and the therapeutic potential of bacteriocins are analyzed. Emphasizing the need for further research, this review underscores the importance of elucidating gut microbiome interactions to improve health and disease management strategies.

Keywords: Gut Microbiome; Probiotics; Bacteriocins; Pathogen Prevention; Dysbiosis

1. Introduction

The gut microbiome consists of trillions of microorganisms, including bacteria, viruses, fungi, and archaea, which collectively form a complex community within the gastrointestinal (GI) tract (Lozupone et al., 2012). This diverse ecosystem plays an integral role in human health by maintaining homeostasis and facilitating various physiological processes. The microbiota is involved in metabolism, immune modulation, and the maintenance of the intestinal barrier (Rajilic-Stojanovic et al., 2009). A well-balanced gut microbiome is essential for immune system functionality and preventing inflammation, as it regulates the interactions between the gut epithelium and the external environment (Matamoros et al., 2013). However, the composition of gut microbiota varies between individuals, influenced by factors such as diet, genetics, environmental exposures, and early-life microbial colonization (Lozupone et al., 2012). This review provides an overview of the dynamics within the gut microbiome, focusing on the role of foodborne pathogens and the potential therapeutic applications of probiotics and bacteriocins. These elements represent promising avenues for addressing gastrointestinal diseases and preventing infections, particularly in the context of the growing concern over antibiotic resistance.

2. Gut microbiome dynamics

The gut microbiome is highly dynamic and can be affected by various factors, including age, stress, lifestyle, and dietary habits (Cresci et al., 2015). Throughout life, shifts in the composition of gut microbiota occur, particularly during critical periods such as infancy, aging, or illness. For example, the gut of infants is colonized by microorganisms during the early years, with breastfeeding, birth mode, and antibiotic use influencing microbial composition. This initial colonization has long-term effects on an individual's health (Matamoros et al., 2013). One of the most significant influencers of gut microbiota is diet. Diet plays a central role in shaping microbial communities, with dietary fibers serving as key substrates for beneficial gut bacteria. In the large intestine, fibers are fermented by bacteria, producing short-chain fatty acids (SCFAs) like butyrate, acetate, and propionate, which contribute to gut health by reducing inflammation and supporting intestinal barrier integrity (Umu et al., 2017). Conversely, a diet high in fats and sugars can encourage the

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growth of pathogenic or pro-inflammatory bacteria, leading to dysbiosis, an imbalance in the microbial ecosystem. Dysbiosis is linked to diseases such as obesity, diabetes, inflammatory bowel disease (IBD), and even neurological conditions, though the specific mechanisms are not yet fully understood (Tiffany et al., 2019; Shreiner et al., 2015).

3. Impact of foodborne pathogens

Foodborne pathogens remain a significant global health threat. Bacteria, viruses, and parasites that contaminate food can cause severe infections, leading to high morbidity and mortality. According to estimates by the World Health Organization (WHO), foodborne illnesses are responsible for approximately 4.2 million deaths annually, primarily due to pathogenic bacteria found in contaminated food (Franz et al., 2019). These pathogens, including *Clostridium perfringens*, *Salmonella Enteritidis*, and *Escherichia coli*, can lead to infections that are often challenging to treat, especially with the rise of antibiotic-resistant strains. Probiotics, beneficial live microorganisms that confer health benefits to the host, have been studied for their ability to prevent and treat infections caused by foodborne pathogens. Studies have shown that certain probiotic strains inhibit the growth of harmful microorganisms by competing for resources, producing antimicrobial substances, or modulating the host's immune response (Schoster et al., 2013; Carter et al., 2017). *Clostridium perfringens*, for example, is a common cause of food poisoning, but the introduction of probiotics like *Lactobacillus* and *Bifidobacterium* can help suppress its growth and reduce the risk of infection (Chingwaru et al., 2017).

4. Bacteriocins: A promising alternative

Bacteriocins are antimicrobial peptides produced by certain strains of bacteria within the gut microbiota. These peptides inhibit the growth of closely related bacterial species and pathogens, while leaving beneficial gut flora unaffected (Eijsink et al., 2002). Unlike broad-spectrum antibiotics that can disrupt the entire gut microbiome, bacteriocins offer a targeted approach to pathogen control, making them a promising alternative or adjunct to traditional antibiotics (Majeed et al., 2011). Bacteriocins work by disrupting bacterial cell walls, interfering with protein biosynthesis, or causing the leakage of cellular contents, leading to the death of target bacteria (Leitsch et al., 2011; Dicks et al., 2011). One well-known bacteriocin, Nisin, is effective against pathogens such as *Listeria monocytogenes* and *Clostridium botulinum*, and has been approved for use in food preservation (Majeed et al., 2011). Studies have demonstrated that bacteriocins can be used synergistically with traditional antibiotics, enhancing their efficacy and potentially reducing the required antibiotic dosage, thus mitigating the risk of developing resistance (Cavera et al., 2015).

5. Interaction between probiotics and pathogenic bacteria

Probiotics interact with pathogens through various mechanisms, including competitive exclusion, secretion of antimicrobial compounds, and immune system modulation. Prebiotics, non-digestible food components that selectively promote the growth of beneficial bacteria, can enhance the effectiveness of probiotics in combating pathogens like *Salmonella* and *E. coli*. Prebiotics such as inulin and fructooligosaccharides provide substrates that support the growth of beneficial bacteria, which in turn alter the gut environment and suppress the proliferation of harmful microorganisms (Nunpan et al., 2009; Tran et al., 2018). Several strains of *Lactobacillus* and *Bifidobacterium* have been shown to effectively inhibit the growth of pathogens through the production of bacteriocins or by altering the gut's pH and competitive niches. For instance, *Lactobacillus rhamnosus GG* has been shown to inhibit *Salmonella* by competing for nutrients and producing antimicrobial substances that prevent pathogen colonization (Schoster et al., 2013). *Bifidobacterium bifidum* has also demonstrated the ability to prevent *Clostridium difficile* infections, a common and dangerous pathogen, especially in individuals with compromised gut microbiota (Carter et al., 2017).

6. Case studies and research findings

Research has identified specific *Lactobacillus strains* that produce bacteriocins with significant antimicrobial activity. For example, *Lactobacillus salivarius* produces a bacteriocin called Abp118, which has been shown to inhibit *Listeria monocytogenes* and *Clostridium perfringens* (Walsh et al., 2008). Another strain, *Lactobacillus plantarum*, produces plantaricin, an antimicrobial peptide that effectively inhibits the growth of *Staphylococcus aureus* (Jothi et al., 2012). Studies on traditional fermented foods have also revealed the presence of lactic acid bacteria (LAB) that produce bacteriocins. In particular, research on the African fermented food fura has shown that LAB isolated from this product possess bacteriocin-producing capabilities. These bacteriocins have demonstrated efficacy against *Bacillus cereus* and *E. coli*, suggesting that natural fermentation processes can contribute to gut health and pathogen control (Owusu-Kwarteng et al., 2012; Lv et al., 2017).

7. Conclusion

The gut microbiome is integral to human health, influencing not only digestion and metabolism but also immune function and pathogen resistance. Probiotics and bacteriocins represent promising strategies for maintaining a balanced microbiome, preventing dysbiosis, and combating foodborne pathogens. Bacteriocins, in particular, offer a targeted approach to pathogen control and present a significant therapeutic potential in the era of increasing antibiotic resistance.

Future research should continue exploring the interactions between probiotics, prebiotics, and pathogenic bacteria to better understand the mechanisms at play. Additionally, further studies on the clinical applications of bacteriocins could pave the way for new therapeutic strategies in treating gastrointestinal infections and preserving gut health. Unlocking the potential of bacteriocins in both food preservation and human health will be essential for advancing innovative treatments and promoting overall well-being.

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