Porcine Research

Gut microbiota and its role in porcine health: a brief review

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Abstract. The gut microbiota plays a vital role in the health and productivity of swine by influencing nutrient metabolism, immune modulation, and pathogen resistance. This review explores the composition and development of gut microbiota in pigs, emphasizing its impact on digestion, growth, and disease resistance. It discusses dietary interventions, including probiotics, prebiotics, synbiotics, and functional feed additives, as practical strategies to optimize gut health. Advances in omics technologies and personalized nutrition approaches are highlighted, offering insights into targeted interventions for improving microbiota balance. The review also addresses challenges such as microbiota variability and the need for standardization in microbiota-based therapies. Future directions focus on interdisciplinary research to enhance swine welfare and productivity through microbiota management.
Key Words: functional feed additives, prebiotics, probiotics, swine health, synbiotics.

Introduction. The gastrointestinal tract (GIT) of pigs hosts a complex and dynamic community of microorganisms collectively known as the gut microbiota. These microorganisms perform critical functions essential for host health, including nutrient metabolism, immune modulation, and pathogen resistance (Xiao et al 2016). Understanding the gut microbiota and its role in swine health has gained increasing attention in recent years due to its implications for animal welfare, productivity, and food safety (Kim et al 2011).

The gut microbiota is a dynamic and complex community of microorganisms inhabiting the gastrointestinal tract, profoundly influencing physiological processes such as digestion, nutrient absorption, immune modulation, and pathogen resistance. In pigs, the gut microbiota has emerged as a critical factor in determining health and production efficiency. Dysbiosis, a microbial imbalance, has been associated with heightened susceptibility to enteric and systemic diseases, chronic inflammation, and impaired growth performance (Zhao et al 2018; Negash 2022).

Advancements in molecular and sequencing technologies, such as metagenomics, transcriptomics, and metabolomics, have revolutionized the study of gut microbiota. These tools enable researchers to identify key microbial species and functional pathways associated with health and disease states. Studies have demonstrated that a balanced gut microbiota enhances nutrient utilization, strengthens immune defenses, and mitigates the impact of environmental stressors (Gilbert et al 2016; Bach Knudsen et al 2018). Furthermore, research has revealed a complex interplay between microbial communities and host genetics, indicating that variations in the microbiota can influence disease susceptibility and production outcomes (Koh et al 2016; Kogut et al 2020).

A healthy gut microbiota is typically characterized by a diverse microbial population dominated by beneficial bacteria, such as *Lactobacillus* and *Bifidobacterium*. These microbes produce short-chain fatty acids (SCFAs) like butyrate, which regulate intestinal barrier integrity, modulate the immune system, and suppress inflammation (Zhao et al 2018). Conversely, dysbiosis often results from factors such as antibiotic use, abrupt

dietary changes, or environmental stress, leading to reduced microbial diversity and an overgrowth of pathogenic species such as *Escherichia coli* and *Clostridium perfringens* (Cox & Blaser 2013).

Dietary interventions have emerged as practical strategies for modulating gut microbiota to enhance swine health and productivity. Approaches such as probiotics, prebiotics, synbiotics, and functional feed additives show promise in restoring microbial balance, improving gut health, and optimizing growth performance. This review aims to provide an in-depth analysis of the gut microbiota's role in swine health, focusing on the mechanisms and outcomes of dietary interventions. The objectives of this review are to summarize the current understanding of gut microbiota composition and functions in swine, evaluate its impact on health and productivity, and explore interventions for modulating microbiota with potential applications in swine production systems.

Composition of gut microbiota in pigs. The gut microbiota of pigs consists predominantly of bacteria, with smaller populations of archaea, fungi, and viruses. Key bacterial phyla include Firmicutes, Bacteroidetes, Actinobacteria, and Proteobacteria, which vary across the gastrointestinal tract. This composition is influenced by factors such as age, diet, genetics, and environmental conditions (Leser & Mølbak 2009).

In the neonatal phase, microbial diversity is low, with facultative anaerobes like *Escherichia* spp. and *Streptococcus* spp. dominating. During the weaning phase, dietary changes cause a significant shift, increasing the prevalence of Bacteroidetes and Firmicutes. In the adult phase, microbial communities stabilize, achieving high diversity that supports optimal digestion and immune function (Jha & Berrocoso 2015). The development and maturation of gut microbiota are essential for ensuring long-term health and resilience against diseases, with a stable adult microbiota correlating strongly with increased growth performance and feed efficiency (Zhao et al 2018).

The role of gut microbiota in swine health. The gut microbiota significantly influences swine health by modulating immune responses, enhancing nutrient metabolism, and providing resistance against pathogens. Understanding these roles is crucial for developing interventions that promote health and productivity in swine.

Immunomodulation. The gut microbiota plays a crucial role in shaping the immune system of pigs. Dysbiosis, characterized by an overrepresentation of pathogenic bacteria, compromises immune defenses, increasing the host's susceptibility to infections caused by *E. coli*, *Salmonella* spp., and *Clostridium difficile* (Negash 2022). Restoring microbial balance can reduce inflammation and bolster immune responses, contributing to improved overall health (Pluske et al 2018). Beneficial bacteria like *Lactobacillus* spp. modulate immune responses by promoting the production of anti-inflammatory cytokines and enhancing mucosal barrier function (Kogut et at 2020). Additionally, microbiota-derived metabolites like SCFAs influence immune cell differentiation and activity, further bolstering the pig's defense mechanisms (Bach Knudsen et al 2018).

Nutrient metabolism and growth. The gut microbiota facilitates the breakdown of complex polysaccharides into volatile fatty acids (VFAs), which serve as energy sources for the host (Bach Knudsen et al 2018). Microbial activity enhances feed conversion efficiency and promotes weight gain. Probiotic supplementation has been linked to improved nutrient absorption, reduced feed costs, and enhanced growth performance (Zhang et al 2023). Gut microbes also synthesize essential vitamins, including B12 and K, which are vital for host nutrition (Leser & Mølbak 2009). Furthermore, microbiota interactions with dietary proteins and lipids result in the production of bioactive compounds that support intestinal health and overall metabolic efficiency (Gilbert et al 2016).

Pathogen resistance. Gut microbiota offers protection against pathogens through competitive exclusion, nutrient competition, and the production of antimicrobial compounds. Beneficial microbes also produce SCFAs, which lower intestinal pH and inhibit the growth of pathogenic bacteria. Additionally, a robust microbial community stimulates

mucosal barrier integrity and enhances immune responses, preventing pathogen colonization (Jha & Berrocoso 2015). The ability of the microbiota to resist colonization by harmful pathogens is crucial during critical periods such as weaning when pigs are particularly vulnerable to infections (Pluske et al 2018).

Gut microbiota and swine health

Growth performance and feed efficiency. Research indicates strong correlations between specific microbial profiles and improved feed conversion ratios. Probiotic and prebiotic supplementation have been employed to enhance gut health and optimize growth performance in pigs (Xiao et al 2016).

Disease resistance. Dysbiosis has been linked to several swine diseases, including post-weaning diarrhea and porcine epidemic diarrhea. Modulating the gut microbiota through dietary interventions and probiotics offers a promising strategy for disease prevention and control (Mach et al 2015).

Stress and behavior. The gut-brain axis mediates the effects of gut microbiota on stress responses and behavior. Microbial metabolites, including SCFAs, influence the central nervous system and contribute to improved stress resilience in pigs (Jha & Berrocoso 2015).

Dietary interventions to modulate gut microbiota. Dietary interventions provide a practical approach to influencing gut microbiota, enhancing its beneficial effects on immunity, growth, and overall health.

Probiotics. Probiotics are live microorganisms that confer health benefits when administered in adequate quantities. Commonly used probiotics in swine production include *Lactobacillus*, *Bacillus*, and *Enterococcus* species (Ding et al 2021). These bacteria enhance gut microbial balance, reduce pathogen colonization, and improve mucosal immunity (Liao & Nyachoti 2017). Long-term use of probiotics has shown positive impacts on growth performance, disease resistance, and intestinal health, highlighting their potential as alternatives to antibiotics (Windisch et al 2008).

Prebiotics. Prebiotics are non-digestible compounds that selectively promote the growth of beneficial gut microbes. Examples include inulin, fructo-oligosaccharides (FOS), and mannan oligosaccharides (MOS) (Bach Knudsen et al 2018). Prebiotics have been shown to improve gut health, stimulate immune responses, and enhance growth performance. The synergistic effects of prebiotics with dietary fibers can further amplify microbial diversity and resilience against stressors such as environmental changes (Timmerman et al 2005).

Synbiotics. Synbiotics, which combine probiotics and prebiotics, offer synergistic benefits by improving microbial diversity and host health. Studies demonstrate that synbiotics reduce diarrhea incidence in weaning pigs and enhance growth performance (Ding et al 2021). The combination of specific strains of probiotics with tailored prebiotics ensures targeted benefits for gut health, reducing the need for therapeutic interventions.

Functional feed additives. Functional feed additives, such as organic acids, essential oils, and enzymes, modulate gut microbial composition and activity (Windisch et al 2008). Organic acids create an acidic gut environment unfavorable to pathogenic bacteria while supporting beneficial microbes (Huyghebaert et al 2011). Essential oils and plant extracts, known for their antimicrobial and antioxidant properties, also contribute to improved gut health and performance metrics (Gilbert et al 2016).

Dietary strategies. Dietary interventions, including the use of probiotics, prebiotics, synbiotics, and fermented feeds, have been shown to enhance gut microbiota diversity and

SCFA production. Probiotics such as *Lactobacillus* spp. and *Bifidobacterium* spp. have demonstrated efficacy in restoring microbial balance, while prebiotics promote the growth of beneficial bacteria (Leser & Mølbak 2009).

Antimicrobial alternatives. With the reduction in antibiotic use, phytogenics, organic acids, and bacteriophages emerge as viable alternatives for maintaining gut health and preventing infections (Kim et al 2011).

Genetic approaches. Selective breeding for host genotypes associated with favorable microbiota profiles presents a novel approach to improving swine health and productivity (Mach et al 2015).

Challenges and future directions

Omics technologies. High-throughput sequencing and metabolomics have revolutionized our understanding of the pig gut microbiota. Integrating multi-omics data offers a comprehensive view of host-microbiota interactions, paving the way for targeted interventions (Xiao et al 2016). Advances in functional genomics are expected to unravel the precise roles of lesser-known microbial taxa, opening avenues for novel dietary or therapeutic interventions.

Personalized nutrition. Tailored dietary strategies based on individual microbiota profiles represent a promising direction for optimizing health and performance (Jha & Berrocoso 2015). Advances in bioinformatics and predictive modeling will further enhance the efficacy of these approaches. Personalized nutrition not only addresses variability among swine populations but also reduces environmental impacts by optimizing feed formulations for efficiency and sustainability.

Microbiota transplantation. Fecal microbiota transplantation (FMT) is gaining traction as a therapeutic approach for restoring microbial balance, particularly in cases of severe dysbiosis (Mach et al 2015). However, standardizing FMT protocols remains a challenge. Ensuring donor microbiota compatibility and avoiding potential pathogen transmission are key considerations for the broader adoption of FMT in swine production systems.

Challenges and limitations. Variability in microbiota composition across individuals and environments complicates standardization. Ethical and regulatory considerations must also be addressed to ensure the safe implementation of microbiota-based interventions (Leser & Mølbak 2009). Despite the promising potential of dietary interventions, variability in outcomes remains a challenge due to differences in genetics, diets, and environmental conditions among swine populations. Advances in omics technologies, including metagenomics and metabolomics, offer opportunities for precision modulation of gut microbiota tailored to specific herds (Gilbert et al 2016). Further research is needed to elucidate the mechanisms by which dietary strategies influence the gut microbiota and to identify optimal intervention combinations.

Conclusions. The gut microbiota plays a central role in swine health, influencing immunity, nutrient metabolism, and growth performance. Dietary interventions, including probiotics, prebiotics, synbiotics, and functional feed additives, offer practical tools for enhancing swine health and reducing reliance on antimicrobials. Continued research and innovation are essential for optimizing gut microbiota and improving the sustainability of modern swine production systems.

The gut microbiota is integral to swine health, influencing digestion, immunity, and disease resistance. Advances in microbiome research provide opportunities to enhance animal welfare and productivity through targeted interventions. However, translating these findings into practical applications requires multidisciplinary efforts and robust validation studies.

Conflict of interest. The authors declare that there is no conflict of interest.

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