Biological Functions of Yeast Polysaccharides and Their Effects on Piglet Intestinal Health

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Abstract

Weaning stress induces intestinal metabolic disorders, disrupts intestinal microenvironment homeostasis, and compromises health in piglets. Yeast polysaccharides can ameliorate piglet intestinal health, enhance systemic immunity, improve intestinal digestion and absorption functions, reduce odor emissions, optimize the piglet rearing environment, and hold great significance for the development of ecological and healthy animal husbandry. This article reviews the biological functions of yeast polysaccharides and their effects on piglet intestinal health.

Full Text

Biological Function of Yeast Polysaccharide and Its Effect on Piglet Gut Health

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Abstract: Weaning stress disrupts intestinal metabolism and the gut microenvironment in piglets, compromising their health. Yeast polysaccharide serves as a natural and effective regulatory agent that can improve piglet gut health and immunity, enhance digestive and absorptive functions, reduce odor emissions, and improve the rearing environment. These benefits hold significant importance for developing ecological and healthy animal production systems. This paper reviews the biological functions of yeast polysaccharide and its effects on piglet gut health.

Keywords: yeast polysaccharide; piglets; gut health; intestinal microflora

Piglet production represents a critical phase in the swine industry, with gut health being paramount. Normal intestinal function ensures piglet health, yet weaning stress damages gut integrity through altered mucosal morphology, increased intestinal epithelial permeability, reduced digestive capacity, decreased mucus layer thickness, elevated intestinal pH, and imbalanced gut microbiota. While antibiotics can modify gastrointestinal microbial colonization, reduce immune stimulation, and promote growth, they create residues, foster resistant bacteria, pose food safety risks, pollute the environment, and threaten human health. Consequently, developing efficient, low-cost green feed additives or physiological regulators to reduce antibiotic use in pig production has become a research priority.

Yeast polysaccharide functions as a natural, highly effective regulatory agent that maintains piglet gut health, enhances immunity, reduces disease incidence, improves digestive function, decreases odor emissions, lowers antibiotic and drug usage, improves the rearing environment, and promotes healthy development of ecological pig production—thereby enhancing both economic and ecological benefits of China' s swine industry. Investigating the mechanisms through which yeast polysaccharide affects piglet gut health carries important scientific, economic, and ecological significance for guiding swine production practices. This review examines yeast polysaccharide composition, biological functions, and its effects on piglet gut health. Current research on yeast polysaccharide in animal production primarily focuses on *Saccharomyces cerevisiae*; unless otherwise specified, yeast polysaccharide discussed herein refers to products derived from this species.

1 Composition of Yeast Polysaccharide

The yeast cell wall consists of three layers from outermost to innermost: mannan oligosaccharide (MOS), protein, and glucan. Yeast polysaccharide is a composite macromolecule comprising 50–60% -glucan and 40% mannan protein. Glucans include -1,6-glucan, -1,3-glucan with -1,6-linked branches, and linear -1,3-glucan. Yeast polysaccharide contains 100–300 mannan units, with -1,6 linkages forming the main chain and -1,2 and -1,3 linkages forming side chains. Through acetolysis reactions that cleave -1,6-glycosidic bonds, mannan can generate various oligosaccharides, namely MOS.

2 Biological Functions of Yeast Polysaccharide

2.1 Immunomodulatory Function

-glucan exerts immunological effects by binding to immune cell receptors and initiating immune responses. It increases white blood cell populations including macrophages, granulocytes, and monocytes, and stimulates production of interleukins (IL-1, IL-2, IL-4, IL-5, IL-6, IL-8, IL-12), tumor necrosis factor-

(TNF-), and interferon- (IFN-). -1,3-glucan enhances tumor suppression by reducing the CD4+/CD8+ ratio and decreasing expression levels of IL-2, IL-6, and TNF- . Additionally, -glucan promotes differentiation of helper T cells (Th1) and activation of cytotoxic T lymphocytes, eliminating tumor-associated immune suppression of dendritic cells.

The primary specific receptors for -glucan include Dectin-1, complement receptor 3 (CR3), and Toll-like receptors (TLR). Insoluble particulate -1,3-glucan with -1,6 branches binds to Dectin-1 to activate innate and adaptive immune responses, whereas soluble -glucan can activate antibody-mediated complement systems via CR3 to reduce inflammatory responses and modulate host defense mechanisms, as detailed in the review by Stier et al. MOS possesses certain immunogenicity, stimulating immune responses and serving as an adjuvant for exogenous antigens such as toxins and viruses, thereby slowing antigen absorption and increasing antigen titer to enhance immune responses. MOS stimulates immune organ development and maturation, promotes plasma cell formation, prolongs immune memory, and activates macrophages, thereby improving disease resistance and stress tolerance.

The immunological mechanisms of yeast polysaccharide involve activation of macrophages, neutrophils, natural killer cells, and B and T lymphocytes, enhancing phagocytosis both in vivo and in vitro, and increasing cytokine production to exert immunomodulatory effects.

2.2 Antioxidant Function

Yeast polysaccharide enhances superoxide dismutase (SOD) activity, reduces malondialdehyde (MDA) content, and improves the capacity to scavenge or inhibit oxygen free radicals, thereby demonstrating antioxidant activity. -glucan exhibits strong defense against peroxynitrite- or hydrogen peroxide-induced lipid peroxidation, significantly reducing platelet protein oxidation by 50% in carbonyl content and 80% in thiobarbituric acid reactive substances. Both in vivo and in vitro studies show that yeast polysaccharide significantly increases SOD activity in mouse liver and serum while markedly decreasing MDA content.

Chemical modification can improve the biological functions of yeast polysaccharide, with common substituents affecting antioxidant activity and solubility influencing free radical scavenging capacity. Modification methods include acetylation, carboxymethylation, phosphorylation, and sulfation. Sulfated glucan demonstrates significant reducing capacity, while phosphorylated glucan shows strong hydroxyl radical and superoxide anion scavenging activity and anti-lipid peroxidation effects. Phosphorylated MOS, sulfated MOS, carboxymethylated MOS, carboxymethylated phosphorylated MOS, and carboxymethylated sulfated MOS exhibit superoxide anion scavenging capacity comparable to vitamin C, with anti-lipid peroxidation capacity exceeding that of yeast MOS.

2.3 Gut Microecological Modulation Function

Yeast polysaccharide can be utilized by intestinal bacteria, benefiting the microecosystem. Irradiated glucan shows obvious inhibitory effects on *Escherichia coli*, *Salmonella*, *Bacillus cereus*, and *Proteus*. Yeast polysaccharide interferes with colonization of intestinal pathogens, reducing pathogenic microorganisms such as *Salmonella* and *E. coli* while serving as a nutritional substrate to promote proliferation of beneficial bacteria like *Lactobacillus* and *Bifidobacterium*, thereby regulating gut microbial balance.

2.4 Adsorption Function

Yeast polysaccharide adsorbs mycotoxins such as aflatoxin and zearalenone. -glucan exhibits toxic inhibition of mycotoxins, binding them in the gastrointestinal tract to mitigate their effects in pigs. The toxic inhibition of another yeast polysaccharide, -D-mannan, may occur through interaction with toxic gene products. MOS can form three-dimensional structures with strong adsorption capacity, binding mycotoxins and pathogenic bacteria in the intestine, with adsorption efficiency increasing with molecular weight.

Consequently, yeast polysaccharide reduces toxin deposition and production, diminishes toxicity, and decreases fecal odor and ammonia emissions. Kogan et al. propose that yeast -glucan and MOS possess immunomodulatory and mycotoxin adsorption activities, prevent bacterial adhesion and transmission, and promote pig health.

3 Effects of Yeast Polysaccharide on Piglet Gut Health

3.1 Effects on Intestinal Morphology

Yeast polysaccharide improves piglet intestinal morphology, enhances nutrient digestion and absorption, and promotes growth. However, some studies report no significant effects on intestinal morphology. These discrepancies may arise from variations in yeast polysaccharide source, type, -glucan to MOS ratio, processing technology, protein impurity content, and supplementation level.

The small intestine plays a crucial role in digestion and absorption, with villus morphology affecting nutrient uptake. An increased villus height-to-crypt depth (V/C) ratio enhances digestive function and growth performance. Studies confirm that yeast polysaccharide increases small intestinal V/C ratio while significantly improving average daily feed intake, average daily gain, and feed conversion efficiency.

Current research primarily focuses on effects on small intestinal villus height and crypt depth, with limited investigation of goblet cells and lymphocytes. Moreover, these morphological indicators are relatively macroscopic and cannot fully elucidate how yeast polysaccharide influences structural changes in piglet intestine. Since -glucan can improve intestinal permeability and tight junction

integrity, and epithelial structural changes correlate with functional alterations, in vitro culture methods could be employed to investigate yeast polysaccharide effects on piglet intestinal epithelial cell proliferation and differentiation for deeper mechanistic insights.

3.2 Effects on Intestinal Microorganisms

Microbial balance is essential for piglet digestion, absorption, and growth. Weaning reduces beneficial bacteria while increasing harmful bacteria, whose proliferation and toxin production damage intestinal mucosa. Yeast polysaccharide maintains microecological balance and improves microbial community structure by reducing pathogenic bacteria such as *Salmonella* and *E. coli*, primarily through the actions of -glucan and MOS.

3.2.1 Effects of Yeast -Glucan -glucan serves as an antibiotic alternative for preventing post-weaning enterotoxigenic *E. coli* (ETEC) infection, with two-week supplementation reducing piglet susceptibility to ETEC. In Stuyven et al.' s study, -glucan protected weaned piglets from ETEC F4 infection but offered no protection to germ-free piglets, suggesting that -glucan influences microbial colonization.

-glucan inhibits *E. coli* proliferation while minimally affecting *Bifidobacterium* or *Lactobacillus* growth, thereby improving microbial structure without harming beneficial bacteria. Generally, prebiotics exert positive effects by shifting microbial community activity or composition, while probiotics inhibit pathogen colonization by competing for nutrients or adhesion sites on intestinal epithelial cells, or by producing antibiotic or immunomodulatory compounds. -glucan exhibits agglutination capacity for certain bacteria, preventing harmful bacteria from attaching to epithelial cells and colonizing mucosal surfaces. However, mechanistic research on -glucan' s effects on piglet gut microbiota remains limited, requiring deeper investigation into whether it promotes competition between beneficial and harmful bacteria and how it prevents pathogen proliferation.

3.2.2 Effects of Yeast MOS MOS affects intestinal microorganisms through mannose-binding proteins on bacterial surfaces (such as *E. coli* and *Salmonella*), preventing bacterial invasion. White et al. found that 0.234% MOS significantly increased fecal *Lactobacillus* counts without affecting *E. coli*. Similarly, 0.2% MOS reduced jejunal *E. coli* numbers without significantly influencing *Lactobacillus* counts. Thus, MOS differentially affects *E. coli* and *Lactobacillus* but improves microbial structure in both cases, though effects may depend on MOS purity and dosage. However, Poeikhampha et al. reported that MOS did not significantly affect *Lactobacillus* or *E. coli* counts in the cecum and rectum of nursery pigs, possibly due to limited impact under good management conditions.

Regarding MOS mechanisms, research suggests that -D-MOS binds to mannose-specific lectin-type receptors on *E. coli*, preventing bacterial mannose from binding to glycoproteins on intestinal villus surfaces and thereby inhibiting pathogen

colonization and dissemination. However, other mechanisms remain underexplored. In vitro studies show that MOS serves as a nutrient for beneficial bacteria, producing organic acids and antimicrobial peptides that inhibit pathogen growth. Harmful bacteria such as *Clostridium* and *E. coli* utilize MOS poorly or at low metabolic rates, slowing their growth, while beneficial bacteria like *Lactobacillus* proliferate more vigorously. MOS also agglutinates *Enterococcus faecalis* and *Salmonella*, preventing their colonization. Although these mechanisms are confirmed in vitro, they were not derived from piglet gut microorganisms. Furthermore, differences in yeast sources and in vivo environments contribute to variations in microbial effects, necessitating further research for practical application.

3.2.3 Effects on Diarrhea Increased pathogen numbers after weaning is a primary cause of piglet diarrhea. Yeast polysaccharide improves microbial structure and reduces diarrhea from microecological imbalance. -glucan supplementation for 14 days decreases fecal ETEC F4 counts and ETEC-induced diarrhea. MOS inhibits toxin-producing bacteria, reducing or preventing diarrhea. Yeast wall polysaccharide at 0.30% and 0.45% significantly reduces cecal *E. coli* and *Salmonella* counts, with diarrhea incidence decreasing by 31.68% at the 0.30% level.

3.3 Effects on Volatile Fatty Acid (VFA) Content

Intestinal microbial composition and metabolites affect VFA quantity and composition. -glucan significantly increases total cecal VFA content. MOS shows a tendency to increase cecal butyrate and total VFA without significantly affecting lactate, acetate, or propionate. Yeast wall polysaccharide significantly increases colonic acetate, with 0.30% and 0.45% levels significantly elevating colonic propionate, butyrate, and total VFA. However, Castillo et al. reported no significant effects of MOS on total VFA, acetate, propionate, butyrate, valerate, or branched-chain fatty acids in the ileum and cecum.

These findings indicate that yeast polysaccharide increases total VFA in the colon and cecum, with some effects on lactate, propionate, and butyrate, but no significant impact on ileal VFA. VFAs are primarily produced through microbial fermentation in the large intestine, with limited synthesis in the small intestine. As the terminal segment of the small intestine, the ileum has minimal microbial fermentation and thus limited VFA synthesis.

Research on yeast polysaccharide effects on hindgut VFA synthesis remains scarce and requires more data. Variations in results primarily relate to microbial species, quantities, and proportions. Beneficial bacteria utilize yeast polysaccharide to synthesize VFAs such as acetate, propionate, and butyrate, which lower intestinal pH, promote beneficial bacteria, and inhibit pathogens, maintaining microecological balance. Butyrate improves intestinal barrier function by inducing oxygen consumption in intestinal epithelium and modulating hypoxia-inducible factors. Additionally, VFAs provide energy for intestinal ep-

ithelial cells, stimulate colonocyte proliferation, increase colonic absorptive surface area, and improve epithelial transport capacity and nutrient utilization efficiency, enabling beneficial bacteria to perform barrier, nutritional, and immunomodulatory functions.

3.4 Effects on Intestinal Immunity

The intestinal immune barrier comprises absorptive epithelial cells and gut-associated lymphoid tissue. Intestinal mucosa prevents bacterial adhesion, distinguishes pathogens from commensal microbes, and organizes immune tolerance and pathogen-specific responses. Gut-associated lymphoid tissue represents the largest immune system component and plays a central role in intestinal defense. MOS shows no significant effects on ileal immunoglobulin A (IgA) content or jejunal intraepithelial lymphocyte or goblet cell numbers. However, *Pichia pastoris* MOS mitigates *E. coli*-induced increases in jejunal intraepithelial lymphocytes and goblet cells, significantly reducing ileal goblet cell counts in challenged groups, thereby enhancing mucosal immunity and immune surveillance.

-glucan significantly increases TNF- relative expression in the ileum and markedly elevates TNF- expression in liver and spleen. Purified (1,3/1,6)- -D-glucan shows no significant effects on intestinal immune development but tends to reduce ileal villus CD3+ cell numbers with increasing dosage. He et al. found that 0.30% and 0.45% yeast wall polysaccharide significantly increased ileal CD4+ lymphocyte counts and moderately elevated CD8+ and CD20+ lymphocyte numbers. *Pichia pastoris* MOS significantly reduced IL-1 and TLR4 relative expression while increasing IL-6 expression in unchallenged piglets; after *E. coli* challenge, it significantly increased mucosal IL-1 and IL-6 expression while tending to decrease TLR4 expression, demonstrating that MOS enhances intestinal immunity and modulates cytokine expression during infection.

Varied piglet responses to yeast polysaccharide immunostimulation result from differences in polysaccharide structure and impurity content. Current research on yeast polysaccharide effects on piglet intestinal immunity remains limited. Known mechanisms involve -glucan interaction with microfold cells in the small intestine. Glucan translocates from the gastrointestinal tract to systemic circulation by binding to intestinal epithelial and gut-associated lymphoid tissue cells, then undergoes microfold cell uptake from the lumen to immune cells within Peyer' s patches or dendritic cell binding. Subsequently, glucan binds to specific receptor sites on immune cells, triggering gene expression and cytokine secretion. However, this complex activation mechanism remains unconfirmed in piglet intestinal immunity and requires further investigation. Secretory IgA plays a crucial role in mucosal immunity by providing an immune barrier against pathogens, yet research on yeast polysaccharide effects on intestinal SIgA is limited. Additionally, oligosaccharides promote *Bifidobacterium* growth, which exhibits immunostimulatory effects, suggesting a potential link between *Bifi-*

dobacterium utilization of yeast polysaccharide and immune modulation that warrants deeper study.

4 Conclusion

In summary, yeast polysaccharide improves weaning stress and promotes gut health in piglets, but its effects on intestinal morphology and underlying regulatory mechanisms require further investigation, primarily due to the complex and diverse impurities and structures in yeast polysaccharide products. Diverse production and processing technologies result in significant variations in purity, solubility, molecular weight, tertiary structure, polymer charge, and solution conformation. Therefore, future research should address: differences in biological functions among yeast polysaccharide chemical structures and derivatives; specific mechanisms of intestinal structure improvement and disease resistance; biological and functional differences among polysaccharides from different yeast strains; interactions between yeast polysaccharide and other nutritional or non-nutritional factors; and synergistic effects with other feed additives.

Yeast polysaccharide improves animal gut health while reducing antibiotic and drug use and protecting the ecological environment. As concepts of "safe production, green health care, and healthy breeding" mature and food safety concerns grow, yeast polysaccharide will gain increasing attention. This additive holds broad application prospects for future green, healthy, and high-quality ecological animal production systems.

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