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Integrative role of yeast culture metabolites in aquatic health and productivity

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ABSTRACT

Aquaculture is an important source for the animal protein obtained through extensive farming. Worldwide aquaculture sector consistently confronts the challenges such as non-specific infections, low productivity and environmental stress. *Saccharomyces cerevisiae* being commonly utilized yeast species in aquaculture nutrition, especially for its growth-enhancing and health-promoting attributes in various cultured fish and crustacean species. Yeast culture metabolites (YCM) have emerged up as valuable feed ingredient to promote essential microbiota in ponds. Research on aquatic species such as tilapia, salmons and shrimps has shown that yeast metabolites beneficially affect growth performance, feed conversion ratio, digestive physiology, and gut morphology. The functional components regulate and activate immune responses, ultimately enhancing resistance to infections and overall aquatic health. Feed utilization efficiency in aquaculture species with an average of between 8 and 18 % reduction in FCR, which is attributed to the use of these yeast metabolites as feed additives in terms of fish production sustainability. Despite the increasing volume of experimental research, the current understanding of application in aquaculture remains limited. This review summarizes what is currently known about yeast functional metabolites, formulations, and various aquaculture applications. The integration of metabolites in feeds promoting sustainable farming methods and resilience in contemporary aquaculture.

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INTRODUCTION

Aquaculture is one of the fastest-growing areas of food production in the world. It is very important for meeting the growing need for animal protein. Aquaculture has emerged as an important source of food products in the world, overtaking capture fisheries as a source of food consumed by humans in 2022 and supplying 52% of the food. Together, capture fisheries and aquaculture provide nearly 17% per cent of all animal-source protein globally. However, the fast growth of aquaculture systems has made it harder to manage health, ensure long-term growth, and limit damage to the environment (Verdegem *et al.,* 2023). These limits, in combination with climate change and increasing demand of protein channels in the world market, underscore technological advances in aquaculture, especially in the formulation of feeds, production efficiency, and green systems of aquaculture, in order to increase the role of aquaculture in the human food supply, with the least negative effects on the environment.

Bacteria, viruses, and parasites are some of the most common pathogens that cause infectious diseases in aqua farming operations. These diseases are among the leading causes of mortality and financial loss (Robinson *et al.,* 2023). Historically, antibiotics have been employed to prevent and cure infections; however, over utilization has precipitated a problem of antimicrobial resistance (AMR) (Bhat and Altinok, 2023). Currently, resistant pathogens such as *Aeromonas hydrophila* and *Vibrio* spp. are prevalent in aquatic ecosystems, jeopardizing both animal and human health (Mzula *et al.,* 2021). Intensive aquaculture practices often induce stress in farmed organisms, resulting in compromised immune systems, diminished feeding efficiency, and reduced growth rates. These issues must be resolved to ensure that aquaculture remains productive and ecologically sustainable without the use of chemical treatments such as antibiotics, which may result in antibiotic resistance and pollutants (Easwaran *et al.,* 2022).

In this context, postbiotics derived from yeast, especially from the well-studied organism *Saccharomyces cerevisiae*, have attracted considerable interest as a sustainable and efficacious approach to improving the health of fish and shrimp (Mohammed *et al.,* 2025). Yeast culture metabolites (YCM) have significantly improves the growth rate, immunity and disease tolerance in endangered species such as *Tor putitora* (Rahman, 2022). Postbiotics are non-viable microbial fermentation products or metabolic byproducts that contribute to the animal health (Vinderola *et al.,* 2025). These are compounds includes β-glucans, mannans, enzymes, vitamins, and organic acids (Ndambuki *et al.,* 2025). YCM can enhance the immune systems of aquatic animals, modify the microbiota to promote gut health, and accelerate the action of enzymes responsible for food digestion (Azam *et al.*, 2025). These factors reduce the likelihood of illness in animals, enhance nutritional absorption, and promote accelerated development (Wisastra *et al.,* 2025). This article seeks to conduct a comprehensive analysis of the functional metabolites generated by *S. cerevisiae* and their biological mechanisms that promote the aquatic health and productivity. The objective is to consolidate existing knowledge regarding the impact of yeast-derived metabolites on immunological regulation, gut microbiota equilibrium, antioxidant defense, and overall physiological health in aquatic creatures. The review discusses the application of yeast postbiotics in contemporary aquaculture, including methods for determining appropriate quantities, species-specific responses, and potential obstacles that may arise.

Yeast culture metabolites

Saccharomyces cerevisiae: A metabolic powerhouse

S. cerevisiae is now a significant component of contemporary biotechnology and has been utilized for the production of bread and beer for an extended period (Parapouli *et al.,* 2020). The U.S. Food and Drug Administration (FDA) have classified it as Generally Recognized As Safe (GRAS), and the European Union (EU) has included it in its list of feed additives (EUC No. 4b1702) (Karathia *et al.,* 2011). This indicates that it has been safe for human consumption for an extended period and is also safe for animal consumption, including in aquaculture. This robust safety profile is essential for animals that produce food, since it guarantees compliance with stringent food security and public health regulations. The metabolic flexibility and intricate cellular architecture of *S. cerevisiae* significantly enhance its utility beyond basic fermentation processes (You *et al.,* 2017). This yeast, when transformed into various postbiotic forms such as heat-inactivated whole yeast, yeast cell wall extracts, or enzymatically hydrolyzed yeast, releases several bioactive chemicals (Parapouli *et al.,* 2020). This postbiotic matrix comprises many functional components that collaboratively produce beneficial impacts on the animal health and metabolism (Perricone *et al.,* 2022).

Functional metabolites

S. cerevisiae possesses a diverse array of structural, intracellular, and extracellular metabolites that collectively improve its utility in the aquaculture industry. These components include immunomodulatory polysaccharides, vitamins, organic acids, nucleotides, enzymes, and postbiotics produced during the process of fermentation (Fu *et al.,* 2023). As postbiotics, these bioactive compounds work together to create a stable, safe, and effective alternative to traditional antibiotics. They also help aquaculture become more sustainable. Here is a more in-depth look at the important functional metabolites: β-glucans, mannanoligosaccharides, enzymes and vitamins (Table 1).

β-Glucans: β-glucans, a type of polysaccharide, constitute 20 to 50 percent of the yeast cell wall. The predominant components of their structure are β-1,3 and β-1,6 bonds (Beikzadeh *et al.,* 2020). These polysaccharides serve as potent immunostimulants that initiate immunological signaling cascades by engaging with immune cells such as macrophages, neutrophils, and hemocytes via pattern recognition receptors like dectin-1 (Vuscan *et al.,* 2024). This activation enhances phagocytosis, stimulates the formation of reactive oxygen species during the respiratory burst, and upregulates cytokines such as tumor necrosis factor-alpha (TNF-α) and interleukin-1 beta (IL-1β) (Yan *et al.,* 2025). These are crucial components of the innate immune response.

Table 1. Types of yeast postbiotics and impact on growth and performance in aquaculture

Postbiotics	Bioactive compounds	Modes of action	Benefits	References
Yeast culture	Metabolites, organic acids, amino acids, vitamins, and enzymes	Immunomodulation, gut microbiota equilibrium and stabilization, enhance nutrient absorption	Improved growth and feed conversion ratio, increased disease tolerance	(You *et al.*, 2017)
Mannan oligosaccharides (MOS)	Mannose-rich polysaccharides	Competitive elimination of infectious agents, prebiotic effects, and better gut morphology	Less colonization by Vibrio spp., higher villi, and more mucin secretion	(Wang *et al.*, 2021)
β-glucan	β-1,3/1,6-glucans	PRR-driven immune activation of Dectin-1-like receptors and cytokine modulation.	Better survival, better ability to handle stress, and better tolerance to bacterial infections	(Yan *et al.*, 2025)
Yeast extract	Nucleotides, peptides, amino acids, B-vitamins	Increased growth of intestinal cells, metabolism of immune cells, and stimulation of enzymes	Better growth, immune response, and health of the hepatopancreas	(Hrubša *et al.*, 2022)
Yeast-derived nucleotides	AMP, IMP, GMP, nucleosides	Support for immune along with gut cells that divide quickly and help with stress recovery	Better growth in stress and better expression of immune genes	(Huang *et al.*, 2023)
Antioxidant postbiotics	Glutathione and polyphenol-like compounds	ROS scavenging and increasing the activity of antioxidant enzymes	Less oxidative stress, better ability to handle stress	(Chen *et al.*, 2019)
Yeast-derived enzymes	Proteases, lipases, and amylases,	Better digestion of feed and better absorption of nutrients	Protein utilization efficiency, Improved FCR	(Liang *et al.*, 2022)
Short-chain fatty acids (SCFAs)	Acetate, butyrate, propionate,	Energy supply for gut epithelium, immune modulation	Energy provision for intestinal epithelium, and immune regulation	(Ma *et al.*, 2025)

Incorporating β-glucans into the diets of various fish and shrimp species has demonstrated a reduced susceptibility to infections from diverse pathogens, including *Vibrio* spp. and *Aeromonas hydrophila* (Huang *et al.,* 2022). Diets containing 0.1–0.5% β-glucans have increased the survival rates of hybrid striped bass (Eissa *et al.,* 2023) and Pacific white shrimp (Uengwetwanit *et al.,* 2025) by 30–50% following exposure to pathogens. These diets have also increased the activity of antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT). These enzymes provide protection against oxidative stress that may occur during illness or environmental stressors.

Mannanoligosaccharides (MOS): MOS are oligosaccharides derived from mannoproteins, constituting the outer layer of the yeast cell wall (Faustino *et al.,* 2021). MOS functions as prebiotics and anti-adhesive agents by binding to mannose-specific lectin receptors on the fimbriae of pathogenic bacteria such as *V. parahaemolyticus* and *Escherichia coli* (Wang *et al.,* 2021). This competitive binding prevents pathogens from adhering to the intestinal lining, hence reducing the risk of infections and colonization (Khodadadi *et al.,* 2021). Consuming MOS supplements can promote the proliferation of beneficial bacteria such as Lactobacillus and Bifidobacterium while regulating harmful bacteria and coliforms. Alterations in the microbiota enhance the functionality of the gut barrier, hence improving villus height and mucosal integrity in shrimp and fish (El-Nobi *et al.,* 2021). This indicates that they can consume reduced quantities of food while still obtaining greater nutrients. Aquafeeds typically contain 2 to 6 grams of MOS per kilogram of feed (Abdel Gayed *et al.,* 2021). This enhances the efficacy of digestive enzymes such as protease and amylase, facilitating a growth increase of 10 to 20% in crustaceans like *Penaeus vannamei* (Novriadi *et al.,* 2024).

Chitin: Chitin and its deacetylated derivative chitosan remain significant functional components of the yeast cell wall, despite their reduced quantities (Sánchez and Roncero, 2022). These biopolymers originate from yeast bud scars and possess germicidal qualities, cellular protection against harm, and immune system enhancement capabilities (Araújo *et al.,* 2020). Chitin and chitosan have been demonstrated to activate phenoloxidase activity, stimulate macrophage function, and enhance non-specific immunity in fish and shrimp, especially in crustaceans where the prophenoloxidase cascade is crucial for pathogen defense (Machuca *et al.,* 2022). Chitosan also helps keep the gut healthy by strengthening tight-junction proteins and acting as a barrier-protective agent when the body is under stress or infection (Loor *et al.,* 2022). The overall immunonutritional effects of yeast culture come from the fact that they are naturally biocompatible and bioactive (Hasan *et al.,* 2023).

Nucleotides and Nucleosides: Nucleotides and nucleosides released during yeast autolysis are important intracellular metabolites that help cells grow, regenerate, and fight off infections. Nucleotides are semi-essential nutrients for tissues that divide quickly (Pastor-Belda *et al.,* 2022). They help make DNA and RNA, grow lymphocytes, repair the gut lining, and make antibodies. Adding nucleotides to the diet has been shown to help several types of fish live longer, fight disease better, have better intestinal morphology, and handle stress better. This makes yeast-derived nucleotides useful immunonutrients in aquaculture (Huang *et al.,* 2023).

Enzymes: There are proteases, amylases, cellulases, and phytases in *S. cerevisiae* postbiotic products. These enzymes are very important for helping aquatic animals digest food better (Takalloo *et al.,* 2020). These enzymes help break down complex proteins, carbohydrates, and anti-nutritional factors that are often found in plant-based feed ingredients that are becoming more popular in aquaculture diets (Liang *et al.,* 2022). Yeast-derived enzymes augment the host's inherent digestive enzyme activity, facilitating more efficient nutrient absorption and energy extraction, ultimately leading to improved growth performance (Abd El-Naby *et al.,* 2024). Research on crayfish (*Procambarus clarkii*) has shown that the inclusion of *S. cerevisiae* in their diet markedly increases amylase activity (by 20–40%), which is associated with enhanced feed conversion efficiency and higher survival rates after a bacterial challenge (Xu *et al.,* 2021).

Phytase derived from yeast fermentation can liberate phosphorus that is bound in plant food. This reduces feed expenses and the quantity of phosphorus released into the environment (Ogunremi *et al.,* 2020).

Short-chain fatty acids (SCFAs): SCFAs, such as acetate, propionate, and butyrate, are important extracellular metabolites produced by yeast and their related microbial interactions (Lv *et al.*, 2022). SCFAs regulate the functionality of gut epithelial cells, enhance mucin secretion, augment the energy supply to the intestines, and mitigate inflammation by modulating the activity of regulatory T-cells (Ma *et al.,* 2025). In aquaculture, SCFAs promote intestinal health, reduce pathogen populations, and enhance the immune response (Tran *et al.,* 2020).

Vitamins and other bioactive compounds: S. cerevisiae is a superior source of B-complex vitamins beneficial for the health and metabolism of aquatic animals. It additionally includes carbohydrates and enzymes. These include thiamine, niacin, riboflavin, pantothenic acid, biotin, pyridoxine, and folate (Demirgul *et al.,* 2022). These chemicals are essential for energy utilization, erythropoiesis, and cerebral function. These vitamins compensate for the nutrients that fish and shrimp may lack while consuming specialized diets with limited nutritional diversity (Hrubša *et al.,* 2022). *S. cerevisiae* also supplies nucleotides such as uridine and inosine, which are produced during RNA degradation (Du *et al.,* 2025). A yeast cells accumulate several antioxidant molecules during fermentation. These encompass glutathione, reductive peptides, and phenolic compounds (Tao *et al.,* 2022). These metabolites assist the body in managing oxidative stress, enhance the activity of antioxidant enzymes (such as superoxide dismutase and catalase), and safeguard tissues against reactive oxygen species that may arise during illness or stress. Enhancing antioxidants is crucial for maintaining the health of intensive aquaculture systems (Chen *et al.,* 2019).

Mechanisms of action of yeast metabolites in aquatic species

Yeast functional metabolites have positive effects on aquatic species through a number of biological processes that work together to improve health, resilience, and performance. Yeast metabolites are not just nutrients; they also help fish and shrimp deal with pathogens, environmental stressors, and intensive farming conditions by acting as immunomodulators, gut health promoters, and metabolic regulators.

Immunomodulatory mechanisms

Yeast culture metabolites especially β-glucans, are known for their strong immunostimulatory effects that boost both innate and adaptive immune responses in aquatic species. Dectin-1, complement receptor 3 (CR3), and toll-like receptors are examples of pattern-recognition receptors tare present in β-glucans and send signals inside cells that activate macrophages, neutrophils, and natural killer cells (Vu *et al.,* 2021). The result is that the body makes more reactive oxygen species (ROS), lysozymes, and nitric oxide that combat the pathogens. β-glucans also change the levels of cytokines, such as interleukins (IL-1β, IL-6) and tumor necrosis factor-α (TNF-α) that controls immunoregularly responses both locally and systematically (Ching *et al.,* 2021). These immuno-regularity effects are especially useful in juvenile fish and shrimp as the early immune systems aren't fully developed yet. Moreover, the repeated dietary administration of β-glucans has been demonstrated to elicit "trained immunity". This is characterized by an increased responsiveness of innate immune cells to subsequent infections, resulting in extended protection and decreased mortality upon pathogen exposure (Machuca *et al.,* 2022).

Gut health and microbiome modulation

Some YCM, like mannan oligosaccharides (MOS) and postbiotic compounds are very important for keeping the gut healthy and changing the microbiome of aquaculture species (Vinderola *et al.,* 2022). MOS act as decoy receptors for harmful bacteria like *Vibrio, Aeromonas*, and *E. coli*. This prevents adherence to the intestinal mucosa and facilitates the body's elimination of them.

The pathogen-exclusion effect mitigates inflammation in the gastrointestinal tract and safeguards tissue against injury. It also facilitates the proliferation of beneficial bacteria, such as *Lactobacillus* and *Bacillus* species (Wang *et al.,* 2021). Incorporating yeast into the diet enhances intestinal fortitude by increasing the height of the villi, deepening the crypts, and densifying the goblet cells. This facilitates the absorption of nutrients into the body and enhances the efficacy of the mucosal barrier (Liao *et al.,* 2022). Furthermore, short-chain fatty acids (SCFAs) and other postbiotic metabolites provide enterocytes with energy and facilitate mucin production, thereby enhancing the epithelial barrier and promoting gut health. The synergistic effects of stabilizing microorganisms, safeguarding the mucosa, and administering nutrients enhance development, illness resistance, and feed efficiency, particularly in aquaculture environments where gut dysbiosis frequently occurs (Li *et al.,* 2023).

Antioxidant and anti-stress activities

Oxidative stress is a significant challenge in intensive aquaculture, attributable to elevated stocking densities, variable temperatures, and pathogen exposure, all of which can result in increased production of reactive oxygen species (ROS) by aquatic species (Ciji and Akhtar, 2021). Yeast-derived antioxidants, such as glutathione, phenolic-like metabolites, Maillard reaction products, and reductive peptides, effectively neutralize free radicals, thereby preventing damage to proteins, lipids, and DNA (Tao *et al.,* 2022). Yeast metabolites exhibit direct antioxidant properties and also synthesize proteins associated with stress, such as heat shock proteins (HSPs). These proteins protect cellular proteins from breaking down and help cells recover from stressors in the environment. The combination of antioxidants and stress-response modulation helps people live longer, boosts their immune system, and keeps their metabolism stable even when things are stressful, like when they are in a high-density culture or when the water quality isn't great. Studies on tilapia and shrimp demonstrate that dietary yeast culture reduces oxidative biomarkers like malondialdehyde (MDA) and increases the activity of antioxidant enzymes (superoxide dismutase, catalase, and glutathione peroxidase), indicating improved systemic stress tolerance and resilience (Zheng *et al.,* 2021).

Antimicrobial and anti-pathogenic actions

Through a number of different ways, yeast metabolites have strong antimicrobial and anti-pathogenic effects. Mannan oligosaccharides (MOS) and chitin/chitosan fragments stop harmful bacteria from sticking to the lining of the intestines (Tiwari *et al.,* 2020). This stops the bacteria from spreading and colonizing. Yeast-derived bioactive peptides and short-chain fatty acids also stop bacteria from growing and killing them by changing the pH of the gut or stopping quorum sensing. The epithelial barrier becomes stronger when mucin production and tight-junction protein expression are increased. This makes it even harder for pathogens to enter the bloodstream (Li *et al.,* 2025). These mechanisms work together to not only stop bacterial infections like *Vibrio*, *Aeromonas,* and *Edwardsiella* species, but they also help the immune system by lowering chronic inflammation in the gut (Mou *et al.,* 2022). Adding yeast to fish and shrimp that are infected with common aquaculture pathogens has been shown to lower death rates and improve health and performance overall (Ayiku *et al.,* 2020).

Metabolic and growth-promoting effects

Yeast culture facilitates the accelerated growth of aquatic animals while reducing their feed consumption. Amino acids, peptides, nucleotides, and B-complex vitamins exemplify bioactive substances that facilitate protein synthesis, energy metabolism, and function as enzyme cofactors. Incorporating yeast into fish diet enhances digestive efficiency by stimulating the activity of proteases, amylases, and lipases. Enhanced nutrient absorption and utilization result in improved feed conversion efficiency, accelerated growth rates, and superior body composition.

Metabolites and organic acids generated from fermentation enhance gut health, maintain microbial balance, and facilitate nutrient absorption (Abdel Gayed *et al.,* 2021). Yeast culture is a multifaceted feed supplement that enhances growth performance, physiological resilience, and overall productivity in aquaculture of fish and shrimp. This is due to its metabolic effects, together with its immunological and antioxidant advantages.

Application of yeast culture metabolites in fish health

Nile tilapia

The addition of dietary yeast fermentation products to Nile tilapia with dose 4kg/kg has demonstrated to be beneficial with growth, feed conversion, and immune system function (Ndambuki *et al.,* 2025). The supplements β-glucan and MOS to the diet made the body more resistant to *S. iniae* and *A. hydrophila*, increased the activity of antioxidant enzymes, and improved the shape of the gut, which all led to better health and productivity in tilapia and cat fish (Cacot *et al.,* 2024). MOS and β-glucans positively influenced the composition of gut microbiota, increase intestinal integrity, enhancing phagocyte activity and lysozyme production (Castro-Zambrano *et al.,* 2025). In intensive farming environments for tilipia, the interplay of immunostimulatory and antioxidant effects was associated with enhanced survival rates and a reduction in illness incidence (Abd El-Naby *et al.,* 2024). Yeast fermentation metabolites increase the protective immune response, growth performance, and bacterial resistance in tilapia (Tao *et al.,* 2025). Studies suggest that addition of 1g/kg of autolyzed *S. cerevisiae* in diet of Nile tilapia diet have shown significant effects on immune regulation, stabilizing gut morphology, and increasing intestinal integrity. These findings offer a valuable feed additive alternative for the aquaculture growth, productivity and sustainability (Odu-Onikosi *et al.,* 2024).

Salmon

Yeast metabolites enhanced the growth rate of and Atlantic salmon, improved the appearance of their intestines, and increased their resistance to microorganisms such as *Vibrio* spp. and *Aeromonas* spp (Hansen *et al.,* 2021). Incorporating YCM into the diets of channel catfish enhanced their weight increase, improved feed efficiency, and strengthened their immune systems. Higher levels of complement and serum lysozyme activity demonstrated this. Yeast metabolites contributed to maintaining the equilibrium of the gut microbiota and inhibited pathogen proliferation, hence enhancing the body's disease resistance and stress management capabilities (Mohammed *et al.,* 2019).

Carp

Common carp that ate diets with yeast culture grew faster, used food better, and were better able to fight off *Aeromonas* infections (Rhema *et al.,* 2022). The dietary additions of MOS in feed to grow grass carp have significantly enhance the antioxidant activity and inhibit the excessive apoptosis in body organs of fish (Lu *et al.,* 2023). Addition of *B. subtilis* and β-glucan in basal feed significantly enhance the villi height, growth rate and health of carp *B. subtilis* increase the lipase and amylase activity in the intestine of fish, while β-glucan enhances the digestive activity in carp (Cao *et al.,* 2019).

Trout

Supplementing yeast extracted β-glucan has beneficial effects on rainbow trout. The higher antioxidant effect, organ protection and lower level of lipid peroxidase marker were observed with 1.9g/ kg of β-glucan (Tkachenko *et al.,* 2023). The use of 8g/ kg of yeast derived postbiotics in the feed of trout has shown carcass weight, FCR, antioxidant potential and survival rate (Lashkarboluk *et al.,* 2024). Feed supplementation with β-glucans altered the gut microbiota in trout and has significant antioxidant and immune regulatory effect. Genus *Aurantimicrobium* was seen in abundance with other good bacteria in gut. β-glucans also enhance the disease tolerance against fish pathogen *Yersinia ruckeri* (Menanteau-Ledouble *et al.,* 2022).

Applications of yeast metabolites in shrimp health

Adding yeast postbiotics to shrimp has a big effect on how fast they grow, how often they molt, and how long they live (Wisastra *et al.,* 2025). Nutrients such as nucleotides, amino acids, vitamins, and peptides derived from yeast facilitate tissue growth, exoskeleton formation, and energy metabolism, all of which are essential for normal molting cycles and overall growth in shrimps (Bunnoy *et al.,* 2024).Yeast postbiotics enhance the survival, immune protection, reduce the risk of antimicrobial resistance that ultimately leads to sustainable shrimp farming (Prabu *et al.,* 2025). Several studies demonstrate that *Litopenaeus vannamei* and *Penaeus monodon*, when provided with diets supplemented with yeast metabolites, show increased weight gain, enhanced feed efficiency, greater molt increment, and improved resilience to environmental stressors, including temperature fluctuations and high stocking density (Ernesto Ceseña *et al.,* 2021).

Vibrio spp. is among the most hazardous bacteria for shrimp farming, including *V. harveyi* and *V. parahaemolyticus* (Yu *et al.,* 2023). Mannan oligosaccharides (MOS) and chitin/chitosan fragments obtained from yeast culture can attach to mannose-specific receptors found on Vibrio cells. This prevents adherence to the shrimp gut epithelium and reduces the bacterial population residing there (Huo *et al.,* 2024). Yeast metabolites enhance mucosal immunity by increasing the concentrations of hemolymph lysozyme and phenoloxidase, which assist in eradicating pathogens (Wang *et al.,* 2021). Studies show that shrimp fed diets enhanced with yeast culture display diminished *Vibrio* bacteria levels in their gastrointestinal tract and hemolymph, and possess a heightened survival rate when confronted with pathogens in controlled laboratory environments. This indicates that the yeast culture is highly effective at preventing bacterial entry into the body (Eissa *et al.,* 2023). Supplementation of 0.45 % of SCFP in diet of whiteleg shirmps enhanced the immune response, intestinal integrity and disease tolerance against *Vibrio* species (Thuy *et al.,* 2025).

Yeast metabolites augment shrimp digestion by promoting enzyme production and nutrient assimilation. Yeast generates extracellular enzymes during fermentation, such as proteases, amylases, and lipases. These enzymes enhance the shrimp's digestion by accelerating the decomposition of proteins, carbohydrates, and fats (Zheng *et al.,* 2021). The inclusion of yeast in shrimp feed has shown improvements in digestive enzymes, enhanced energy conversion from food, and promoted growth. The organic acids and fermentation byproducts produced by yeast alter the gut's pH, promoting the proliferation of beneficial bacteria, hence enhancing digestion and nutritional absorption (Chen *et al.,* 2023).

Applications of yeast metabolites in oyster health

Addition of high β-glucan producing mutant *S. cerevisiae* in the feed of juvenile oyster efficiently improved the immune status, less tissue damage, better disease resistance upon exposure to *Vibrio* species (Loor *et al.,* 2023). Yeast served as the major protein source for the aquaculture farming. Supplementing the yeast and its products in oyster farming promoted the growth rate, higher antioxidant activity, and intestinal integrity (Liao *et al.,* 2020). Higher survival rate and resistance to infection of *Vibrio* species was found in oyster treated with high glucan producing mutant *S. cerevisiae* (Loor *et al.,* 2022).

Comparative efficacy: Whole yeast vs. yeast culture metabolites

How well a yeast-based feed additive works in aquaculture depends on the type of yeast, how it is processed, and what it is meant to do. Whole yeast, yeast autolysates, cell wall extracts, and isolated metabolites all have different kinds of bioactive compounds and ways of working, which means they work differently to boost growth, immunity, and gut health (del Valle *et al.,* 2023).

Whole yeast comprises intact cells containing cell wall components and internal nutrients, including β-glucans, mannan oligosaccharides (MOS), nucleotides, amino acids, and vitamins (Ma *et al.,* 2023). The presence of these beneficial substances within the cells facilitates their gradual release in the gastrointestinal tract, benefiting overall nutrition, immunity, and microbiome equilibrium (Gu *et al.,* 2022).

The metabolites of yeast culture have a number of unique benefits over live yeast cultures that render them more useful in many of their applications. The metabolites are highly stable and resistant to the conditions of heat, pressure and moisture exposures found during feed manufacturing processes such as pelleting and extrusion unlike live yeast, which usually kill and make live yeast products ineffective (Perdichizzi *et al.,* 2023). This stability ensures that there is a high degree of bioavailability of desirable compounds such as vitamins, organic acids, enzymes and bioactive peptides regardless of the course of processing or storage (Cacot *et al.,* 2024).

Postbiotics may enhance stress resilience, promote antioxidant activity, and modify the gut microbiome. Yeast metabolites are nutritionally and functionally beneficial to the host as the bioactivity substances are already formed and poised to be absorbed whereas live yeast requires time to colonize the gut and become metabolically active, and viability through the supply chain is essential to guarantee effectiveness. Also, metabolites remove apprehensions about the lot-to-lot fluctuations in cell counts, rates of survival, and metabolic activity that bedevil live yeast items, and give manufacturers predictable and trustworthy results (Ogunremi *et al.,* 2020).

Live cells are not always necessary for their functionality. They are very useful when live yeast might not be stable or when exactly how much of an active compound is avaliable (Melaku *et al.,* 2024). To get the most out of yeast-based feed additives, the dose rate is crucial. If the doses are too low, they might not have enough bioactive compounds to make big changes in the body or the immune system. If the doses are too high, on the other hand, they may not be worth the money or, in rare cases, they may upset the stomach. The best dose usually depends on the type of yeast product, the species, the stage of life, and the conditions in which it is grown (Jannathulla *et al.,* 2021). For instance, adding β-glucan to shrimp's diet may be anywhere from 0.1% to 0.5%, while adding whole yeast or autolysates may be anywhere from 1% to 5%, depending on the nutritional goals (Eissa *et al.,* 2025). The pre-digestion of metabolites also implies that nutrients may also be used directly without the need to utilize energy to degrade the cell walls of the yeast making such nutrients especially useful in young animals whose digestive systems are not yet fully formed or in stressful conditions where digestive system efficiency may be impaired. Such applied benefits as better stability, constant efficacy, convenience and ready bioavailability causes that yeast culture metabolites is a more practical option compared to live yeast in most commercial feed applications (Moustafa *et al.,* 2024).

Safety, regulatory status, and practical considerations

Most people think that yeast-based feed additives are safe to use with fish and shrimp, which are both types of aquaculture species. The U.S. Food and Drug Administration (FDA) say that *S. cerevisiae* is "Generally Recognized As Safe" (GRAS), and it is widely used in aquaculture around the world (Sharma *et al.,* 2020). It doesn't have any toxic metabolites, so it doesn't have harmful impact on public health (Ansari *et al.,* 2023). It has been used in food and feed for a long time (Abid *et al.,* 2022). The recommended dose varies depending on the type of yeast product, the species, and the stage of life. Whole yeast and autolysates are usually added to feed at a rate of 1–5% (Sirisena *et al.,* 2024), while β-glucans or MOS are added to the diet at a rate of 0.1–0.5%, depending on how strong or fast the immune or growth response to be (Moustafa *et al.,* 2024). Getting the right amount is very important because not getting enough of a supplement may not help in health, and getting too much can make the food taste bad or make the pellets less stable. Extrusion and high-temperature pelleting are two ways that feed is made. These processes may affect the viability of live yeast and the stability of sensitive metabolites. To keep bioactivity, sometimes encapsulation methods or post-extrusion supplementation are used (Dadkhodazade *et al.,* 2021). Practical limitations include differences in metabolite concentrations between different types of yeast, the cost of yeast products, and the fact that different species respond differently to yeast. Even with these problems, aquaculture operations can still get the most out of yeast if they choose the right products, make them the right way, and store them properly (Agboola *et al.,* 2021).

Future trends and research directions

The future of yeast-derived feed used in aquaculture is subject to change due to recent development in omics and biotechnology (Shan *et al.,* 2021). Precision fermentation may be used to produce targeted β-glucan structures, short-chain fatty acids or bioactive peptides which are most effective at promoting growth or disease resistance in fish and shrimp (Hoppenreijs *et al.,* 2024). The omics technologies of metabolomics, metagenomics, and transcriptomics are increasingly being used to discover more about the interaction of the microbiome and the host, to identify significant bioactive metabolites, and to monitor the impact of the addition of yeast at both the molecular and microbial scales (Nadal-Ribelles *et al.,* 2024). It is particularly the case in fish farms that have a high number of fish and no antibiotics. The next study ought to focus on metabolite products of yeast to be used in shrimp and explore the combinations of compounds that can improve the immune system, fight free radicals, and promote growth (Zhao *et al.,* 2024).

It might also respond better by adding yeast culture to other feeds, probiotics or plant-based additives so as to make aquaculture practices long-lasting and environmental-friendly (Islam *et al.,* 2021).

CONCLUSION

Yeast culture metabolites have become potential functional feed additives in aquaculture due to their multifactorial advantages that can be used to solve major problems in the production of aquatic sustainably. Together with immune-modulating effects and capacity to control the composition of the gut microbiota and enhance beneficial bacterial communities, these immune-enhancing effects make yeast metabolites an effective substitute to antibiotics in disease prevention and health management programs. Antioxidant activities and mitigation of stress of these compounds have also led to enhanced welfare and survival rate in different culture conditions, which promotes these metabolites as scientifically supported, feasible and sustainable method of enhancing the productivity and health of aquaculture organisms. Since the aqua-industry is still trying to find alternatives to chemical therapeutics and methods of intensification without reducing aquatic welfare or environmental sustainability, yeast metabolites have become a promising alternative that should be implemented more extensively and investment made in research efforts.

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