# Probiotics and Biofloc Technology in Sustainable Aquaculture: A Review of Current Practices

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**Abstract**

In 2022, global aquaculture production surpassed the wild-capture fisheries for the first time to become the biggest contributor of aquatic animals as a resource to produce aquatic protein at scale (FAO, 2024). Yet, disease outbreaks, water quality degradation and increasing restrictive regulations over antibiotic drug use for disease prevention and control persist as persistent limitations for the industry o this growth (Cabello, 2006). Two approaches, probiotic supplementation and biofloc technology (BFT) have been consistently studied as sustainable solutions to enhance water quality, animal health, and productivity without the use of antimicrobials. This review takes a cue from recent research to look at the available data on the effectiveness of the individual approaches and the often-fierce debate about whether or not the benefit of their simultaneous application is reliably additive. Live microorganisms that exert measurable benefits to the host animal when consumed in sufficient quantities have been shown to offer clear health benefits when fed to a variety of cultured finfish and crustaceans, and are known as probiotics. By controlling C:N ratios to encourage heterotrophic bacterial dominance in the intensive culture systems, BFT also controls toxic nitrogenous compounds, produce supplementary protein feed and establishes a microbial community consisting of bacterial dominance with natural probiotic like properties. There is mixed evidence of mixed (commercial probiotics + established BFT) systems: some have shown synergistic effects whereas others have shown mixed systems carried out no better than an already established BFT system. Methodological differences between studies, such as different probiotic dose/culture species/organism maturity, makes comparing studies difficult. This review focuses on priority areas for future research and calls for greater context-specific designs for experimental work to turn potential successes in the lab into practice in the field.

**Keywords:** probiotics, biofloc technology, sustainable aquaculture, water quality, immunostimulation, Litopenaeus vannamei

## 1. Introduction

Over the last 30 years aquaculture has been a dazzling development. Aquaculture was responsible for about 94.4 million tonnes or 51 per cent of the total fish production in the world in 2022, for the first time in history, the farmed production exceeded the production of the wild fisheries (FAO 2024). This is also a sector that has seen itself increasingly becoming a component of the world's protein intake, a share that is expected to grow further and further since the per capita demand in aquaculture has increased from 9.1 kg in 1961 to 20.7 kg in 2022 and seems to be growing at a steady rate. There have been serious problems with the expansion. Focusing on waste accumulation, pathogens and water quality as cultures increase and become more intensive, managing these becomes more difficult. History of aquaculture has been characterised by the widespread overuse, possibly for routine purposes, of antibiotics to control bacterial diseases, which has led to the development of antibiotic resistant bacteria in aquaculture and, via transfer, in clinical situations (Cabello, 2006). In many countries the regulations on antibiotic use in food-animal farming have become stricter and new methods which are able to control the microbial risk without the emergence of microbial resistance are sought. In that context, two methods have garnered constant research attention: probiotics as live microbial feed supplements, and biofloc technology (BFT), the system-level manipulation that converts nitrogenous wastes into bacterial biomass created by the animals that is palatable to the animals. They differ in their scale and mechanism; probiotics operate mostly at the animal level, enabling residents of the intestinal flora to alter water quality and boost the immune system; BFT operates at the system level, by increasing the carbon-to-nitrogen ratio of the water, which facilitates the growth of heterotrophic bacteria while simultaneously removing unwanted substances from the water and adding a needed source of protein. They, however, all have one thing in common—the desire to have less of the chemical "intervention" and maintain production efficiency required by modern aquaculture. An important research question that has just started to gain science-based interest is if and how the addition of probiotics to BFT systems reinforces the existing BFT microbial community or if it is largely replaced by the existing BFT microbiome since it already contains some of the properties of probiotics. Each approach is now reviewed in isolation and then the more restricted, but instructive, literature on their use together. It also signals to researchers where there is a lack of evidence or a confusion in the evidence base (which areas, after all, would be more telling?) — as well as where the evidence exists and is settled, research efforts will be directed into.

## 2. Probiotics in Aquaculture: Definitions, Diversity and Mechanisms

The concept of probiotics has evolved multiple times from the field of terrestrial animal production to aquaculture and has been defined and extended accordingly. A live microbial feed supplement which beneficially affects the host by altering the microbial balance in the intestinal tract was the definition that has gained wide acceptance in the general science of microbial feed supplements (MFS) (Fuller 1989). To encompass aquatic systems, where the organisms introduced into the system act as probiotics not only in the digestive track but also in the water column, Verschuere et al. (2000) edicted a more general definition of probiotics. The list of microorganisms that have been tested as fish food supplements ranges from many sources that include the cultured microalgae, bacteria, yeast and algae. A strong record of antimicrobial production, especially of siderophores and bacteriocins, and the ability to use Bacillus species (typically B. subtilis, B. licheniformis) producing heat-resistant endospores that survive feed pelleting are largely responsible for their extensive documentation. Various genera of lactic acid bacteria have been screened in various finfish and crustaceans, and in most cases, these bacteria were found to be beneficial in improving gut microbiome stability and immunity (Nayak, 2010). Composting trials have been carried out with selected Vibrio and Pseudomonas strains for use as pathogen-inhibiting water additives; however, safety issues involve some Vibrio spp., making use at a wider scale more complicated (Verschuere et al., 2000). The yeast, especially Saccharomyces cerevisiae, have gained research interest either as a direct immunostimulant via the innate immune pathway utilizing beta-glucan surface antigen, or for providing exogenous digestive enzymes (Akhter et al., 2015). Probiotics are recognized to act in a number of overlapping mechanisms. One of the well-documented effects is competitive exclusion, which is the ability to exclude pathogens from the water column or gut by occupying the same ecological niche. By producing inhibitory substances like the bacteriocin, hydrogen peroxide and short-chain fatty acids, the pathogen's growth is directly suppressed. The third pathway involves increased stimulation of the immune responses of the host, which has been shown in fish and crustaceans with enhanced lysozyme activity, upregulation of immune genes and heightened quality of phagocytes and leucocytes (Nayak, 2010; Akhter et al., 2015). Increases in growth and/or performance reported in a number of trials may be due in part to increases in digestive enzyme activity, as Wang (2007) found for juvenile Penaeus vannamei fed mixed cultures of the bacteria Bacillus spp. plus photosynthetic bacteria, resulting in greater final production compared to unsupplemented controls, and higher protease and amylase activities.

El-Saadony et al. (2021) and Dawood et al. (2019), in two of the most comprehensive recent syntheses, both note that gains in growth and immunity are real but dose- and strain-specific; a positive result with one Bacillus isolate cannot reliably predict outcomes with a different strain of the same genus. Most trials have also been conducted under controlled laboratory or tank conditions that do not reproduce the microbial complexity of commercial settings. This is not merely a methodological complaint — it matters directly for how probiotic outcomes in a clear-water system should be interpreted when predicting what the same preparation will do in the ecologically richer environment of a mature BFT system.

Table 1 summarises the key genera, mechanisms, and example target species associated with probiotic applications in aquaculture.

**Table 1. Common probiotic genera used in aquaculture: key species, primary mechanisms, and target organisms.**

| Genus | Key Species | Primary Mechanisms | Target Species (examples) | Key References |
|---|---|---|---|---|
| Bacillus | B. subtilis, B. licheniformis, B. cereus | Enzyme production; bacteriocin secretion; competitive exclusion; immune gene upregulation | Litopenaeus vannamei, Oreochromis niloticus, Labeo rohita | Nayak (2010); Hoseinifar et al. (2018); El-Saadony et al. (2021) |
| Lactobacillus | L. plantarum, L. acidophilus | Lactic acid production; intestinal colonisation; mucosal immune modulation | Oncorhynchus mykiss, tilapia, shrimp | Nayak (2010); El-Saadony et al. (2021) |
| Lactococcus | L. lactis | Bacteriocin production; gut microbial balance; competitive exclusion of pathogens | Salmo salar, various finfish | Verschuere et al. (2000) |
| Saccharomyces | S. cerevisiae | Beta-glucan immunostimulation; digestive enzyme enhancement; growth promotion | Cyprinus carpio, shrimp, tilapia | Akhter et al. (2015) |
| Pseudomonas / Vibrio | Various strains | Siderophore production; competitive exclusion; pathogen suppression in water column | Salmo salar, Scophthalmus maximus | Verschuere et al. (2000) |

Note. Species names are given in italics throughout. BFT = biofloc technology.

**3. Biofloc Technology: Principles and Water Quality Management**

Biofloc technology is based on insights from an ecologist, present as a N-CAR formula by Avnimelech (1999) that explicate that in a water body with a high C:N ratio (can be created by supplementing with carbohydrates), the heterotrophic bacteria will be the main group that will convert the ammonium and organic nitrogen into microbial biomass, instead of allowing accumulation to become toxic to the fish. For intensive culture systems, when the amount of feed added to the water is15:1 to 20:1 (C:N ratio), the process is quick enough not to result in harmful concentrations of total ammonia nitrogen, which are below the target levels in conventional intensive husbandry (De Schryver et al., 2008). The result is a system capable of both water quality control and providing a proteinaceous supplemental food source, all the while solving a waste disposal problem.

The physical body on which BFT-based bacteria, micro-algae, protozoa, detritus and extracellular polysaccharides are formed is the biofloc, which consists of a loose conglomeration of these things, bound together by bacterial mucus and electrostatic attraction (Hargreaves, 2013). They vary from micro to macro particles (floc) of 50-200 microns, and are maintained in suspension with continuous mechanical aeration. The nutrient value varies significantly among them, from about 12% to almost 50% of dry matter as published value, depending on the type of carbon source, C:N ratio and the age of the system (Emerenciano et al., 2013). The importance of continual provision of additional protein, lipids and micronutrients to cultured animals provided as they eat biofloc, with partial replacement of manufactured feed, by lowering feed conversion ratios and costs.

Wasielesky et al. (2006) provided early and influential empirical support for this dual benefit in a super-intensive, zero-water-exchange trial with Litopenaeus vannamei, showing that shrimp cultured in a biofloc-based system achieved production metrics comparable to conventionally managed systems while exchanging virtually no water. That result catalysed much of the research that followed. Subsequent work, reviewed by Crab et al. (2012) and Ogello et al. (2021), extended BFT to Nile tilapia (Oreochromis niloticus), African catfish (Clarias gariepinus), freshwater prawns, and other species, with broadly consistent findings across contexts: reduced water consumption, improved nitrogen efficiency, and partial feed substitution.

The practical constraints of BFT deserve the same attention as its benefits. High-intensity aeration — necessary to keep biofloc in suspension and maintain dissolved oxygen for both cultured species and the aerobic bacteria driving the system — translates to substantial energy demand that can be economically prohibitive where grid power is unreliable (Dauda, 2020). Managing the progressive accumulation of total suspended solids in enclosed systems is an ongoing operational challenge; unchecked build-up can exceed levels tolerable for gill function. The startup period before the microbial community reaches functional maturity — typically two to six weeks — also represents a window during which ammonia control is incomplete (Hargreaves, 2013; Crab et al., 2012). These operational realities bear directly on the question of when and whether probiotic supplementation might usefully complement BFT, since the answer likely depends on which phase of BFT operation is under consideration.

Key operational parameters governing BFT system performance are summarised in Table 2.

**Table 2. Key operational parameters of biofloc technology (BFT) systems.**

| Parameter | Recommended Range | Function | Key References |
|---|---|---|---|
| C:N ratio | 15:1–20:1 | Drives heterotrophic bacterial dominance; assimilates inorganic nitrogen into microbial biomass, preventing toxic accumulation | Avnimelech (1999); Panigrahi et al. (2018) |
| Total suspended solids (TSS) | 200–600 mL/L | Indicator of biofloc volume and activity; excessive TSS impairs gill function and reduces dissolved oxygen | Hargreaves (2013); Dauda (2020) |
| Dissolved oxygen | ≥4 mg/L | Required for aerobic heterotrophic bacteria and cultured species; maintained by continuous mechanical aeration | De Schryver et al. (2008) |
| pH | 6.5–8.5 (species-dependent) | Affects microbial enzyme activity; alkalinity management required to prevent system acidification during nitrogen assimilation | Crab et al. (2012) |
| Carbon source | Molasses, starch, wheat flour, tapioca (most common) | Adjusts C:N ratio; type of carbon source influences biofloc protein content and microbial community composition | Panigrahi et al. (2018); Khanjani et al. (2022) |
| Aeration rate | High intensity; species- and volume-dependent | Maintains biofloc in suspension; prevents anoxic zones; provides oxygen for aerobic heterotrophic processes | Hargreaves (2013) |
| System startup period | 2–6 weeks (typical) | Required for microbial community to reach functional maturity and provide reliable nitrogen management | Crab et al. (2012); Hargreaves (2013) |

Note. C:N = carbon-to-nitrogen; TSS = total suspended solids.

## 4. The Inherent Biology of Biofloc: Immunity, Health, and Probiotic-like Effects

One of the most consequential findings in BFT research over the past decade is that biofloc consumption does not merely provide protein — it measurably modulates host immune function in ways that closely parallel the documented effects of deliberately administered probiotics. Ekasari et al. (2014) demonstrated this clearly in L. vannamei: shrimp reared in biofloc systems supplied with four different carbon sources — molasses, tapioca, tapioca by-product, and rice bran — all showed significantly elevated haemocyte counts, higher phenoloxidase activity, and greater post-challenge survival following experimental Vibrio harveyi infection compared to controls reared in clear water. Critically, the immune enhancement was consistent regardless of carbon source, pointing to the microbial community itself, rather than the chemistry of any particular substrate, as the responsible agent.

Ferreira et al. (2015) extended this finding by characterising the probiotic potential of bacteria actually isolated from a mature L. vannamei biofloc. The dominant strains recovered — Bacillus cereus and Bacillus licheniformis — are among the genera most widely used in commercial probiotic preparations. When incorporated into experimental feed at concentrations comparable to those in published probiotic trials, these biofloc-derived isolates significantly elevated total haemocyte count and phagocytic activity relative to controls. The implication is direct: a mature BFT system is already doing, in situ, much of what a deliberately administered probiotic is designed to do — cultivating and delivering beneficial bacteria in concentrations that stimulate host immunity.

The probiotic effect is also present during digestion. Keeping them in BFT at C:N ratios of 15:1 and 20:1, Xu and Pan (2012) noticed a significant upregulation of both protease and amylase activity in the digestive glands and intestine of their L. vannamei juveniles, which is similar to the digestive enzyme uptake noted by Wang (2007) for L. vannamei fed on probiotics. To further complicate the mechanistic picture of probiotic vs. diet, a molecular level was added, as Panigrahi et al., (2018) showed that upregulating key genes in the immune system such as crustin, anti-lipopolysaccharide factor, and serine protease happened in a similar way when varying the ratio of C:N in L. vannamei culture versus supplementation with probiotics.

Khanjani et al. (2022) provided a community-level review on the role of three classes of microorganisms: photoautotrophs, chemoautotrophs and heterotrophs in BFT for water quality, nutrition and disease control. Kumar et al. (2021) highlighted the bioremediation and health-promoting functions of the biofloc microbiome, noting that the functional redundancy across the diverse microbial consortium may provide a form of biological buffering against pathogen incursion that no single probiotic strain, however effective in isolation, can replicate. These findings together raise the question of whether adding exogenous probiotics to a system already generating such a rich and active microbial community is likely to produce a detectable marginal benefit.

## 5. Combining Probiotics and Biofloc Technology: What the Evidence Shows

Given that BFT systems generate microbial communities with documented probiotic-like properties, the expectation that combining exogenous probiotic supplementation with BFT would yield additive or synergistic benefits is not unreasonable. The empirical record, however, is more equivocal.

Ramasubburayan et al. (2025), in the most comprehensive synthesis of this intersection published to date, reviewed studies involving probiotic, prebiotic, and microbiome manipulation within BFT systems across multiple species and concluded that synergistic benefits are achievable, but conditionally. Supplementation during the startup phase of BFT — before the autochthonous community has matured and before host immunity has been continuously stimulated by biofloc grazing — appears to offer the clearest benefits. In contrast, introducing commercial probiotics into a fully mature BFT system appears less likely to generate measurable returns, because the ecological niche they would occupy is already well-populated.

The clearest empirical test of this principle under realistic conditions is provided by Arias-Moscoso et al. (2018), who evaluated two commercial probiotic preparations in a commercial-scale L. vannamei nursery operating under established BFT conditions in Mexico. After monitoring total ammonia nitrogen, nitrite, vibrio density, survival, and final biomass across six weeks, they found no statistically significant difference between probiotic-supplemented and control tanks on any metric. Vibrio densities — an outcome that probiotic supplementation most consistently reduces in clear-water systems — were similar across all treatments, consistent with the interpretation that the mature BFT community was already providing equivalent biological control. This null finding, obtained at commercial scale rather than in the laboratory, deserves greater weight than it has received in subsequent literature.

Studies in finfish BFT systems — particularly tilapia and catfish — have produced more positive outcomes from combined approaches, with several reporting growth and immune benefits above those achieved by BFT alone when Bacillus-based probiotics were added (Hoseinifar et al., 2018; El-Saadony et al., 2021). However, most of these trials were conducted at laboratory scale, with younger animals and less-mature BFT communities than the commercial shrimp nursery of Arias-Moscoso et al. (2018). Whether benefits observed in controlled fish trials translate to commercial conditions, and whether the effect arises from the probiotic per se or from secondary effects on the BFT community, is generally not examined. Whether introduced strains persist, are outcompeted, or simply pass through the BFT system without establishing meaningful populations has received almost no attention in the published literature.

Table 3 summarises selected studies that examined the combined use of probiotics and BFT, or that used BFT as an indirect probiotic-delivery system.

**Table 3. Selected studies examining the combined or related application of probiotics and biofloc technology (BFT).**

| Study | Species | Probiotic | BFT Setting | Key Findings |
|---|---|---|---|---|
| Ferreira et al. (2015) | L. vannamei | B. cereus and B. licheniformis isolated from biofloc | Intensive zero-exchange system | Biofloc-derived bacteria elevated haemocyte count; BFT demonstrated to function as an in situ probiotic production system |
| Arias-Moscoso et al. (2018) | L. vannamei | Two commercial probiotic preparations | Commercial-scale nursery with established BFT | No significant improvement over BFT-alone control in TAN, survival, or final biomass; mature BFT community appears to limit benefit of exogenous probiotic addition |
| Ekasari et al. (2014) | L. vannamei | None — biofloc as sole intervention, across four carbon sources | Laboratory-scale tanks; four carbon sources; C:N 15:1 | Elevated haemocyte count, phenoloxidase activity, and post-challenge survival across all carbon sources; BFT alone confers substantial immune benefit comparable to probiotic supplementation |
| Ramasubburayan et al. (2025) | Multiple species (systematic review) | Various exogenous probiotics, prebiotics, and synbiotics | Multiple BFT configurations (synthesis across studies) | Probiotic benefit in BFT most pronounced during system startup phase; diminishes in mature BFT communities; strain- and species-specific factors dominate outcomes |

Note. L. vannamei = Litopenaeus vannamei; TAN = total ammonia nitrogen; C:N = carbon-to-nitrogen ratio.

## 6. Discussion and Synthesis

Three broad conclusions emerge from the evidence reviewed. First, both probiotics and BFT are individually well-supported tools for sustainable aquaculture intensification. Each has a mechanistically coherent basis, and the literature on each shows consistent effects — at least in controlled settings — on water quality, animal growth, immune function, and disease resistance. Second, BFT systems are not biologically neutral contexts into which probiotics can simply be dropped; they already generate substantial probiotic-like biological activity through the in situ cultivation of beneficial bacteria within the floc. The baseline against which any exogenous probiotic must be evaluated in a BFT system is therefore markedly different from, and generally higher than, the baseline in a clear-water system. Third, the evidence that deliberately adding probiotics to an established BFT system reliably improves on BFT alone is, at present, weak — and the null result of Arias-Moscoso et al. (2018) at commercial scale deserves greater emphasis in future reviews of this field.

The practical implication is nuanced rather than straightforwardly discouraging. For aquaculture operations managing clear-water intensive systems, or for producers in the startup phase of a new BFT system before its microbial community has matured, probiotic supplementation with well-characterised Bacillus strains is likely to deliver measurable returns in immune function and disease resistance (Dawood et al., 2019). As BFT systems mature and their communities stabilise, the marginal benefit of adding commercially produced probiotics diminishes, and the cost justification weakens. This does not eliminate targeted uses — at high-risk windows such as early post-stocking, following a disease treatment that disrupts the BFT microbial community, or during a pathogen challenge — but it cautions against routine simultaneous application without system-specific justification.

Broader sustainability considerations are also relevant. BFT is energy-intensive and technically demanding to maintain reliably at commercial scale; not all farming contexts support it economically (Dauda, 2020). Commercial probiotics add financial cost and, depending on jurisdiction, regulatory complexity. The case for using both simultaneously must ultimately be made on cost-benefit grounds, not on biological plausibility alone. That evidence base does not currently exist.

### 7. Research Gaps and Future Directions

Despite the substantial body of literature reviewed here, several important questions remain open — and the nature of the gaps suggests that the field needs more than additional empirical studies of existing design. It needs methodological restructuring.

The most consequential gap is the near-complete absence of studies examining what happens to exogenous probiotic strains after introduction into a BFT system — whether they persist in the water column or within the floc matrix, whether they colonise the host gut in meaningful numbers, and how they interact dynamically with the established autochthonous community. Without this mechanistic foundation, rational design of probiotic-BFT combinations is not possible, and the field remains limited to empirical screening rather than guided microbial management.

Standardisation is a pervasive problem throughout both the probiotics and BFT literatures. Probiotic studies vary enormously in strain identity, preparation method, dose, delivery vehicle (water additive versus feed inclusion), and duration. BFT studies vary in carbon source, C:N ratio, aeration rate, tank volume, and system maturity. When these variables compound in combined studies, cross-experiment comparison becomes close to meaningless, and the meta-analytic synthesis needed to identify which combinations reliably outperform single-strategy approaches cannot be done credibly.

Species coverage is uneven in ways that limit generalisation. The majority of both probiotic and BFT research has been conducted with L. vannamei and O. niloticus, with much smaller and generally less rigorous bodies of evidence for marine finfish, freshwater fish other than tilapia, and molluscs. Given the breadth of global aquaculture, the risk of falsely extrapolating from two well-studied models to the wider industry is real.

Long-term effects across multiple production cycles are almost entirely absent from the literature. Whether the benefits of either approach persist over successive cycles — or whether pathogen populations adapt and erode the protective effect — is unknown. There is also a near-complete absence of enterprise-level economic analyses that follow biological findings through to farm profitability, which means practitioners lack the cost-benefit evidence needed for rational adoption decisions.

Table 4 summarises the principal research gaps and suggested approaches for addressing them.

**Table 4. Priority research gaps in the combined application of probiotics and biofloc technology (BFT).**

| Research Gap | Current Status | Priority | Suggested Approaches |
|---|---|---|---|
| Probiotic persistence and community dynamics in mature BFT systems | Virtually absent from published literature | High | 16S rRNA community profiling before and after supplementation; in situ persistence assays within biofloc matrix; competitive exclusion assays under BFT conditions |
| Standardisation of probiotic strain identity, dose, and timing relative to BFT maturity | Highly inconsistent across studies; prevents meaningful cross-study comparison | High | Multi-site collaborative trials with harmonised protocols; adoption of minimum reporting standards for aquaculture probiotic studies |
| Mechanistic characterisation of interaction between exogenous probiotics and autochthonous BFT microbiome | Not characterised in any published study | High | Shotgun metagenomics and community dynamics analysis; culture-independent tracking of introduced strains |
| Long-term effects across multiple production cycles | Single-cycle trials dominate the literature; multi-cycle data are absent | Medium | Multi-cycle commercial-scale trials under farmer-relevant conditions; monitoring of pathogen adaptation over time |
| Species coverage beyond L. vannamei and O. niloticus | Limited; marine finfish, molluscs, and most freshwater fish are underrepresented | Medium | Pilot trials targeting commercially important species in developing-country aquaculture contexts |
| Economic cost–benefit analysis of combined probiotic + BFT strategies | Not available in the published literature | High | Enterprise-level economic modelling linked to biological trial data; farm-level adoption studies |

Note. L. vannamei = Litopenaeus vannamei; O. niloticus = Oreochromis niloticus.

## 8. Conclusion

The global aquaculture sector faces converging pressures — rising demand, tightening restrictions on antibiotic use, and growing environmental scrutiny — that make sustainable intensification both a commercial and a public-health priority. Probiotics and biofloc technology represent two of the best-evidenced tools currently available for meeting this challenge. Their mechanisms are distinct but complementary: probiotics act directly on the host's immune and digestive systems, while BFT transforms the culture environment into an active biological system that generates nutrition, controls waste, and supports health at the population level. When used together, the biological rationale is coherent, but the evidence supporting routine combined application as a universal best practice is not yet strong. What the current literature supports, instead, is a more context-aware approach — one that recognises that a mature BFT community already provides much of what an exogenous probiotic preparation is designed to deliver, and that identifies the specific conditions (early system startup, post-disturbance recovery, targeted disease-risk windows) where supplementation is genuinely likely to add value above what BFT alone provides. That shift — from reflexive co-application toward guided microbial management grounded in an understanding of the system's existing biology — is the most defensible direction for both research and commercial practice in this field.

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