

future of the grass carp industry depends not only on maintaining high output, but on shifting from conventional expansion toward healthy aquaculture that balances productivity, fish welfare, environmental control, and product safety.

Despite its scale and value, grass carp farming faces persistent health problems that are intensified by high-density culture and environmental stress. Across aquaculture systems, disease outbreaks remain a major constraint because intensification increases host susceptibility and pathogen transmission. In grass carp specifically, bacterial diseases remain a major threat, and *Aeromonas hydrophila*-associated enteritis alone has been reported to cause substantial economic losses estimated at \$164 million annually. More generally, the rapid development of aquaculture has often been accompanied by environmental degradation, disease emergence, and reduced productivity, creating strong pressure for better health management strategies. Historically, farmers have relied on antibiotics, chemotherapeutics, disinfectants, and other medicinal products to suppress these problems. However, the widespread and sometimes indiscriminate use of these agents has created serious concerns about drug residues, environmental contamination, and selection for antimicrobial resistance in aquaculture settings. Reviews focused on China further show that livestock farming and aquaculture are major areas of antibiotic misuse, with consequences including residue pollution and heightened risks of antibiotic resistance affecting animals and humans. Internationally, antibiotic governance remains uneven: many countries still permit critically important antibiotics in aquaculture, and compliance with international recommendations and certification standards is often incomplete (Luthman et al., 2024). Surveys from freshwater aquaculture likewise indicate that heavy dependence on aquaculture medicinal products can leave gaps in disease management while contributing to public-health and ecosystem risks. At the policy level, current regulatory thinking increasingly emphasizes stricter enforcement, species-appropriate supporting measures, and the development of substitutes for antibiotics rather than continued dependence on them. For grass carp farming, these regulatory and health pressures converge into a practical challenge: producers need disease-control strategies that are effective under pond conditions, compatible with food-safety expectations, and less likely to aggravate antimicrobial resistance or environmental pollution.

Within this context, probiotics have emerged as a promising green technology for healthy aquaculture because they offer a biological route to improve fish performance while reducing reliance on antibiotics and other chemical inputs. Recent reviews consistently describe probiotics as beneficial microorganisms that can enhance growth, feed utilization, immunity, disease resistance, gut microbial balance, and water quality in cultured aquatic animals. Their mechanisms are multifactorial: probiotics can modulate the intestinal microbiota, strengthen innate immune responses, produce antimicrobial substances such as bacteriocins and organic acids, and promote the breakdown of organic matter and toxic metabolites in the rearing environment. These properties make them especially relevant to healthy grass carp culture, where gut health, nutritional efficiency, stress resistance, and pond-water quality are tightly linked. Broad aquaculture syntheses therefore regard probiotics as eco-friendly alternatives to antibiotics that can support disease prevention and environmental sustainability at the same time. Interest has also shifted toward host-associated probiotic strains, because microbes derived from the host or its environment can improve digestion, inhibit pathogen colonization, and stimulate hematological and immune responses more specifically. Among candidate taxa, *Bacillus* spp. have drawn particular attention because they are non-pathogenic, stress tolerant, and associated with improvements in feed utilization, antioxidant defense, immune function, water quality, and disease resistance. Field evidence from freshwater farming also suggests that probiotic and fermented products can reduce disease outbreaks, improve fish growth, lower costs, and decrease dependence on conventional medicinal products. More recent syntheses place probiotics within the wider response to antimicrobial resistance, arguing that they are integral to sustainable aquaculture and to the search for non-antibiotic disease-control strategies. Although practical issues remain, including host specificity, formulation stability, delivery methods, and commercialization, the overall evidence supports probiotics as one of the most promising tools for advancing healthy grass carp farming. Accordingly, evaluating probiotic applications in grass carp is scientifically and practically important for developing culture systems that are more productive, disease-resilient, environmentally responsible, and aligned with the regulatory transition toward greener aquaculture technologies.