

products significantly reduced mortality after *A. hydrophila* challenge, and the probiotic treatments also decreased Aeromonadaceae and Enterobacteriaceae abundance in the intestine, linking disease control to microbial exclusion of potential pathogens (Gao et al., 2024).

The disease-resistance effect extends across diverse probiotic taxa and delivery strategies. Autochthonous intestinal bacteria reduced cumulative mortality after *A. hydrophila* challenge from 80% in controls to 26.67% in the mixed-strain group, showing that consortia can outperform single strains in protection efficiency. Additional lower-ranked but relevant studies support the same pattern: *Paenibacillus polymyxa* S3 increased survival after *A. hydrophila* infection while upregulating C3, lysozyme, IgM, TLR-4, and MyD88. *Bacillus methylotrophicus* XA-8 also reduced *A. hydrophila* virulence by downregulating aer, act, hylA, lafA, hcp, and luxS, and supplemented fish showed 52.63% infection resistance together with lower intestinal *Aeromonas* abundance (Figure 2) (Khan et al., 2024). Overall, probiotics strengthen grass carp health by improving innate immunity, antioxidant defense, and pathogen resistance. The evidence across many strains supports probiotics as a practical strategy for reducing disease incidence and lowering dependence on antibiotics in healthy grass carp farming.

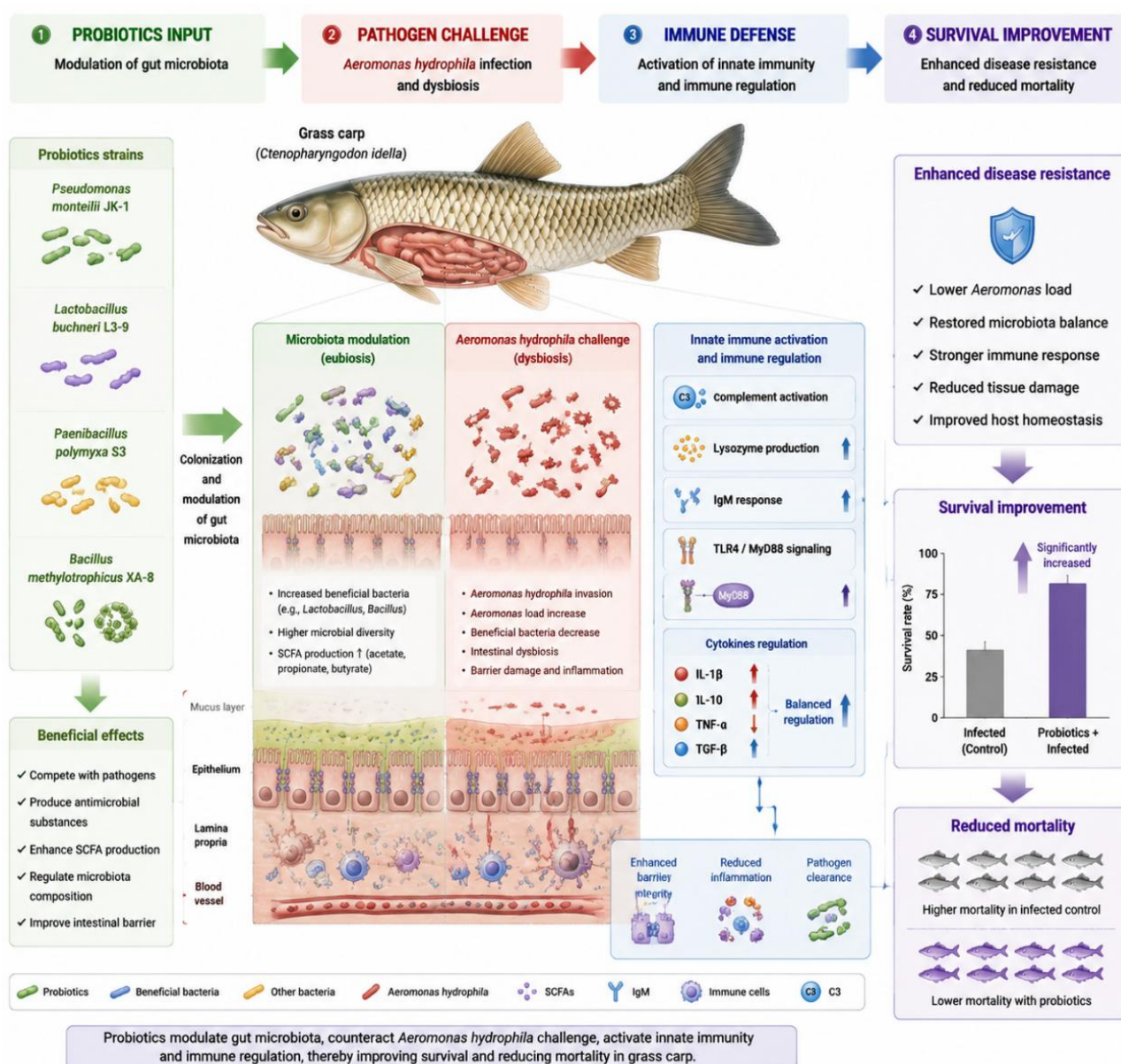


Figure 2 Mechanisms of probiotic-mediated enhancement of disease resistance in grass carp following pathogen challenge