Unlocking the synergies of halophilic purple bacteria for seaweed aquaculture

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The growing global population and rising life standards demand food systems that not only meet increasing nutrition and health needs but also minimize environmental impact. In this context, seaweed aquaculture emerges as a sustainable solution for nutritional, nutraceutical and pharmaceutical applications. On a global scale, the commercial seaweed market is projected to grow from USD 15 billion in 2021 to USD 25 billion in 2028 (Centre for the Promotion of Imports from developing countries (CBI), 2022). However, open-sea cultivation of seaweed faces significant challenges, including heat waves and storms, which can cause substantial biomass loss and reduced yields. Onshore cultivation has gained attention as a viable alternative, though concerns about land use remain. In order to overcome those concerns, we should increase the productivity and reduce the areal footprint.

One promising way to boost productivity are bacterial biofertilizers already present in the seaweed holobiont (Wichard, 2023). Among these, purple phototrophic bacteria, for instance *Rhodobacter* species, stand out as strong candidates. These bacteria have demonstrated significant potential as biofertilizers and biostimulants, improving nutrient availability and terrestrial plant growth (Sakarika *et al.*, 2020; Wambacq *et al.*, 2022). Advantages in growth and development are due to phytohormones such as auxins. Building on this concept, our research investigates the potential of halophilic purple bacteria to support macroalgae aquaculture by optimizing nitrogen cycling and nutrient enhancement.

Many purple bacteria exhibit remarkable versatility, capable of utilizing both ammonium (NH_4^+) and atmospheric nitrogen (N_2) as nitrogen source, making them particularly valuable in nitrogen-limited environments. Our study confirmed that purple bacteria can grow robustly using either nitrogen source with maximum growth rates for *Rhodobacter capsulatus* and *Rhodopseudomonas palustris* respectively 3.93 d^{-1} and 2.76 d^{-1} with NH_4^+ and 1.34 d^{-1} and 3.21 d^{-1} with N_2 at 30°C (unpublished data).

Ongoing experiments are exploring whether purple bacteria excrete ammonium into the surrounding medium under diazotrophic conditions, potentially creating a steady supply of bioavailable nitrogen for macroalgae. This mechanism could reduce the need for synthetic nitrogen inputs, fostering more sustainable and natural nutrient cycling in aquaculture systems.

In this mutualistic relationship, macroalgae could provide dissolved organic carbon to the purple bacteria, supporting their metabolic activity and growth. Additionally, next to providing nutrients and growth hormones such as auxins, purple bacteria present on the seaweed microbiome furthermore have the potential to produce other important nutritional compounds such as vitamin B12 (ongoing research), a vitamin not only vital in seaweed metabolism, but also crucial to prevent anemia in humans among other things (Luhila *et al.*, 2022). Stimulating purple bacteria in the seaweed holobiont may therefore give a biofortification effect in the produced biomass.

This synergistic interaction positions purple bacteria as a promising biofertilizer and biofortifier that can enhance macroalgae cultivation while promoting resource efficiency and environmental sustainability in aquaculture. By leveraging the bacteria's unique capabilities, this innovative approach could pave the way for a more resilient and sustainable seaweed aquaculture sector.

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