Seaweeds: a new crop on the rise

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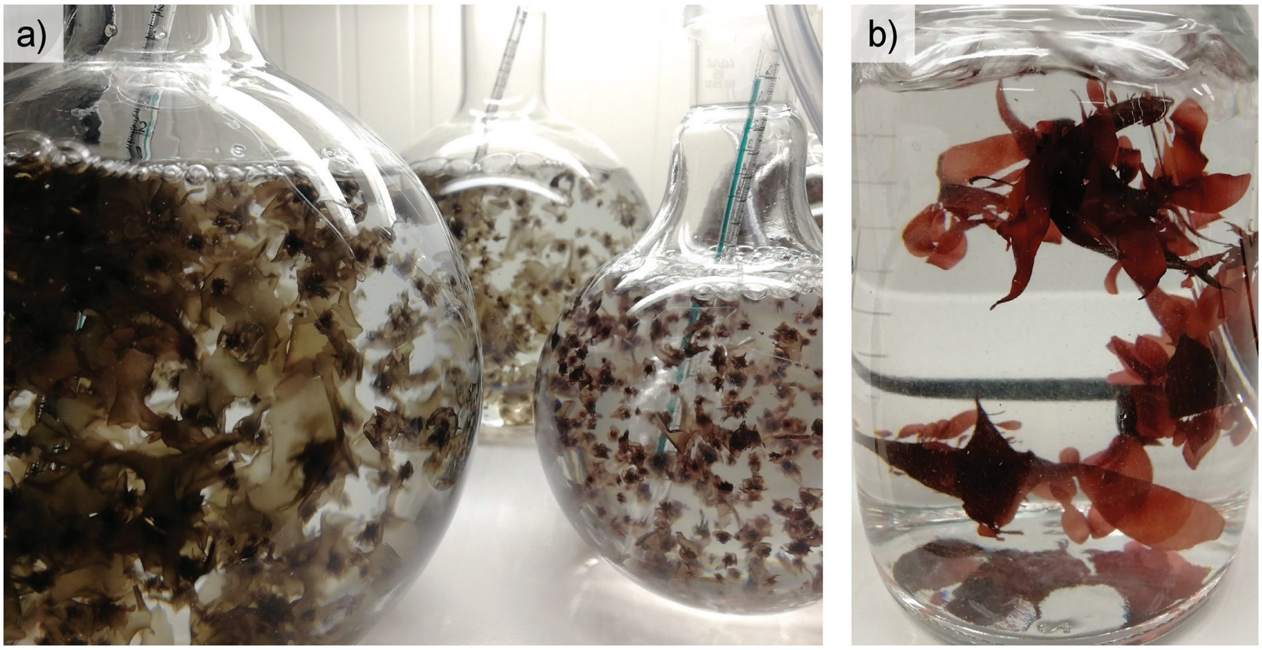

Figure 1. *Porphyra umbilicalis* (a) and *Palmaria palmata* (b) stock cultures maintained at Ghent University for up-scaling experiments optimizing growth conditions for land-based seaweed cultivation.

Seaweeds – the announced superfood of 2021 – are packed with healthy antioxidants, minerals and vitamins. It has been a typical part of Asian cuisine for a long time and is steadily gaining popularity as a food source in Europe. Besides being highly nutritious, seaweeds and their extracted compounds offer a huge potential for applications in animal feeding, cosmetics and pharmaceutical industries. However, most of the required seaweed biomass in Europe originates from harvesting wild populations, with a serious risk of overexploitation. To meet rising demands, seaweed aquaculture is a rapidly emerging sector in Europe with the need to develop reliable cultivation protocols for local species of interest at commercial scale and to demonstrate economic feasibility. A multidisciplinary team from Ghent University, Belgium, along with industrial partners aims to tackle bottlenecks to advance land-based cultivation of high-value seaweeds.

Seaweed farming – open sea versus land-based cultivation

Seaweeds can be successfully cultivated in open sea farms or in land-based tank cultivation systems depending on species and local conditions. In Europe, especially large kelps such as sugar kelp (*Saccharina latissima*), are suitable candidates for open sea cultivation as they are robust enough to withstand the harsh conditions in the North Atlantic and offer the possibility of extensive biomass production. Usually, substrates such as ropes or nets are seeded with small juvenile kelps and transferred to the open sea farms where the seaweeds grow to meter-long plants over a single growth season – without any further addition of nutrients or other chemicals. For successful growth, seaweeds only require sunlight, CO_2 and dissolved nutrients with the latter being normally extensively abundant in temperate coastal waters. However, the growth season for cultivated kelp in the North

Atlantic is restricted to the cooler months, ranging from late autumn to spring, limiting the possible production window. Furthermore, as seaweeds take up pollutants from the environment, such as heavy metals, good water quality is crucial depending on the targeted downstream processing. While open sea cultivation requires minimal maintenance and has the potential to produce large quantities of biomass, the short production window combined with the harsh conditions experienced in the North Atlantic limit the diversification of cultivatable species in offshore environments.

Land-based cultivation of seaweeds, on the other hand, offers the opportunity to cultivate more delicate and higher value species in comparison to kelp. Depending on the system, land-based cultivation allows for complete control of the cultivation conditions, such as temperature, light and nutrient availability, enabling a year-round production under optimal growth conditions. A constant short supply chain with fresh and high-quality biomass will be of great importance for seaweeds to become a common crop for human consumption in Europe.

Figure 2. *Palmaria palmata* fragments with young proliferations growing from the tissue margins used for vegetative propagation.

Seaweed composition in terms of protein, carbohydrates and bioactive compounds, such as antioxidants, shows great seasonal differences and changes with environmental conditions. This is a factor to take into consideration for biomass designated for human consumption as great nutritional differences between batches can exist when seaweeds originate from natural sources. Controlling the cultivation conditions, therefore, allows for a stable and optimized nutritional composition of seaweeds grown in land-based systems with great potential for product tailored, high-quality seaweed.

Land-based cultivation systems for seaweeds range from flow-through systems, in locations where a direct connection to seawater is available, to completely closed recirculation aquatic systems (RAS). These systems usually have in common that seaweeds are cultivated in tumble cultures through strong aeration to allow for even exposure to light and nutrients. While a flow-through system with a direct seawater connection can supply sufficient nutrients for the cultivated seaweeds, nutrient addition is crucial for closed RAS systems. Seaweeds can be co-cultivated with marine fish or invertebrates in an Integrated Multi-Trophic Aquaculture (IMTA) setting. In an IMTA setting, released nutrients by fish or invertebrates in the form of dissolved nitrogen and phosphorus are taken up by the co-cultivated seaweeds, creating a nutrient cycle and eliminating further nutrient addition.

RAS systems offer the advantage to fully control the cultivation conditions and therefore allow for maximum quality control. Furthermore, they do not rely on a constant supply of seawater and therefore offer higher flexibility regarding site selection. This is a positive aspect considering that coastal locations are in high demand and usually very expensive along the densely populated European coastline. For high performance, closed RAS systems require a thorough understanding of the cultivated species' ecology to maximize growth, minimize water exchange rates and for an efficient nutrient addition to minimize contamination resulting in higher economic profit.

Suitable high-value species

Suitable seaweed species for land-based cultivation would favorably exhibit high growth rates, to allow for fast production, combined with high market value. The two red seaweeds *Porphyra* (Fig. 1a) and *Palmaria* (Fig. 1b) fall into this category. *Palmaria*, also known as dulse, has recently gained popularity as vegan bacon but has a long tradition as dulse flakes in soups, cheese and bread. *Porphyra* is especially known from nori sheets, an essential ingredient for sushi.

While farming of Asian nori forms an extensive industry with over 2 million tons produced annually in South East Asia, commercial production of *Palmaria* is limited to a handful of small-scale companies in North America and Ireland, mainly relying on vegetative propagation of wild-collected biomass. Both species are characterized by a complex life cycle consisting of different life-history stages, requiring extensive knowledge of the respective biology for the successful life cycle control. However, the complex reproductive pathway can be bypassed via vegetative propagation, in the case of *Palmaria* (Fig. 2), or asexual reproduction, in the case of *Porphyra*, allowing for an easier supply of initial biomass. Vegetative propagation or asexual reproduction enables quick up-scale production but has the risk of lowered productivity and emerging diseases due to reduced genetic diversity.

Therefore, reliable control of the sexual reproductive pathway will be of most importance for a sustainable seaweed cultivation industry in the long term. Research efforts have developed cultivation protocols for *Palmaria* and *Porphyra* from the North Atlantic. However, the developed protocols are mainly based on laboratory-scale observations with the need for establishing cultivation methods for large-scale commercial applications.

Moving forward

Interest in seaweed aquaculture in Europe is high. However, while there is a growing knowledge foundation for cultivating local species, these protocols need to be adapted and optimized for large-scale commercial operation. The collaborative team of scientists from Ghent University and industrial partners aims to tackle some of these hurdles by optimizing cultivation parameters and investigating the technical and economic feasibility of land-based cultivation of high-value seaweeds for human consumption on a commercial scale in Belgium – advancing an emerging sector in Europe.

Acknowledgements

This project is funded by the Industrial Research Fund (IRF) and is a collaborative project between different groups of Ghent University: the IRF consortium BLUEGent (Dr. ir. Margriet Drouillon, MBA), the Laboratory for Phycology (Prof. Dr. Olivier De Clerck), the Laboratory of Aquaculture & Artemia Reference Center (Prof. Dr. ir. Peter Bossier), the Laboratory for Environmental Toxicology (Prof. Dr. Colin Janssen, Prof. Dr. ir. Jana Asselman) and Dr. ir. Bert Groenendaal (consultant).

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