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Seaweeds as a future protein source: innovative cultivation methods for protein production

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Akademisk avhandling för filosofie doktorsexamen i naturvetenskap med inriktning marina vetenskaper, som med tillstånd från Naturvetenskapliga fakulteten kommer att offentligt försvaras fredagen den 8 december, 2023 kl. 10:00 i hörsalen på Tjärnö marina laboratorium, Institutionen för marina vetenskaper, Laboratorievägen 10, 452 96 Strömstad.

ISBN 978-91-8069-411-7 (PRINT)
ISBN 978-91-8069-412-4 (PDF)
Tillgänglig via http://hdl.handle.net/2077/78605

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Abstract

As the global population is projected to reach approximately 10 billion people by 2050, it is estimated that we will need to produce up to 60% more food compared to 2010. Although the current food production system contributes to 25% of greenhouse gas emissions worldwide, accounts for 70-80% of eutrophication and freshwater usage, and occupies half of all ice- and desert-free land, it fails to meet the global nutritional needs. Furthermore, with extreme weather events and heat waves affecting terrestrial food production systems, it is evident that we need to look elsewhere to produce sustainable, protein-rich, and nutritious food. Recently, seaweeds have emerged as a promising part of this solution. Cultivating seaweeds requires no arable land, freshwater supply, or high nutrient input. Furthermore, seaweeds have high productivity that outperforms many terrestrial crops such as wheat, seeds, and soybeans. The protein often contains all the essential amino acids, making seaweeds a favorable protein source for human consumption. However, even though seaweeds often have protein contents in the range of some beans and pulses, it is lower than in soybeans. Therefore, their protein content needs to be increased if seaweeds are to become a competitive protein source in the future.

This thesis aims to explore the potential of seaweeds as a sustainable future protein source. It specifically focuses on optimizing seaweed cultivation to boost both growth rates and protein content. To achieve this, the effects of different cultivation conditions and the potential of one kelp and three green seaweed species are investigated. A novel nutrient loop is explored, wherein industrial food production process waters (FPPWs) are used as seaweed growth media. By conducting a meta-analysis, as well as land-based experiments that combine physiological, biochemical, chemical, and sensory analyses, the thesis aims to establish the potential for seaweed cultivation in nutrient-rich process waters.

The findings from this thesis show that seaweeds can become a promising alternative food source in the ongoing dietary protein shift. The results show that all groups of seaweeds (brown, green, and red) can be cultivated in various nutrient-rich process waters; but green seaweeds have the highest potential. After identifying the green seaweed species *Ulva fenestrata*, which usually has a crude protein content of 10-20% dry weight, as a promising candidate, its cultivation in FPPWs yielded protein content of up to 37% dry weight. Furthermore, the biomass yield was up to six times higher compared to when grown in seawater. The safety aspects of consuming the biomass were confirmed by showing that large quantities of the biomass can be consumed every day without exceeding health-based reference points for heavy metals. Also, no sensory attributes regarded as negative were found after cultivation in the FPPWs. In conclusion, this thesis illustrates a novel nutrient loop, where the disposal of industrial food production process waters can be turned into nutrient-rich and valuable biomass through seaweed cultivation.

Keywords: Macroalgae, *Saccharina latissima*, *Ulva fenestrata, Ulva intestinalis*, *Chaetomorpha linum*, cultivation conditions, nitrogen content, amino acids, heavy metals, food safety, wastewater, process water, circularity, blue economy