Journal of Applied Phycology
https://doi.org/10.1007/s10811-023-03003-1

EDITORIAL

ULVA: Tomorrow's "Wheat of the sea", a model for an innovative mariculture

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Received: 2 May 2023 / Revised and accepted: 17 May 2023

Abstract
A growing interest in the development of oceanic coastal shores has arisen over the past decade, seeking alternative sustainable food sources and other valuable products. Our initiative aims at exploiting the potential of marine seaweeds in Europe. Building on the successes of previous EU and pan-European projects on seaweeds, and due the unique characteristics of the genus *Ulva* (Linnaeus, 1753), we have identified these green algae as the most suitable candidate and model organism for a novel kind of European mariculture. Much of the knowledge on *Ulva*, generated in diverse scientific disciplines and different communities, is not easily comparable nor is it shared among scientists, stakeholders, end users and the public. This COST Action, "SeaWheat" (CA20106—TOMORROW'S 'WHEAT OF THE SEA': ULVA, A MODEL FOR AN INNOVATIVE MARICULTURE), proposes an innovative conceptual pathway to address these issues, significantly improving knowledge in the biology of the most promising *Ulva* spp., capitalising on their economic potential, and exploring commercial applications in the human food, animal feed, pharmaceutical industries and ecosystem service. The COST Action combines interdisciplinary approaches to the sustainable use of marine resources, encompassing all the facets of *Ulva* biology, ecology, aquaculture, engineering, economic and social sciences. This Action will lead to the development of advanced science, create business and job opportunities in the maritime and coastal economies, and have a significant impact on societal welfare. This COST Action fulfils the current 'Societal Challenges Priorities' of European Horizon 2020 strategy for food security, and its application will contribute to the UN Sustainable Development Goals 14 (UNSDG) to conserve and sustainably exploit natural resources.

Keywords Seaweed · Mariculture · Production · Ecosystem service · Food security

Introduction

Shrinking agriculture resources undermine the increasing global struggle to secure enough food for the swelling human population. Over the past decades, a growing interest in developing coastal and offshore marine water bodies as a sustainable alternative to food procurement and a source of other valuable substances has arisen. The potential substrates for aquatic cultivation—water and coastal plains—cover 75% of the planetary surface. Sustainable marine food production will come from lower trophic levels, mainly through extractive species mariculture, such as seaweed (Duarte et al. 2022; Krause et al. 2022). This development can occur by establishing innovative, cost-effective production technologies, guaranteeing food security and reducing the nutrients and carbon footprint of global food production through carbon sequestration. In the last 20 years, seaweed culture has grown faster than any other marine food production sector, experiencing an annual global growth average of 7.7% from 1990 (FAO 2020). More than 96% of global seaweed yield (35.07 million tonnes, FAO 2022) is via aquaculture, with a total production currently similar to the sum of marine mollusks, crustaceans and fish produced from aquaculture (Olsen 2015). Seaweed

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Published online: 21 July 2023

is considered a food of high nutritional value (Holdt and Kraan 2011; Bolton et al. 2016; Muñoz and Díaz 2022), but currently accounts for only 1.14% of the world's total plant food crops (FAO 2020). Seaweed food production could be greatly and sustainably expanded to cover this current food deficit and meet the growing demand by farming the largely underexploited aquatic environment. However, in Europe, seaweed production in 2018 was relatively low, around 41,600 t, approximately 0.1% of seaweed world production. The production in Europe was too marginal to match the local demand (FAO 2020). With its extensive coastal zone and wide climate ranges, European aquaculture can contribute significantly to global food security. Many initiatives to exploit this potential in the EU converge on marine algae. The industry has recently expanded and now includes algae production as a commodity on an industrial scale. Other uses are evaluated, including animal feeds and high-value bioactive molecules (e.g., nutraceutical, cosmetics, and medicine), while prioritizing human wellbeing and fostering a circular economy (Cai et al. 2021; Pardilhó et al. 2022).

The green algae *Ulva* spp. (class Ulvophyceae) belong to a genus inhabiting shallow marine and brackish waters. Many of these algae—known as 'sea lettuce' -are edible. *Ulva* spp. are ubiquitous throughout the world's oceans and constitute important primary producers. In Europe, 38 species of *Ulva* are known, eight of which are endemic (Guiry and Szpak 2020). Species of *Ulva* have been extensively analysed for their value as food, feed, food ingredients, (e.g., pigments), chemical constituents (e.g., protein, carbohydrates), and medicinal properties (e.g., antioxidants) (Yu-Qing et al. 2016; Mantri et al. 2020; Prabhu et al. 2020). In mariculture, *Ulva* can be cultured in either land- or sea-based facilities. *Ulva* produces more biomass per square metre than land plants—25–40 t dry weight ha^{-1} $year^{-1}$, compared to 2.1, 4.1 and 5.1 t for soybean, wheat and maize, respectively (Bruhn et al. 2011; Shpigel et al. 2017).

Production in sea-based systems provides a sustainable alternative to agriculture, as land availability remains a key issue for *Ulva* biomass production in Europe.

There are multiple features unique to *Ulva* spp., and their importance is indicated by the number of scientific publications involving RTD on these algae, which has increased from 1,140 papers in 2000 to 7,710 in 2019 out of a total of 84,900 Google Scholar entries.

The *Ulva* genus has been found to be of excellent aquaculture potential based on the following characteristics:

- Worldwide distribution of *Ulva* spp. in the accessible intertidal zone, from the polar regions to the equator. Ease of collection from the wild to start a culture (www.algaebase.com).
- Faster growth rate (can double their dry weight per day) and larger areal yield throughout the year, whether in a sessile or free-floating system (Bruhn et al. 2011; Praeger et al. 2019). Easy reproduction, both vegetative (asexual) and spores (sexual) (Praeger et al. 2019). Ease of culture in both sea- and land-based facilities (Bolton et al. 2016; Shpigel et al. 2019).
- A proven source of sustainable biomass production (fresh or dry) for human consumption, animal feed, and a reliable source of high-value by-products (nutraceutical and cosmetic industries) (Bikker et al. 2016; Kidgell et al. 2019).
- Plasticity in biochemical composition, with numerous documented bioactive metabolites (primary and secondary) exhibiting antimicrobial, antiviral, antioxidant, anti-inflammatory, and anticancer activities (Mantri et al. 2020).
- Microbiome engineering can trigger growth and enhance the production of specific algal constituents (Polikovsky et al. 2020).
- Excellent efficiency as an ecological biofilter for ecosystem services, supporting the sustainability of the growing industry of land- and sea-based fish farming, preventing eutrophication in coastal waters (Gao et al. 2018; Neveux et al. 2018).
- The ability to assimilate carbon efficiently may contribute to reducing global warming and its deleterious implications (Gao et al. 2018).
- Potential biomass for biodegradable (bioplastic) packaging as an alternative to plastic and other synthetic polymers (Helmes et al. 2018; Zhang et al. 2019).
- Its genome has been sequenced and can be genetically manipulated (de Clerck et al. 2018)
- Ideal model for clarifying fundamental aspects of seaweed biology (e.g., growth, metabolism, and algae-bacteria interactions) (Wichard et al. 2015).
- Suitable for ecosystem service, carbon sequestration, restoration and other types of ecological engineering (Bruhn et al. 2011).

Based on the aforesaid unique characteristics, we regard the green algae of the genus *Ulva* as the most suitable organisms for biomass production in European mariculture. This innovative blue biotech industry will be able to compete with Asian markets (which currently meet most of the global demand for seaweed in Europe), boost regional employment and income, promote climate mitigation and improve marine environments.

Since 1971 the European Cooperation in Science and Technology (COST) has operated an EU-funded instrument that enables researchers and innovators to set up a collaborative research network across a wide range of scientific disciplines (COST 2018). The main goal of the COST Action network project applied for and funded here, called "Sea-Wheat" (CA20106—TOMORROW'S 'WHEAT OF THE

SEA': ULVA, A MODEL FOR AN INNOVATIVE MARICULTURE), is to create a comprehensive step change in the knowledge of the entire *Ulva* genus. The "SeaWheat" project consists of 235 experts and specialists from 36 countries, and this number is constantly increasing. The "SeaWheat" project combines interdisciplinary approaches to sustainable marine resource use, covering all facets involving *Ulva* spp.: biology, ecology, aquaculture, engineering, economics, and social sciences. "SeaWheat" will bridge *Ulva*'s scientific, regulatory, and social practical gaps, paving the way to commercial production in the blue-biotech industries. This advanced knowledge promoted by SeaWheat Action will create businesses and job opportunities in maritime and coastal economies, resulting in a significantly positive impact on societal welfare.

In this COST action, different events are offered that have the dissemination of knowledge (e.g., conferences), the education and training of students and scientists (workshops and training schools), as well as the dissemination of information (homepage, newsletter, flyers, etc.) as their objective. In 2022, a conference "From Fundamental Biology to Aquaculture: State of the Art, Bottleneck and Gaps", was held in the Faculty of Philosophy and Arts, University of Cádiz in Spain.

The following publications represent the topics discussed at this conference. The abstracts of all papers presented are available in the on-line Supplementary File.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10811-023-03003-1.

Acknowledgements The authors are grateful for funding from the EU. This proceeding was supported by the Cost Action No. CA20106 "Tomorrow's 'Wheat of the Sea': Ulva, a Model for an Innovative Agriculture (SEAWHEAT)".

Author contributions The Co-Editors of the proceedings BHB and MS wrote the main manuscript text and reviewed the manuscript as well.

Funding This work was supported by COST Action (European Cooperation in Science and Technology) No. CA20106.

Declarations

Both authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Competing interests The authors declare no competing interests.

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