Fuel 320 (2022) 123780

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Development of an innovative macroalgae biorefinery: Oligosaccharides as pivotal compounds

Cristiana Andrade, Pedro L. Martins, Luís C. Duarte, Ana Cristina Oliveira, Florbela Carvalheiro *

Unidade de Bioenergia e Biorrefinarias, LNEG – Laboratório Nacional de Energia e Geologia, Estrada do Paço do Lumiar, 22, 1649-038 Lisboa, Portugal

ARTICLE INFO

Keywords:
Accelerated solvent extraction (ASE)
Blue Bioeconomy
Conventional Soxhlet extraction
Dilute acid hydrolysis
Hydrothermal treatment
Ulva lactuca

ABSTRACT

Macroalgae have significant advantages over land-living biomass resources and are promising pivotal feedstocks for the onset of the blue bioeconomy. Among these, *Ulva lactuca* has demonstrated a high potential due to its wide distribution and high productivity.

In this work, a detailed chemical characterization of *U. lactuca* enabled the identification of polysaccharides as the main macromolecular component of the organic fraction. They present a high diversity of sugar constituents and hence can be a relevant source of added-value oligosaccharides for the food/feed industries.

Four processes, with increasing operational temperatures, were compared for the selective production of oligosaccharides: Conventional Soxhlet Extraction, Accelerated Solvent Extraction, Hydrothermal treatment (HT) and Dilute Acid Hydrolysis (DAH). All processes presented high oligosaccharide/monosaccharide ratios, with HT and DAH exhibiting the highest oligosaccharides yields (10.6 and 16.6 g/100 g initial biomass, respectively). These oligosaccharides were obtained under milder, more economic conditions than the reported for lignocellulosic (land) plants and can represent an important added-value income of the algae biorefineries and thus contribute to their economic sustainability.

1. Introduction

According to the United Nations, by 2050, the World population is expected to grow by around 2 billion people as compared to 2019, making a total of 9.7 billion individuals. So, new strategies are needed to meet the growing needs of the population for food, feed, fuels, and other chemicals. As the continuous extraction and use of fossil fuels have created serious environmental problems, these new strategies must be based on the use of renewable raw materials. Specifically, they have to be, at least, carbon–neutral, but preferably, carbon negative. The oceans cover about 70% of the planet's surface and hence they can not be dismissed as potential contributors to the required solutions. Namely, oceans can be a promising source of renewable raw materials, most noteworthy, macroalgae [1].

Macroalgae can be obtained from natural sources *e.g.* as a residue from algae blooms in the open sea [2], in beaches [3], or harvested from shallow waters [4], or areas dedicated to their cultivation [5]. The latter has been gaining great relevance since it has a relevant potential for countries with limited availability of arable land. Macroalgae cultivation can be achieved, mainly, by two possible routes: an area dedicated strictly to its production, or areas dedicated to Integrated Multi-Trophic Aquaculture (IMTA) [6]. IMTA simulates a natural ecosystem, based on the combination of the cultivation of several species belonging to different trophic levels [7], most typically characterized by being an association between the production of species with exogenous food (fish), extractive species of organic matter (crustaceans/bivalves) and extractive species of inorganic matter (macroalgae) [6]. This type of association, between different species, has numerous advantages, most noteworthy, the improved yields by area/volume, or the reduction of water eutrophication [8,9]. This can lead to a minimization of the environmental impacts associated with fish farms since, in the case of macroalgae, they promote a decrease in dissolved effluents. When grown on a large scale, macroalgae, in association with other crops, thus assist in the bioremediation of waters.

Macroalgae are usually classified based on their color, as green, red, or brown macroalgae. Their biochemical composition differs according to the group, however, there are also differences within the same group and even intraspecific differences [4] brought about by the

* Corresponding author.
E-mail address: florbela.carvalheiro@lneg.pt (F. Carvalheiro).

https://doi.org/10.1016/j.fuel.2022.123780
Received 10 December 2021; Received in revised form 10 February 2022; Accepted 4 March 2022
Available online 16 March 2022