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Microalgae as a sustainable source of carotenoids: Strategies to improve yield and productivity

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ABSTRACT

This review explores current strategies to improve carotenoid yield and productivity in microalgae, positioning them as a sustainable source of high-value bioactive compounds. It delves into the biochemical pathways of carotenoid synthesis and highlights the significance of microalgae in various industrial applications, including nutraceuticals, cosmetics, and functional foods. Emphasis is placed on innovative cultivation techniques such as the use of light-emitting diodes (LEDs), two-stage culture systems, and optimization of light wavelengths and flashing light, all aimed at enhancing carotenoid accumulation. A techno-economic analysis evaluates the cost-effectiveness and market dynamics of carotenoid production from microalgal biomass, assessing outcomes from case studies and comparative assessments to illustrate economic advantages. This review also discusses policy development and government support as crucial drivers for the sustainable growth of microalgal biorefineries. It also examines challenges related to scalability and explores future directions, including genetic engineering for enhanced carotenoids production. The review is aligned with the goals of fostering industrial sustainability through the application of innovative biotechnological processes, presenting pathways for advancing both economic and ecological goals.

1. Introduction

Carotenoids are naturally occurring pigments found in photosynthetic organisms, including microalgae (e.g. *Chlorella, Haematococcus*), plants (e.g. saffron, pumpkin, yam), and fungi (e.g. *Rhodotorula*) [55,61]. These pigments play a vital role in photosynthesis, capturing light energy while also protecting cells from oxidative stress by scavenging reactive oxygen species (ROS) [33,70]. While carotenoids can be obtained from natural sources, synthetic carotenoids dominate the global market, accounting for 90 % of total production due to their lower cost and large-scale manufacturability [23,102]. Synthetic carotenoids are often produced as mixtures containing two distinct structural forms

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