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Trends and novel strategies for enhancing lipid accumulation and quality in microalgae

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ABSTRACT

In order to realize the potential of microalgal biodiesel there is a need for substantial impetus involving interventions to radically improve lipid yields upstream. Nutrient stress and alteration to cultivation conditions are commonly used lipid enhancement strategies in microalgae. The main bottleneck of applying conventional strategies is their scalability as some of these strategies incur additional cost and energy. Novel lipid enhancement strategies have emerged to research forefront to overcome these challenges. In this review, the latest trends in microalgal lipid enhancement strategies, possible solutions and future directions are critically discussed. Advanced strategies such as combined nutrient and cultivation condition stress, microalgae–bacteria interactions, use of phytohormones EDTA and chemical additives, improving light conditions using LED, dyes and paints, and gene expression analysis are described. Molecular approaches such as metabolic and genetic engineering are emerging as the potential lipid enhancing strategies. Recent advancements in gene expression studies, genetic and metabolic engineering have shown promising results in enhancing lipid productivity in microalgae; however environmental risk and long term viability are still major challenges.

Contents

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1. Introduction

Microalgae have attracted significant interest from researchersas a biodiesel feedstock due to its capacity to accumulate substantial amount of lipids, high growth rate and environmental benefits. Production of value added by-products and utilization of lipid-extracted biomass (animal feed, aquaculture and biomethane production) have further strengthened the case for microalgae as a sustainable feedstock for biodiesel production. Despite many advantages, commercial realization of microalgal biodiesel is still a challenge owing to its high production cost [1–5]. Enhancement of microalgal lipid content could improve the economics of biodiesel production. Nutrient limitation and induction of stress by controlled cultivation have been the norm to improve lipid content in microalgae [1,6,7]. Recently, novel strategies have been explored to overcome the challenges of conventional approachesand to achieve maximum possible outcomes in terms of lipid yields, sustainability and cost effectiveness [8,9]. These strategies include a combination of stress factors, co-culturing with other microorganisms, addition of phytohormones and chemical additives [10–13].

Developing microalgal strains with high lipid accumulation capability using genetic and metabolic engineering tools has recentlygainedmomentum as alternative strategies for strain improvement [14,15]. The recent advancements in decoding the full genome of several microalgal strains and identification of key genes involved in lipid synthesis pathways makes genetic and metabolic engineering an alluring strategy to enhance lipid accumulation in microalgae [16]. The major challenges for genetically modified microalgal strain for high lipid accumulation are their long term viability and environmental risk assessment at open cultivation systems.

The present review deals with recent advancements and novel strategies for lipid enhancement in microalgae and their challenges.Molecular approaches for enhancing the lipid accumulation and quality are also described in detail (Fig. 1).

2. Nutrient regime and cultivation conditions to enhance lipid accumulation

Microalgae are able to survive in extreme environments as they can alter their metabolism according to varied environmental conditions. Under unfavorable conditions, microalgae have the tendency to accumulate neutral lipids to protect cells from photo-oxidation [7,17,18]. Lipid enhancement strategies involving alteration of the nutrient regime and cultivation conditions are widely applied in microalgal cultivation. Factors such as nutrient stress, light, temperature, CO_2, salinity etc. have been explored by several researchers to enhance lipid accumulation in microalgae [19,20].

2.1. Effect of nutrient regimes on lipid accumulation

Nutrients such as nitrogen, iron, phosphorus, magnesium, sulfur and silicon are very important for cellular mechanism viz, photosynthesis, cell division, respiration, intracellular transportation, protein synthesis etc in microalgae [6,21]. Under stressed conditions; microalgae tend to accumulate energy in the form of polysaccharides, and/or neutral lipids. This defense mechanism of the microalgal cell has been exploited widely for the production of neutral lipids, carotenoid, polysaccharides and many other metabolites [22–24].

Nitrogen starvation is the most widely used strategy to improve lipid accumulation. Nitrogen is provided in the form of nitrates, urea and ammonium salts. Uptake and utilization of these nitrogen forms by microalgae however vary; ammonia is utilized more efficiently compared to the other forms of nitrogen as it can be directly converted to amino acids [25–27]. Nitrogen deprivation conditions could lead to reduced cell division [28]. Reduced cell division shifts the lipid biosynthetic pathways to synthesize more neutral lipids than synthesizing membrane lipids required for the cell wall formation [29,30].Subsequent accumulation of NADH due to the slower photosynthetic rate inhibits enzyme citrate synthase and prevents acetyl CoA from entering into the TCA cycle. Elevated concentrations of acetyl CoA activate acetyl CoA carboxylase, which converts acetyl CoA to malonyl CoA. This irreversible conversion reaction is the rate limiting step infatty acid biosynthesis which leads to enhanced lipid accumulation in microalgal cells [31]. Tao et al. [32] studied the effect of nitrogen limitaion on lipid yields of *Chorococcum* spp. and *Scenedesmus destricola.* Under nitrogen deficent conditions, the lipid conent was increased from 31.6% to 40.7% in *Chlorococcum nivale* and 48% to 54% in

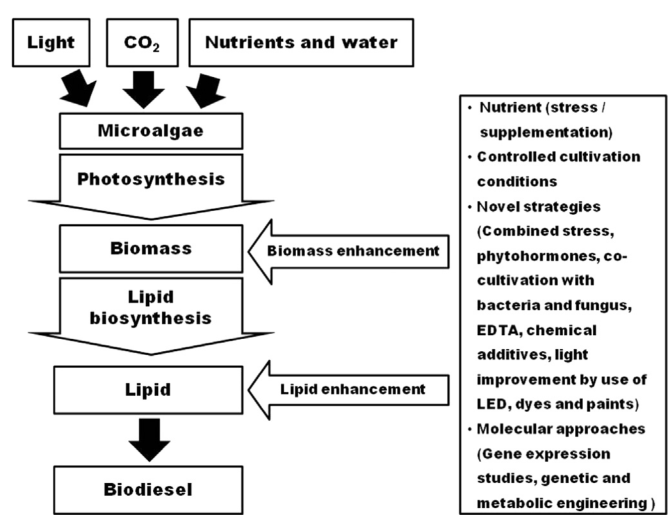

Fig. 1. Lipid enhancement strategies for sustainable microalgal biodiesel production.