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Reviews and Progress Open Access

Research Progress on The Effects of Salt Stress on Photosynthesis and Lipids of Microalgae

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Abstract High salinity, temperature, light intensity, and cold environment are generally sensitive to higher plants. These pressures are a challenging environmental stress for plant growth and distribution. High salinity is an environmental stress for organisms to overcome. Due to their attractive properties, microalgae are important freshwater algae, widely used for human and animal, food source and industrial applications. This review summaries the progress on the effects of microalgae's photosynthesis and lipid content by salinity. At the same time, the application value of microalgae is briefly summarized.

Keywords Microalgae; Salt stress; Research progress

Introduction

Microalgae, are an autotrophic organism, which contain a high potential photosynthesis and rich nutrients. They are widely distributed on land and oceans. Polysaccharides, proteins and pigments produced by cell metabolism can be utilized in food, medicine, genetic engineering, liquid fuel and other fields. As one of the world's largest primary producers, more than 350 000 species of algae have been discovered. In 2016, the balance of plant's metabolism was affected by salinity and soil salinization has been widely concerned by Guo et al. (2016). Since then, research on microalgae has become a hot topic and these mainly focus on photosynthetic pigment and protein content. However, there are few studies on the effects of microalgae's photosynthesis and lipid content in salt stress (Guo et al., 2016). Nearly half of the world's arable land will be stabilized up to 2050, this phenomenon is posing a great threat to sustainable agricultural development and food security (Butcher et al., 2016). Therefore, developing and planting crop varieties is the most effective way to improve soil salinity (Huang et al., 2020). As an important primary producer, microalgae have the advantages of wide distribution, easy availability, short growth cycle and strong adaptability. They are excellent materials for studying the resistance mechanism of plants under alkaline stress (Wang et al., 2015).

Unfortunately, only a few reports of salt tolerance microalgae's mechanism are described. It is far from enough to research the mechanism of microalgae by salt tolerance, and need for further research. For example, Elloumi et al. (2020) proposed that *Scenedesmus* sp. can be cultured at 0-60 g/L NaCl treatment. The strain has a high content of total chlorophyll and carotenoids in 10 g/L^{-1} NaCl treatment (Elloumi et al., 2020). Among photosynthetic organisms, algae are considered as promising biofuel resources because they can efficiently convert solar energy into chemical energy. Seaweed can efficiently fix carbon (Venkata-Subhash et al., 2014). In recent years, microalgae have been widely used in food and feed because of the advantage of rapid growth and reproduction, high photosynthesis rate, diversified nutritional methods and rich organic substances. Drawing on insights, microalgae become a potential biomass raw material and fuel production, which meet global challenges brought by sustainable food (Venkata-Subhash et al., 2017). Compared with fossil-driven biofuels, microalgae biofuels also have renewable, degradable and friendly (Vicente et al., 2010). Based on this, we will summary details on photosynthesis and lipid content of microalgae by salinity are discussed in later sections, and hope to provide reference for related studies.

1 Effects of Salt Stress on Microalgae

1.1 Effects of salt stress on photosynthesis of microalgae

Photosynthesis is an energy conversion proceeding, green plants can convert light energy into chemical energy. With the release of chemical energy, plant growth activities are promoting. Then the monosaccharides produced by photosynthesis be used as fuel in cell respiration (Wang et al., 2015). For example, high salinity leads to inhibition of photosynthesis in most plants, but enhances the photosynthetic activity in the halophilic eukaryotic microalgae Dunaliella (Liska et al., 2004). Bicarbonate is an effective carbon source for the growth of microalgae. When the concentration of carbon source (sodium bicarbonate) is 1 000 mg/L, *Chlorella vulgaris* ESP-31 have the maximal biomass and carbon source. *S. javanicum* (*Pseudobranchia javanica*) is very sensitive to salt stress. As the salt concentration increasing, the biomass yield is reducing and protein content is increasing (Chen et al., 2003). Similarly, Anabaena 7 120 is a filamentous cyanobacteria, which can carry out oxygen-release photosynthesis. With NaCl concentration increasing, the net photosynthetic oxygen-release and respiration rate was decreasing (Ouyang et al., 2003).

There are many studies on the effect of CO_2 on the growth of microalgae. For example, *Arabidopsis thaliana* can grow well under the condition of 5-15% CO_2 concentration. However, when the CO_2 concentration of the culture is higher, the biomass and lipid production will be constant. Previous studies on *Chlorella* sp. have similar results. When the CO_2 concentration is 2%, *Chlorella* sp. obtains the maximum growth rate by fixing CO_2, while stress caused by high CO_2 concentration can inhibit the growing *Chlorella* and strictly reduce biomass (Wang et al., 2015). In addition, transportation of the bicarbonate solution is not only cheaper than transportation of compressed CO_2, but also provides a better choice for transportation of CO_2 to algae cultivation systems (Chi et al., 2011). At present, the research about microalgae and cyanobacteria's evaluation have been 50 years (Fernández-Sevilla et al., 2010), because their growth rate is much faster than terrestrial plants, carbon fixation efficiency is about 10-50 times higher than higher plants, has excellent research value (Costa et al., 2000). Microalgae can usually capture carbon dioxide from three distinct sources: carbon dioxide in the atmosphere, in power plants and industrial processes, in soluble carbonates (Brennan and Owende, 2010). Vulgaris ARC1 had the ability to fix carbon, and its biomass increased at 6% CO_2 concentration (Venkata-Subhash et al., 2017). Production of biofuels by photosynthetic microorganisms is envisaged a process of producing renewable energy to mitigate global warm (Spolaore et al., 2006). Most microalgae convert CO_2 into chemical energy through photosynthesis to realize sustainable development. With the increase of light intensity, the neutral lipid content of most microalgae increases (Gwak et al., 2014). In recent years, microalgae have received extensive attention as a renewable energy source (Takagi et al., 2000).

1.2 Effects of salt stress on lipid content of microalgae

With the aggravation of environmental problems and energy prices, people are interested in the production and utilization of biofuels originated domestic biomass resources. In 1998, Sheehan et al. (1998) widely confirmed and studied the potential of producing biofuels (especially biodiesel) from algae (Sheehan et al., 1998). Oil can be synthesized by algal cells in an adverse environment. As a high-energy storage compound, it has a wide range of application value (Goncalves et al., 2016). Microalgae have obtained broad prospects in the global large-scale production of biodiesel because of its simple structure, high photosynthetic efficiency and lipid content (Salama et al., 2013). However, most algae have low oil production efficiency, and the production of large-scale biofuels is still a long and difficult road. Finding a suitable method to induce algae to synthesize lipids, opening the door for the use of algae fuel to increase lipid production (Sibi et al., 2016). Numerous microalgae associated with saline tolerance have been identified. Kakarla et al. (2018) found the lipid accumulation of algal cells was influenced by environmental stress factors. Under the 60 g/L NaCl, 1 g/L bicarbonate and 5.0 g DW/L treatment, the content of biological lipids increased significantly. The redistribution of cellular carbon may promote the formation of lipid droplets under high salt stress (Kakarla et al., 2018). Algae has the ability to survive or proliferate under various environmental conditions, and can regulate lipid metabolism effectively in response to ecological conditions changes (Guschina et al., 2006). Some studies have demonstrated that Chlorella has the highest biomass and lipid productivity at pH of 7.0-8.0 (Moheimani, 2012). The lipid content of microalgae is affected by nitrogen deficiency, high light intensity, salt and iron concentration. The lipid content is usually increased from 30% to 60% and the protein content of Chlorella can be increased from 37.60% to 46.48% in salt environment. Therefore, high salinity environment can promote protein and lipid accumulation, but cannot conducive to carbohydrate accumulation (Ma et al., 2020). Salt stress treatment has been shown to be a successful method to increase the high starch lipid yield of algae. The lipid productivity of freshwater microalgae was increased to 19.66 mg/L in 20 g/L NaCl treatment. This study shows that low starch freshwater microalgae, which can also cover carbon flow in salinity and produce biodiesel with ideal cold flow characteristics (Zhang et al., 2018). For example, the intracellular starch (carbohydrate) of *Dunaliella salina* is metabolized and transferred to the biosynthesis of triacylglycerol (oil) (Ishika et al., 2018). Otherwise, it was found that the nitrogen deficiency and high salt stress may be a feasible way to improve glycerol production in microalgae. Studies have verified that some green algae and diatoms can store carbon and energy in the form of lipids (TAGs) in addition to photoautotrophic growth. Nutritional deficiency (especially nitrogen or phosphorus limitation) will increase the accumulation of TAG in microalgae (Campenni et al., 2013).

Vazquez-Duhalt et al. (1991) reported that the growth of Bratryococcus braunii (race-A) was affected for the biomass yield and cell composition in different NaCl concentrations. The content of α-layeredibiose (O-β-d-glucopyranosyl-(1→3)-α-D-glucopyranosyl) has huge change, which is the main osmotic protective agent. *Chlamydomonas* JSC4 cut off from the marine environment is a salt tolerant strain and shows high lipid accumulation under high salt stress. The strain was used to identify the mechanism of lipid biosynthesis (Ho et al., 2017). Chlorella was induced to prepare biodiesel in salt stress. The lipid content was increased to 54.9% than that of the wild variety (Cheng et al., 2016). The lipid and biodiesel accumulation of microalgae were affected by nitrogen, phosphate, initial cell concentration and NaCl concentration. The content of saturating fatty acids can increase from 56.40% to 73.41%. This result shows that *Chlorococcum pamirum* is a promising biofuel production (Feng et al., 2014). It should be that noted that lipid accumulation is not characteristic of all algae, especially salt tolerant algae. A study in *Chlamydomonas* sp. *JSC4* showed lose the conversion ability from starch synthesis to lipid synthesis in response to salinity (Shetty et al., 2019). As a promising producer of biodiesel, microalgae have many advantages such as carbon neutralization, rapid growth, and response to external stimuli. What's more, it has the ability to accumulate related lipids in without competing for cultivated land (Zhang et al., 2018). These studies clearly show that salt adaptation can occur in multiple different ways.

2 Application Value of Microalgae

At present, China has become the largest microalgae producer all over the world, and the embryonic form of microalgae bioeconomy is being bred. Microalgae were widely distributed in lakes, soils, oceans, rivers and other environments, and even live in some extreme environments (North and south poles, arid and saline alkali soils). With small population, simple structure and high photosynthetic utilization rate features, microalgae have wide application value (Chen et al., 2016). For example, *Tetraselmis* sp. is an environment-friendly biological fertilizer, can instead of chemical fertilizer without affecting the environment and soil quality (Imen et al., 2018). Due to its fast growth rate, strong environmental adaptability and high unit yield, the application field of algae to purify sewage gradually expanded in the 1980s (Oswald et al., 1978). Studies have shown that the microalgae, include *spirulina*, *chlorella*, and *Oscillatorija*, have the highest absorption rate of nitrogen and phosphorus in sewage. Chlorella is one of the most effective algae. As an important application value in microalgae, with the study of its components, various nutrients and unique polysaccharides contained in *Naked algae* have a wide application potential. Animal experiments showed that nude polysaccharide could significantly improve the symptoms of allergic dermatitis, and have hypoglycemic activity (type II diabetes) (Oswald et al., 1978), inhibit liver injury activity (Sugiyama et al., 2009), and anti-tumor activity (Ak Sonat et al., 2018). In addition, Chlorella has rich vitamins, minerals and nutrition containing 8 kinds of essential amino acids. Chlorella growth factor (CGF) unique to *Chlorella*. CGE can enhance immunity and inhibit inflammation, bacteriostasis and anti-tumor. Microalgae have been used in aquaculture and poultry production. For example, adding different levels of spirulina to shrimp feeding, which can protect shrimp liver. It can also improve the reproductive performance of breeding pigs and the immunity of chickens. (Zhao et al. 2020)

3 Expectation

Common salt tolerant plants include *Mongolska vila*, *Suaeda salsa*, *bacteria*, *fungi* and microalgae have been found, which are important primary producers. Microalgae, as a diverse photosynthetic organism of low plants, not only have wide distribution, easy availability, short growth cycle, strong adaptability, carbon fixation and high photosynthetic efficiency, but also do not occupy cultivated land. It is an excellent material to study the stress resistance mechanism of plants in salt environment. The development of modern molecular biology technology provides a tool to further clarify the action mechanism of microalgae and help to verify the commercial potential of microalgae. Microalgae are important resources for sustainable environment development, which needs to establish a broader and a deeper understanding.

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