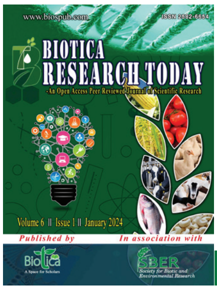

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Cyanobacteria: A Potential Microalgae for Climate Smart Rice Cultivation

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Abstract

Soil carbon sequestration is a significant strategy for lowering atmospheric CO_2 emissions and mitigating negative environmental effects. The use of Cyanobacterial or Blue Green Algal systems (BGA) for long-term sequestration of CO_2 is a promising solution to reduce the CO_2 content in atmosphere. Cyanobacteria are suitable candidates in carbon sequestration as they are easier to grow in paddy fields. Understanding the process of organic and inorganic carbon sequestration mediated by Cyanobacteria and the possibility of controlling these processes are necessary to develop a technology for CO_2 sequestration in rice soils. Rice cultivation with Cyanobacterial biofertilization could also reduce the carbon footprint by reducing fertilizer requirement and carbon enrichment as mineral carbonates. Their potential for carbon sequestration and enhancement of grain yield could be explored for climate smart adaptation in cultivation of rice.

Keywords: Carbon Sequestration, Climate smart agriculture, Cyanobacteria, Paddy

Introduction

The present level of CO_2 in the atmosphere is around 410 ppm and it is expected to rise above the level of 480 ppm by 2050. Agriculture being a climate dependent activity is largely affected by this increase in CO_2 and climate change. It's a real fact that agriculture being an anthropogenic activity contributed to this climate change by emitting greenhouse gases. This claims for reduction in emission by agricultural activities by eco-friendly management practices. One among the options for climate mitigation strategy in rice cultivation is usage of cyanobacteria as CO_2 sinks. Due to their fast growing and easier management characteristics Cyanobacteria are noted as attractive candidate. Through calcification, they sequester carbon dioxide as inorganic carbon which is recalcitrant for several years. Cyanobacteria being a diazotroph can be utilized to fix nitrogen and improve rice crop yield. Cyanobacteria can offset nitrogen requirement in agriculture at the rate of 20-30 kg ha^{-1} and enhance organic matter in soil. Recent reports state that biofertilization with cyanobacteria in rice fields aides in carbon sequestration.

Due to their fast growing and easier management characteristics Cyanobacteria are noted as attractive candidate. They possess capacity to increase CO_2 at the site of photosynthetic carboxylation (around Rubisco) through a biophysical mechanism similar to C_4 plants (carbon concentrating mechanism, CCM). The CO_2 sequestration by Cyanobacteria is gaining attention for reducing the CO_2 concentrations in the atmosphere. A lion's share of global photosynthesis is done by Cyanobacteria. The carbon dioxide fixation rate of cyanobacteria is through photosynthesis is about 10-50 times faster in than plants. Thus the use of these biological agents is regarded as one of the effective approaches minimize the intimidating levels of CO_2 concentration in atmosphere. The carbon dioxide captured as cyanobacterial biomass can be used in various purposes since the retrieval of the biomass is simple. Cyanobacteria store carbon dioxide as $CaCO_3/CaHCO_3$ through photosynthesis and calcification (Singh *et al.*, 2016). Calcium is copious in many ecosystems as calcium or silicate

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minerals due to biological accelerated weathering which favours Cyanobacteria.

Rice Cultivation and Green House Gases (GHGs)

About 190.3 million ha is under rice cultivation globally, of which 43 million ha is in India producing 23% of world's rice production mainly under submerged system of cultivation. Climate change includes global warming, unpredictable weather patterns, sea level rise and numerous consequences. The Inter-governmental Panel on Climate Change (IPCC) has stated that observed warming over the last 50 years is due to the increase in concentration of (GHGs) greenhouse gases. Rice cultivation is associated with emission of CH_4, CO_2 and possibly N_2O, which have major role in global warming potential. Rice fields account for about 60-80 Tg-CH_4 year^{-1} which is 6-20% of global methane emissions (Qian *et al.*, 2023).

Carbon dioxide being the dominant GHG, mitigation of CO_2 is mandatory to alleviate the serious threat that it causes on global climate. The global potential for mitigation of 80% of greenhouse gas from agriculture would be through carbon sequestration. Among the strategies for climate change mitigation, carbon capture and storage promises effective results. There are three main types of C sequestration where the sequestered carbon is not leaked in to the atmosphere in short duration of time: (i) based on how plants naturally convert carbon dioxide from the atmosphere into biomass, soil organic matter, humus, and other elements of the terrestrial biosphere; (ii) using engineering methods; and (iii) utilizing chemical reactions (mineral carbonation). Soil carbon sequestration is a better option because it could have positive effects on food security, improves the environment and mitigates global warming.

Cyanobacterial Systems as Carbon Sequesters

The oxygenic photosynthetic Gram-negative bacteria classified as Cyanobacteria has versatile physiology and high ecological adaptation that has allowed them to be successful on wide range of environments. They are also found in numerous terrestrial environments. It is believed that Cyanobacteria has a key role in increasing the oxygen (O_2) concentration in atmosphere during the Archaean and Proterozoic Eras. Cyanobacteria are highly efficient at carbon fixation due to their simpler structure (Singh *et al.*, 2016). Cyanobacteria being more resistant to drier conditions, occur in paddy fields even at higher elevations. Cyanobacteria being a diazotroph can be used as carbon sequester in variety of wetland crops, including rice, wheat along with increase in yields. The growth of BGA significantly contributes to fertility of paddy soils. A twenty five percent increase in rice yield due to soil inoculation of blue green algae was reported in many findings (Zhang *et al.*, 2021). Application of gypsum ($CaCO_3$) to paddy fields promoted the growth of cyanobacteria, increased nitrogen fixation and rice yields. In addition to having a beneficial effect on soil carbon sequestration, the combined activity of cyanobacteria and rhizobacteria in increasing rice output resulted in 30-40 kg of nitrogen savings in terms of chemical fertilizers. Cyanobacteria reduces CO_2 to organic compounds through photosynthesis and mineralize CO_2 to recalcitrant carbonates, such as $CaCO_3$ (Figure 1) (Blondeau *et al.*, 2018).

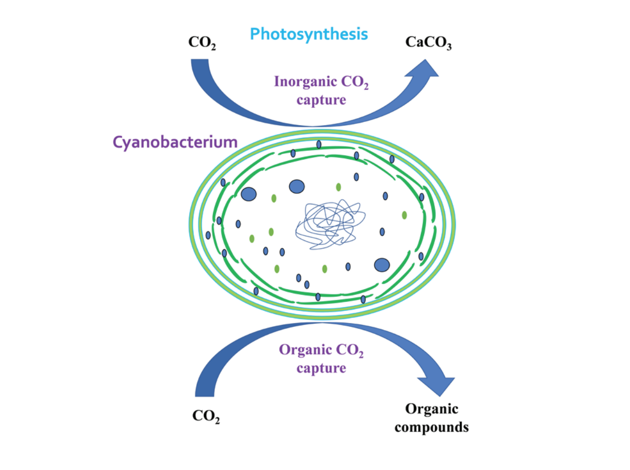

Figure 1: Carbon sequestration by cyanobacteria

Organic Carbon Sequestration by Cyanobacteria

The organic carbon sequestration denotes the carbon dioxide assimilated as biomass in cyanobacteria. This is done by Rubisco enzyme in the presence of sunlight. 1.83 kg of CO_2 is utilized to produce 1 kg of dry algal biomass. Although cyanobacterial species vary in specifics, the main method for uptaking carbon in cyanobacteria is the transfer of HCO_3. It diffuses as CO_2 into the cytosol in some situations after passing through the plasma membrane and outer membrane via ATP-driven uniports or HCO_3/Na^+ symports. On the membranes of thylakoids, NADPH dehydrogenase (NDH) complexes convert cytosolic CO_2 into HCO_3. After entering the protein-enclosed carboxysome, HCO_3 is transformed to CO_2 by carbonic anhydrase (CA), increasing the concentration near Rubisco (Song *et al.*, 2022). This forces the enzyme to reduce the carbon dioxide into organic molecules and assimilate as biomass.

Inorganic Carbon Sequestration by Cyanobacteria

Calcium and magnesium carbonates are the primary forms of Carbon sequestration in the global carbon cycle. Some bacteria and fungi can precipitate calcite through a number of processes like photosynthesis, ammonification, sulphate reduction and anaerobic sulphide oxidation. Employment of cyanobacteria for bio mineralization of CO_2 by $CaCO_3$ precipitation presents innovative and sustainable methods for sequestering and capturing carbon at its point of generation (Song *et al.*, 2022). As cyanobacteria are organisms sensitive to light but found in high light radiation regions, because of which a calcified sheath functioning as light shade is present. The mechanism of inorganic carbon uptake (CCM) during photosynthesis influences precipitation of calcite as shown in figure 1. Calcification and photosynthesis are at the molar ratios of about 1:1 in the case where HCO_3^- is used as a carbon source. Cells can control the movement of calcium in and out of cells and calcite formation could be regulatory process. Calcite precipitation takes place on the proteinaceous surface layer (S-layer) or exopolysaccharide sheath (EPS) around the cells.

Cells that are completely covered by calcite ($CaCO_3$) die due to inhibition in uptake of essential nutrients.

Conclusion

Cyanobacteria are amazing model organisms that can give biotechnologists new genes and biomolecules with a variety of applications in industry, agriculture, and environmental sustainability. These systems have the potential as effective devices for capturing greenhouse gasses like methane and carbon dioxide. The carbon sequestered as calcite by Cyanobacteria remains in the soil pool for a long duration and it is an effective climate change mitigation strategy in rice cultivation.

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