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The Cyanobacterial Application as Biofertilizer for Sustainable Paddy Cultivation: An Overview

Review Article

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Abstract

The population of the world is increasing in an alarming rate day by day, and the increased population needs to be fed with healthy and nutritious food without any contaminants. The Green Revolution mainly focused to increase the productivity of agriculture crops especially rice using inorganic chemical-based fertilizers such as urea. The indiscriminate use of herbicides, insecticides and fungicides deteriorates our soil ecosystem and interferes with the growth of useful soil biota which ultimately affects the human health. This is usually done to increase global food production by killing crop pests, but it is polluting the environment at the same time. Cyanobacteria play a major role in nitrogen fixation and can be used as eco friendly mode of biofertilizer for paddy. In this context, cyanobacterial biofertilizers are getting priority in modern agricultural practices throughout the world.

Keywords: Biofertilizers; Cyanobacteria; Paddy plants

Introduction

Cyanobacteria are the oldest prokaryotic photosynthetic microorganisms on the earth. They are found in diverse habitats such as marine, freshwater, salt pans, hot springs and even in Arctic and Antarctica. They are microscopic microorganism occur in filamentous or unicellular colonial forms. They show symbiotic association with waterfern *Azolla,* which can fix atmospheric nitrogen in paddy fields [27]. They are rich in biologically active compounds which possess antifungal, antiviral, antibacterial, and anticancer activities. Some strains of cyanobacteria accumulate polyhydroxyalkanoates, which can be used as a substitute for non-biodegradable petrochemical-based plastics.

Bio-fertilizers are living microorganisms which can add nutrients to the soil, improves soil properties, solubilizes insoluble phosphatic compounds and produces plant growth-promoting substance in the soil and thus plays a beneficial role in the overall growth of the plants. Biofertilizers when applied to seeds, plants, or soil, it promotes plant growth by increasing the supply of nutrients to the host plant [24,40].

Rice is a staple food for majority of the population in the world. It is consumed by 3 billion peoples and the 95% of the rice production comes from Asian countries alone. Cyanobacteria can be used as biofertilizer in paddy fields owing to its nitrogen fixing potential and at the same time it releases various bioactive compounds into the soil which are beneficial to the growth of paddy plants. Rice is cultivated in the naturally flooded areas such as clay soil [25]. There are thousands of varieties of rice grown throughout the world and India produces 6000 varieties at present. India had above 110,000 genetically diverse varieties of rice till 1970s, but by the implementation of Green Revolution, many varieties were lost because it focuses on monoculture and hybrid crops. According to Indian culture and tradition, rice is a symbol of prosperity, auspiciousness, and richness because of its life-sustaining status. There are several rituals, songs and some festivals related to rice cultivation in different parts of India and among different tribes of people usually during sowing of seeds in field, shifting of the saplings into the fields, separation of weeds from the fields, during harvesting of paddy, thrashing of paddy and also on the storage of paddy [18]. The cyanobacterial strains such as *Nostoc linckia, Nostoc muscorum, Oscillatoria animalis, and Phormidium*

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foveolarum, can degrade methyl parathion, an organophosphorus insecticide [10,37]. In this context, the farmers are using biofertilizers especially microscopic organism like cyanobacteria which is termed as "green technology" for building an eco-friendly environment in paddy fields [11,13]. The paddy plants are benefitting by using cyanobacteria as a biofertilizer such as it provides rich source of nutrients, micro chemicals, provides organic matter in the form of carbohydrates and proteins, production of growth hormones, vitamins, alkaloids, etc. and also reduces the deleterious impact of chemical fertilizer. Thus, both the ecological as well as economic benefits are getting by using cyanobacteria as biofertilizers.

Role of cyanobacteria as biofertilizer and its beneficial effects for paddy plants

Cyanobacteria are an important component of the wetland paddy ecosystem which usually appears as floating mass on the surface of water and their role as bio-fertilizers is well documented [4]. According to Alam *et al*., the cyanobacterial inoculation increases rice yields by 5.03% to 20.06%. In rice fields [1], cyanobacteria contribute significantly, and they grow on the surface of paddy soil and also in water logged in paddy fields.

According to Hasan, the propagation of rice seeds was tremendously fast when treated with cyanobacteria such as *Anabaena* and *Nostoc* [13]. An increase in 51% of plant height, 68% in root length, 56% in fresh shoot weight, 92% in fresh root weight, 120 % in dry shoot weight, 146 % in dry root weight, 32 % in soil moisture, 30 % in soil porosity and 9.3 % decrease in soil bulk density was noticed by the application of *cyanobacterium Nostoc*. It was found that an increase of 47 % in plant height, 54.8 % in root length, 50 % in fresh shoot weight, 80 % in fresh root weight, 100 % in dry shoot weight, 115 % in dry root weight, 28.6 % in soil moisture, 28 % in soil porosity, and a decrease of 7.1 % in soil bulk density and 2.7 % in soil porosity by the application of *Anabaena*.

Cyanobacteria produces a wide range of bioactive compounds such as amino acids, carbohydrates, proteins, vitamins and growth hormones like auxins, gibberellins and cytokinin which are necessary for the growth of paddy plants [14,19,35]. These bioactive compounds play a variety of important roles in plant growth, metabolism and development [14]. IAA and cytokinin were thought to promote growth by increasing seed germination, shoot length, tillering, the number of lateral roots, spike length, and grain weight [15,18,23]. Cyanobacterial decomposition also gives organic matter rich in nitrogen and phosphate to the soil. Moreover, *Anabaena* spp. has been shown to have bio control capacity against phytopathogenic fungi [23]. *Nostoc*, *Phormidium* and *Oscillatoria* possess the ability to break organophosphorus pesticide and eliminate herbicides, making soil healthier for agriculture [31].

Cyanobacteria are known to release various extra cellular compounds like polysaccharides, peptides, and lipids into the soil. They can increase soil fertility by fixing atmospheric nitrogen and it attaches with soil particles, helps to retain moisture of the soil, and reduces soil erosion. Usually cyanobacteria fix 25-30 kg N/hectare/ cropping season. Cyanobacteria can also dissolve insoluble calcium phosphate; ferric orthophosphate and aluminum phosphate present in the soils and enhance phosphate decomposition and mineralization, converting it to readily available soluble organic phosphates/ orthophosphates [38]. Furthermore, the use of Cyanobacteria in crop fields aids in the mobilization of organic phosphates via extracellular phosphates and the excretion of organic acids.

The cyanobacterial genera rich in vitaminsare *Spirulina, Anabaena flosaquae, Anabaena hassali, Microcystis pulverana, Nostoc punctiforme, Phormidium bijugatum, Oscillatoria jasorvensis,* and *Chroococcus minulus* and they all have been found to contain thiamine (vitamin B_1), riboflavin (vitamin B_2), folic acid, ascorbic acid nicotinic acid (vitamin B_3), cyanocobalamin (vitamin B_{12}) and pantothenicacid [30]. One of the most important vitamins in cyanobacteria is vitamin B_{12} (cyanocobalamin). It serves as an essential growth factor for most of the marine phytoplankton since it is required for the activity of several key enzymes in central metabolism [9].

The amino acids which are commonly found in cyanobacterium *Nostoc muscorum* are threonine, glutamic acid, proline, valine, glycine, aspartic acid, and serine, arginine, while cystine arginine, serine, aspartic acid, glycine, histidine, isoleucin, lysine, and ornithine and cystine were found in *Hapalosiphon fontinalis*. The amino acids cystine, tyrosine, and phenylalanine were found in the extract of *Calothrix muscicola* have been linked to rice growth stimulation. At various stages of growth, the strains such as *A. fertilissima* and *Anacystis nidulans* produces the amino acid aspartate in the extracellular filtrate, along with proline, valine, and glycine [34].

Richness of cyanobacteria in the paddy fields

Cyanobacteria are rich in paddy fields of many Asian countries like India, Indonesia, Pakistan, Bangladesh, Sri Lanka, Philippines, etc. The most efficient nitrogen-fixing strains of cyanobacteria are heterocystous forms such as *Nostoc linkia, Anabaena variabilis, Aulosira fertilisima, Calothrix spp., Tolypothrix spp., and Scytonema spp*., *Westiellopsis prolifica, Anabaena oryzae, Anabaena doliolum, Phormidium fragile, Calothrix geitonos, Hapalosiphon intricatus, Aulosira fertilissima, Tolypothrix tenuis, Oscillatoria acuta,* and *Plectonema boryanum*etc. These strains of cyanobacteria are very common in paddy fields which usually float on the surface of water.

Factors influencing the growth of cyanobacteria

Several ecological as well as environmental factors influence the cyanobacterial colonization in the rhizosphere of paddy plants, as well as their subsequent growth, abundance, physiological and biochemical activity. The roots of the paddy plant release sugars, amino acids, and a variety of other substances which can attract or repel microbial communities either directly or indirectly, by providing resources for their metabolic processes [2]. The environmental conditions such as pH of the soil, nature of the soil such as acidic or alkaline, temperature, light, moisture availability and crop canopy and soil nutritional status may have a significant impact on colonization [8]. But pH is one of the most critical soil parameters for cyanobacterial abundance and growth. They prefer a neutral to slightly alkaline pH for optimal growth. Acidic soils are stressed environments for these organisms, and they are normally flourished well in alkaline soil. Moreover, soil pH also influences the establishment of native cyanobacterial flora [19,32].

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Nitrogen fixation by cyanobacteria

Nitrogen is the second most important element of any organism. It is a component of amino acids and is required for the formation of protein peptide bonds. Nucleic acids such as deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), and peptidoglycan cell wall contain nitrogen. Nitrogen is required for the synthesis of chlorophyll in phototrophic organisms. Cyanophycin is an intracellular nitrogen storage polymer made up of the amino acids such as arginine and asparagine. About 78% of our atmosphere is nitrogen gas. But this is scarce in soil due to inability of higher plants to fix atmospheric nitrogen, but which is accomplished with the help of some microscopic prokaryotic organism like cyanobacteria. Dinitrogen is very stable and inert due to the high energy triple bond between the nitrogen atoms. Chemical reduction of N_2 to NH_3 is possible, but only at extremely high temperatures and pressures of N_2 and H_2 (Haber–Bosch process). In this context, it is remarkable that N_2 fixing organisms such as cyanobacteria can carry out this reaction at room temperature and pressure. For N_2-fixing organisms, however, it is still an energetically expensive process. The enzyme nitrogenase uses 16 ATP molecules and 8 low-potential electrons to convert N_2 to NH_3 [29].

However, not all nonheterocystous cyanobacteria show this circadian rhythm. The unicellular cyanobacteria such as *Gloeothece* and *Synechococcus spp*. also fix N_2 during the day and can grow slowly under continuous illumination [6].

Cyanobacterial symbiont *Azolla* bio-fertilizer for rice crop

Azolla is a free-floating water fern that contributes a significant quantity of biologically fixed nitrogen to rice crops through a symbiotic relationship with the *cyanobacterium Trichormusazollae*. In China, India, Vietnam, Thailand, the Philippines, Nepal, Pakistan, Burma, Brazil, and West Africa, *Azolla* is being utilized as a biofertilizer because the cyanobacterial symbiont is lodged in its leaf pockets. *Azolla*can fix 25-30 kg N/ha/cropping season.

According to Srinivasan [36], *Azolla* as a green manure could cut nitrogen input by 25-30% in low-land rice. Subramanian *et al*., studied that the rice grain yields were maximum, when gypsum at 5 t ha^{-1} was combined with 60 kg N ha^{-1} as urea and *Azolla* inoculation as a dual crop. Gopalaswamy et al., investigated the possibilities of *Azolla* hybrids and found that inoculating *Azolla* hybrids increased the soil organic carbon status while also improving rice yield [12]. The usage of *Azolla* in rice fields has significantly boosted soil microbial and enzyme activity, hence maintaining soil fertility. Thus it is an ecofriendly mode of cultivation practices which enhances the soil quality in sustainable rice growing fields [17]. Inoculation of paddy fields with *Azolla* has significantly boosted soil microbial and enzyme activity using 22.5 - 37.5 tonns of fresh *Azolla* biomass per hectare before planting the rice seedlings in the field [41]. It can also reduce weed competition in paddy fields and is resistant to water contaminated herbicides [3].

Conclusion and prospects

The role of cyanobacteria as a bio-fertilizer is well documented. The cyanobacterial bio-fertilizer benefitted paddy plants in many ways such as increase in the number of seeds, grain yield, and weight of the grains, protein content and straw yield. Moreover, these cyanobacterial bio-fertilizers releases various substances into the soil such as vitamins, phytohormones like auxins, gibberellins, andamino acids, carbohydrates, etc. which influences the growth of paddy plant as well as improves the texture and quality of the soil.Moreover, the availability of quality inoculum is a major constrain in bio-fertilizer technology cultivation practices. Since many Asian countries are gifted with lots of paddy fields and wheat fields, the use of eco-friendly mode of bio-fertilizers is highly recommendable.

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