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Comparative Study of Nitrogen-Fixing Bacteria in Terrestrial and Aquatic Habitats: Insights and Future Prospects

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Nitrogen is an essential nutrient utilized by living organisms to produce a number of organic molecules such as nucleic acid, amino acid and protein. A special class of microorganisms known as diazotrophs that are able to fix atmospheric nitrogen into biological form of nitrogen which is directly utilized by plants. Moreover, they stimulate plant growth by decreasing or preventing deleterious effects of pathogens through synthesis of antibiotics, competition for nutrients through production of siderophores. Along with terrestrial diazotrophs, various marine bacterial species are well known which involves in biological nitrogen fixation process. In an open oligotrophic ocean, pelagic and sympagic nitrogen fixation has been shown a significant source of biological nitrogen for survival of oceanic living organisms. A different range of diazotroph have been reported at low temperature ice sea environment. The community of nitrogen fixing bacteria under deep anoxic bottom water is gradually increase. It may be possible that due to genetic variation population of nitrogen fixing bacteria increases under sea water. In this review article, authors have focused on nature of diazotrophs in terrestrial as well as in aquatic conditions. Moreover, the bacterial habitat and their classification, latest approaches and future prospects is also included in the manuscript. Thus, the study would be helpful for understanding the mode of action, their behavior and survival rate in different environment and beneficial for improvement in agricultural sustainability.

Keywords: Biological Nitrogen Fixation, Diazotroph, Marine, Symbiotic; Terrestrial; Pelagic.

In the terrestrial ecosystem, biological nitrogen fixation in the rhizosphere is directly influenced by the exudates of root secretions. This is the major contribution for nitrogen economy of biosphere i.e 30-50% of the total nitrogen used in the crop fields[1,2]. Nitrogen is an essential nutrient which is taken by all organisms for production of a variety of organic molecules such as nucleic acids, proteins and amino acids. It is a limiting factor that is responsible for growth of plant and yield production as nitrogen is a major constituent of chlorophyll (most vital pigment mandatory to carry out photosynthesis). Plants can acquire only combined form of nitrogen by three different ways such as Haber-Bosch process or manure to soil through decomposition of an organic matter, conversion of nitrogen present in an atmosphere to usable compounds through natural processes

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such as lightning and biological nitrogen fixation (BNF)[3,4,5]. A BNF system is the most suitable process to sustain the agricultural land naturally. BNF was initially discovered by Beijernick[6] which belongs to a special class of prokaryotic bacteria[7]. There are special types of microorganisms known as diazotrophs that are able to grow without external source and can fix atmospheric nitrogen into biological form of nitrogen which is directly utilized by plants. It is a natural process that is till date limited to prokaryotes but research has been going on to find the potent eukaryotes. These microorganisms can perform a variety of transformation reactions such as oxidation of nitrogen compounds to nitrite or nitrate, reduction of oxidized nitrogen compounds to ammonium or fixing of atmospheric nitrogen into ammonia encoding by nitrogenase enzyme[8,9].

Although diazotrophs are phylogenetically diverse with different physiological properties but still it is observed that rate of nitrogen fixation affected by various physiological and environmental factors like temperature, water holding capacity, nitrogen level, pH, salinity, water stress etc. The ability of BNF has been observed in phototrophic microorganisms include aerobic phototrophic cyanobacteria[10,11,12], anaerobic green sulphur phototrophs like *chlorobium* and anaerobic purple sulphur phototrophs like *chromatium*[13]. *Pseudomonadales* and *Rhizobiales* are two dominant diazotrophs are reported in bulk paddy soil rhizosphere[14]. It was found that due to increasing contamination of PCB (polychlorinated biphenyl) in paddy crops diazotroph community increases[15]. *Gluconacetobacter spp., Herbaspirillum, Bradyrhizobium sp. Burkholderia spp.* and *Rhizobium sp.* are also examined as predominant diazotrophs from sugarcane field[16]. Furthermore, some of the *Agrobacterium* and *Bacillus* species are also found in coastal saline soils of Sundarbans, West Bengal which depicts the BNF capacity of diazotroph under saline conditions well[17]. There is a huge bacterial diversity in switch grass (*Panicum virgatum*). It is characterized that *Methylobacterium* and *Rhizobium* belong to alpha proteobacteria, *Burkholderia, Geobacter* and *Desulfuromonas* belonging to delta proteobacteria and *Azoarcus* belonging to beta proteobacteria as predominant diazotrophs in switch grass on the basis of *nif*H RNA sequences[18]. Besides nitrogen fixation, diazotrophs can also affect growth of plant directly *via* production of plant hormones and vitamins, inhibition of ethylene synthesis, enhancement in stress resistance, improvement in uptake of nutrients, mineralization of organic phosphate and solubilization of inorganic phosphate. However, diazotrophs indirectly affect plant growth by decreasing or preventing harmful effects of pathogens through synthesis of antibiotics, competition for nutrients *via* production of siderophores.[19, 96]

Diazotrophs are not only fix nitrogen in terrestrial but it can also fix nitrogen in marine water[20]. In an open oligotrophic ocean, the dominant source of nitrogen is a pelagic nitrogen fixation. Various research studies have revealed that biological nitrogen fixation plays a major role in ocean[21-30]. Microbial mediated redox reactions are the main source of available biological nitrogen in the ocean. The whole process is regulated by denitrification, anaerobic ammonium oxidation and nitrogen fixation[31,32]. Although all the processes having equally important to fix the nitrogen under water conditions but nitrogen fixation is one of the most important pathways which plays a significant role in control of oceanic nitrogen. In marine ecosystem *Trichodesmium* is a non-heterocystous *cyanobacterium* providing fixed nitrogen to the oligotrophic sea. *Trichodesmiun* can occur at a depth of 200 m with extensive filaments. These filaments can cluster into puff or tuff colonies *to form* extensive annual blooms. Mainly diazotrophic bacteria under sea water form water blooms regulated by temperature. Some of the nitrogen fixing microorganisms in the sub-tropical north pacific gyre can fuel to surface phytoplankton blooms over several month[33]. *Trichodesmiun* have unique capacity in forming visible bloom which are very dense in nature[34]. They are probably the best studied marine N_2 fixer bacteria. N_2 fixation by *Trichodesmium* spp. has been shown to be an important source of nitrogen for tropical as well as for subtropical marine systems[35,19,20,36]. It can help nitrogen fixation under marine via direct as well as indirect, through synthesis of amino acids, dissolved organic nitrogen (DON), NH_4^+ and indirect through regeneration of Dissolved Inorganic Nitrogen (DIN)respectively[37,38]. Moreover, it is also reported that at high-latitude water of the Danish Strait and Western Arctic region, a unicellular cyanobacteria symbiont (UCYN-A) alga sustained the marine N_2-fixation to waterat low temperature with high concentration of fixed inorganic nitrogen[27].

In addition to this, diversity of nitrogen fixing bacteria can also depends on physiological criteria such as nutrient regime preferences, temperature, tolerance range and iron requirement under sea[39, 20, 96]. Some of the basic requirements for the diazotrophic bacteria in sea water is stable water column with an upper mixed layer around 100 m, low nutrients, very clear water and depth light penetration. Furthermore, other factors such as range and optimum temperature, salinity and light influences provide an empirical framework for the growth of bacteria. In comparison with photosynthesis, the nitrogen fixation phenomenon is quite related as both the processes are strongly tied to a circadian rhythm[40]. Diazotroph grows well in subtropical as well as tropical surface water due to high light photon flux and acclimatize themselves to the photosynthesis characteristics as per its position in the water column and availability of light[14]. Community of Diazotroph in marine also depends on their environmental or sea conditions (Coastal Canadian Arctic, Arctic Tundra and Glacial Antartica lakes). One of the important sources of nitrogen is atmosphere which is utilized by diazotrophs for providing bioavailable N_2 in pelagic ecosystems[41]. In an open oligotrophic ocean, pelagic and sympagic nitrogen fixation has been shown a significant source of biological nitrogen for survival of oceanic living organisms. A different range of diazotrophs has been reported in low-temperature ice sea environments[42,43].

Microbial communities which are present in the shallow marine sediments have a significant role in the oxidation of complex organic compounds and regeneration of the nutrients. Recentre search suggests that percentage of nitrogen fixating bacteria increases in deep anoxic bottom water. Similarly in South Pacific Ocean more nitrogen fixation was observed in dark subtoxic zone[44, 23].

Classification

The organisms which fix nitrogen can be categorized broadly into two types one is agricultural and another is natural systems which further divided into different groups. Based on habitat, diazotrophic bacteria can be classified into four groups: free-living, associative, endophytic and symbiotic nodule formers (Table: 1).

Nitrogen fixation by free living Diazotrophs

Most of the heterotrophic soil bacteria participating in nitrogen fixation without direct interaction with other microorganisms for example *Azotobacter, Clostridium, Bacillus, Klebsiella*, *Burkholderia, Desulfovibrio, Enterobacter,* and *Serratia*[45,46,47]. *Klebsiella pneumoniae* has applied as a model system for studying the regulation of nitrogen fixation by *nif* genes. The by-products of the nitrogen control genes ntrA, ntrB, and ntrC control the expression of the 17 *nif* genes in *Klebsiella* in response to the nitrogen source as shown in Fig: 1. The bacteria belonged to free living group are grown on decomposed organic matter in soil. Free living microorganisms use organic molecules in oxidized form that are synthesized by other organisms or from decomposition as their source of energy. Some of them are using chemo-lithotrophic method for utilization of inorganic compounds as source of energy. Since, oxygen could inhibit the activity of nitrogenase, free living diazotrophs works under anaerobic or micro-aerophilic condition for nitrogen fixation reactions.

In natural conditions suitable carbon and energy sources are very low to fix nitrogen by diazotrophs. Researchers are using various approaches to improve the agronomy conditions for biological nitrogen fixation as well as nitrogen use efficiency. A similar type of study is supported in Australia on intensive wheat rotation farming system showed that free living diazotrophs contributed 20 kg/hectare per year to the long term demands of nitrogen of this cropping system. In this system, wheat stubble is maintained to provide optimum carbon and nitrogen conditions, optimizing the activity of free-living organisms[48].

Nitrogen fixation by associative Diazotrophs

The rhizospheric bacteria belonging to associative group proliferate on the surface of roots and nourished on root exudates[49]. The most studied examples of this class are *Azospirillum Acetobacter, Burkholderia Azoarcus* and *Herbaspirillum* which have ability to make close association with *Poaceae* members such as rice, corn, oats, wheat, barley, sugarcane and other non-leguminous plants[50,51]. In addition to this, occurrence of microsites associated with plant residues decomposition, in mixtures containing decomposable particulate organic matter and in termite habitats were also shown. This class of bacteria is able to perform suitable amount of nitrogen fixation within the rhizosphere of the host plants. An amount of nitrogen fixation depends on several factors such as soil temperature (*Azospirillum* survive in more temperate environment), area of host plant for rhizosphere, low oxygen pressure in environment, competitiveness among bacteria and efficacy of nitrogenase enzyme[52]. *Azospirillum* can convert atmospheric N_2 into NH_3^+ under low aerobic conditions at low nitrogen levels using nitrogenase enzyme complex. This enzyme is comprised of two components: the dinitrogenase protein (MoFe protein, NifDK), site of nitrogen reduction containing molybdenum-iron cofactor and dinitrogenase reductase protein (Fe protein, NifH) which transfers electrons from an electron donor to nitrogenase[53].

Nitrogen fixation by endophytic Diazotrophs

Similar to rhizospheric bacteria, endophytic bacteria belong to distinct class of bacteria that can colonize within plant tissues and offer a variety of benefits to the plant[54]. This group of diazotrophs invade and multiply internally in plant parts without causing any plant disease and responsible to promote plant growth. Endophytic bacteria include *Gluconacetobacter Herbaspirillum,* and *Burkholderia* act as plant growth promoters for grasses such as sugarcane and maize. Both endophytic and associative groups of bacteria may involve in promoting plant growth by establishing intimate and reciprocal associations with plants. The advantages of these diazotrophic bacteria include role in biological nitrogen fixation (BNF), production of plant hormones and solubilization of phosphate[55,56].

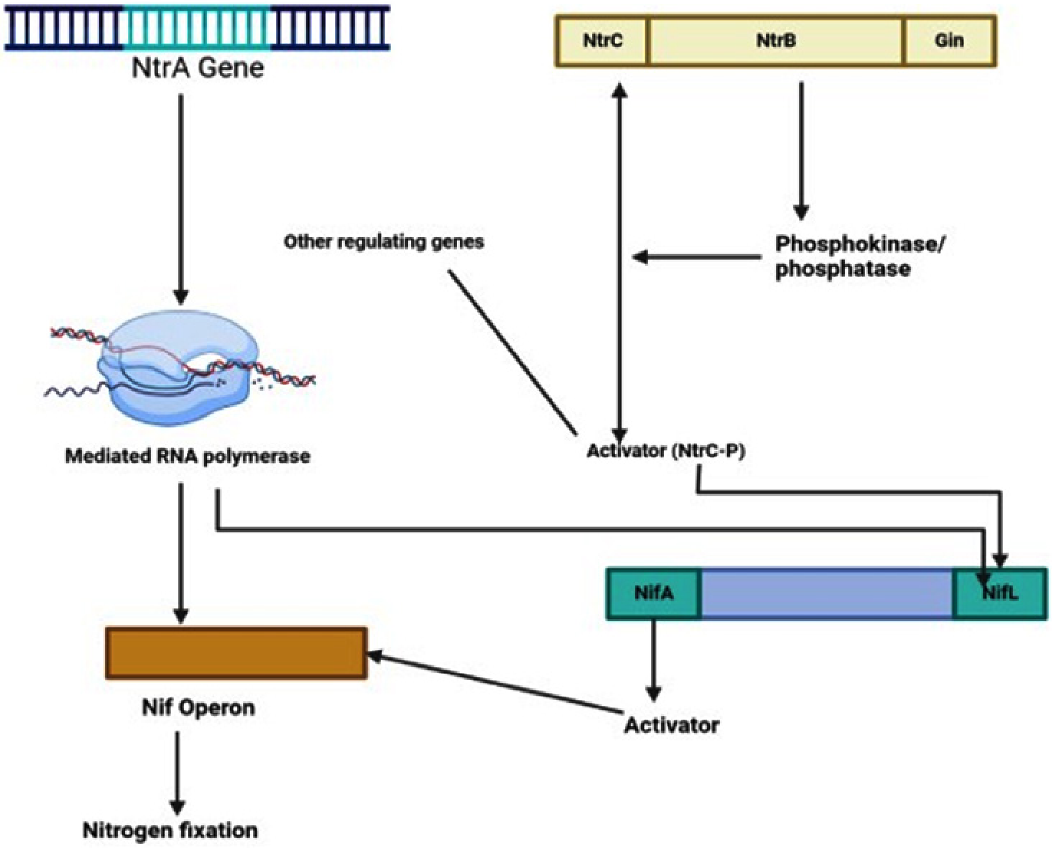

Fig. 1. Showing regulation of *nif* genes in *Klebsiella pneumonia*

Nitrogen fixation by nodule formation

The diazotroph belonging to symbiotic group form nodules and established symbiotic relation with several shrubs and woody species. The important examples of this group are collectively known as rhizobia which form symbiotic relation with plants of *leguminosae* family. The other examples are nodule forming bacteria *Actinobacter* of Frankia genus with Casuarina and Allocasuarina species. Rhizobium are gram negative, motile bacteria (thin cell wall), easily grown on culture media while Frankia, a gram-positive-bacteria, growing by elongating branched hyphae, fused and producing vesicles and sporangia which release spores for dispersal[57]. The nodule-forming bacteria, especially rhizobia's symbiotic association with legumes are particularly the most efficient approach in exploiting nitrogen fixation in agriculture. The symbiotic and associative nitrogen fixers can be found in rhizosphere of legumes and non-legume plants[29,58]. Diazotrophs can be classified into two groups based on their associations: free-living and symbiotic.

The most important example of nodule formation is legume nodule formation[59,60]. Species of *Bradyrhizobium* or *Rhizobium* bacteria invade root system of host plant and cause the formation of root nodules to reside and begin nitrogen fixation. The process of nodulation shows an ordered association between host and bacteria[61]. The process starts with an attraction of *Rhizobia* to flavonoid produced by roots of host legumes leads to an attachment of bacteria to root hairs. This process completes in two steps first attachment of bacteria using Ca^{+2} binding protein (rhicadhesin) and then accumulation to root hair surface. A strong attachment involves lectins (produced by host plant) and fimbriae (produced by bacteria). The host plant then attracts towards chemicals released by rhizobia known as Nod factors (lipochitin oligosaccharides) which is responsible for colonization of root hairs to form curls known as shepherd's crook. After, penetration of rhizobia into root hair, a tubular structure known as infection thread will be formed. After reaching to roots, bacteria stimulate cortical cell division which leads to nodule formation. The bacteria lose their cell wall and undergo various morphological changes to form large, irregular shaped branching cells known as bacteroids after reaching inside and entirely dependent on host legume for their energy requirements and fix nitrogen for plant[62].

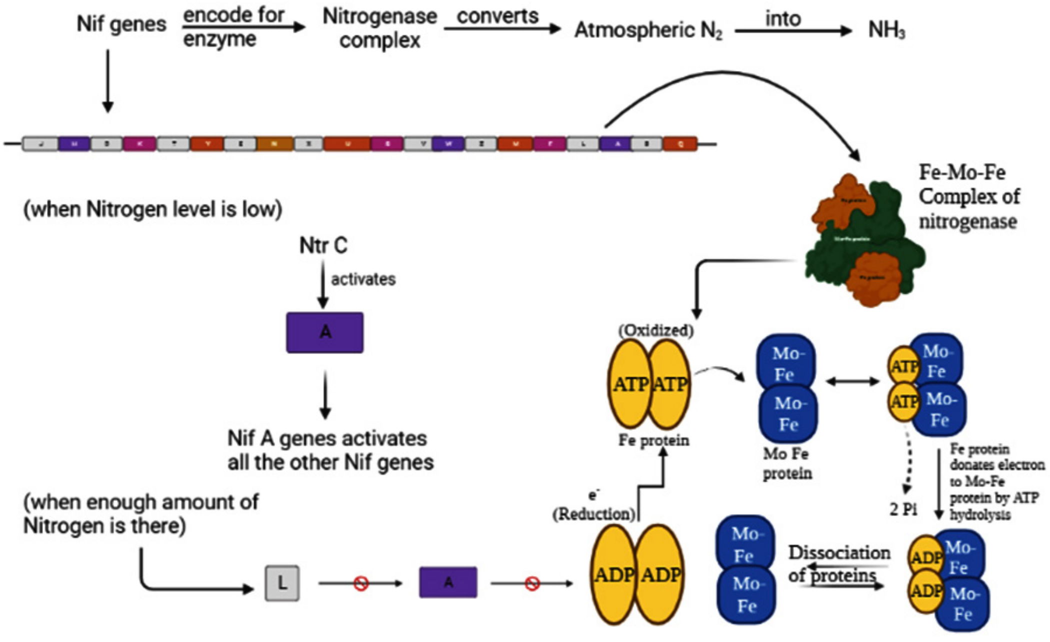

Fig. 2. Important roles of *nif* genes in biological nitrogen fixation and functioning of nitrogenase under low level and high level of nitrogen

Table 1. Classification of nitrogen fixing bacteria in different crop system

S. No	Types of nitrogen fixation	Description	Name of bacterial strains	Plants / Crops involved	References
1	Symbiotic nitrogen fixation	Mutual interaction between host plant and bacteria to fix nitrogen.	*Rhizobia, Frankia,* some of *cyanobacteria* etc.	Pea, chickpea and other legumes	[57, 58, 61, 62]
2	Free living nitrogen fixation	There is no symbiosis between host and microbes and bacteria are freely present in soil to fix nitrogen.	*Azotobacter, Beijerinckia, Clostridium, cyanobacteria*	Corn, wheat, rice and other cereals.	[90, 95,97]
3	Endophytic nitrogen fixation	Bacteria present within the plant tissues, fix nitrogen asymbiotically.	*R. leguminosarum, G. diazotrophicus, Enterobacter sp., Bacillus sp, Burkholderia* etc.	Sugarcane, corn, canola etc.	[55, 56]
4	Associative nitrogen fixation	Nitrogen is fixed by some associative bacteria present in common association with plants (not symbiosis).	*Azoarcus, Pseudomonas stutzeri, Herbaspirillum, Paenebacillus* etc.	Rice, sugarcane and other non-legumes	[90]

Many diazotrophs perform nitrogen fixation by making symbiotic relation with host plant. The plants produced carbohydrates through photosynthesis which are utilized by nitrogen fixing diazotrophs as their energy source. The diazotrophs provide nitrogen in a usable state to host plants to promote growth and development. An example of this association is *Azolla* (water fern) with cyanobacterium *Anabaena azollae.* A significant amount of nitrogen is fixed by Cyanobacteria in specialized cells known as heterocysts. This symbiotic association has been utilized as a biofertilizer in wetland paddies in Southeast Asia from many years. It was reported that during growing season, rice paddies are typically covered with Azolla known as bloom which fix nitrogen upto 600kg N ha^{-1} Yr^{-1}[63].

Although, symbiotic association plays a vital role in nitrogen fixation ecology worldwide but the most significant symbiotic associations are those among legumes (alfalfa, beans, clover, cowpeas, peanuts, soybean and lupines) and *Rhizobium*. In agricultural production, among all legumes, soybeans are grown on 50% of world's agricultural land and represent 68% of total legume production globally[3]. It is also known that the methanotrophic bacteria and coverered deadwood are capable for nitrogen inputs n boreal forest[64].

The symbiotic association between bacteria and host legume[65] is specific such as specific *Rhizobium* or *Bradyrhizobium* will only nodulate a limited number of plant genus. For example, *Rhizobium melilotii* could be able to nodulate alfalfa while *Rhizobium leguminosarum biovartrifolii* only able to nodulate clover (*Trifolium*). The term host specificity refers to cross inoculation group cell signaling between legume host and bacteria which is mainly due to Nod factors[65,66]. The major cross inoculation groups are mentioned in Table 2.

Regulation of N_2 fixation

Nitrogenase is an essential metalloenzyme that has specific features to convert atmospheric nitrogen into biological nitrogen. Three different nitrogenase system (molybdenum (Mo) nitrogenase, vanadium (V) nitrogenase, and iron (Fe) only) were known among the nitrogen-fixing bacteria Table: 3. It includes a catalytic protein (dinitrogenase) and an electron-transferring reductase protein (Fe protein) that transfers

Table 2. Nodule forming bacteria in specific host

S.No.	Host plant	Nodule forming bacteria
1	Sesbania	*Azorhizobium caulinodans*
2	Soybean	*Bradyrhizobium japonicum*, *Bradyrhizobium elkanii*, *Rhizobium fredii*
3	Lotus	*Mesorhizobium loti*
4	Peas	*Rhizobium leguminosarum biovar viceae*
5	Alfalfa	*Sinorhizobium melilotii*
6	Beans	*Rhizobium legumninosarum biovar phaseoli* and *Rhizobium tropici*
7	Clover	*Rhizobium leguminosarum biovar trifolii*

Table 3. Group of Nitrogenase *nif H* genes

S.No.	Groups	Genes
1	Cluster I	Mo-containing *nifH* and *vnfH*
2	Cluster II	*anfH, nifH*
3	Cluster III	A diverse group, many that are strictly anaerobes
4	Cluster IV	A divergent, loosely coherent group with *nifH*-like sequences

the electrons necessary for dinitrogen fixation. Both enzymes are highly sensitive to oxygen or inactivate nitrogenase. Furthermore, some specific genes such as nif genes control the expression of the nitrogen fixation process within plant system. Basically, *nif* gene regulon is a set of seven different operon which includes total 17 *nif* genes. Some of the important *nif* genes are *Nif A, D, L, K, F, H S, U, Y, W, Z. Nif A* is one of the essential gene which regulates the expression of further *nif* genes Fig 2. When plants have no sufficient biological nitrogen, *Ntr C* trigger *nif* A and immediately *nif* A activates all the required *nif* genes for biological nitrogen fixation. In reverse conditions (sufficient biological nitrogen) another protein encoded by *nif* L is activated which inhibit *nif* A for further processing. *Nif* K, D and H are basically codes for subunits of metal ions within nitrogenase enzyme. Dinitrogenase is a hetero-dimeric (alpha/beta) protein which is encoded by *nifK* and *nifD* gene[66]. It is studied that wide diversity of diazotroph found in marine due to *nif H* sequence variation as it contains four different groups (Table: 3)[67,68]. Similarly, the expression of V-nitrogenase enzyme is regulated by some special sets of genes (*vnfH/vnfDGK* and *anfHDGK)*[69,70].

The activity of nitrogenase enzyme is inhibited under aerobic condition (presence of oxygen)[71,72,73]. To protect the nitrogenase in marine, cyanobacteria have special arrangement of non-photosynthetic cell known as heterocyst[74] which separates the sensitive nitrogenase from oxygen producing photosynthetic reaction. There is another process such as temporal separation of photosynthesis in day and N-fixation at night is also reported in hetrocyst lacking cyanobacteria spp[75,76]. Similarly, *Trichodesmium* having a different way to protect the nitrogenase. For protection of nitrogenase, they have some special cells where no photosynthesis process is allowed[25]. An alternative way to protect the nitrogenase is well studied in aerobic soil bacterium (*Azotobacter vinelandii)* is to maintain a low intracellular oxygen concentration through a high respiration rate[61,77].

Different approach to identify the diazotrophs

The most often method used in 19th century for determination of total amount of nitrogen is Kjeldahl method. It involves acid digestion of the total tissue which converts most nitrogen-containing materials to ammonia, distillation of the ammonia into dilute acid, followed by either a colorimetric or a titrimetric determination[78,79]. Although it measures nitrogen but it does not calculate accurate nitrogen at different stages. With time various advanced analytical techniques have been developed for nitrogen determination. A simple instrument such as manometer is utilized to measure the disappearance of N_2 from a sealed system[70]. However, till late 1948, only few bacteria were recognized as N_2-fixer such as *Clostridium*, *Azotobacter*, *Nostoc* and *Rhizobium*. Furthermore, a new assay for detection of nitrogen fixing bacteria based on N isotope (15N) nitrogen enrichment was introduced[80,81,82]. This assay is about 1000-times more sensitive than the Kjeldahl method. Simultaneously, an acetylene reductase assay is discovered for nitrogen content measurement in bacteria. This assay detects the ethylene production using gas chromatography and flame-ionization detectors[83,84,85]. ARA is a simple, rapid, more accurate and cost-effective technique than ammonia production and $15N_2$ tracer method, microdiffusion and distillation methods[56]. Recently, an innovative method has been used in soybeans to increase Bradyrhizobium diazoefficiens nodulation by continuously inducing ROS using manganese ferrite nanoparticles[86]. However, this study could be applied using various nitrogen fixing bacteria to see the effect of them on cereals to enhance the BNF.

CONCLUSION AND FUTURE PROSPECTS

As per research, biological nitrogen fixation is the most significant approach for nitrogen input. It is a low-cost procedure and can replace the use of synthetic nitrogen fertilizer which has harmful effects on environment as well as on human health[87,88]. Diazotrophs is a biological source to fix the atmospheric nitrogen in terrestrial as well as in marine water[89]. Nitrogen fixation by diazotrophic bacteria is a remarkable source of fixed nitrogen into an open ocean and hence controls carbon flux and primary production. It is now established that the total global nitrogen deposition has been increased by anthropogenic activities results in destabilization of biogeochemical cycles such as nitrogen cycle. Hence, there is an urge for detailed understanding of biological nitrogen fixation process to accurately address the consequences of anthropogenic activities on nitrogen cycle. Based on the available research, it has been concluded that biological nitrogen fixation is a global phenomenon across ecosystems which significantly contributed to the nitrogen inputs in various ecosystems[90,91]. According to previous knowledge gaps, there is an urgent need to dissolve uncertainties between rates of nitrogen fixation per unit area with spatial distribution of nitrogen fixing bacterial species[92]. A framework should be proposed for better understanding of free-living nitrogen fixation and ecology of free nitrogen fixing bacterial species. We should deepen our knowledge related to different factors such as biotic and abiotic factors which have impact on diversity and abundance of nitrogen fixing bacterial species present in rhizosphere which in turn influence the rate of nitrogen fixation[93].

We conclude that biological nitrogen fixation proved to be the best technology in fixation of total nitrogen globally because of its economic and environmental benefits. Thus, in agriculture, the use and benefits of BNF can be enhanced by addition of legumes in the cropping systems[94]. Legumes have more than 3000 species with several opportunities to develop agricultural cropping systems that are both ecological sound and profitable. A study concluded that the use of diazotrophs to legumes and non-legumes can substitute 30-50% of the nitrogen demand of crops and save farmer input (by saving synthetic fertilizer) thus, it also improves overall yield (by decreasing pollution and increasing sustainability). There are some problems such as inadequate availability, non-uniformity of results, old technology and climate issues hamper the use of BNF technology by farmers on large scale. To overcome these problems and maximum use of BNF technology, nano-hybrid formulations should be developed which will improve stability, efficacy, applicability, shelf life and uniformity of product. Isolation and characterization of nitrogen fixing bacteria with pesticide degradation effeciency would be beneficial approach for improvement of agriculture[97]. Government should also encourage private sector and farmers to come forward regarding nano-hybrid formulations and evaluations to harness the maximum implementation of BNF technology. For maximum utilization of benefits of BNF for ecosystem, a comprehensive approach and better implementation of agricultural policies, legislation, better market consideration and investment of private sector will support.

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Conflict of Interest

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Authors' Contribution

Soniya Goyal- Written the manuscript; Amit Kumar- Written the manuscript; Pooja Sharma- The author has designed the concept of manuscript; Anita Rani Gill- The author has written the manuscript; Anil Kumar Sharma- The author has reviewed the manuscript; Ashwanti Devi- The author has written the oceanic diazotrophs; Chahat Sharma- The author has written the manuscript

Data Availability Statement

Authors have no issue for providing any information related to manuscript with prior request on corresponding author email.

Ethics Approval Statement

None.

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