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**EFFECTIVENESS OF *BACILLUS* AS BIOFERTILIZERS AND  
BIOPESTICIDES FOR SUSTAINABLE AGRICULTURE: AN  
OVERVIEW ON RECENT TRENDS**

**BARMAN D<sup>1</sup>, SALVIA T<sup>2</sup>, SARMA A<sup>1</sup>, SARMA J<sup>1</sup>, SINGH LS<sup>1\*</sup>**

**1:** Department of Microbiology, Assam Down Town University, Guwahati-781026, Assam,  
India

**2:** Department of Microbiology, Sikkim Manipal Institute of Medical Sciences, Sikkim  
Manipal University, Tadong, Gangtok-737102, Sikkim, India

\*Corresponding Author: Dr. Laishram Shantikumar Singh: E Mail: [sk1laishram@gmail.com](mailto:sk1laishram@gmail.com)

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**ABSTRACT**

Sustainable agricultural productivity is related to ecological, crop management, plant disease supervision as well as soil nutrient status. Plant beneficial microorganisms have been employed to augment crop production and served as substitutes to chemical fertilizers and pesticides. *Bacillus* species are the foremost plant growth-promoting bacteria. The genus, *Bacillus* has been utilized as a model organism for exploring sporulation, biofilm development, secondary metabolite production, plant root attachment etc. In addition to its various benefits for plant health, its ability to produce spores with high resilience makes it an attractive target for agricultural usage. Several of *Bacillus* spp. produce plethora of metabolites which activate plant growth and avert infection by pathogens. They also provide safeguard against hostile environmental circumstances. A number of *Bacillus* species, including *B. thuringiensis*, *B. subtilis* and others, have potential effects on plant development and stress resistance. Numerous studies on the effects of several *Bacillus* species, particularly *Bacillus thuringiensis*, on promoting plant development have been conducted during the past several years with a noticeably increased rate of phosphate solubilization in addition to its biopesticide action. The effectiveness of the *Bacillus* species as a potential biopesticide will be outlined in this review.

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Additionally, a few currently marketed *Bacillus* based biopesticides and some of the most current developments of *Bacillus* based biofertilizer and its efficacy in the area of agricultural advancement and the environment friendliness will also be covered.

**Keywords: *Bacillus*, Biopesticide, Biofertilizer, Sustainable agriculture**

## INTRODUCTION

Biofertilizers are the materials comprising of microorganisms which has the potential to augment plant nutrient acquisition by colonizing the rhizosphere and make the nutrients readily available to plant root hairs. Biofertilizer improves soil fertility variety and plays a critical role in organic farming practice. They are currently regarded as environmentally favourable soil input for sustainable agriculture. To achieve the desired goal of increasing crop output, it is essential to consider soil quality, nutrient availability, environmental conditions, and the biological health of the soil [1]. Plant nutrients play a crucial role in sustainable agriculture since they are required for the growth of wholesome crops for the world's rising population. Using the right fertilisers to supply plants' necessary nutrients will increase crop production. The amount of nutrients that fertilisers offer depends on their nature; each type of fertiliser has benefits and drawbacks for soil fertility and crop growth. An improved and protected environment must be the goal of fertiliser management. Thus, it is necessary to follow a balanced fertilisation strategy [2]. To be precise, biofertilizers are substances that have living microorganisms in them; these

organisms colonise the rhizosphere of the plant and boost the supply or availability of primary nutrients and/or growth stimuli for the target crop. Many different types of soil bacteria colonise primarily in the rhizosphere of plants. Plant growth-promoting rhizobacteria (PGPR) is the collective name for these group of bacteria. Some PGPR act as biofertilizers to aid in the growth of plants. Microorganisms which act as biofertilizers are the nitrogen fixers, phosphate solubilizers etc. The manufacturing of biofertilizers makes use of microorganisms like *Bacillus* [3]. *Bacillus* is one of the most commonly used genera in agriculture because it has a number of mechanisms that make it a biofertilizer and a biopesticide. While a plant is growing, *Bacillus* can exert multiple direct and indirect effects concurrently. The ability to absorb nutrients such as nitrogen, phosphate, potassium, and minerals, as well as the ability to modify plant hormone levels, are examples of the direct methods. The indirect techniques include inducing pathogen resistance or the release of antagonistic chemicals to prevent plant diseases [4]. *Bacillus* has been used as a model organism to research the generation

of secondary metabolites, sporulation, biofilm growth, attachment to plant roots, and other processes. A promising target for agricultural use, in addition to its many advantages for plant health, is its capacity to produce spores with high resistance. Due of spores' strong resistance to abiotic stressors such nutritional deficiency, temperature change, and drought, *B. subtilis* becomes convenient to work on [5]. *B. thuringiensis* is one of the most widely used biopesticides in the world. By highlighting the genus *Bacillus*, one of the most commonly utilised microbes for this purpose, it is crucial to visualise the contributions of microorganisms in agriculture from this point of view [6]. Bio-fungicidal *Bacillus* spp. are crucial in the increase of biotic and abiotic stress [7]. The selection of bio-fungicidal *Bacillus* spp. must be carried out meticulously as well as carefully because there exists a correlation between PGPR traits and antimicrobial resistance, thereby suggesting that they have modified the drug resistance mechanism to gain tolerance in stress and tough environmental conditions [8]. *B. subtilis* colonisation of roots is advantageous to the bacteria and the host plant. A third of the fixed carbon that plants create is secreted through root exudates. By colonising the roots, bacteria supply a source of nutrients, and in return, plants receive bacterial chemicals and activities that promote plant growth and protect their

hosts from stress [9]. *B. subtilis* displays both a direct and indirect biocontrol mechanism to overcome plant diseases. This mechanism may be by the secretion of several secondary metabolites, hormones, cell-wall-degrading enzymes as well as antioxidants which help the plant in its protection towards the attack by pathogens. The indirect mechanisms are the triggering of plant progress and the initiation of acquired systemic resistance. This organism can also solubilize soil P, improve nitrogen fixation, and release siderophores that promote its growth and overturns the advancement of pathogens. *B. subtilis* boosts stress tolerance in their plant hosts by bringing the expression of genes needed for stress-response, phytohormones, and stress-mediated metabolites [9]. In the past two decades, extensive research has been done on the impact of various *Bacillus* species, notably *B. thuringiensis*, on boosting plant development. In addition to its biopesticide activity, *B. thuringiensis* exhibits a substantially higher rate of phosphate solubilisation [10].

Microbial interaction with plants and the role played by microbes are the features emphasized in order to produce biofertilizers. Many microorganisms employed as bio-fertilizer are usually isolated from rhizosphere that is in interaction with root system of plants. In this context it is pertinent to mentioned that

*Bacillus* species obtained from tomato rhizosphere and identified as PGPR, could boost growth of tomato plants [11]. Environmentally friendly approach such as use of microbial biopesticides and bio-fungicides are being opted in order to combat plant diseases and pests. In this regard, generation of bioformulations, which are made from *Bacillus* having PGPR traits along with biocontrol activity, is exceptional among these options, and their use is continuously rising [12].

#### **BACILLUS AS BIOCONTROL AGENT AND BIOFERTILIZER**

Plant diseases damage the output, quality as well as safety of agricultural products which leads to economic losses. The undesirable harmful cause by application of fungicides of chemical origin is a concern for farmers, and global population. Furthermore, the advent of phytopathogens gaining resistance to regularly used fungicides underpins the requirements for new approaches to tackle them. In this regard biological control agents offers a deserving attention as an alternative due to its safeness and environmental-friendliness features. In a broader sense, biological control agents emphasize the application of living organisms, like plants, insects as well as microorganisms, to curb the unwanted effects due to pathogens or pests. In this context, *Bacillus*-based biocontrol agents have appeared as an approach to exterminate or diminish the use

of synthetic fungicides that are considered harmful to well-being and the eco-system. For example, *B. subtilis* exhibits biocontrol activity to which indirect processes can be attributed. Additionally, there is evidence that *B. subtilis* grows on plant roots as an endophyte. *B. subtilis*'s ability to induce cell lysis, the ability to build biofilms, plant growth promotion (PGP), competition for nutrients and colonisation sites, ability to cause systemic resistance, and other indirect processes are linked to its biocontrol efficacy against plant diseases [9]. The bio-fungicide *Bacillus* is extremely important in contemporary agriculture. A key role in supporting sustainable agriculture may be played by *B. velezensis* strain Lle-9, which has broad-spectrum antifungal activity against *Botryosphaeria dothidea*, *Fusarium oxysporum*, *Fusarium fujikuroi*, and *Botrytis cinerea* as well as several plant growth-promoting features. Some strains of *B. velezensis* have been used in agriculture as biological control agents and plant growth promoters as a result of these qualities [13]. It is of paramount significance to mentioned here that *B. velezensis* P1 exhibits potential as biofungicide against Ochratoxin A producing pathogen, *Aspergillus carbonarius* throwing a light on the opportunity to harvest grapes devoid of ochratoxin and to deliver superior wines [14]. Another *Bacillus* species, *B. siamensis* CNE6, exhibits remarkable reduction in the

quantity of phytopathogens such as *R. stolonifer*, *C. lunata*, and *F. oxysporum*. *A. alternata*, *H. compactum*, *C. accutatum*, *f. sp. pisi* [15]. Some of other significant *Bacillus* and their exemplary potential are being discussed below.

***B. megaterium*:** *B. megaterium* has been very classically highlighted to phosphate-dissolving biofertilizer and can solubilize the free phosphate. When biofertilizer is produced using charcoal as a carrier, the bacteria can receive the appropriate nourishment they need to survive. After six months, the biofertilizer's cell count, of  $5 \times 10^{13}$  CFU, is sufficient enough to exert its potential in the field. *B. megaterium* with charcoal can be utilised commercially since the cell count remains suitable stable after six months [16]. Furthermore, *B. megaterium* mj1212's capacity to dissolve phosphate was improved by ideal culture conditions at pH 7.0 and 35 °C, when subjected to culture medium containing malic and quinic acid. An increase in shoot length, root length, and fresh weight of plants were indicators of *B. megaterium* mj1212's favourable effects on mustard plants [17]. By secreting organic acids like oxalic, citric, gluconic, humic, and acetic and changing phosphorous forms from unprepared forms to plant-available ones, it has the capacity to increase the solubility of phosphate compounds in the soil. The interaction between such a bio-fertilizer and

yeast has demonstrated that the treatment obtained by spraying yeast on the vegetative part has much outperformed the treatment obtained by omitting yeast. The role of yeast in boosting the percentage of nitrogen and phosphorus in the vegetative development is assumed to be the reason for such increase efficacy [18].

***B. amyloliquefaciens*:** *B. amyloliquefaciens* may colonise the rhizosphere of plants and thrive in stressful environments. It has been looked into as a non-toxic, environmentally friendly way to promote plant growth. *B. amyloliquefaciens* strains can stimulate plant growth in a variety of ways. For instance, the fungal phytopathogens were strongly inhibited by the *B. amyloliquefaciens* strains B1, B5, and B21 [19]. Reduced chlorophyll content, increased proline accumulation, and enrichment of osmo-protectant using microbes in the rice rhizosphere are some possible mechanisms by which *B. amyloliquefaciens* NBRISN13 treatment to rice under hydroponic and soil conditions which can reduce salt stress [20]. Optimising the ambient and dietary elements to allow *B. amyloliquefaciens* ON261680.1 to remove 99.84% of the lead through bioremediation. It is an ideal new lead-resistant bacterium that has been discovered in industrial effluents [21].

***B. thuringiensis*:** *B. thuringiensis*, a soil-based bacterium is well for its ability to

control insect and pest populations in addition to treating plant diseases. A powerful phosphate-solubilizing agent, *B. thuringiensis* also produces a wide spectrum of compounds that are advantageous to plant growth and ultimately crop yield. Additionally, it can be used as a biofertilizer or commercial biostimulator to promote plant growth in general. *B. thuringiensis* strains have characteristics that help promote plant growth which are shared by other prominent PGPB. The synthesis of phytohormones like IAA (indole acetic acid) and ACC-deaminase, biological nitrogen (N<sub>2</sub>) fixation, ammonia (NH<sub>3</sub>) generation, phosphate solubilization, formation of siderophores, and production of volatile organic compounds are among the properties documented for *B. thuringiensis*

that promote plant growth [22]. In the past two decades, extensive research has been done on the impact of various *Bacillus* species, notably *B. thuringiensis*, on boosting plant development. In addition to its biopesticide activities, *B. thuringiensis* has reportedly demonstrated a significantly greater rate of phosphate solubilization. When co-inoculated with mycorrhiza in pot settings, *B. thuringiensis* has shown to boost drought tolerance and oxidative metabolism of *Lavandula* plants. In addition to leguminous plants like pea or lentils, *B. thuringiensis* can also colonise rice, cabbage, and cotton as endophytes [23]. Some of the commercially available biopesticides of *Bacillus* origin are highlighted below in **Table 1**.

**Table 1: Some commercially available *Bacillus* based Biopesticides [24, 25]**

Sl. No	Name of <i>Bacillus</i>	Action	Brand Name
1	<i>B. amyloliquefaciens</i>	Fungicide	Serifel, Integral, Taegro, Seranade, Companion, Maxxx, Amylo-X, Aveo
2	<i>B. subtilis</i>	Fungicide	Cilius, Kodiak, Biotilis
3	<i>B. thuringiensis</i> var. <i>aizawai</i> <i>B. thuringiensis</i> var. <i>israelensis</i>	Insecticide Insecticide	Xen Tari, Agree, Turex, Solbit, Bactimos Teknar, VectoBac, VectoMax, Aquabac, Bacticide, BTI granules
4	<i>B. thuringiensis</i> var. <i>kurstaki</i>	Insecticide	Dipel, Foray, Cordalene, Lipel SP, Lipel, Biolep, BMP 123, Baturad, Belthirul, Deliver, Delfin, Condor, Crymax, Javelin WG, Lepinox WG, Turex, Turicide, Safer BTK, Rapax, Lepinox plus
5	<i>B. thuringiensis</i> var. <i>tenebrionis</i>	Insecticide	Novodor
6	<i>B. pumilus</i>	Fungicide	Yield Shield, Sonata AS, Ballad Plus
7	<i>B. sphaericus</i>	Insecticide	VectoLex

## RECENT DEVELOPMENTS IN *BACILLUS* BIOFERTILIZERS

*B. subtilis* CH008 which is environmentally acceptable and proven potential as biofertilizer may be use as a replacement for

chemical fertiliser [26]. The outcome of this biofertilizer's impact on tomatoes and soil activities demonstrates that the newly developed biofertilizer has no negative effects on the advantageous soil activities.

When compared to the control and NPK treatment, the biofertilizer made from *B. subtilis* enzymes demonstrated a higher amount of soil respiration. There is a growing market for algae-based wastewater remediation for the manufacturing of biofertilizers, and this aspect has enormous potential. Since algae growing are a carbon-absorbing process while the manufacture of chemical fertiliser releases a significant quantity of CO<sub>2</sub> into the atmosphere, using algal biofertilizer can substantially reduce greenhouse effect. Furthermore, even if *Bacillus* sp., which are extensively distributed in the environment, cropland, and water, reach the soil and water via wastewater or irrigation water, they won't trigger a biological invasion [27]. By using cotton straw biochar (a charcoal-like substance made from plant materials) and *Bacillus* compound biofertilizer, it is possible to improve soil C/N ratio, soil enzyme activities, and the synthesis of L-histidine, L-valine, and L-isoleucine as well as organic acid compounds like D-pantothenic acid, caffeic acid, and ferulic acid. It is also possible to decrease the amount of Cd that is available in Cd-contaminated alkaline soil by encouraging the conversion of exchangeable and carbonate-bound Cd into residual Cd and boosting the quantity and metabolites of dominating bacteria in soil, the use of cotton straw biochar and *Bacillus* compound

biofertilizer could increase the tolerance of cotton to Cd stress [28]. The accomplishment of commercial carrier-based biofertilizer strongly depends on formulation which directs the shelf live and cell viability as well. The addition of several zeolite and liquid inoculants in any population of biofertilizer influence the total count as indicated by a study conducted by Hindersah *et al* [29] where it was observed that the *Bacillus* and *Azotobacter* counts were increased after treatment with zeolites and liquid mixed inoculant. In rice cultivation early growth is generally sluggish in direct seeded system. The approach to overwhelmed this difficulty can be addressed by application of biofertilizers as substantiated by a study conducted by Agake *et al* [30] where in the potential of *B. pumilus* TUAT1 based biofertilizer has been discussed. The efficacy of Kikuichi - a biofertilizer comprising of *B. pumilus* TUAT1 spore in encouraging rice growth in a direct sowing system indicates that rice seeds coated with Kikuichi powder along with poly (vinyl) alcohol followed by another coating with calcium peroxide, molybdenum (Benmoly), and iron powder enhances early growth of rice plant in direct sowing system. The suitable and successful timing of application of the coating, has been highlighted mainly at the sprouting stage prior to the emergence of coleoptile [30]. Certain reports emphasize the potential

of *B.subtilis* biofertilizer in reducing volatilization of Ammonia and enhance the copiousness of functional genes and ammonia-oxidizing bacteria [31]. In a previous study from China, it has been observed that Biofertilizers, such as *Bacillus* (TTB biofertilizer comprising of *B. amyloliquefaciens*, *B. licheniformis* and *B. subtilis* along with polyglutamic acid at concentrations exceeding 4200 mg/L as per manufacturer guideline) and microalgae (VZ biofertilizer) attractively promoted biomass accumulation of biomass, especially in the underground parts of medicinal plant, *Salvia miltiorrhiza*, and expressively improved the quality of the rhizome by enhancing bioactive compound buildup and reducing Pb uptake [32]. The study reported by Sodip et al [33] illustrated the significant effect of application of biofertilizer of *Bacillus* and *Lysinibacillus* sp. on Paprika Plants (*Capsicum annum* L). on plant nutrient content and production. It has been reported by Seerat et al [34] suggesting that *Bacillus* spores (*B. pumilus*, *B. altitudinis*, and *B. megaterium*) could bring about inducement of growth in paddy rice by physical contact of spore-specific residues, such as peptidoglycan or polysaccharides, with the root cells. There are report regarding the application of biofertilizer such as *B. pumilus* TUAT1 spores which leads to improvement in plant development, yield as well as providing

resistance to lodging with respect to forage rice. The study further highlights the enhancement of plant development led to upsurges of not only produce components like the total panicle number and the spikelets number in a panicle in rice cultivar LTAT-29 but also the straw harvest and quality as well. The resistance to lodging of these forage rice plants were reported to be better because of the amplified root progress and photosynthesis producing harder culms [35].

## CONCLUSION

Agricultural practices face a number of difficulties, notably dealing with stress and the demand for vital fertilisers and manures. Pesticide and chemical fertiliser use has resulted in a progressive deterioration of soil quality, which ultimately causes significant crop losses each year. The crops must endure biotic and abiotic stress, which has an impact on crop production globally. Effective methods for reducing crop yield losses and controlling plant diseases should be supported in order to overcome such challenges in agricultural practices and to advance the goal of sustainable farming. By highlighting the genus *Bacillus*, one of the most predominant bacteria utilised for this purpose, it is crucial to visualise the contributions of beneficial microorganisms in agriculture. It has been revealed that the biocontrol potential of genus *Bacillus* play a significant role in the dealing with biotic and

abiotic stress and also exhibited stress-tolerance features.

The selection of *Bacillus* for overall agricultural avenues must be relied on logical data, meticulous features as there occurs a correlation between PGPR traits and antimicrobial resistance, thereby signifying that these marvellous organisms often adopt the drug resistance mechanism to attain tolerance in stress and hard ecological set ups. The use of *Bacillus* based biofertilizer has been the subject of several studies on productivity improvement, rhizosphere management, plant development, nodulation, nitrogen fixation, nutrient uptake, and seed production of a variety of plants, including mustard, soybean, cowpea, mung bean, and okra plants. The assessment of environmental risk is an imperative task for examining the hazards of agricultural application of bacteria in the environment. It is presumably true that microorganisms employed in agriculture are often expected to be in contact with human beings as remainders on crops taken for food and therefore in this context it is reasonable that such organisms do not cause ailments. In this regard, most *Bacillus* species are not pathogenic with only few species within the *B. cereus* group considered to be pathogenic. However, it is apt to underline the simplicity to distinguished amongst the pathogenic and non-pathogenic *Bacillus* species. The use of

microorganisms in agriculture must be guided by stringent protocols and regulations after thorough validations by authorised agencies. The use of microbial based formulations in agriculture needs to be encouraged to lessen the overall use and menace of chemical pesticides and this will confidently swift up the approval procedure and ensure the stronger rooting in fundamentals of microbiological science. The organic farming approach by use of biofertilizers especially *Bacillus* would be ecologically beneficial as far as sustainable agriculture is concern. The *Bacillus* based biofertilizers or the biopesticides are thus regarded as convenient as their large-scale production process is easier, cost is low, and the application is simple and easy storage. The genus *Bacillus* has been attaining increased successes towards addressing the challenges of agriculture globally. Therefore, this communication further reiterates and endorses the adoption of an environmentally welcoming system of farming, such as the use of biofertilizers based on *Bacillus* species, which is central to preserving soil quality and reviving soil status while also improving harvest quality.

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## REFERENCES

- [1] Kumar S, Diksha, Sindhu S. S, Kumar R. Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. *Current Research in Microbial Sciences*, 2022, 3, 100094. <https://doi.org/10.1016/j.crmicr.2021.100094>
- [2] Mazumdar M, Sultana T, Sinha S, Sadhukhan, S, Datta A, Mandal M, Mitra A. K. Comparison of a novel combination of bio-organic fertilizers vis-a-vis a chemical fertilizer. *Indian Journal of Biochemistry & Biophysics*, 2022, 59: 197-204.
- [3] Jain G. Biofertilizers - A way to organic agriculture. *Journal of Pharmacognosy and Phytochemistry*, 2019, SP4: 49-52.
- [4] Sansinenea E. *Bacillus* spp.: As Plant Growth-Promoting Bacteria. In *Secondary Metabolites of Plant Growth Promoting Rhizomicroorganisms*, Springer Singapore, 2019, 225–237. [https://doi.org/10.1007/978-981-13-5862-3\\_11](https://doi.org/10.1007/978-981-13-5862-3_11)
- [5] Blake C, Christensen M. N, Kovacs A. T. Molecular Aspects of Plant Growth Promotion and Protection by *Bacillus subtilis*. *Molecular Plant-Microbe Interactions*, 2021, 34(1): 15-25. <https://doi.org/10.1094/MPMI-08-20-0225-CR>
- [6] Ortiz A, Sansinenea E. The Role of Beneficial Microorganisms in Soil Quality and Plant Health. *Sustainability*, 2022, 14 (9): 53-58. <https://doi.org/10.3390/su14095358>
- [7] Mehmood S, Muneer M. A, Tahir M, Javed M. T, Mahmood T, Afridi M. S, Pakar N. P, Abbasi H. A, Munis M. F. H, Chaudhary H. J. Deciphering distinct biological control and growth promoting potential of multi-stress tolerant *Bacillus subtilis* PM32 for potato stem canker. *Physiology and Molecular Biology of Plants*, 2021, 27(9): 2101-2114. <https://doi.org/10.1007/s12298-021-01067-2>
- [8] Wash P, Batool A, Mulk S, Nazir S, Yasmin H, Mumtaz S, Alyemeni M. N, Kaushik P, Hassan M. N. Prevalence of Antimicrobial Resistance and Respective Genes among *Bacillus* spp., a Versatile Bio-Fungicide. *International Journal of Environmental Research and Public*

- Health, 2022, 19 (22), 14997.  
<https://doi.org/10.3390/ijerph192214997>
- [9] Hashem A, Tabassum B, Fathi Abd\_Allah E. *Bacillus subtilis*: A plant-growth promoting rhizobacterium that also impacts biotic stress. Saudi Journal of Biological Sciences, 2019, 26 (6): 1291-1297.  
<https://doi.org/10.1016/j.sjbs.2019.05.004>
- [10] Bandopadhyay, S. Application of Plant Growth Promoting *Bacillus thuringiensis* as Biofertilizer on *Abelmoschus esculentus* Plants under Field Condition. Journal of Pure and Applied Microbiology, 2020, 14 (2): 1287-1294.  
<https://doi.org/10.22207/JPAM.14.2.24>
- [11] Sarbani N.M.M, Yahaya N. Advanced Development of Bio-fertilizer Formulations Using Microorganisms as Inoculant for Sustainable Agriculture and Environment-A Review. Malaysian Journal of Science, Health & Technology, 2022, 8(1): 92-101,  
<https://doi.org/10.33102/2022228>
- [12] Borriss, R. Use of Plant-Associated *Bacillus* Strains as Biofertilizers and Biocontrol Agents in Agriculture. Bacteria in Agrobiolology: Plant Growth Responses, 2011, 41-76. Springer Berlin Heidelberg.  
[https://doi.org/10.1007/978-3-642-20332-9\\_3](https://doi.org/10.1007/978-3-642-20332-9_3)
- [13] Khan M. S, Gao J, Chen X, Zhang M, Yang F, Du Y, Moe T. S, Munir I, Xue J, Zhang X. The Endophytic *Bacteria Bacillus velezensis* Lle-9, Isolated from *Lilium leucanthum*, Harbors Antifungal Activity and Plant Growth-Promoting Effects. Journal of Microbiology and Biotechnology, 2020, 30 (5):668-680.  
<https://doi.org/10.4014/jmb.1910.10021>
- [14] Niewierowski T.H, Veras F.F, Silveira R.D, Giocastro B, Aloisi I, Tranchida P. Q, Dugo P, Brandelli A, Zini C.A, Welke J.E. A *Bacillus*-based biofungicide agent prevents ochratoxins occurrence in grapes and impacts the volatile profile throughout the Chardonnay winemaking stages. International Journal of Food Microbiology, 2023, 16;389:110107.  
<https://doi.org/10.1016/j.ijfoodmicro.2023.110107>
- [15] Gorai P. S, Ghosh R, Mandal S, Ghosh S, Chatterjee S, Gond S. K, Mandal N.C. *Bacillus siamensis* CNE6- a multifaceted plant growth

- promoting endophyte of *Cicer arietinum* L. having broad spectrum antifungal activities and host colonizing potential. *Microbiological Research*, 2021, 252: 126859. <https://doi.org/10.1016/j.micres.2021.126859>
- [16] Patel G, Singh S, Saxena S.K, Kaur K.J. Isolation, Biochemical Characterization and Production of Biofertilizer from *Bacillus megaterium*. *The International Journal of Life-Sciences Scientific Research*, 2016, 2 (6), <https://doi.org/10.21276/ijlssr.2016.2.6.16>
- [17] Kang S. M., Radhakrishnan, R., You, Y.-H., Joo, G.-J., Lee, I.-J., Lee, K.-E., & Kim, J.-H. Phosphate Solubilizing *Bacillus megaterium* mj1212 Regulates Endogenous Plant Carbohydrates and Amino Acids Contents to Promote Mustard Plant Growth. *Indian Journal of Microbiology*, 2014, 54 (4): 427-433. <https://doi.org/10.1007/s12088-014-0476-6>
- [18] Mahdi Abdul-Hussein H. Hassan, K.U. Effect of the Biofertilizer (*Bacillus Megaterium*) and the Addition of Yeast Spraying on the Vegetative growths in Phosphorous Availability, Growth and Yield of Onions (*Allium Cepa* L.). *Bionatura*, 2021, 13, <https://doi.org/10.21931/RB/xxx>
- [19] Luo L, Zhao C, Wang E, Raza A, Yin C. *Bacillus amyloliquefaciens* as an excellent agent for biofertilizer and biocontrol in agriculture: An overview for its mechanisms. *Microbiological Research*, 2022, 259, 127016. <https://doi.org/10.1016/j.micres.2022.127016>
- [20] Nautiyal C. S, Srivastava S, Chauhan P.S, Seem K, Mishra A, Sopory S. K. Plant growth-promoting bacteria *Bacillus amyloliquefaciens* NBRISN13 modulates gene expression profile of leaf and rhizosphere community in rice during salt stress. *Plant Physiology and Biochemistry*, 2013, 66: 1-9. <https://doi.org/10.1016/j.plaphy.2013.01.020>
- [21] Emara N.S, Elwakil B. H, Zakaria M, Olama Z. A. Mechanistic action of lead removal by the native isolate *Bacillus amyloliquefaciens* ON261680.1. *Arabian Journal of Chemistry*, 2023, 16 (8): 104962. <https://doi.org/10.1016/j.arabjc.2023.104962>

- [22] Gomis Cebolla J, Berry C. *Bacillus thuringiensis* as a biofertilizer in crops and their implications in the control of phytopathogens and insect pests. *Pest Management Science*, 2023, 79 (9): 2992-3001. <https://doi.org/10.1002/ps.7560>
- [23] Bandopadhyay S. Application of Plant Growth Promoting *Bacillus thuringiensis* as Biofertilizer on *Abelmoschus esculentus* Plants under Field Condition. *Journal of Pure and Applied Microbiology*, 2020, 14 (2): 1287-1294. <https://doi.org/10.22207/JPAM.14.2.24>
- [24] Ortiz A, Sansinenea E. The Role of Beneficial Microorganisms in Soil Quality and Plant Health. *Sustainability*, 2022, 14(9): 5358. <https://doi.org/10.3390/su14095358>
- [25] Ortiz A, Sansinenea E. Microbial-based biopesticides: commercialization and regulatory perspectives. *In: Development and Commercialization of Biopesticides: Cost and Benefits.* (Editor,. Koul O) Academic Press, UK. Elsevier, 2023. Pp: 103-118.
- [26] Oluwaseun A.C, Phazang P, Sarin N.B. Production of ecofriendly biofertilizers produced from crude and immobilized enzymes from *Bacillus subtilis* CH008 and their effect on the growth of *Solanum lycopersicum*. *Plant Archives*, 2018, 18 (2): 1455-1462.
- [27] Zou Y, Zeng Q, Li H, Liu H, Lu Q. Emerging technologies of algae-based wastewater remediation for biofertilizer production: a promising pathway to sustainable agriculture. *Journal of Chemical Technology & Biotechnology*, 2021, 96 (3): 551-563. <https://doi.org/10.1002/jctb.6602>
- [28] Zhu Y, Zhong M, Li W, Qiu Y, Wang H &Lv X. Cotton straw biochar and *Bacillus* compound biofertilizer decreased Cd migration in alkaline soil: Insights from relationship between soil key metabolites and key bacteria. *Ecotoxicology and Environmental Safety*, 2022, 232, 113293. <https://doi.org/10.1016/j.ecoenv.2022.113293>
- [29] Hindersah R, Rahmadina I, Harryanto R, Suryatmana P, Arifin M. *Bacillus* and *Azotobacter* counts in solid biofertilizer with different concentration of zeolite and liquid inoculant. *IOP Conference Series: Earth and Environmental Science*, 667(1), 2021, 012010. <https://doi.org/10.1088/1755-1315/667/1/012010>

- [30] Agake S, Artigas Ramirez M.D, Kojima K, Ookawa T, Ohkama-Ohtsu, N, Yokoyama T. Seed coating by biofertilizer containing spores of *Bacillus pumilus* TUAT1 strain enhanced initial growth of *Oryza sativa* L. *Agronomy Journal*, 2021, 113(4): 3708-3717. <https://doi.org/10.1002/agj2.20747>
- [31] Sun B, Bai Z, Bao L, Xue L, Zhang S, Wei Y, Zhang Z, Zhuang G, Zhuang X. *Bacillus subtilis* biofertilizer mitigating agricultural ammonia emission and shifting soil nitrogen cycling microbiomes. *Environment International*, 2020, 144, 105989, <https://doi.org/10.1016/j.envint.2020.105989>
- [32] Wei X, Bai X, Cao P, Wang G, Han J, Zhang Z. *Bacillus* and microalgae biofertilizers improved quality and biomass of *Salvia miltiorrhiza* by altering microbial communities. *Chinese Herbal Medicine*, 2023, 15(1): 45-56, <https://doi.org/10.1016/j.chmed.2022.01.008>
- [33] Sodiq A. H, Setiawati M.R, Santosa D. A & Widayat D. The Effect of Bio-Fertilizer Applications *Bacillus cereus* and *Lysinibacillus sp.* On Paprika Plants (*Capsicum annuum* L) On Plant Nutrient Content and Cultivation Media. *IOP Conference Series: Earth and Environmental Science*, 2022, 978 (1), 012032. <https://doi.org/10.1088/1755-1315/978/1/012032>
- [34] Seerat A Y, Ookawa T, Kojima K, Ohkama-Ohtsu N, Maeda M, Djedidi S, Habibi S, Sekimoto H, Abe A, Yokoyama T. Evaluation of the effects of spores and their heat-treated residues from different *Bacillus* strains on the initial growth of rice plants. *Soil Science and Plant Nutrition*, 2019, 65: 122-136. <https://doi.org/10.1080/00380768.2018.1551042>
- [35] Agake S, Ohwaki Y, Kojima K, Yoshikawa E, Ramirez MDA, Bellingrath-Kimura SD, Yamada T, Ookawa T, Ohkama-Ohtsu N, Yokoyama T. Biofertilizer with *Bacillus pumilus* TUAT1 Spores Improves Growth, Productivity, and Lodging Resistance in Forage Rice. *Agronomy*, 2022, 12(10): 2325; <https://doi.org/10.3390/agronomy12102325>