VOLUME - XI, ISSUE - I - JANUARY - MARCH - 2022
AJANTA - ISSN 2277 - 5730 - IMPACT FACTOR - 6.399 (www.sjifactor.com) CC - 4

7. Endophytic Microorganisms: Important Role in Sustainable Environment & Agriculture - A Review

Nilkanth S. Bhalerao
Assistant Professor, Department of Microbiology, Khare-Dhere-Bhosale College, Guhagar, Maharashtra-India.
D. C. Kamthane
Professor, Department of Microbiology, Shri Guru Buddhiswami Mahavidyalaya, Purna, Maharashtra-India.
Santosh V. Jadhav
Assistant Professor, Department of Microbiology, Khare-Dhere-Bhosale College, Guhagar, Maharashtra-India.

Abstract

To meet the food demand of ever-growing global human population, agricultural practices are largely relied on the application of chemical fertilizers. Chemical fertilizers synthesis highly contributes in Global warming through greenhouse gases production. To feed the overgrowing human population as well as to maintain the global environmental & agricultural sustainability, understanding of soil complex is primarily important not only to supply sufficient food but also to maintain global environmental sustainability for upcoming generations. Soil microbial population has immense potential in attaining the agricultural sustainability in present environmental conditions Endophytic microorganisms are ubiquitous in most plant species, residing latently or actively colonizing plant tissues locally as well as systemically. Endophytes will be defined as those microorganisms that can be isolated from surface-disinfested plant tissue that do not visibly harm the plant. Historically, endophytic microorganisms have several beneficial effects on host plants such as plant growth promotion and increased resistance against plant pathogens and parasites. Phosphate solubilisation, biological N_2 fixation, production of siderophore & production of plant-growth substances used by endophytes for growth promotion of crops. Synthesis of antimicrobial compounds are the tools of endophytes to use for crop protection. Hence, it's high time to explore nonconventional resources for the development of sustainable crop production technologies without damaging the environmental sustainability.

Key Words: Chemical fertilizers, Agriculture Sustainability, Environmental Sustainability, Endophytic Microorganisms, Plant Growth Promoting Compounds.

1. Introduction

Today's world facing immense challenge in agriculture sector particularly for the production of environmentally sound and sustainable crops. Large amount of chemical fertilizers and pesticides are used for enhancing agricultural yield to fulfil the demands of ever-increasing population. Since this has placed a considerable burden on the agriculture, ecologically safe alternatives are required to improve productivity and sustainability in agriculture [1]. One of the options is the use of microorganisms, as they have huge potential, thereby reducing the consumption of chemical fertilizers [2].

Soil microorganisms provide several benefits to agriculture through improving plant nutrient availability, plant health, and soil quality [3]. Endophytes are defined as microorganisms, commonly bacteria and fungi which live the whole or some stage of their life cycle in inner plant cells without expressing any adverse effect. Owing to the potential role of endophytic bacteria in plant-growth promotion and disease management properties, endophytes can be used as bioinoculants in agriculture to increase crop productivity. Many reports are available with regard to the application of endophytic bacteria to enhance the plants resistance to disease and promote plant growth. Thus, employing endophytes in agricultural practices would result in better soil health and sustainable crop production [4].

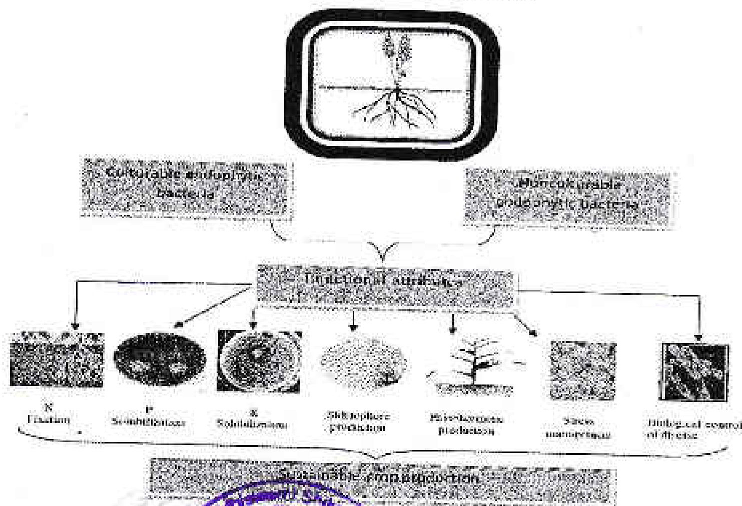

Fig: Role of Endophytic Bacteria for Sustainable Agriculture [5]

2. Diversity & Distribution of Plant Associated Endophytes

Sr.No	Endophytic Microorganism	Plant Species	Reference
1	*Pseudomonas putida, Bacillus pumilus, Aureobacteriumsaperdae, Burkholderia solanacearum,* and *Phyllobacterium rubiacearum*	Cotton	Chen et al., (1995)
2	*α-Proteobacteria: Erwinia sp., Agrobacterium sp. γ-Proteobacteria: Pseudomonas citronellolis, P. oryzihabitans, P.stamnea, K. pneumoniae, K.oxytoca, Enterobacter sp., Pantoea sp., P. agglomerans Firmicutes,Bacillus fastidiosus*	Soybean	Zinniel et al. (2002); Kuklinsky-Sobral et al., (2004)
3	*Achromobacter xylosoxidans, Alcaligenes sp*	Sunflower	Forchetti et al., (2007)
4	*β-Proteobacteria: Burkholderia cepacia γ-Proteobacteria: Klebsiella sp. Firmicutes: Bacillus polymyxa Actinobacteria: Mycobacterium sp.*	Wheat	Balandreau et al., (2001), Zinniel et al., (2002), and Iniguez et al.,(2004)
5	*Bacillus and Sphingopyxis*	Strawberry	Dias et al., (2009)
6	*γ-Proteobacteria: Pseudomonas sp., P. syringae, P. aeruginosa, Escherichia coli,Firmicutes: Brevibacillus brevis*	Tomato	Pillay and Nowak (1997),Yang et al., (2011), and Patel et al., (2012)
7	*Trichoderma citrinoviride,Paecilomyces marquandii, Acremonium furcatum, Cylindrocarpon pauciseptatum, and Chaetomium globosum*	Actinidia macrosperma	Lu et al., (2011)
8	*Aspergillus niger, A. flavus, A. nidulans, Penicillium chrysogenum, P. citrinum, Phoma, Rhizopus, Colletotrichum, Cladosporium, and Curvularia*	Cannabis sativa	Gautam et al., (2013)
9	*Ramichloridium cerophilum*	Chinese cabbage	Xie et al., (2016)
10	*α-Proteobacteria: Rhizobium etli β-Proteobacteria: Burkholderia pickettii, B. cepacia, Achromobacter, Herbaspirillum seropedicae γ-Proteobacteria: Erwinia sp., Enterobacter sp., E. cloacae, Stenotrophomonas sp., Klebsiella sp., K. terrigena, K. pneumoniae, K. variicola, Pseudomonas sp., P. aeruginosa, P. fluorescens Firmicutes: Bacillus sp., B. mojavensis, B. thuringiensis, B. megaterium, B. subtilis, B. pumilus, Lysinibacillus, Paenibacillus Actinobacteria Corynebacterium sp., Arthrobacter globiformis, Microbacterium testaceum*	Maize	Fisher et al., (1992), McInroy and Kloepper (1995), Palus et al., (1996), Chelius and Triplett(2001), Zinniel et al., (2002), Rosenblueth and Martinez Romero (2004), and Rai et al., (2007)

Endophytes may enter the interior of the root through auxin-induced tumors, wounds, lateral branching sites by hydrolysing wall bound cellulose. Many plant species in the globe, each one hosts several to hundreds of endophytes creating an enormous biodiversity [6].

Distribution of endophytes depends on their ability to colonize and suitability of host plant resources, probably isolated endophytic bacteria from plants for the first time and till now, in 16 phyla more than 200 bacterial genera have been reported as endophytes [7].

3. Important Role of Endophytes in Sustainable Agriculture

Endophytic bacteria play a major role in increasing plant growth through beneficial effects on host plant. These bacteria enhance plant growth through increase in germination percentage, leaf area, chlorophyll content, biomass production, root & shoot ratio, nitrogen concentration, protein content, hydraulic activity and stresses tolerance against drought, flood, salinity, etc. These bacteria also enhance plant-growth actively by increasing plant nutrient availability, reduction in ethylene production, and passively by developing tolerance against myriads of plant pathogens [8].

4. Biological Nitrogen Fixation

Nitrogen is the most important nutrient for plant growth [9], 78% of the N_2 gas present in the environment but it is unavailable to most of the plants and animals. Plants absorb nitrogen in the form of nitrate and ammonium ions. Conversion of gaseous nitrogen into ammonium ion through bacterial activity is called as biological nitrogen fixation (BNF). The Nitrogenase enzyme is a key enzyme in this Biological Nitrogen fixation.

Table: Biological Nitrogen Fixation by Endophytes (Name and associated Plants) [10].

Endophytes	Associated Plants
1. *Rhizobium leguminosarum bv. Trifolii*	Rice
2. *Burkholderia*	Rice
3. *Azospirillum*	Rice
4. *G. diazotrophicus, H. seropedicae, H. rubrisubalbicans, A. amazonense and Burkholderia sp.*	Sugarcane

Co-ordinator IQAC Shri Guru Buddhiswami Mahavidyalaya Purna (Jn) Dist. Parbhani - 431511 (M.S.)

Shri Guru Buddhiswami Shikshan Prasarak Sanstha, Shri Guru Buddhiswami Mahavidyalaya, Purna (Jn), Estd. 1983

PRINCIPAL Shri Guru Buddhiswami Mahavidyalaya Purna (Jn.) Dist. Parbhani

Endophytes may enter the interior of the root through auxin-induced tumors, wounds, lateral branching sites by hydrolysing wall bound cellulose. Many plant species in the globe, each one hosts several to hundreds of endophytes creating an enormous biodiversity [6].

Distribution of endophytes depends on their ability to colonize and suitability of host plant resources, probably isolated endophytic bacteria from plants for the first time and till now, in 16 phyla more than 200 bacterial genera have been reported as endophytes [7].

3. Important Role of Endophytes in Sustainable Agriculture

Endophytic bacteria play a major role in increasing plant growth through beneficial effects on host plant. These bacteria enhance plant growth through increase in germination percentage, leaf area, chlorophyll content, biomass production, root & shoot ratio, nitrogen concentration, protein content, hydraulic activity and stresses tolerance against drought, flood, salinity, etc. These bacteria also enhance plant-growth actively by increasing plant nutrient availability, reduction in ethylene production, and passively by developing tolerance against myriads of plant pathogens [8].

4. Biological Nitrogen Fixation

Nitrogen is the most important nutrient for plant growth [9]. 78% of the N_2 gas present in the environment but it is unavailable to most of the plants and animals. Plants absorb nitrogen in the form of nitrate and ammonium ions. Conversion of gaseous nitrogen into ammonium ion through bacterial activity is called as biological nitrogen fixation (BNF). The Nitrogenase enzyme is a key enzyme in this Biological Nitrogen fixation.

Table: Biological Nitrogen Fixation by Endophytes (Name and associated Plants) [10].

Endophytes	Associated Plants
1. *Rhizobium leguminosarum bv. Trifolii*	Rice
2. *Burkholderia*	Rice
3. *Azospirillum*	Rice
4. *G. diazotrophicus, H. seropedicae, H. rubrisubalbicans, A. amazonense and Burkholderia sp.*	Sugarcane

Co-ordinator IQAC Shri Guru Buddhiswami Mahavidyalaya Purna (Jn) Dist. Parbhani - 431511 (M.S.)

Estd. 1983

PRINCIPAL Shri Guru Buddhiswami Mahavidyalaya Purna (Jn.) Dist.Parbhani

5. Phosphorus Solubilisation

The use of endophytic microorganisms in agriculture has increased in recent years. Such microbes promote the growth of plants and facilitate the control of biological pests and phytopathogens, as well as the production of metabolites of pharmaceutical interest [11]. Several soil microorganisms, including bacteria and fungi are able to mineralize organic phosphates and solubilize inorganic phosphates. Phosphate solubilization might be achieved via several mechanisms such as hydrolysis or processes involving enzymes like phosphatases. Phosphatases produce organic and inorganic acids through pH reduction, carbon dioxide formation and the enzymatic reduction of metals [12]. Among the bacteria able to solubilize phosphate, the genera *Rhizobium* [13] *Agrobacterium, Pseudomonas, Burkholderia, Erwin, Paenibacillus, Bacillus and Lysinibacillus sp.* [14].

Table: Mechanisms in Microorganisms for P-Solubilisation [15]

Sr.No	Microorganisms	Features	References
1	*Serratia marcesence*	Produce gluconic acid and solubilizes P	Krishnaraj and Goldstein (2001)
2	*Rahnella aquatilis*	Solubilize P and produce gluconic acid in E. coli DH5a	Kim et al., (1998)
3	*Enterobacter agglomerans*	Solubilize P in E. coli 109, does not lower pH	Kim et al., (1997)
4	*Pseudomonas cepacia*	Solubilize P and produce gluconic acid in E. coli JM 109	Babu-Khan et al., (1995)
5	*Erwinia herbicola*	Solubilize P and produce gluconic acid in E. coli HB 101, probably involve in synthesis of PQQ	Goldstein and Liu (1987)
6	*Bacillus subtilis CB8A*	Solubilise P and produce gluconic acid	Mehta et al., (2013)

6. Potassium Solubilisation

K solubilisation is done by a wide range of saprophytic bacteria, fungal strains and actinomycete [16]. There are strong evidences that soil bacteria are capable of transforming soil K to the forms available to plant effectively. There is considerable population of KSB in soil and in plant rhizosphere. These include both aerobic and anaerobic isolates that the most frequently KSB in soil are aerobic. A considerably higher concentration of KSB is commonly found in the rhizosphere in comparison with non-rhizosphere soil. Solubilization of K by KSB from insoluble and fixed forms is an import aspect regarding K availability in soils. The ability to solubilize the silicate rocks by *B. mucilaginous, B. circulanscan, B. edaphicus, Burkholderia, A. ferrooxidans,* *Arthrobacter sp., Enterobacter hormaechei, Paenibacillus mucilaginosus, P. frequentans, Cladosporium, Aminobacter, Sphingomonas, Burkholderia, and Paenibacillus glucanolyticus* has been reported. Among the soil bacterial communities *B. mucilaginosus, B. edaphicus and B. circulanscan* have been described as effective K solubilizers [17].

Table- Classification of potassium-solubilizing microorganisms (KSM) [18]

Sr.No	Isolation Source	Closes related Species	References
1	Weathered materials of denatured rock mountain in Vietnam	*A. tumefaciens*	Diep and Hieu (2013)
2	Soil in India	*B. metallica*	Saiyad et al., (2015)
3	Wheat in India	*A. piechaudii*	Verma et al., (2015)
4	Tea soil in India	*P. putida*	Bagyalakshmi et al., (2012a, b)
5	Agricultural soils in India	*F. aurantia*	Ramarethinam and Chandra (2006)
6	Mica mine in India	*B. amyloliquefaciens*	Gundala et al., (2013)
7	Soil in India	*B. mucilaginosus*	Sukumaran and Janarthanam (2007)

7. Antimicrobial Activity

Application of endophytic bacteria for suppression of diseases (biological control) can be an eco-friendly approach in sustainable agricultural practices [19]. Application of endophytes and their metabolites were found to have promising potential in control of plant & human pathogens and diseases.

Table- Examples of the endophytic activities against microbes [20] [21]

Sr. No	Endophytic isolates	Plants	Pathogenic fungi/bacteria
1	*Phomopsis sp*	*Excoecaria agallocha*	*Candida albicans* and *Fusarium oxysporum*
2	*Penicillium sp.*	*Acrostichum aureurm*	*Staphylococcus aureus, Candida albicans*
3	*Nodulisporium sp*	*Juniperus cedre*	*Bacillus megaterium, Microbotryum violaceum, Septoria tritici, Chlorella fusca*
4	*Bacillus pumilus*	*Pea*	*F. oxysporum f. sp. Pisi*
5	*Bacillus cereus*	*A. thaliana*	*Pseudomonas syringae*
6	*P. fluorescens*	*Tomato*	*F. oxysporum f. sp. radicislycopersici*

8. Conclusion

Large use of chemical pesticides and fertilizers for increasing agriculture productivity has disturbed the ecological balance which has led to the buildup of pesticide resistance among pathogens. The application of endophytic bacteria for sustainable agriculture is an economically sound, attractive, and eco-friendly approach. These bacteria have shown many beneficial impacts on their host plant and contribute significantly to maintain sustainable agriculture. They have been documented for promoting plant growth through several functional attributes viz., increase in nutrient availability to the plants through fixation and solubilization of nutrients in soil and by producing plant-growth regulators. The major impact regarding application of endophytic bacteria in the agriculture is the significant reduction in the indiscriminate application of agrochemicals like pesticides, inorganic fertilizers, other artificial chemicals, etc. Successful utilization of endophytes would make crop production eco-friendlier and sustainable. In the future, researchers would be able to engineer microbial endophytes for increasing their potential to be used as microbial inoculants, after fully understanding their function.

9. References

1. Vyas, P. (2018). Endophytic microorganisms as bio-inoculants for sustainable agriculture. In *Microbial bioprospecting for sustainable development* (pp. 41-60). Springer, Singapore.
2. Adesemoye, A. O., & Kloepper, J. W. (2009). Plant–microbes interactions in enhanced fertilizer-use efficiency. *Applied microbiology and biotechnology, 85*(1), 1-12.
3. Barea, J. M., Pozo, M. J., Azcón, R., & Azcón-Aguilar, C. (2013). Microbial interactions in the rhizosphere. *Molecular microbial ecology of the rhizosphere, 1*, 29-44.
4. Mei, C., & Flinn, B. S. (2010). The use of beneficial microbial endophytes for plant biomass and stress tolerance improvement. *Recent patents on biotechnology, 4*(1), 81-95.
5. Sturz, A. V., Christie, B. R., & Nowak, J. (2000). Bacterial endophytes: potential role in developing sustainable systems of crop production. *Critical reviews in plant sciences, 19*(1), 1-30.

6. Qin, S., Xing, K., Jiang, J. H., Xu, L. H., & Li, W. J. (2011). Biodiversity, bioactive natural products and biotechnological potential of plant-associated endophytic actinobacteria. *Applied Microbiology and Biotechnology*, *89*(3), 457-473.

7. Mundt, J. O., & Hinkle, N. F. (1976). Bacteria within ovules and seeds. *Applied and Environmental microbiology*, *32*(5), 694-698.

8. Bhattacharyya, P. N., & Jha, D. K. (2012). Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *World Journal of Microbiology and Biotechnology*, *28*(4), 1327-1350.

9. Ahemad, M., & Kibret, M. (2014). Mechanisms and applications of plant growth promoting rhizobacteria: current perspective. *Journal of King saud University-science*, *26*(1), 1-20.

10. Prasad, M., Srinivasan, R., Chaudhary, M., Mahawer, S. K., & Jat, L. K. (2020). Endophytic bacteria: Role in sustainable agriculture. In *Microbial Endophytes* (pp. 37-60). Woodhead Publishing.

11. Azevedo, J. L., Maccheroni Jr, W., Pereira, J. O., & De Araújo, W. L. (2000). Endophytic microorganisms: a review on insect control and recent advances on tropical plants. *Electronic Journal of Biotechnology*, *3*(1), 15-16.

12. Souchie, E. L., Azcón, R., Barea, J. M., Saggin-Júnior, O. J., & Silva, E. M. R. D. (2005). Solubilização de fosfatos em meios sólido e líquido por bactérias e fungos do solo. *Pesquisa Agropecuária Brasileira*, *40*, 1149-1152.

13. Sridevi, M., & Mallaiah, K. V. (2009). Phosphate solubilization by Rhizobium strains. *Indian journal of microbiology*, *49*(1), 98-102.

14. Andrade, L. F., de Souza, G. L. O. D., Nietsche, S., Xavier, A. A., Costa, M. R., Cardoso, A. M. S., ... & Pereira, D. F. G. S. (2014). Analysis of the abilities of endophytic bacteria associated with banana tree roots to promote plant growth. *Journal of Microbiology*, *52*(1), 27-34.

15. Walia, A., Guleria, S., Chauhan, A., & Mehta, P. (2017). Endophytic bacteria: role in phosphate solubilization. *Endophytes: crop productivity and protection*, 61-93.

16. Ahmad, M., Nadeem, S. M., Naveed, M., & Zahir, Z. A. (2016). Potassium-solubilizing bacteria and their application in agriculture. *Potassium solubilizing microorganisms for sustainable agriculture*, 293-313.

17. Etesami, H., Emami, S., & Alikhani, H. A. (2017). Potassium solubilizing bacteria (KSB): Mechanisms, promotion of plant growth, and future prospects A review. *Journal of soil science and plant nutrition*, *17*(4), 897-911.

18. Velázquez, E., Silva, L. R., Ramírez-Bahena, M. H., & Peix, A. (2016). Diversity of potassium-solubilizing microorganisms and their interactions with plants. In *Potassium solubilizing microorganisms for sustainable agriculture* (pp. 99-110). Springer, New Delhi.

19. Backman, P. A., & Sikora, R. A. (2008). Endophytes: an emerging tool for biological control. *Biological control*, *46*(1), 1-3.

20. Prasad, M., Srinivasan, R., Chaudhary, M., Mahawer, S. K., & Jat, L. K. (2020). Endophytic bacteria: Role in sustainable agriculture. In *Microbial Endophytes* (pp. 37-60). Woodhead Publishing.

21. Yu, H., Zhang, L., Li, L., Zheng, C., Guo, L., Li, W., ... & Qin, L. (2010). Recent developments and future prospects of antimicrobial metabolites produced by endophytes. *Microbiological research*, *165*(6), 437-449.