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An updated review on endophytic bacteria in agronomic plants

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Abstract
Endophytic microbes carry nutrients from the soil into plants, promote plant development, increase stress tolerance of plants, suppress pathogens, develop disease resistance in plants, and defeat the growth of opponent's plant species. In a natural ecosystem, plants maintain symbiotic associations with endophytic bacteria supporting growth and protecting plants from biotic and abiotic stresses. Long-term cultivation and domestication of agronomic crops lead to altering endophytic bacterial community and diversity. So there is a need to know the beneficial endophytic bacteria playing a role in plant's metabolism and protecting them. The present review outlines the endophytic bacteria present in agronomic crop plants that benefit their growth and survival.

Keywords: endophytic, bacterial, beneficial, agronomic plants

Introduction

The plant-microbes interaction relies on intact organisms and environmental factors, which affect the plant physiology and its nutrition [1, 2]. "Endophytes" are microorganisms living plants without showing antagonistic effects to the host [3]. The endophytes passed through the host tissue, seed, plant propagules [4]. They are distinct from plant pathogenic microorganisms being not deleterious; cause no diseases to plants [5]. Endophytes are beneficial in promoting plant growth and yield and demoting the growth of pathogens enduring in the plant. Endophytes comprising fungi and bacteria [6] inhabit the plant endosphere during their entire life cycle without causing any harm to the plant [7]. Lately, *endophytes* are microorganisms that include archaea, bacteria, fungi, and protists that colonize the interior of plants, nevertheless of the benefit of their association [8]. Bacteria are among the endophytes that invade the healthy plant tissue without showing apparent symptoms or disinfecting plants [9]. These bacteria colonize many different types of plants and are host-specific. The studies revealed that the richness and diversity of endophytic bacteria are enormous under field conditions [10]. Endophytic bacteria originate from seeds, vegetative plant cuttings, rhizosphere soil, and phylloplane. They usually penetrate plant tissue through stomata, lenticels, wounds, germinating radicles or actively colonize in the apoplast [11], conducting vessels and in intercellular spaces [12]. Endophytic bacteria utilize carbohydrates, amino acids, and inorganic nutrients from plants for their metabolism. The colonization of endophytes confers an ecological niche indistinguishable from phytopathogens, thereby producing biocontrol agents [13]. Endophytes influence the quantity and chemical compounds of exudates from the host root [14].

Endophytic Bacteria as Plant- Growth Promoter

Several studies report that endophytic bacteria such as *Sphingomonas* and *Pseudomonas play a* crucial role in increasing plant biomass, cadmium uptake, nitrogen fixation, and phytohormone production. They were found widely distributed in most plants like *Solanum lycopersicum, Dendrobium officinale, Sedum alfredii* [15, 16, 17]. Jasim *et al*., (2013) screened plant growth-promoting properties like phosphate solubilization, ACC deaminase production, siderophore production from twelve bacteria isolated in *Piper nigrum*, which resulted in the identification of *Klebsiella sp.* (PnB 10) and Enterobacter sp. (PnB 11) excellent growth-promoting properties. [18] Aswathy *et al*., (2013) noticed the indole 3 acetic acid production of two species of endophyte Paenibacillus in the rhizome of *Curcuma longa*; whereas [19] Jasim *et al*., (2014a) isolated four different endophytic bacterial strains from a ginger rhizome in which *Pseudomonas* sp. have the ability to produce IAA, ACC deaminase and siderophore. [20] Jasim *et al*., (2014b) studied endophytic *Pseudomonas aeruginosa* from ginger in their other work. It shows inhibitory effect on the fungus *Pythium myriotylum* identified an antifungal compound, Phenazine 1-carboxylic acid from *P. aeruginosa*. [21] Jimitha *et al*., (2014) focussed on the isolation of endophytic bacteria such as *Ralstonia* sp. and *Bacillus* sp. from somatic embryogenic suspension cultures of *in vitro* propagation banana (Musa acuminate AAA cv. Grand Naine).

These bacterial strains revealed the potential to solubilize phosphate and production indole acetic acid, siderophore, and ammonia. The endophytic bacterial strain was isolated from *Morinda citrifolia* L. fruits and using MALDI-TOF Mass Spectrometry, it was identified as *Paenibacillus polymyxa* 19 by [22] Liu, *et al*., (2018). The strain shows good antagonistic property against smut pathogen Aspergillus aculeatus 23 NP-1, which was proved by acquiring the draft genome of Paenibacillus sp. NEB by Illumina HiSeq 2000 sequencing platform resulting in the annotation of three coding sequences for glucanases. Another species of *Paenibacillus* (*P. polymyxa* CICC10580) were identified by [23] Xu *et al*., (2014) from *M. citrifolia* fruits which have good antagonistic activity against many pathogens, and the coding sequences (CDSs) related with antagonism were annotated. [24] Kumala and Siswanto

(2007), in their work, have isolated five bacterial isolates and eleven fungal isolates from *Morinda citrifolia* and studied broad-spectrum antifungal activity against *Candida albicans*.

Table 1: List of endophytic bacteria associated with agronomic crop plants

Bacteria	Host	References
Bacillus sp.	Papaya,	[25]
	Coffee,	[26]
	Cucumber	[27]
	Strawberry,	[28]
	Black pepper	[29]
	Paddy, cucumber, Hybrid spruce, pine, potato, Red clover.	[30]
	Wheat	[31]
	Mulberry	[32]
	Potato	[33]
		[34]
	Sugar beet	[35]
	Rambutan	[36]
	Jojoba	[37]
	Grapevine	[38]
	Citrus	[39]
	Canola and wheat	[40]
	Red clover	[41]
	Cotton	[42]
		[43]
	Rice	[44]
		[45]
	Maize	[46]
		[47]
	Rough lemon	[48]
	Corn	[49]
Corynebacterium sp.	Maize, potato, lemon, Beet	[30]
	Rambutan	[36]
	Rough lemon	[48]
	Corn	[49]
	Rice	[45]
Chryseobacterium sp.	Corn	[50]
	Sugar beet	[35]
	Rambutan	[36]
	Paddy, Coffee	[26]
	Cucumber	[30]
		[27]
Azospirillum sp.	Rice	[44]
	Maize	[46]
Lactobacillus sp.	Sugar beet	[35]
Agrobacterium sp.	Rice	[44]
	Cucumber	[27]
	Potato	[34]
	Cotton	[43]
Klebsiella sp.	Red clover	[41]
	Grapevine	[38]
	Arabidopsis	[51]
	Corn	[52]
	Wheat	[53]
		[51]
	Maize	[51]
	Alfalfa	[51]
	Rice	[54]
		[51]
Staphylococcus sp.	Maize	[50]
	Vitis sp.	[55]
	Rambutan	[36]
	Grape vine	[38]
	Cotton	[42]
Flavobacterium sp.	Potato	[34]
	Rice	[54]
Vibrio sp.	Corn	[52]
Gluconacetobacter sp.	Wheat	[56]

	Sorghum	[46]
	Maize	
	Rice	[57]
		[58]
	Sugarcane	[58]
Erwinia sp.	Sugar beet	[35]
	Cotton	[43]
	Alfalfa	[59]
Stenotrophomonas sp.	Cucumber	[27]
Curtobacterium sp.	Maize	[50]
	Red clover	[41]
	Soybean, Strawberry	[28]
	Vitis sp., potato, Red clover	[55]
	Grape vine	[38]
	Rambutan	[36]
	Citrus	[39]
Clavibacter sp.	Grapevine	[36]
	Cotton	[43]
Streptomyces sp.	Jojoba	[37]
Arthrobacter sp.	Red clover	[41]
	Cucumber	[27]
	Cotton	[42]
Rhodococcus sp.	Jojoba	[37]
Acidovorax sp.	Red clover	[41]
Oceanobacillus sp.	Jojoba	[37]
Burkholderia sp.	Citrus	[39]
	Cucumber	[27]
	Rice	[60]
		[45]
	Cotton	[43]
	Maize	[46]
	Wheat	[31]
	Sugarcane	[60]
	Corn	[42]
Methylobacterium sp.	Jojoba	[37]
	Red clover	[41]
	Citrus	[39]
	Rice	[54]
	Cucumber	[27]
	Red clover	[41]
	Sugar beet	[35]
	Rough lemon	[48]
	Grape vine	[38]
	Rice	[44]
	Cotton	[42]
	Alfalfa	[59]
	Corn	[49]
		[52]
Herbaspirillum sp.	Sugarcane	[51]
	Rice	[54]
	Wheat	[46]
Sphingomonas sp.	Rice	[54]
Variovorax sp.	Red clover	[41]
	Cotton	[42]
Serratia sp.	Rough lemon	[48]
	Red clover	[41]
	Cotton	[43]
Alcaligenes sp.	Citrus	[39]
Rhodopseudomonas sp.	Rice	[54]
Acetobacter sp.	Sugarcane	[51]
Acinetobacter sp.	Cotton	[42]
	Red clover	[41]
	Grape vine	[38]
	Sugar beet	[35]
	Rough lemon	[48]
	Cotton	[43]
Cytophagales sp.	Rice	[54]
Pantoea sp.	Red clover	[41]

	Citrus	[39]
	Grape vine	[38]
	Rice	[54]
Enterobacter sp.	Red clover	[41]
	Grape vine	[38]
	Cucumber	[27]
	Rough lemon	[48]
	Cotton	[42]
	Corn	[52]
		[42]
	Maize	[46]
	Wheat	[31]
Micrococcus sp.	Red clover	[41]
	Potato	[34]
	Canola and wheat	[40]
Rhizobium sp.	Red clover	[41]
	Cotton	[42]
Azorhizobium sp.	Rice	[44]
		[54]
Rathayibacter sp.	Canola and wheat	[40]
Rhodococcus sp.	Grape vine	[38]

Conclusion

Bacterial endophytes could be employed to improve plant health and enhance productivity in commercial crop plants. The current attempts to update the bacterial diversity prevailing in crop plants are a start to protect such microbes used to alleviate plant production. Continuous cultivation for long periods and usage of agrochemicals may harm the growth of such beneficial microbes that, in turn, leads to damage of crops variety due to lack of endophytes that focus on pathogens suppression, insect damage, and competes with weedy plants. Also, endophytes could help to cultivate crops with fewer fertilizers which envision a change in the practice of growing crop plants and also optimizing the plants-microbes relationship.

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Conflicts of Interest

The authors declare that we have no conflict of interest.

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