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Endophytic Bacteria: an Essential Requirement of Phyto Nutrition

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Abstract

An incessant upsurge in the use of chemical fertilizers has led to several disastrous effects on agriculture and environment. Biological control has provided a plausible alternative to lower down the usage of chemical fertilizers. Plant associated microorganisms play an important role in sustainable agriculture for enhancing plant growth, productivity as well as stress amelioration. Endophytic microbes, residing in plant play a powerful role in exerting their beneficial attributes with a higher consistency, particularly since they dwell in a relatively secure environment, largely protected from the externally induced abiotic/biotic stresses. However, irrespective of the multi-faceted benefits of endophytic bacteria, the role of these microbes in agriculture still remains unrealized and unexploited. In this work, we have described the endophyte-plant interactions taking into consideration the several aspects of endophytic activity to enhance awareness towards the application of endophytic bacteria in organic farming.

Keywords : Endophytic bacteria; Biofertilizer; Plant nutrition; Oxidative stress; Antioxidants

Abbreviations : Aims: Agriculturally Important Microbes; NAFTA: North American Free Trade Agreement; PGP: Plant Growth Promotion; PGPR: Plant Growth Promoting Rhizobia; IAA: Indole Acetic Acid; ACC: 1-Aminocyclopropane-1-Carboxylate; Alss: Acetolate Synthase; Alsd: Acetolactate Decarboxylase; ISR: Induced Systemic Resistance; SAR: Systemic Acquired Resistance

Chemical Fertilizers: The Archaic Practice of Sustainable Agriculture

Agricultural advancements, particularly green revolution, enforced the use of chemical pesticides for greater production and higher yield. However, persistent chemo inputs into soil over the years have rendered a catastrophic effect on the soil micro-biota as well as on human health [1-3]. This is quite evident from the fact that many Indian states have been rendered completely unproductive while there is a significant upsurge of certain deadly diseases, such as cancer, diabetes, hypertension etc. due to a constant exposure to the chemical compounds. Degradation rates of the chemical fertilizers are quite negligible owing to their complex structures. This leads to their bioaccumulation and bio-magnification thereby resulting in a loss in specific biodiversity apart from severe groundwater contamination. Apart from the aforementioned concerns, an exponentially increasing human population along with a persistent caveat of abiotic stress, particularly with respect to Indian perspective, is demanding the utilization of other eco friendly alternatives chiefly to ensure food security.

This paves the way for plausible cost efficient, eco-friendly and sustainable alternatives for yield improvement, such as use of agriculturally important microbes (AIMs) which have for long attracted the attention of agriculturists and extensive research is being carried out globally to enhance agro-sustainability using such microbes.

Biofertilizers: The Plausible Alternative

Biofertilizers, a subclass of AIMs, are the naturally occurring biologically safe microorganisms, used for enhancing plant growth and enabling control and regulation of pests. Taking into concern the impressive role of biopesticides and biofertilizers in the promotion of sustainable agriculture, which basically include, target-specificity, environmental safety, and biodegradability [4-6], several government agencies are actively funding research and enhancing development and marketing of these green inputs In spite of the above notable mentions, it is extremely crucial to note that Asian countries consume only 5% of the total biopesticides sold globally while the North American Free Trade Agreement (NAFTA) countries claim to be the major global consumers of biopesticides [7,8]. Significantly, USA, Mexico and Canada consume about 47% of the biopesticides sold globally.

Microbes, particularly bacteria, have an inherent capability of plant growth promotion (PGP) and bioremediation. Bacterial genera, in particular, have been used as plant growth promoting agents since 1970s with a variety of reports justifying their capability of phosphate solubilization, nitrogen fixation, biological control of plant diseases and other PGP attributes. The current shift in agricultural practices has thereby gradually incorporated minimal use of agrochemicals in field practices while simultaneously employing bacterial microbiota as bio-inoculant, either singly or in consortia. Extensive research is being pursued in context of enhancing plant growth, yield and simultaneously conferring tolerance to unfavorable environmental or soil conditions by inoculating plants with PGPBs. The microbes are amalgamated with plant roots, shoots, leaves, as well as fruits or seeds thereby inducing a symbiotic relationship between plants and microorganisms. Earlier studies, mainly focused on the usage of PGPBs via rhizosphere application but continual explorations in this field, reported that these microbes can also be used through foliar application/sprays and inoculation via wounds (endophytic application), thereby enabling the retrieval of farmlands not formerly cultivable for fodder and feed.

Endophytes: The Fundamental Branch of Bio-Fertilizers

Endophytes are primarily soil-borne bacteria completing a major part of their life cycle within plants without causing any apparent symptoms [9]. The term “endophytes” is mainly used for those microorganisms which reside in vascular tissues of plant and move freely inside the plant, or it can be used more broadly to refer to any microorganism which resides inside the plant regardless of the tissue colonized.

Endophytes have particularly garnered the attention of sustainable agriculture as an alternative to rhizospheric PGPBs, particularly since; benefits conferred by endophytes acquire a competitive advantage over plant growth promoting rhizobia (PGPR) [10]. For instance, the survivability and colonizability of PGPR largely depend upon their intrinsic physiological properties as well as the biotic and abiotic factors of soil, whereas such is not the case with endophytes. Being in an intimate contact with the hosts, the endophytes remain largely protected from the abiotic and biotic stress conditions in the soil [11,12]. Another conspicuous feature of marked prominence is that re-introduction of endophytic bacteria does not affect the indigenous bacterial populations within host plants, unlike the introduction of PGPR in soil which causes an exemplar shift in the soil microbial community [13].

Nutritional Benefits by Endophytic Bacteria

Endophytic microbes endow hosts with a diversity of beneficial attributes, such as plant growth promotion, enhanced plant mineral uptake and yield [14-16], and as well as reduction of oxidative stress responses [17-21]. Thus it may be predicted that endophytes establish a dual fitness trait with the host wherein both the partners get synergistically benefitted [22]. In addition, endophytic microbes are also reported to cause an enhancement in water retention, and increment in biomass attained by a delay in flowering and leaf senescence, which further fix a greater amount of carbon within the host [23].

Endophytic microbes play a significant role in enhancing plant growth and yield. Endophytic production of plant auxin, indole acetic acid (IAA) from tryptophan is reported to occur via three alternative pathways:

a) Indolepyruvate and indole-3-acetaldehyde.

b) Tryptamine and indole-3-acetaldehyde and

c) Indole-3-acetamide and indole-3-acetonitrile [9].

The IAA so produced plays a significant rolein induction of 1-aminocyclopropane-1-carboxylate (ACC) synthaseand 1-aminocyclopropane-1-carboxylate (ACC) oxidase multigene family in hosts. Taghavi et al. [24] reported the presence of all the three pathways in endophyte Pseudomonasputida W619. Apart from the growth hormones, endophytic population is also reported tosecrete organic acids for solubilization of insoluble phosphates into soluble form followed by its uptake which is one of the pivotal elements involved in energy transfer, photosynthesis, carbohydrate transformation and transfer of hereditary characteristics [25]. Similarly, potassium and sodium ion content is also reported to be elevated within hosts. While, potassium ions play a pivotal role in enzyme activation, protein synthesis, cell metabolism and photosynthesis, sodium ionsare required in trace amounts in plants and primarily act as a vacuolar osmoticum [26]. In addition to the above perspectives, endophytic bacteria restrict the growth and development of phyto pathogens by releasing side rophores having strong affinity towards Fe (III) [27]. Post release, the microbes have certain Ton-B dependent membrane receptors for specific uptake of ferric-siderophore complexes or other small molecules [28].

Apart from aforementioned mechanisms, production of volatile substances such as 2-3 butanediol and aceotin seem to be a newly discovered mechanism responsible for plant growth promotion [29]. Acetolate synthase (AlsS) and acetolactate decarboxylase (AlsD) catalyze the switch from pyruvate to acetoin which further gets converted to 2, 3-butanediol either by the host or the endophyte. AlsDSacetoin synthesis pathway has been reported in endophytic Serratia proteamaculans 568 and Enterobacter 638 [24]. In yet another report, endophytes are recognized as producers of adenine nucleotides augmenting growth as well as diminishing browning of pine tissues [30].

Remediation of Oxidative Stress

A plethora of reports suggest endophytic microbes as having the capacity to control phytopathogens [31,32]. Several antagonistic endophytic bacterial species have been isolated from the xylem of lemon root, against root pathogens [33]. Endophytes enhance biocontrol activities in planta either directly by antibiosis or niche occupation [34] or indirectly

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by stimulating plant defense mechanisms [35]. Potentiality of endophytes as biocontrol agents are dependent on many factors, such as: host specificity, population dynamics and pattern of host colonization, ability to move within host tissues, and the ability to induce systemic resistance. It is believed that certain endophytic bacteria trigger induced systemic resistance (ISR), which is phenotypically similar to systemic acquired resistance (SAR). ISR is effective against different types of pathogens but differ from SAR in that the inducing bacterium does not cause visible symptoms on the host plant [36] (Figure 1).

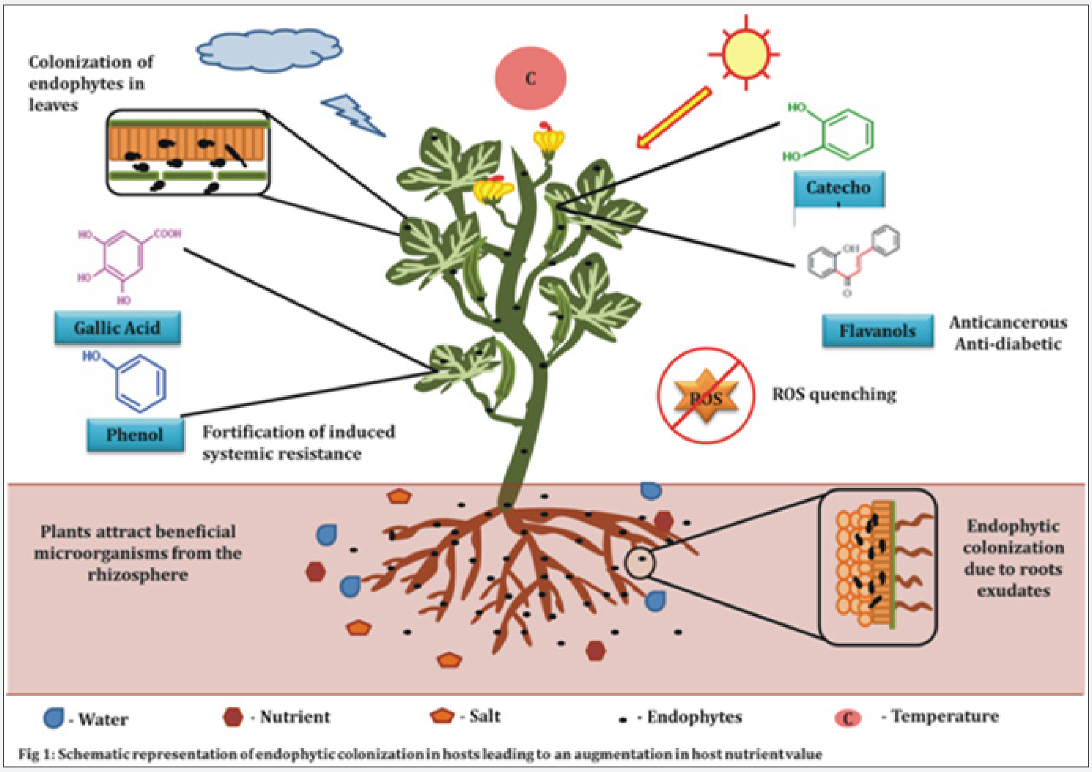

Figure 1: Schematic representation of endophytic colonization in leading to an augmentation in host nutrient value.

Hardoim et al. [37] suggested endophytes as reservoirs of enzymes possessing detoxification capacities, such as glutathione peroxidase (btuE), glutathione S-transferase (gst), catalase (katE), and nitric oxide reductase (nor). These enzymes probably function as mitigators of host oxidative burst process in response to endophytic colonization. Post colonization, these enzymes are responsible for fortification of the host to deal with any form of sudden stresses. In this context, Ray et al. [38] reported the augmentation of phenylpropanoid pathway have reported the augmentation of phenylpropanoid pathway thereby leading to a simultaneous increase in peroxidase and polyphenol oxidase enzymes against biotic stress.

Endophytes as Generators of Antioxidants

Due to challenge by any form of biotic or abiotic stress, an immediate release of reactive oxygen species (ROS), such as hydroxyl radical, hydrogen peroxide (H2O2), and superoxide anion (O2-) occurs so as to mitigate the challenge [39,40]. However, these ROS are extremely catastrophic to the host tissues as these cause damage to cell membrane integrity as well as damage the cellular molecules, such as nucleic acids, proteins, etc. [41]. In order to diminish the disastrous effects of the ROS, plants generate antioxidants to quench the ROS and reactive nitrogen species so formed. Reports suggest that plants with an augmented antioxidant status are more beneficial to humans, particularly from the perspective of cure of chronic diseases, such as diabetes, cancer etc. [42,43].

In terms of antioxidant status, endophyte inoculated plants expressed an elevated level of antioxidant production particularly when exposed to abiotic or biotic stress [44]. An augmented antioxidant activity can be directly correlated to an increase in host biomass and root length [38,45]. In another report, Matsouri et al. [46] suggested endophyte inoculated hosts expressed an alteration in ratio of reduced and oxidized forms of glutathione and ascorbate. Similarly, Bae et al. [47] reported augmentation in levels of certain amino acids, for instance proline, which performed as osmoprotectants particularly when subjected to drought stress.

Conclusion

Irrespective of the significant contributions, study on endophytic bacteria, particularly with respect to

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enhancement in nutritional value of plants has still remained a realm quite unexplored. Though, having completed 71 years of independence, India still faces major challenges as far as agricultural development is concerned. Since India is primarily an agriculture based country, thus it is high time to exploit alternative modes of farming to yield improvement as well as nutritional benefit. This review is a minor attempt to appreciate the endophyte benefit bestowed upon hosts in terms of nutrient augmentation which is particularly significant with respect to sustainable agriculture as well as human health.

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