MEETING REPORT

Endophytes in agriculture*

A symposium on endophytes and their applications in agriculture was held recently. The subject of the symposium is of immediate relevance to crop production considering the emerging fact that the performance of plants and their response to abiotic and biotic stresses are controlled not only by the plant genome but also by its microbiome, which includes the endophytes. To the best of our knowledge, a symposium exclusively devoted to the application of endophytes in agriculture has not been organized in the country till now.

Conventional crop improvement approaches to render plants tolerant to abiotic stress and resilient to climate change have had limited success, primarily due to the combination of stressors and the multitude of plant traits involved in determining tolerance. A more recent and exciting approach has emerged from the use of endophytes to alter plant responses and adaptation to abiotic stresses.

The endophytes are bacteria and fungi which invariably reside in the living tissues of plants without causing any disease. It is only in the last few years that the role of endophytes in enhancing the fitness of their host plant and their ability to produce an array of novel and biologically active metabolites have been recognized. The more recent findings that endophytes could alleviate abiotic and biotic stresses in crop plants have led to the notion that these microbes could be used as an alternative for plant breeding.

Of particular interest in crop improvement are seed biopriming technologies leading to the development of high-quality seeds through advanced genetic interventions to meet the challenges of food security needs of a country. In this context, seed biopriming using endophytes offers a non-genetic invasive method to alter plant phenotype when compared to conventional and molecular breeding approaches; furthermore, it is rapid and cost-effective. Seed priming with the desired consortium of endophytes could offer a quick and safe strategy to mitigate abiotic stresses in plants. At the University of Agricultural Sciences (UAS), GKVK, Bengaluru, and other laboratories in India and abroad, efforts have been made over the last few years to harness this potential of endophytes in agriculture. Several endophytes have been identified and demonstrated to positively impact the growth of crops such as paddy, chilly, maize and tomato under abiotic stresses such as drought, high temperature and salinity.

The symposium brought together scientists and students working in the area of endophytes and their application to agriculture. The meeting was inaugurated by S. Rajendra Prasad (Vice-Chancellor, UAS, GKVK, Bengaluru). He stressed the need for a greater conversion of basic findings of endophyte biology to translation in the field for applications to address abiotic and biotic stressors. The formal technical session was initiated by a keynote address by Ralf Oelmüller (Friedrich-Schiller University, Jena, Germany). He spoke on root-colonizing endophytes in enhancing plant performance, and described the little understood molecular mechanisms of plant communication through interconnected fungal hyphae residing in roots. Oelmüller emphasized that systemic distribution of information is *sine qua non* in endophyte–root symbioses for the benefits to be accrued by plants. He also explained the different molecular tools which could be used to unravel root endophyte-mediated signal propagation in an ecosystem and concluded by underscoring the importance of studying endophyte–root symbiosis more critically for obtaining information for agricultural applications in particular and influence of microbes on the ecosystem in general. In all, his talk, based on studies with model organisms, drew attention to the critical role of root endophytes in influencing plant performance and shaping ecosystems. The subsequent invited talk by R. Uma Shaanker (UAS, GKVK, Bengaluru) addressed plant microbiome and its role in modulating plant growth and development. His work demonstrated how endophytes could be used for alleviating abiotic stress of crops. Uma Shaanker and his group transferred a salt-tolerant endophyte isolated from the salt-adapted Pokkali rice to IR-64 rice which is salt-sensitive, and demonstrated that IR-64 harbouring the endophyte could tolerate salt stress; such plants also registered higher assimilation rates and chlorophyll stability index compared to plants not colonized by the endophyte. Furthermore, through transcriptome analysis, his group also showed that more than 1000 genes involved in stress tolerance were upregulated in the endophyte-enriched IR-64, indicating an endophyte-mediated plant gene regulation. His talk reinforced the possibility of exploiting endophytes in crop improvement.

This was succeeded by eight lead talks delivered by the following experts. T. S. Suryanarayanan (Vivekananda Institute of Tropical Mycology, Ramakrishna Mission Vidyapith, Chennai), emphasized the need to understand the dynamics of the endomicrobiome of a plant, the interaction of endophytes with their plant host and among themselves, since such basic information could vastly improve the prospects of employing endophytes in agriculture. In this context, he mentioned that the information accrued on fungal endophyte of non-crop plants is of heuristic value; he underscored the gaps in our knowledge with reference to endophytes in crop plants and stressed that focused studies on fundamental issues would fill these knowledge gaps, thus improving the prospects of successfully using endophytes for crop improvement.

A. K. Saxena (ICAR-National Bureau of Agriculturally Important Microorganisms, Maunath) highlighted the importance of bacterial endophytes in the bioforfication of wheat. His work showed that inoculation with these endophytes resulted in a twofold increase in the accumulation of iron and zinc by wheat growing in soils deficient in these elements. Colonization of the roots by the endophytes resulted in changes in root anatomy, increased production of organic acids and overexpression of

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TaZIP3 and *TaZIP7* genes. The presence of endophytes significantly increased root and shoot biomass, seed yield and weight. In another lead talk dedicated to bacterial endophytes, Pious Thomas (formerly ICAR-Indian Institute of Horticultural Research, Bengaluru) explained the importance of cytoplasmic bacterial endophytes. These intracellular endophytes are an integral part of the plant cell, and are possibly involved in different plant processes and metabolic pathways. He indicated that endophytes could be transmitted vertically through seeds and underscored the importance of next-generation sequencing exercises to track the presence of nonculturable bacterial endophytes to get a more complete picture of the holobiome of plants.

Smita Srivastava (IIT Madras, Chennai) stressed on an integrated approach to overcome the limitations of using endophytes as biofactories to produce high-value bioactive compounds. She indicated that techniques such as co-cultivation of endophytes with co-occurring microbes and host plant tissues, use of epigenetic modifiers and mixed fermentation could be attempted to enhance the chances of discovering novel bioactive metabolites from endophytes. The lead talk by Saroj Kanta Barik (CSIR-National Botanical Research Institute, Lucknow) brought to the fore the need to comprehend the patterns and mechanisms of host–endophyte interactions for improving agricultural productivity. He emphasized that data regarding the evolutionary perspective of endophytism and molecular mechanisms of host–endophyte interactions are critical in harnessing the potential of endophytes in agriculture.

Ravindra Kharwar (Banaras Hindu University, Varanasi) presented an overview on the use of fungal endophytes in plant protection through their antimicrobial metabolites. He detailed his work on the biosynthesis of antimicrobial metal nanoparticles using endophytic fungi isolated from various plants including *Azadirachta indica*. Such nanoparticles could be prepared in large scale without involving solvents or capping agents, he added. The talk by C. S. Vivek Babu (CSIR-Central Institute of Medicinal and Aromatic Plants, Bengaluru) was on the enrichment of endophytes *in planta* to achieve higher production of secondary metabolites, especially in medicinal and aromatic plants. His group has determined the role of crop-specific functional endophytes in this phenomenon and posits that these microbes modulate the expression of genes of secondary metabolite biosynthesis of the host plant. Nataraja N. Karaba (UAS, GKVK, Bengaluru), highlighted the limited success we have had so far with the various methods adopted to improve abiotic stress tolerance of crops. He reiterated the relevance of using endophytes exhibiting stress adaptive traits to refine the success of agriculture under stressful conditions.

The symposium was attended by 110 participants from various parts of the country; students and faculty presented 28 talks and 33 posters related to endophytes and agricultural crops. In summary, the symposium highlighted how the potential of endophytes may be harnessed for applications in agriculture. Hopefully in the days to come, several leads and insights gathered from the symposium will encourage various scientific groups to reach this goal.

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