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T. S. Suryanarayanan

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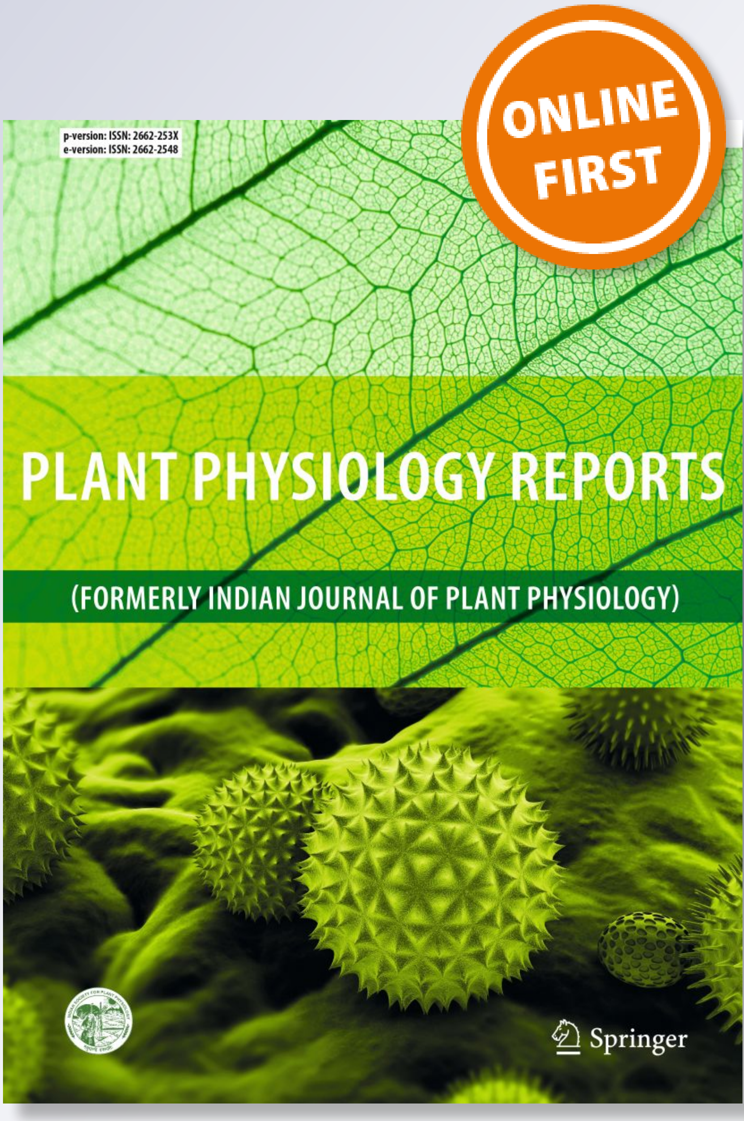

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REVIEW ARTICLE

Endophytes and weed management: a commentary

T. S. Suryanarayanan[1]

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Abstract The inside of plant tissues are the home for some bacteria and fungi. Called the endophytes, these microbes are constantly associated with all plants and constitute their endobiome. Endophytes, probably owing their interaction with their plant hosts, produce many novel biochemicals exhibiting interesting bioactivities. They promote crop growth by increasing nitrogen fixation, hormone production, phosphate and iron utilization. Endophyte association makes the plants more tolerant to pathogens, pests and abiotic stress. As a consequence of such desirable traits, although endophytes have been studied for crop improvement, their possible use in weed management has not been addressed adequately. This mini review cogitates on this facet of endophyte technology.

Keywords Weedicides · Herbicides · Plant microbiome · Endobiome

Introduction

Weeds, under certain conditions cause more economic loss to agriculture than insect pests and pathogenic fungi. Apart from competing with the crop for water, light, nutrients and space, weeds could also harbor pests which attack the crop thereby reducing the yield and increasing production cost. Gharde et al. (2018) estimate that the total economic loss due to weeds in 10 major crops in India is around USD 11 billion. Furthermore, some weeds are responsible for health concerns as they produce allergenic pollens (Gadermaier et al. 2014). The most common method of weed management is by the application of selective chemicals (weedicides/herbicides) which kill the weeds and not the crop owing to certain physiological difference between these two plant species. Although around 25 target sites at the molecular level have been identified for herbicide action, only a few of these have been constantly used owing to cost and ease of application (Harding and Raizada 2015). Such a unilateral dependence on a few herbicides has resulted in the evolution of rapid herbicide resistance among weeds (Darmency 2013; Délye et al. 2013). Currently, 50 herbicide-resistant weed biotypes have been recorded (Heap 2015). Apart from employing different strategies such as chemical and biological control (Harding and Raizada 2015) to manage weeds, it is imperative that new methods of weed control are identified to keep pace with the development of chemical resistance by the weeds. One such novel method is the possibility of using endophytes for weed control. Considering the paucity of information, this mini article can only hint at employing endophytes for weed management and possibly galvanize scientists to explore this angle to improve crop productivity.

Why endophytes?

Endophytes (bacteria and fungi) which make up the endobiome of plants, have evolved with the plants and together with plant constitute a holobiome. They produce an array of metabolites with novel molecular architecture exhibiting many interesting bioactivities. Endophyte infection of a plant contributes to the plant's resistance (Kang et al. 2007) by the upregulation of hundreds of defense related genes of the plant (Mejía et al. 2014).

✉ T. S. Suryanarayanan
t_sury2002@yahoo.com

[1] Vivekananda Institute of Tropical Mycology (VINSTROM), Ramakrishna Mission Vidyapith, Chennai, Tamil Nadu, India

Furthermore, endophytes increase the ecological fitness of their host plants by enhancing their nutrient uptake (Paungfoo-Lonhienne et al. 2010), tolerance to abiotic (Hyde et al. 2019) and biotic (Gond et al. 2015) stressors and increase plant growth and yield (Ryan et al. 2008; Gaiero et al. 2013). These attributes of the endophytes make them an attractive alternative to plant breeding as a method of improving crop traits. Although there are many studies of the species diversity (Kandel et al. 2017; Suryanarayanan et al. 2018a, b) and bioactive metabolites of endophytes (Suryanarayanan et al. 2009), there are only a few investigations addressing the effect of weedicides and herbicides on the endophyte status of plants and the possible production of metabolites by endophytes which may act against weeds. Among the only thirteen authorized bioherbicides currently used, ten are of fungal origin reinforcing the need to screen fungi assiduously for novel weedicides (Samad et al. 2017). With reference to fungi, although their estimated diversity ranges from 2.2 to 3.8 million species, only about 8% of these are currently known (Hawksworth and Lücking 2017); thus exploring fungi, especially the endophytes due to their extraordinary synthetic ability, for novel herbicidal compounds would be worthwhile.

How may endophytes be used for weed management?

A few studies endorse the potential of endophytes in weed control (Kowalski et al. 2015). Considering the high synthetic potential of endophytes (Suryanarayanan et al. 2009), one immediately obvious method of using endophytes to manage weeds is to look for their metabolites which are toxic to weeds. The use of a weedicidal compound secreted by a microbe is a better option in weed control than the use of a biocontrol agent whose efficacy depends on its continued survival in the introduced environment. Schulz et al. (2002) showed that fungal endophytes produce metabolites exhibiting herbicidal activity. Suryanarayanan et al. (2018a) reported that fungal endophytes produce metabolites which induce chlorosis followed by necrosis in *Lemna minor*. Although the authors did not identify the chemicals which induced the death this weed, the study showed that fungal endophytes could be a source of weedicides. Singh et al. (2018) showed that endophytic actinomycetes could be a source of herbicidal metabolites. A *Chaetomium globosum* isolated as an endophytic fungus from the leaves of *Amaranthus viridis* produce phytotoxic azaphilone derivatives (Piyasena et al. 2015). Having said that, it is imperative to screen the effective endophyte metabolites for their specificity of action and that they do not act on the crop at the effective concentration. It is also essential to ascertain that the effective chemicals are not mycotoxins as the introduction of such chemicals in the food chain is not desirable. Our study shows that foliar endophytic fungi do produce various mycotoxins (Thirumalai et al. 2013). More detailed investigations are needed addressing interspecific competition among introduced candidate endophytes and the native ones in a plant, and the role and location of each component of the endomicrbiome in plant tissue to fully harness the weedicide potential of endophytes in agriculture (White et al. 2019).

The other side: impacts of herbicides on endophytes

Although endophytes promote crop growth by increasing nitrogen fixation, hormone production, phosphate and iron utilization (Xia et al. 2015), the use of agrochemicals such as pesticides (da Costa Stuart et al. 2018) and fungicides (Mohandoss and Suryanarayanan 2009) alters the endomicrobiome of plants. Treatment of soybean with the herbicide Fenoxaprop-*P*-ethyl decreased the diversity, richness, and evenness of its fungal endophyte assembly (da Costa Stuart et al. 2018). Similarly, imidazolinone herbicides brought about changes in the composition of fungal endophytes in sugarcane (Stuart et al. 2010). Such alterations in the endobiome could affect negatively the crop performance.

Some bacterial (Rylott 2014) and fungal endophytes (Khan et al. 2014) are known to biotransform many chemicals including xenobiotics and perhaps as a consequence, their species composition in the crop tissue is altered when crops are exposed to chemicals like herbicides. Application of glyphosate herbicide alters the native bacterial endophyte community in soybean by promoting those which could use this chemical as a source of energy and nutrient and eliminating those which are susceptible to it (Kuklinsky-Sobral et al. 2005; Kryuchkova et al. 2014). Wang et al. (2017) showed that *Neurospora intermedia*, an endophytic fungus isolated from sugarcane roots degrades the phenylurea herbicides diuron, fenuron, monuron, metobromuron, isoproturon, chlorbromuron, and linuron. Many endophytic bacteria and rhizobacteria increase the resistance of their host plants to herbicides by metabolizing them (Liu et al. 2011; Tétard-Jones and Edwards 2016). Inoculation of pea plants with the bacterial endophyte *Pseudomonas putida* POPHV6 aided in the disappearance of 2,4-D from soil and resulted in reduced translocation of the herbicide in the plant (Germaine et al. 2006). Thus, it is possible that the microbes of the weed endobiome get selected for weedicide tolerance and ultimately add to weed resistance to weedicides. Indeed, Tétard-Jones and

Edwards (2016) allude to the possibility of endophytes priming 'the resistance mechanisms in plants such that they enhance herbicide tolerance by inducing the host's stress responses to withstand the downstream toxicity caused by herbicides.' Thus, various aspects evolution of herbicide resistance including the attendant fitness cost which are primarily host gene controlled (Baucom 2019), need to be revisited considering the role played by endophytes.

Although endophytes are known to enhance the abiotic and stress tolerance of plants under laboratory conditions, their role in increasing the fitness of crops may not be as considerable in the field (Serfling et al. 2007). It is known that the differential tolerance to weedicides exhibited by the crop and the weed is due to the difference in the vulnerability of the biochemical process targeted by the weedicide and the relative capacity of these plants to detoxify the weedicide. Recent investigations add a microbial facet to this phenomenon viz. the endobiome of weeds and crops. This warrants focused basic studies on the endophytes, the interaction among them, between their host plant as well as the environment which could ultimately lead to better use of endophytes in weed management.

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