NEW ERA AGRICULTURE MAGAZINE

Role of Fungal Endophytes in Plant Disease Management

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1. Introduction

The use of agrochemicals as a single control measure in the field to protect crops from their pests has been generating resistance in these pests, and also represents a high risk to field workers and consumers. To cope with these problems, Biological control has become an utmost important tool for plant disease management. Endophytic microorganisms offer great-untapped potential as biological agent for plant disease management, due to their antagonistic properties.

Endophyte

An endophyte is an endosymbiont, often a bacterium or fungus, that lives within a plant for at least part of its life cycle without causing apparent disease (Promputtha *et al*., 2005 and Porras-Alfaro and Bayman, 2011).

History

The term 'endophyte' consists of two Greek words, 'endo' meaning within and 'phyte' meaning plant. It was first time used by Anton de Bary in 1866 and stated that fungi that colonize internal tissues of plants. In 1887, Galippe reported occurrence of bacteria and fungi in interior of vegetables. In 1991, Orlando Petrini defined endophytes as all organisms inhabiting plant organs that at some time in their life cycle can colonize internal plant tissues without causing apparent harm to their host.

2. Mechanisms of Action of Endophytes

There are various mechanisms of endophytic inhibition of pathogens including direct and indirect parasitism.

2.1. Direct parasitism

In direct parasitism, endophytes directly suppress pathogens by the production of antibiotics and through secretion of lytic enzymes.

2.1.1. Antibiosis

Antibiosis is the inhibition or death of an organism as a result of the toxic action of metabolites produced by another organism. Secondary metabolites produced by many fungal endophytes are antifungal and antibacterial in nature, which strongly suppresses the growth of other microorganisms or plant. Several endophytic bioagents are capable of producing single or multiple types of antibiotics including alkaloids, terpenoids,

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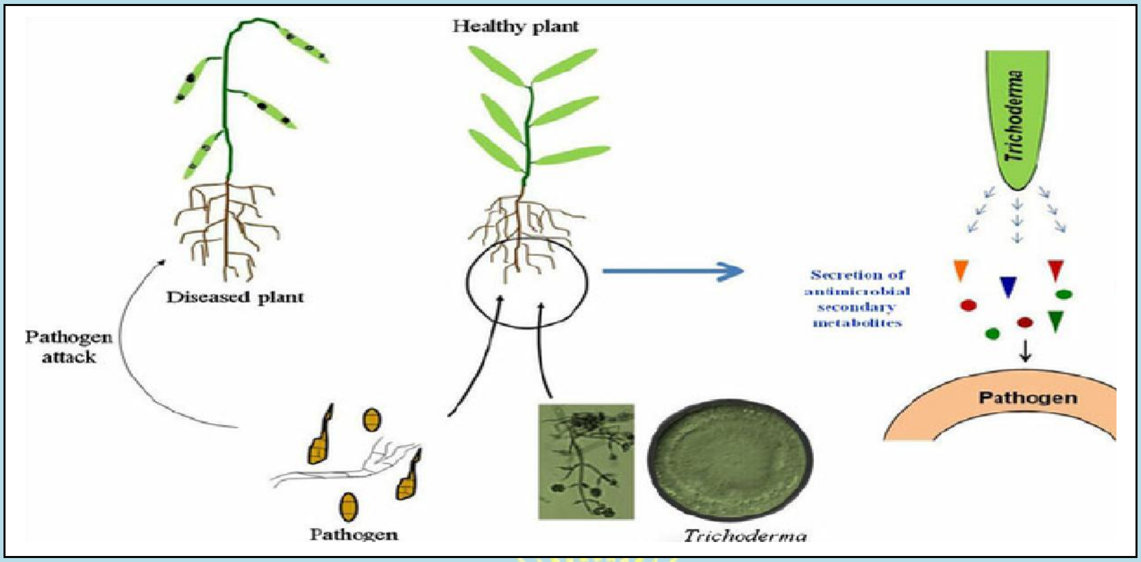
polypeptides and aromatic compounds, and plant pathogens are sensitive to those antibiotics (Chen *et al.*, 2016).

cell wall material). These enzymes include cellulases, β-1, 3-glucanases and chitinases. The enzymes may not be the sole factor for



Production of antibiotics by *Trichoderma* against plant pathogens		
Endophyte	**Antibiotic**	**Target pathogens**
Acremonium zeae	Pyrrocidines A, B	*Aspergillus flavus, Fusarium verticillioides*
***Verticillium* sp.**	Massariphenone, ergosterol peroxide	*Pyricularia oryzae* P-2b
Phomopis cassiae	Cadinane, sesquiterpenes	*Cladosporium sphaerospermum, Cladosporium cladosporioides*
Muscodor albus	Tetrahydofuran, 2- methyl furan, 2-butanone, aciphyllene	*Stachybotrys chartarum*

2.1.2. Production of lytic enzymes

Lytic enzymes produced by many microorganisms can hydrolyse a variety of polymeric compounds, including proteins, cellulose, hemicellulose, chitin and DNA. During colonization of the plant (host) surface, endophytes produce enzymes and hydrolyse plant cell. Therefore, these enzymes are effective at suppressing pathogenic activities directly and have the ability to degrade the cell walls of fungi (chitin as the cell wall component) and oomycetes (cellulose as the

antagonism but they may contribute as part of a combination of mechanisms.

Endophytic Fungi	Hosts	Pathogens Targets
Trichoderma koningii	*Allium cepa*	*Sclerotium cepivorum*
Trichoderma harzianum	*Phaseolus vulgaris*	*Botrytis cinerea*

2.1.3. Hyperparasites and predation

Hyperparasitism is the phenomenon where the endophytic antagonist or biocontrol agent either directly kills the pathogen or its propagules. Hyperparasitism in fungi is evidenced by the antagonist colonizing the pathogen's hyphae by twisting around them or by the antagonist penetrating the pathogen's hyphae initially and later secreting lytic enzymes that decompose the pathogen's cell wall. In contrast to this mechanism of hyperparasitism, microbial predation is a general means of suppressing pathogens by endophytes under nutrient-limited conditions (Latz *et al.*, 2018).

2.2. Indirect effects

The indirect defence mechanism of plants associated with endophytes is triggered through induced resistance enhancement and by promotion of plant growth and physiology.

2.2.1.Induction of plant resistance

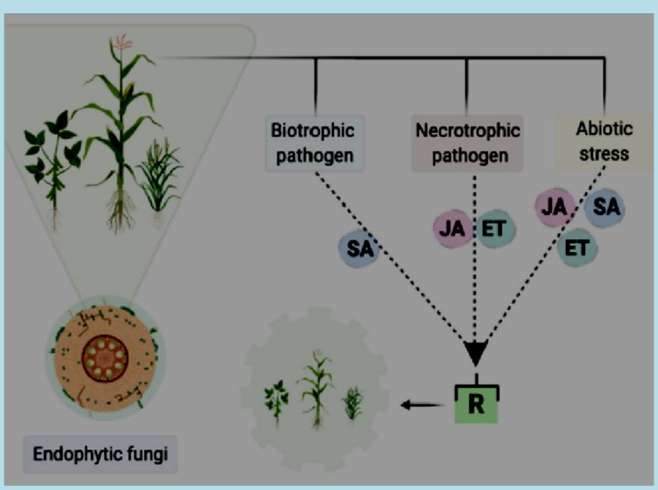
Endophytic microorganisms indirectly protect plants from pathogens by inducing resistance. Systemic acquired resistance (SAR) and induced systemic resistance (ISR) are two

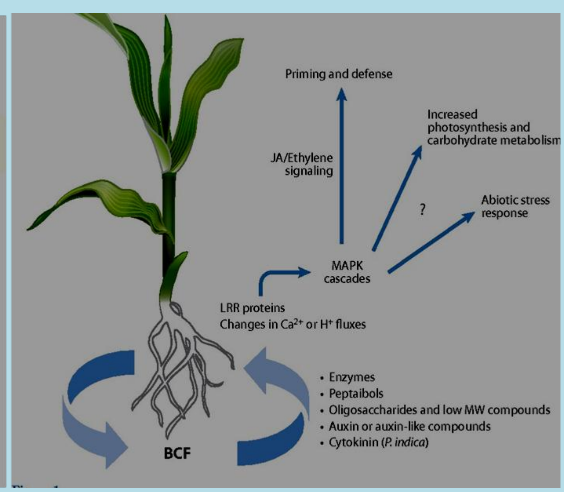
Endophyte	Host	Target pathogens
Acremonium strictum	*Dactylis glomerata*	*Helminthosporium solani*
Epichloë festucae	*Festuca rubra*	*Sclerotinia homoeocarpa*

2.1.4. Competition

Competition between endophytes and pathogens mainly occurs for their nutrition (e.g. sugars, carbohydrates, growth factors, etc.) and/or space (host surface for colonization). As a result of their rapid colonization, endophytes exhaust the limited available substrates and thereby prevent the entry of the pathogens into the host.

forms of induced resistances. ISR is a non-pathogenic (beneficial) rhizobacteria-induced resistance mechanism and is regulated by the jasmonic acid or ethylene pathway. ISR is not associated with the accumulation of pathogenesis related (PR) proteins. SAR is induced as a result of host–pathogen interaction and is mediated by the salicylic acid pathway. SAR is associated with PR





protein accumulation. Mechanisms in inducing resistance include increased synthesis of phytoalexins and PR proteins,cell wall thickening through depositing lignin and glucans, increased cuticle thickness (Dutta *et al.*, 2014) . associated with defence responses are provided by primary metabolic pathways. It has been established that enhancement of plant growth promotion induced by fungal endophytes increase protection against pathogens indirectly.

Induced resistance by endophytic fungi		
Endophytic Fungi	**Hosts**	**Pathogens Targets**
		Fungi
Trichoderma harzianum	*Capsicum annum*	*Phytophthora capsici*
Trichoderma virens	*S.lycopersicum*	*Fusarium oxysporum* f. sp. *Lycopersici*
Piriformospora indica	*Musa* spp.	*Fusarium oxysporum* f. sp. *cubense* (FocTR4)
Fusarium solani sensu lato	*S.lycopersicum*	*Septoria lycopersici*
		Viruses
T. harzianum	*Solanum lycopersicum*	*Cucumber mosaic virus* (CMV)
T. harzianum and Metarhizium anisopliae	*Zea mays*	*Sugarcane mosaic virus* (SCMV)
		Bacteria
T. asperellum	*Solanum lycopersicum*	*Ralstonia solanacearum*
T. asperellum	*Cucumis sativus*	*Pseudomonas syringae pv. Lachrymans*

2.2.2. Promotion of plant growth and physiology

Endophytes contribute towards protection of their host plant against phytopathogens through control of plant physiology Plant growth promotion may be enhanced due to the influence of phytohormones produced by fungal endophytes. Indole acetic acid (IAA) is produced by *Colletotrichum* sp., an endophytic fungus in *Artimesia annua*, and IAA regulates plant processes. Increased demands for energy, carbon skeletons and reducing equivalents

3. Advantages of endophytes in plant disease management :

- ✓ Biological control of plant diseases by exploitation of endophytes is considered as an alternative to pesticides and reduces the use of harmful chemicals in crop production.
- ✓ Endophyte–plant interactions can be exploited to promote plant health and may play a significant role in sustainable low-input agriculture for both non-food and food crops.

- ✓ Use of specific endophytes is more preferable than the use of non-specific chemical pesticides or fertilizers due to their effectiveness, low cost and contributions to sustainable agricultural production.
- ✓ Biocontrol agents provide control consistently well throughout crop cycles, whereas chemicals remain active only for very short period as far as suppression of plant pathogens are concerned.
- ✓ If biocontrol agents (endophytes) are used as one of the components of integrated pest management (IPM) of seed production, this reduces costs and pollution levels as compared with use of chemicals.
- ✓ In nature endophytes are easily available and specific as they suppress or kill only the target pathogens or organisms.

4. Conclusion

Due to high production cost by the use of chemical fertilizers and pesticides and its negative effect on environment, the use of endophytes may have an advantageous role in sustainable agriculture if the added inoculants are potential. It is strongly believed that several endophytes with unique modes of action exist in our ecosystem, and only strong research can find out about them.

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