Ecofarming (e-Magazine)

Agriculture

Ecofarming
e-Magazine for Agriculture and Allied Sciences
http://www.ecofarming.rdagriculture.in
e-ISSN: 2583-0791

Interactions between Endophytic fungi

Host Plant- Insects: A Multitrophic association

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Received: February, 2024; Accepted: February, 2024; Published: April, 2024

Introduction

Insect pests cause enormous amount of loss in crop production. Plant pests and diseases can cause losses up to 40% of the world's crop production. The annual cost of invading insects to the world economy is at least $70 billion. Globally, the application of agrochemicals has demonstrated its effectiveness in raising crop yields, however, overuse of these chemicals has led to a number of adverse consequences, including the development of resistance in insect pests, the resurgence of secondary pests, and the destruction or reduction of natural enemies' populations, all of which have impeded efforts to control pests naturally. The sustainability and environmental concerns within food systems have to be addressed by changing or reforming traditional methods and by utilising agroecological principles. A new frontier has been developed in agricultural production which is microorganisms associated with plants, specifically endophytic fungus (EFs), which have helped to meet global needs for nutrient-dense foods and are eventually essential for sustainable agriculture by boosting crop productivity. Due to their remarkable ability to produce beneficial bioactive chemicals and function as biocontrol agents to manage the populations of plant pests, EFs are reshaping the world of agriculture.

Endophytes are bacteria or fungus that develop asymptomatically inside plant tissue without endangering their host. They are associated with most plant species in both managed and natural settings. They are primarily transmitted by seeds and start to support plant growth and health as soon as the seeds germinate but some may be obtained from the soil still provide similar benefits like the forementioned (Verma and White, 2018) It can be purposefully introduced to plants by foliar spraying, root dipping, and seed coating. (Vega *et al.*, 2008). In addition, conferring pest and disease resistance endophytic microorganisms play a crucial role in plants by improving the nutrients uptake, boosting plant stress tolerance, controlling plant development, inhibiting weed growth *etc.* These alterations induced in the physiology of the plant also can significantly contribute to increased defence against insect herbivores even though there is little evidence supporting this. In normal circumstances, an infection by fungi modifies the metabolism of the host plant, by either enhancing the production of defensive chemicals or limiting the amounts of nutrients. (Raman and Suryanarayanan, 2017). Along with this, these fungus in the course of its infection and spread can also alter the host and insect's lifecycle in its favour. Two distinct areas that might be investigated further for research are the utilization of these chemicals produced and the increased applications of endophytic fungus as beneficial biocontrol agents.

Recruitment and association of endophytic fungi by plants

The endophytic fungi usually occur in the growing environment around the host plants and these primarily employ one of three transmission patterns: (i) horizontally by sexual spores from infected individuals (such as *Epichloe* spp.), (ii) vertically from infected plant to offspring via seeds (*Neotyphodium* spp.), or (iii) a combination of two life cycles (Schardl *et al*., 1997). Plant habitat, soil type, plant species, and ambient microorganisms have a significant impact on the occurrence of endophytic fungus. (Bonito *et al*., 2014).

The association between endophytic fungi and plants are usually symbiotic in natural ecosystems and are usually occurring in response to the distinctive adaptations taken up by the endophytes that helps them to thrive within the host plant and synchronize the growth together. A variety of relationships exist between endophytes and their host plants, ranging from (i) mutualism to (ii) hostility to (iii) neutralism. Inside the host tissue, the endophytic fungus assumes a quiescent (latent) state, which they maintain for the course of the host plant's life (neutralism) or for a longer period of time (mutualism or antagonism) until endophytic fungi are supported by their environment in favour to them. (Sieber, 2007). The plant-fungal endophytic association can be an example of balanced antagonism in which host plants provide shelter for the fungus in terms of nutrients and other benefits and fungus in turn triggers the host plants' virulence systems to colonise and defend itself (Baron *et al*., 2020). The genetic makeup and phenotypic expression of hosts can be impacted by the dynamic regulation of endophytic fungus that provide resistance against pathogens and herbivores and also alter host nitrogen metabolism which the aids host plants in different ways. Therefore, the precise control of host genes, phenotypes, and metabolism results in an association between endophytic fungi and their host plant.

Colonization Mechanism

In their tissues, endophytic fungi typically take up a mutualist lifestyle. Additionally, they possess comparable potentials in terms of rhizosphere competency, plant immunity-overcoming ability, motility to reach the host plant, and mechanisms to facilitate entrance and proliferation inside the plant. (Mitter *et al*., 2013). From the site of infection, the microbes can systematically colonize plants through their roots, branches, blooms, fruits, or seeds. The variety of defence mechanisms and response put forward by the plants differs to the colonization of endophytes. These fungi prefer specific parts and establish as *Metarhizium* is primarily found in roots and *Beauveria* within multiple plant tissues (Behie *et al*., 2015). The fungus also avoids various defence mechanisms which are intervened by certain diffusible molecules to get established as an endophyte and also produces certain enzymes to cope up the stress provided by the plant during the process of colonization. In case of *M. robertsii,* a raffinose transporter and an extracellular invertase is playing a crucial role in sucrose hydrolysis thus establishing the fungus in the plants since raffinose and sucrose primarily dominate the molecules in the root exudates (Fan *et al*., 2017).

Increase of plant resistance to herbivores by endophytic fungi

Endophytic fungi enable the host plants to produce certain antimicrobial metabolites which are toxic to insects and other pathogen invading plants and thus provide protection against herbivory. Research has shown that endophytic fungus is capable of producing defensive compounds that give their plant hosts protection against the digestion of herbivores. These protective substances can lower insect performance (antibiosis) or deter feeding (antixenosis) (Braman *et al*., 2002). These toxic substances can be categorised into various classes, including phenol and phenolic acids, alkaloids, terpenoids, isocoumarin derivatives, quinones, flavonoids, and chlorinated metabolites (Strobel *et al*., 2004). In the above-mentioned compounds alkaloids were first founded fungal metabolites to have insecticidal activity that can increase host resistance to herbivores. The type and quantity of these alkaloids produced in turn depend upon the fungal isolate and plant- fungal genotype interaction (Lane *et al*., 2000). The groups into which these alkaloids are further divided are pyrrolizidines, amines and amides, and indole derivatives in which peramine from group of amines and amides and lolitrem C and F from indole derivatives, are highly toxic to insects and are found safer for mammals (Rowan and Latch, 2018). Sesquiterpenes and diterpenes from terpenoids isolated from *Phyllosticta* sp., and Rugulosin from Quinones are found to have negative effect on spruce budworm (Calhoun *et al*., 1992). Similarly, tricin from flavonoids against mosquito larvae (Findlay *et al*., 1997), Phenol and phenolic acids obtained *Cladosporium* sp., had a prominent lethal effect on development and survival of tobacco cutworm (Singh *et al*., 2015).

Other mechanisms

Apart from the production of antimicrobial metabolites endophytic fungi resist to the insect herbivores through other mechanisms. It may be through playing an important role in plant defence mechanism thus creating physical barriers for preventing the attack by pathogens and other herbivores. It also confers resistance to the invading insects by plant defensive hormonal pathways even when the fungus is incapable to produce active alkaloids (Bastias *et al*., 2017). The stimulation of JA signalling, which results in the accumulation of secondary metabolites and plant pathogenesis-related (PR) proteins that offer protection against chewing insects even in the absence of alkaloids, may be the plausible explanation. (Guerreiro *et al*., 2016). There is also the possibility of the repression of salicylic acid (SA) signaling in endophytic colonized plants because of the consequent decrease in the amount of the loline alkaloids that provide decreased resistance against aphids (Pozo *et al*., 2015). In addition to these endophytes also increase the resistance by the production of certain phytohormones that helps to regulate the plant growth actively or passively. According to Hamayun *et al*. (2019), gibberellic acid produced by the fungal endophyte *Cladosporium sphaerospermum*, which was isolated from soybean plants and stimulated plant growth in rice and soybean.

Interaction between insect partners and endophytic fungi in the complex association

In the case of association and interactions of plants-fungal endophytes-plant-feeding insects, there exists a higher level of complexity because the interactions are taken to a multitrophic level due to the involvement of three components and this area has been less focused by the researchers. More frequently, the injuries imposed by the insects on the plants could serve as a strong point of entrance of the endophytes and once they get established inside the plants, in turn attract insects to the plant which depend up on the metabolites produced by endophytic fungi which is in association with the plant. Van Bael *et al*. (2009) observed that interactions between fungi in the leaf endobiome and fungal endophytes. These fungi produced different chemicals that made the environment less attractive for *Atta colombica.* Suryanarayanan *et al*. (2011) observed that an indirect relationship exists between insects and fungal endophytes as there was a notable reduction in the density of fungal endophytes in

Bt (Bacillus thuringiensis) gene-incorporated varieties of *Gossypium hirsutum* in comparison with wild type thus preferably suggesting that these endophytes could be transferred by the insect visitors of the plant and at several times these could be utilized to regulate plant pest population.

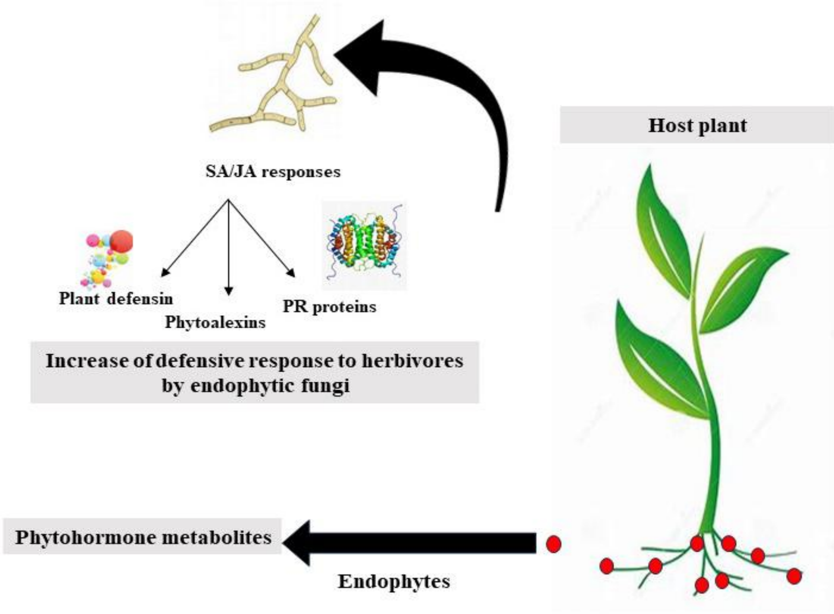

Fig 1. The interactions between insect herbivores, host plants and endophytes (Khare *et al*., 2018)

Conclusion

As extremely effective and promising biocontrol agents, endophytic fungus can be employed to control plant pest populations, improve plant growth, and also to strengthen plant resistance to the difficulties posed by climate change. An increased knowledge regarding the interactions happening among three participants *viz*. fungal endophytes, plants and insects that constitutes for the single intertwined complex would pave the way for the effective management of pest and crop loss caused by pestiferous insects. In order to promote the adoption of endophytes and to ascertain the efficacy of the endophytes in a natural setting, it is also imperative to encourage a greater understanding of this developing field among farmers and also to encourage field experiments to determine the effectiveness of the endophytes under natural environment. Adoption of all these measures will aid in the development of tactics for maintaining plant fitness in the face of various environmental stress and also combat the pest induced losses.

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