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# AN OVERVIEW OF TRICHODERMAL INTERACTIONS WITH PATHOGENS AND PLANTS

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One of the most significant requirements of modern world agriculture is to achieve higher yields in an environment permissive manner. Among various plant growth promoting microorganisms, *Trichoderma* occupies a unique position. Genus *Trichoderma* represents a very large and diverse group of fungi which plays a crucial role in uplifting the plant productivity. This fungus has a distinct property to infect and colonize in the roots of various plants. Interaction of plant roots with *Trichoderma* induces various genetic and physical changes in the plants. *Trichoderma* employs various tactics like antibiosis, competition, iron chelation, Hyperparasitism/Mycoparasitismetc to inhibit the growth of pathogens residing in the neighborhood. Additionally they secrete various chemicals/ Proteins /hormones to uplift the growth of infected plants. Some of them resides as endophytes and promotes plant growth in many ways. Some *Trichoderma spp*. are known to induce systemic resistance against plant pathogens and tolerance against abiotic stress.

**Keywords**: Antibiosis; Competition; Endophytes; Induced systemic resistance; Iron Chelation; Mycoparasitism; plant growth promotion.

## Introduction:

From the first decade of the last century, scientists knew the usefulness of filamentous fungi *Trichoderma* as a potential bio control agent against many plant pathogens[1].In this millennium *Trichoderma* has helped to sustain the agriculture yields and hence proved be a boon for human kind. This fungi is known to– enhance the soil fertility, improve the wellbeing of the crop plants, uplift the capability of the plants to degrade the toxic compounds, show antagonistic effect against pathogenic fungi and nematodes, modify rhizosphere, enhance plant defense mechanism, impart tolerance against abiotic stress, solubilize plant nutrients, increase the reproductive capability andimprove the plant defense mechanism[2,3,4].Symbioticassociation of some species of *Trichoderma* with plant roots is known to result in induced systemic resistance (ISR) and systemic acquired resistance (SAR) in plants. Because of the above mentioned reasons many species of *Trichoderma* have been used as commercial bio-pesticide/ bio-fungicide. In fact, globally 60% of the bio-fungicides companies use *Trichoderma*as main bio- fungicide.

Some species of *Trichoderma* are also known to produce pigments (greenish-yellow, reddish and colourless), clinically important secondary metabolites and industrially important enzymes.

*Trichoderma* was first described long back in 1794[5]. This fungi is ubiquitous and is found predominantly in the agriculture and native soils throughout all climatic zones (nearly all tropical and temperate soils).They can grow as endophytes (in between living cells) or as saprophytes (in soil organic matter)or as human pathogens (in between mammalian tissues)[6,7,8]. They can colonize in both herbaceous and woody plants. *Trichoderma* generally reproduces asexually with a few showing sexual telomorphs. In general they are found as clonal heterokaryotic individual. The extensive study of the genome of many species of *Trichoderma* like *T. virens, T. reesei, T. atroviride, T. harzianumetc*has revealed the presence of many genes that can produce a variety of expression patterns. Such differential pattern of gene expression allows this fungus to adapt to varied set of environmental conditions. The genomic study has revealed, to some extent, the changes that occur in the plant, pathogen and *Trichoderma* itself when they interact with each other[9]. This review deals with the recent phylogenetic position of the fungi *Trichoderma*. It also aims to give an insight on various Trichodermal interactions.

***The systematics and phylogenetics of Trichoderma:***

The name *Trichoderma*was introduced byPersoon[5] and from then onwards the systematics and taxonomy of this fungus has developed. *Trichoderma* belongs to - Family: Hypocreaceae, Order: Hypocreales, Class: Sordariomycetes and Phylum: Ascomycetes. Up to very long i.e. 1969,only one species of this fungi namely *T.viride* was known[10]. Since then many species of genus *Trichoderma* like *T. harzianum* Rifai, *T. hamatum, T. viride, T. polysporum* and several others have been identified. In early nineties, 27 species and five sections ofthe genus *Trichoderma* were described byBissett[11,12,13]. Many workers tried to rearrange the genus *Trichoderma* on the basis of its morphology but most of the classification system encountered one or the other problem and lead to false identification of certain species, for instance – name *Trichodermaha rzianum*was used for many different species[14]. More reliable classification came after the development of molecular biology techniques. Using advanced molecular biology tools, scientists identified few more species of the genus *Trichoderma.* Number of identified *Trichoderma* species moved to 47 in the year 2002[14]. Further advancement in molecular biology techniques (like oligonucleotide barcoding) along with the development of search tools like Tricho Blast added tremendously to our knowledge of species diversity of the genus *Trichoderma*[15,16]. Many workers used phenotypic microarrays for identification[17].Till now a total of 104 species have been listed by the International Sub-commission on *Trichoderma/Hypocrea*[18]. Some endophytic species have been reported by Chaverri and Samuels[19]. These species were analyzed on the basis of preference of their habitat and mode of nutrition. As a result various groups of endophytic *Trichoderma spp* were identified and their potential use in the development of innovative strategies of biological control was studied.

***Trichoderma and its interactions:***

*Trichoderma*is aubiquitous asexually reproducing fungi that can be frequently isolated from the soils of nearly all environments. They are known to colonize in various plants ranging from herbaceous to woody. This genus is a fast growing strong opportunistic invader and is known to produce spores. Many of them can produce antibiotics and colonize in highly competitive environments[20]. They can compete with a number of other microbes (both pathogenic and nonpathogenic) for nutrients and space[21]. The mechanism of competition and efforts of colonization by different species of *Trichoderma* in various ecological niche are diverse and well developed[22].

*Interactions with plant pathogens:*

In the event of establishing itself in the niche, *Trichoderma* interacts with the pathogenic and nonpathogenic microbes in many ways. In the process it proves itself as a very strong contender against many plant pathogens. Among various processes Antibiosis, Hyper-Parasitism and Competition are the main strategies employed by this fungus.

*Antibiosis:* Antibiosis is one of the most common mechanisms used by many microorganisms to inhibit growth of other microbes present within the same niche. *Trichoderma* also produce and release a range of antibiotics which down-regulate the growth of pathogenic microbes present in the vicinity[23].Three classes of antibiotics *viz* peptaibols, volatile and water soluble have been isolated and characterized form *Trichoderma.* Examples of Peptaibols antibiotics are trichodecenins, trichotoxins A, trichotoxins B, trichorovins, tricholongins BIand BII, atroviridins A-C, neoatroviridins A-D and trichocellins. These compounds show antagonism against many pathogenic and non-pathogenic fungi, some Gram positive bacteria and few viruses. One or more of these are produced by various species of *Trichoderma* like *T. viride, T. harzianum, T. longibrachiatum, T. koningii, T. atroviride*etc. Peptaibolsanti biotics have a molecular weight of 500-2200 Da and are polypeptide in nature with a high concentration of non-proteinogenic amino acids[24]. Alfa amino isobutyric acid is the most abundant non-proteinogenic amino acid found in Peptaibols antibiotics. Wiest*et al*[25], reported that the exogenous use of peptaibols stimulated the defense responsive genes in Tobacco plants. More over treated plants have reduced susceptibility towards Tobacco mosaic virus.

The typical smell of coconut in *T. viride*is suggestive of the presence of volatile compounds. 6-Pentyl-α-Pyrone(6 PAP)produced by *T. harzianum*, *T. viride* and *T. koningii* is a typical example of volatile antibiotic. 6 PAP so produced plays a key role in biological control of *Fusariumoxysporum, Botrytiscinerea* and*Rhizoctoniasolani.* Other volatile compound include salamethicins, tricholin, harzianic acid, massoilactone, gliovirin, glisoprenins andheptelidic acid.Viridin, Dermadin, Lignoren, Koningins, Trichoviridin and Koningic acid are examples of soluble antibacterial and antifungal compounds released by various species of *Trichoderma*[26]. These compounds show antagonism against *Aspergillus niger, Penicilium expansum, Bacillus subtilis, Escherichia coli, Pseudomonas aeruginosa, Fusarium oxysporum* etc.

Monte[27]emphasized that many species of *Trichoderma* are especial in the sense that they can secrete lytic enzymes along with the antibiotics. Their combined action is more lethal. Lytic enzymes so produced have capacity to degrade the fungal cell walls and thus aids the penetration of antibiotics in the cell[1].

*Hyperparasitism:* Another important

mechanism employed by *Trichoderma* which has established it as a biocontrol agent is Hyperparasitism or Mycoparasitism. This process involves direct attack of a fungal species on another fungus. In this mechanism a direct contact of *Trichoderma* and the pathogen is established. This process is accompanied in many stages *viz*; (1) pathogen recognition (after receiving signals from the host) (2) Chemotrophic growth of *Trichoderma*(3) Attack by secretion of extracellular enzymes (4) Gradual penetration of the hyphae into the pathogen cell (5) Lysis of the host and cell death[22,28].

*Trichoderma* synthesizes cell wall degrading lytic enzymes like Glucanase, Cellulase, Xylanase, Proteases and Chitinases which facilitate the hydrolysis of the fungal cell wall[29,30]. Chitinases are the most important hydrolytic enzyme that plays key role in cell wall degradation.

Some *Trichoderma* species can produce siderophores. Some species of *Trichoderma* are also known to create acidic environments thereby establishing hostile conditions for the growth of pathogenic fungi[31]. Different *Trichoderma*s trains may show varied responses. Gajera*et al*[32], has shown that the secretion of low levels of exochitinases by some *Trichoder maspp*can damage the cell wall of other fungi and hence play a significant role in inhibition of the growth of many pathogenic fungal strains. Some *Trichoderma spp.* Under go morphological changes like coiling and formation of appressorium that contain high amount of osmotic solutes like glycerol. Coiling aids in penetration inside the host cells. Once attached to the pathogen, *Trichoderma*c oils around the pathogen and forms appresoria. The appresoriathus formed releases its content. This result in production of peptides that cause pathogenesis, facilitate entry of *Trichoderma* hyphae in the pathogen and digestion of pathogen cell wall[1].Many factors are known to affect this process including some 20 to 30 proteins and other metabolites[33]. Few *Trichoderma spp*. have been reported to kill nematodes and hence they can be used as potential bio-nematicides. Gene- for- Gene experiments are been done for further understanding[33].

*Competition:* Within a niche, *Trichoderma* acts as a very dominant competitor and do not permit intense growth of fungal and bacterial neighbors. Hence, competition proves to be a powerful weapon for the eradication of the pathogens. This eradication is primarily done by starvation and scarcity of the growth limiting nutrients. Hence, strategy of competition proves most significant when effective biological control of fungal and bacterial pathogens is needed.

*Trichoderma* effectively competes with other microbial pathogens for carbon and iron. Under starvation conditions, like other fungi, it also produces siderophores. Siderophores are iron chelating substances which are used to mobilize and take up iron from the surrounding environment. The siderophores produced by *Trichoderma* are highly efficient and chelates iron more effectively as compared to other fungi in the neighborhood[34]. Hence iron becomes limiting factor and this is how *Trichoderma* can effectively control the growth of fungal pathogens. Similarly, *Trichoderma* competes effectively for carbon source and can limit the growth of other fungi. The extraordinary utilization of nutrients by *Trichoderma* can be attributed to the fact that it has unique capability to synthesize ATP from a variety of nutrients. *Fusarium oxysporum, Pythium, Ceratocystis paradoxa, Botryotinia cinerea, Rhizoctonia, Phytophthora* and many more pathogens are by *Trichoderma.* Use of *Trichoderma* in many pre and post-harvest damage.

*Trichoderma-plant interactions:*

The colonization of *Trichoderma* in the rhizosphere provides multifaceted benefit. A facultative symbiotic relation develops between the plants and the *Trichoderma* where the fungal partner obtains nutrient like sugars, vitamins etc from the plant partner and in turn the presence of *Trichoderma* help to improve the overall growth of the plant partner[35]. *Trichoderma* has auniquedual property where on the one hand it can attack and limit pathogens present in the soil while on the other hand it grooms the plant defense.

Moreover, *Trichoderma* are also known to produce chemicals capable of enhancing seed germination like gibberellin and zeaxanthin. Some species of *Trichoderma* are capable of producing acids like coumaric acid, gluconic acid and citric acid. These acids help to release phosphorous and other microelements from the soil and the organic matter. Thus this fungus ensures availability of nutrients to the plants[35].

Interaction of *Trichoderma* with plants starts with colonization (both internally and externally) in roots. The initial course of fungus-root association is not much understood as compared to the later part where fungal attachment, penetration and internal colonization takes place. Many species of *Trichoderma* are known to generate signals in the form of chemicals, proteins and hormones which promotes colonization of the fungus in the roots. Some of the species produce hydrophob in like proteins. They are cysteine rich proteins that assist in attachment. Qid74 of *T. harzianum* and TasHyd1 from *T.* of such proteins[36,37]. Both these proteins play important role in fungal attachment to the roots and lateral growth of roots together with the formation and elongation of root hairs. As a result of the above said modifications, uptake of nutrient and their translocation in various parts of shoot takes place. This results in an overall increase in the plant biomass. *Trichoderma*is also known to secrete Auxins. Auxins promote the growth of the roots and enhance its surface area. The increased surface area of the root aids in fungal colonization[38]. Some Trichodermal species can produce a cellulose binding expans in like protein which facilitates their penetration in the root. They can also synthesis endopolygalacturonase which aids in their penetration inside the root. After penetration, fungi start to grow intercellularly within the epidermal layer and the outer cortex. Interaction of some species of *Trichoderma* with plant roots also results in – boosting of photosynthesis, activation of various metabolic processes, induction of defense and stress related pathways to boost the plant immunity and induction of cell wall metabolism to strengthen cell barriers.

Here this is tonote that *Trichoderma* are generally resistant to the compounds like terpenoids, flavonoids, phytoalexins, and phenols which are secreted by the plant partners in response to the fungal infection. Plant partner generally secrets these compounds to inhibit root colonization by the fungus.

Many workers[1,39,40-42]havereported that *Trichoderma* can also stimulate systemic resistance in plants i.e. presence of *Trichoderma* provides resistance to the plants against the bacterial, fungal and viral diseases. *T. asperellum, T. virens T. atroviride and T. harzianum* are representatives that have been studied extensively for induced systemic resistance.

Many metabolites like Chitinases, Xylanases, low molecular weight compounds (released from the fungal cell wall or infected plants) etc play a critical role in inducing this resistance. Fungal infection in plants results in an increase in the concentration of enzymes and metabolites like chitinases, phytoalexins, glucanasescand phenylalanine ammonia lyase (PAL) which areresponsible for induced systemic resistance (ISR)[43]. Rubio *et al*[44], reported induction of 40 genes (related to stress management and metabolism of RNA, DNA and proteins) in tomato plants infected with *Trichodermahamatum*382.Similarly about 200 differentially expressed proteins were identified in Maize plants infected with*Trichodermaharzianum*T226.

Immediately after infection, the infected plants undergo a prompt ion flux followed by an oxidative burst. Callose deposition and polyphenol synthesis follows the oxidative burst. These events stimulate the jasmonate/ ethylene (JA/ET) and salicylate(SA) signaling. All such events enable the plants to acquire resistance against a variety of pathogens[42]. This resistance resembles the action of plant growth stimulating bacteria and is termed as JA/ET-mediated induced systemic resistance (ISR). When present in higher concentrations, *Trichoderma* can elicit salicylate mediated acquired resistance. Many chemicals released by *Trichoderma* like xylanase, trichovirin II etc can also stimulate immune responses in plants.Sm1/EPL1 a small hydrophobin like protein belonging to cerato-platanin (CP) familyis the best characterized elicitor[16,45].

Some comparatively new species of *Trichoderma* like *T. evansii, T. martiale, T. amazonicum etc* have been reported to live as endophytes[46]. They can induce transcriptomic changes in plants.Theirpresence induces expression of many genes which in one way or other protect the plants from abiotic stress. The changes are also seen in gene expression pattern of the shoot. Such changes alter the plant physiology, helps in better uptake of fertilizers and enhanced photosynthetic efficiency[19].They may colonize in the surface of glandular trichomes and forms appressoria-like structures[6].

**Conclusion:**

*Trichoderma spp.*provides a great tool for the betterment of agriculture yields. They help the plants to resist abiotic stress, uptake nutrients and develop systemic resistance. Thus they help the plants in many ways so as to improve the productivity. They have a great gene pool. Through extensive study, this pool can be utilized for various biotechnological applications. Hence, further detailed study of this fungal genus can be of great help for the mankind in an environmentally acceptable manner.

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