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Trichoderma: A Complete Tool Box for Climate Smart Agriculture

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Abstract

The green revolution practiced at a great cost of environment to meet the ever-increasing demands for food and fiber. The indiscriminate use of agrochemicals resulted in a damaged ecosystem, food and water contamination, lost of local cultivar, pesticide tolerance, and disease resistance along with different climate change vulnerability. All these pressurize further on agricultural system to increase its productivity. Short-termed chemical remedy turns into today's hot topics of both environment and health concern. There is an urgent need to develop a sustainable approach for maximum crop production with minimum damage in climate vulnerable zone. *Trichoderma* are eco-friendly bio-reliance similar to organic and integrated management (IPM) recognized globally. In Bangladesh, the time is to avail *Trichoderma* as substitute of agrochemicals and fertilizers to combat biotic, abiotic both stresses. This study is for searching beneficial arsenal of *Trichoderma* to discover the whole tool box to counteract climate threat in rising demand of crop.

Keywords: *Trichoderma*; Fertilizers; Climate change; Agrochemicals.

Introduction

Trichoderma is a member of the largest group of fungi Ascomycota belonging to the Class Deuteromycetes. *Trichoderma* are soil born, free living, asexually reproducing filamentous fungi. Members of the genus are commonly isolated from soil and well known as avirulent plant symbiontas well as opportunistic invader. Kubicek et al. [1] explored its ubiquitousness and found *Trichoderma* as cosmopolitan and prevalent components of different ecosystem. They compete for food and site as a dominant component of soil microflora and predominantly occur in dead things and plant litter [2]. The high reproductive capacity with long self-lived profuse conidia, ability to grow under any irritable conditions, easy and inexpensive cultivation facilitates them to be used as a unique tool in organic agriculture. They also introduced as potential antagonist and being used as biopesticides globally for their driving force of disease suppressiveness to fungi and some nematodes. Apart from biocontrol aspect they nourished plant by solubilize plant nutrients, remediate pollutants and heavy metals thus impart abiotic stress tolerance. There are many products in market relying on microorganism but the inconsistency under field conditions and lack of proper information restricts their efficacy. It is necessary to know how *Trichoderma* interact with plant and other microbes to expand its use. Genome sequencing of *Trichoderma* species has done at certain level, provide data on understanding tetrahedron molecular interactions of mycoparasitism and *Trichoderma*-root symbiosis [3]. Now a wave of interest is addressed by growers and researchers to mitigate climate difficulty with a sustainable approach. We review the findings on several studies regarding environmental stress to un-mask and design a complete safeguard.

Rhizosphere Competence and Plant Root Colonization

The capabilities of microorganism to compete with others for nutrients secreted by roots and colonizing ability into root surface are termed rhizosphere competence. Plant rhizosphere is a complex ecological niche where a huge number of biological interactions occur and each organism struggles to survive here. *Trichoderma* are the key genus of Agricultural soil and rhizosphere is their common ecological niche as they are highly rhizosphere competent for availing both biotrophy and saprotrophy. Most soil inhibits the fungal germination and growth to a certain extent; the phenomenon is soil fungistasis. *Trichoderma* as dominant inhabitant are very successful to overcome fungistatic effect of soil and establish long-lasting colonization of plant root internally and externally. Organic compound exuded by root facilitates the plant to communicate with soil microorganism and *Trichoderma* secreted cysteine-rich hydrophobin- like proteins [4] have been found to help them colonize and attach to plant roots. All beneficial traits of *Trichoderma* are intimately associated with the propound ability of species to grow and colonize in rhizosphere as well as free soil. Sometimes expansin like proteins with cellulose binding modules facilitates root penetration [5]. Once inside the root *Trichoderma spp*. must suppress plant defense mechanisms in order to create root invasion [6] and dubbed as a multifunctional endophytic plant symbiont.

Growth Promotion in Plants

Apart from the direct inhibition of plant pathogens, *Trichoderma* spp. is reported to improve crop health. *Trichoderma* draw nutrients from plants by facultative symbiosis, in return to boost fertility and immunity by coordinated transcriptomic, proteomic and metabolomic response in the plant [3]. Treatment with *Trichoderma* generally reduces the activity of deleterious microorganisms in the rhizosphere of plants, improves the nutrient status of soil and prevents the depletion of soil organic matter to sustain fertility. Secretion of hormone-like metabolites of plants stimulated by *Trichoderma* and release of nutrients from soil or organic matter has been proposed as the mechanisms involved in plant growth promotion. Secondary metabolites produced by *Trichoderma koningii* (koninginin A) and *T.harzianum* (6-penyl-apyrone) act as plant growth regulators [7]. Production of auxin (TasHyd1 from *T. asperellum*) after root colonization induce modification in root architecture such as increase number of root hairs and absorptive surface thereby increase nutrients up-take [8]. Qid74 from *T. harzianum* is involved in lateral root hair formation and elongation [4]. *Trichoderma* spp. can acidify their surroundings by producing organic acid [9] and these organic acids solubilize phosphates, micronutrients [10] that lead to more nutrient availability in soil. *Trichoderma* also produce chelating metabolites and used redox activity for solubilizing the minerals. *T.harzianum* is good solubilizer of plant nutrients and also reported to solubilize MnO_2, metallic zinc, and rock phosphate. Crop productivity has increased up to 30% after the addition of *T.harzianum* T22 *and T.atroviride* P1 in lettuce, tomato, pepper plants [11].

Induced Resistance

Induced systemic resistance (ISR) similar to Systemic Acquired Resistance (SAR) is activated by *Trichoderma* relies on signaling pathways regulated with jasonate (JA) and ethylene (ET) [12], that response to a wide spectrum of pathogens and adverse environmental conditions. About 205 proteins induced by several genes were expressed differentially in maize roots and shoots inoculated by *T.harzianum* T22 [13]. After invasion of *Trichoderma* plant that responds quickly by rapid ion fluxes and oxidative burst then accumulates the signal molecule, salicylic acid (SA) and jasmonic acid in the vascular tissue or epidermal cell of plant root [14]. PR gene function induced by this compound has coding pathogenesis-related proteins (PR protein), secreted to inhibit pathogen infection [15]. Among variable type of PR protein, cell wall degrading enzymes like chitinase and β-1,3-glucanase are capable of lysing the cell wall of fungal plant pathogen. *Trichoderma* produced Xylanase and peptaibols has shown to elicit plant defense. Sm1/Epl1 are best elicitor which found an abundant amount is nothing different than cysteine-rich hydrophobin-like protein [16].

Biological Control

Parasitize and kill other fungi is apparently an ancestral trait of *Trichoderma* that made them successful in commercial bio-fungicides and bio-nematicides. Environmental signaling plays an important role in *Trichoderma* and their cell signaling is limited compared to model fungi (*Neurospora crassa*) but improved gradually by genetic approaches. In terms of biological control, now research focused on understanding how disease control is achieved. The combined mode of action for disease suppression of *Trichoderma* is stated below.

Competition for nutrients

Trichoderma has a superior capacity to mobilize and take up soil nutrients compared to other organisms. *Trichoderma* obtain ATP from the metabolism of different sugars by the production of different enzymes, all cellulose, glucan, chitin from environment converted as glucose used for their carbon and energy source which make them strong competitor. Limiting nutrients in rhizosphere result starvation which is the most common cause of death for other microorganisms. Eisendle et al. [17] ascribed that Iron uptake is essential for viability of filamentous fungi, and they produce siderophores (low-molecular-weight ferric-iron specific chelators) to mobilize environmental iron. Subsequently, iron from the ferri-siderophore complexes is recovered via specific uptake mechanisms. Some *Trichoderma* produce highly efficient siderophores that chelate iron and stop the growth of other fungi. Thus, iron availability influences the biocontrol effectiveness of *Trichoderma* to *Pythium* was evident [18].

Mycoparasitism

A number of significant studies have been conducted on the mycoparasitism of *Trichoderma* species with a wide range of commercially important plant pathogens and considered as more aggressive antagonist among all BCAs. The mechanism employed by *Trichoderma* is a complex sequential process responded with several genes, enzymes, secondary metabolites or elicitor in different species and different stages of their predation [19]. Parasitic fungi have a positive chemotrophic growth towards their host then coiling them around. Formation of apresorium take place during coiling which serve to penetrate the host and contain osmotic solutes [20]. Howell [21] also demonstrated the occurrence of coiling and formation of appresoria caused for the production of cell wall degrading enzymes and peptaibols, facilitates both the entry of *Trichoderma hypha* into the lumen of pathogen and the assimilation of the cell-wall content. Lytic enzymes in biological control act for over expression and deletion of there respective genes [22]. Production of cell wall degrading hydrolytic enzymes is a key step in the successful establishment of mycoparasitic relationship because cell wall is the first barrier between the fungal prey and parasite. Sequential expression of cell wall degrading enzymes, mostly chitinase, glucanase and protease (Prb1/Sp1) which regulates the remote sensing, partially in mycoparasitism [23].

Antibiosis

Antibiosis occurs during interactions involving low-molecular-weight diffusible compounds produced by *Trichoderma* strains that inhibit the growth of other microorganisms. Weindling [24] demonstrated a "lethal principle" excreted by *T.lignorum* into the surrounding medium termed as gliotoxin which kill both *R. solani* and *Sclerotinia americana*. The metabolites produced by *Trichoderma* are harzianic acid, tricholin, gliovirin, glisoprenins, heptelidic acid, alamethicins etc. [25]. These volatile and non-volatile toxic compounds impede colonization of pathogen. Monte [26] described the combined effect of hydrolytic enzymes and antibiotics results supreme antagonism than that of single one. Mycoparasitism by coiling of hyphae (*in vitro*) and enzyme-mediated antibiosis (*in vivo*) were the main mechanisms of biocontrol of *T. harzianum* against *Rhizoctonia solani* in sheath blight of rice which was evident by Cumagun and Ilag [27]. Wiest et al. [23] found peptaibols; another strong antimicrobial metabolite, synergistically act with cell wall degrading enzymes to inhibit fungal pathogen.

Tricho-Remediation

T. viride, T. harzianum and *T. reesei* being extensively studied to produce extracellular cellulolytic enzymes, namely EGs, endoglucanase, Cello biohydrolase, xylo-glucanases, Glucan endo-1,6 β glucosidase, endochitinase, xylanase and cellobiase which act synergistically in the conversion of cellulose to simple sugars like glucose. These cost-effective enzymes play the key role in the recycling of cellulose from cellulosic waste materials in biofuel and bio-refinery technologies also deployed in textile and paper industries [28]. Hazardous organic wastage including degradable municipal solid waste can be digested quickly with the enzymes cocktail thus recycling of residues increases usable energy as well as resolving the pollutions. Tricho-composting of farm accumulated crop residues is the best remedy for managing debris in short duration to nullify the bad-impact of Agricultural burning. Enzymes of *Trichoderma* to break the polymers of the lignocelluloses complex are potentiality reported by Michael et al. [29]. Different *Trichoderma* strains possess innate resistance to synthetic chemicals including herbicides, fungicides and pesticides such as DDT, contaminants at different levels [30]. *Trichoderma inhamatum* exhibited a remarkable capacity to reduce Cr (V1) concentration completely [31] as a result myco-remediation initiated in Cr(V1) contaminated waste water. Shukla and Vankar [32] studied biosorption by *Trichoderma* species and found 100% chromium up-take in a culture plate. Micro-organism implies various physico-chemical interactions for metal up-taking and most understood methods are extracellular precipitation, cell surface sorption and Intracellular accumulation. Vast release of industrial effluents makes our surroundings toxic to plant and human, metal recovery and mitigation can be done by *Trichoderma* biosorption and enzymatic digestion in a potential manner. The fungi of interest opened-up a large premise for obtaining agricultural sustainability in adverse climate by eliminating toxicants from soil and water.

Climate Stress Reliever

Trichoderma are now studied in respect to abiotic stress and observed some of this species improve survival of plants in hostile environment by increasing plant tolerance. During fungal-plant interaction at rhizosphere, a mechanism is happen connecting to an increase in the water absorption effectiveness because of increased root architecture. *Trichoderma* alter the response of plant like drought avoidance through morphological adaptation, drought tolerance through physiological adaptation [33], and can also induce systemic resistance to abiotic plant stress including water deficit, salt and temperature stress. Singh et al. [34] observed in an experiment on wheat crop raised from *Trichoderma* treated seed can tolerate drought better than crop raised from non-treated seed due to excellent root growth and more availability of nutrients. Viterbo et al. [35] demonstrated that arabidopsis and cucumber plants treated with *Trichoderma* prior to salt stress imposition showed improve seed germination significantly through expression of several gene related to osmoprotection. These applications have major implication for plant agriculture because the use of beneficial-organism is eco-friendly and cost effective which will be a further contribution to environmental sustainability.

Conclusion

Hazard based agrochemicals withdrawn from European market also emphasize to research for easy alternatives on exploiting beneficial organism. Study on other beneficial microorganism to overcome the limitations of crop production is still limited. *Trichoderma* is a single multiplex for climate resilient Agriculture to ensure green growth. Genetic study is necessary to develop an integrated understanding of complex 'plant – *Trichoderma* – pathogen – soil interaction' in resolving program.

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