



Agronomical importance of *Trichoderma* species: A review

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Abstract

Plants frequently experience unfavourable changes in the environment. Crop yield is significantly reduced by abiotic stresses around the world. Salt found in both irrigated and non-irrigated soils, is one of the most important abiotic stresses. Soil salinity stress is accountable for loss of plant growth, crop yield, and productivity. In addition, the infections caused by phytopathogens also cause biotic stress, which could further reduce produce yield and quality. Most fungal phytopathogens in saline soils are salt-tolerant and are difficult to control using traditional approaches.

In recent years, the significance of plant growth promoting microbes (PGPM) in the regulation of abiotic stresses has increased. Some PGPMs have been shown to be able to withstand salt stress, offering the possibility of using these PGPRs as a promising option to reduce salinity stress in plants.

Trichoderma is regarded as the most advantageous and versatile fungal genus, providing food security for a population that is exponentially expanding and also resolving agricultural issues with relatively few negative impacts. *Trichoderma* species are widely used as biocontrol agents in management of fungal diseases of crop plants demonstrating mycoparasitism against a wide range of phytopathogens. The agronomical importance of *Trichoderma* also lies in its potential of producing a range of enzymes, bioremediation etc.

Present review will also explore the possible applications of *Trichoderma* species in direct and indirect plant growth promotion by production of IAA, Siderophore production, and bioremediation of agro-waste. Salt tolerant *Trichoderma* is a promising candidate for use in saline and alkaline agricultures oil.

Keywords: *Trichoderma*, biological control agent, salinity tolerance, agronomical importance

Introduction

Soil salinity refers to the presence of high concentrations of soluble salts in the soil moisture of the root zone. Soil salinization occurs naturally or improper anthropogenic activities such as farming practices^[1]. Soil salinity is a major concern in agricultural productions and its management in the arid and semi-arid areas. These high concentrations of soluble salts, through their high osmotic pressures, affect plant growth by restricting the uptake of water by the roots^[2]. Several studies have indicated that increased salt (NaCl) concentration in soils affects the morphological, physiological, and biochemical processes. All plants are subject to this influence, but sensitivity to high osmotic pressures varies widely among plants species. Due to the high concentration of salts in the soil solution, salinity can also have an impact on plant growth. These factors include dehydration, nutrient deficiencies, membrane dysfunction, and oxidative stress, all of which can cause tissue damage or premature senescence in plants.^[4, 5] The main effects of salinity on plant growth and crop production are: The spread of plant pathogenic fungi which cause damping off, wilt and root-rot diseases, insufficient germination of seeds, physiologic drought, wilting, and smaller seeds; Growth of salt-tolerant or halophilous weed plants. As a result of all these unfavorable factors, low yields of seeds and other plant parts occurs^[3]. Salinity stress causes complex problems which are more difficult to be addressed than other abiotic stresses. Minimizing the negative effects of salinity is practical management for economic reasons, easier to be adopted and implemented. The coastal saline soils occur in the different districts of Maharashtra due to

periodical inundation of cultivable land by creek/sea water during high tides. Such periodical inundation renders the otherwise fertile soils progressively saline and in time makes it completely unfit for growing any crop. These coastal saline soils are locally called as khar or khajan soils. The coastal saline soils of Maharashtra are estimated to be 65,465 ha^[4]. Biological control offers the chance to improve crop production within the existing resources, besides avoiding the problem of pesticide resistance^[8]. However; it has been considered as a more natural and environmentally acceptable alternative to existing chemical treatment methods^[6]. Therefore, the use of adaptive microbes becomes a new approach to alleviating abiotic stress^[8]. *Trichoderma* spp. offers various functions and abilities regarding beneficial relationships with the plants^[3]. Priming rice seeds with *Trichoderma* improves root and shoot growth, increases water and nutrient uptake, and increases plant resistance to biotic stresses^[8], increases salt tolerance and hence lowering the stress of agronomic parameters^[9]. Application of *Trichoderma* reduces the adverse effects of salinity stress on wheat growth^[9,10] and French bean^[11]. *Trichoderma* are closely related with their ability to produce a wide range of lysing enzymes, to degrade substrates and to possess high resistance to microbial inhibitors^[12]. *Trichoderma* spp include a number of fungal strains that are used as biocontrol agents due to their abilities to antagonize a wide range of phytopathogenic fungi, bacteria. Biological control of plant disease by rhizomicrobes involves several mechanisms such as production of antifungal metabolites, cell wall degrading enzymes, induced host resistance, and competition for

nutrition and niches ^[11]. In this review, the main goal is to obtain the potent salt tolerant *Trichoderma* species which are able to produce natural compounds vital for disease resistance of soil, and functions as a Plant growth promoting microbes.

Trichoderma spp

Trichoderma is a genus of fungi in the family Hypocreaceae, that are found in a large variety of ecosystem, typically they are found in agricultural soils. Genus *Trichoderma* have about 10,000 species ^[12]. These *Trichoderma* strains appeared white and cottonish, than developing in to yellow - green to Deep green compact tufts especially at the center of growing spot or concentric ring like zones on agar surfaces, repeatedly branched conidiophores, irregularly arranged in whorls. The distinctive spp. Categorized in the genus *Trichoderma* were very hard to differentiate morphologically. Hence the various techniques such as molecular, morphological, genomic and physiological analysis were used to discover the characterization of a new spp. ^[13]. Now a days Multigene phylogeny and morphological characters are

integratedly used together to determine the species level description of *Trichoderma*. There are different genus in *Trichoderma* species. The pattern of genetic divergence also allows researchers to identify the gene that is responsible for strain diversification within *Trichoderma* genus.

Salt Tolerant Trichoderma spp

Salinity is a widespread soil problem for agricultural productivity. Due to salinization water osmotic potential lowers which results in decreased water availability of water to roots and hence secondary osmotic stress appears to plants. To reduce the effects of salinity on plant growth fungal endophytes such as *Trichoderma* spp. play an important role and gives fitness benefits to plants including increased yield and pathogen tolerance activity. *Trichoderma* genus induce resistance to salinity and other abiotic stresses in plants ^[3]. These genus have their specific functions and mechanisms such as cell wall degradation hypha growth and stress tolerance due to having chitinase, xylanase, protease, glucanase, monooxygenase etc. Genes.^[20]

Table 1: List of *Trichoderma* species effective in different functions under salt stress:

Sr. No.	Names of <i>Trichoderma</i> spp.	Functions
1.	<i>T.herzianum</i>	Biocontrol agent. Increase length and fresh weight of shoot and root of rice plant. ^[15]
2.	<i>T.herzianum</i> (T22)	Increase tomato plant resistance to salt stress and increase in germination of seed of tomato plant ^[15]
3.	<i>T. longibrachiatum</i> (TL-6)	Increase Wheat plant resistance to salt stress ^[16] Increase water content in leaves, root and chlorophyll content and root activity ^[17]
4.	<i>T. asperellum</i>	Enhance the availability of phosphorus iron to plant with increase in shoot length, dry weight and leaf area ^[2]
5.	<i>T.virens</i>	Induce photosynthesis rate in Maize plant ^[18]
6.	<i>T. longibrachiatum</i> <i>T. aggressivum</i> <i>T. saturnisporum</i>	Biocontrol activity and plant growth promotion under saline stress. ^[19]

It is also reported that presence of *Trichoderma* in saline environment increases antioxidant enzymes in plants. ^[20]

Mechanism of salt tolerance in Trichoderma

Trichoderma longibrachiatum contains amino acids called trilongins ^[21]. The trilongins formed voltage-dependent, Na⁺/K⁺ permeable channels in biomembranes. Which enhance more absorption of Na⁺/K⁺ ion and leaves Cl⁻ ion weak to affect normal functioning of cell under salt stress. Enzym ACC deaminase can use multiple substrates, equally the production of ACC deaminase can be important for cleavage of substances, thus, giving *Trichoderma* organism the strength to use other nutrient sources or to grow under otherwise toxic conditions. This can have key implications in fungi fitness, especially when living under limiting conditions. Alternation of *acdS* genes encoding ACC deaminase. Affect its production. This suggests that organisms that produce ACC deaminase more readily survive in stressed environments by the mutualistic interaction with or without a plant host ^[22]. *Trichoderma* under salinity stress, produces increased catalase enzyme activity by the fungi enhanced its survival and functioning on saline stressed environment ^[11]. Fungi *Trichoderma* synthesize and secrete Indole-3-acetic acid (IAA) which account for a mechanism for their growth and tolerance to stress ^[23]. *Trichoderma* produces enzymes such as peroxidase (POD), polyphenol oxidase (PPO), phenylalanine ammonia-lyase (PAL), catalase (CAT), superoxide dismutase (SOD), ascorbate peroxidase (APX),

and glutathione reductase (GR), increased the levels of proline, soluble sugars, soluble protein, ascorbic acid (AsA) and chlorophyll as well as improving root activity of host plants ^[24].

Trichoderma as a Biocontrol Agent

Trichoderma as a biofungicide is widely used in an agricultural market to get better yield. *Trichoderma* can be used as a biocontrol agent against fungal phytopathogens such as *Phythium*, *Phythora*, *Botrytis*, *Rhizoctonia* and *Fusarium* ^[1]. Numerous studies were carried out on biological control of *F. oxysporum* by *Trichoderma*. Root colonization of *T.herzianum* results in increased levels of various plant enzymes such as peroxidases, chitinase and lyase leads to accumulation of phytoalexins and phenols, providing resistance against pathogens ^[6]. *Trichoderma* can use different mechanisms according to temperature, pH, and nutrient concentration such as-

- *Trichoderma* grow faster or use its food source more efficient than pathogen and crowding out pathogen called nutritional competition. 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 ^[6].

- Mycoparasitism: feed directly on pathogen by producing cell wall degrading hydrolytic enzymes such as chitinase, glucanase and protease [15]
- Antibiosis: secreting a compound that inhibit /kill the pathogen such as the metabolites produced by *Trichoderma* are harzianic acid, tricholin, gliovirin, glisprenins, heptelidic acid, alamethicins etc.
- Induced resistance in plant: producing a chemical which protects plants from pathogens.
- Endophytic growth of *Trichoderma* in other pathogen species supports plant growth [25].

Trichoderma as a Plant Growth Promoting Fungi (PGPF)

Trichoderma is frequently associated with the root ecosystems of the host plants. Hence, *Trichoderma* is always defined as the genus of symbiotic, opportunistic, and avirulent microorganisms that colonize the roots and stimulate plant growth through mechanisms analogous to those used by mycorrhizal fungi [6]. Various *Trichoderma* isolates have revealed the availability for increasing plant growth by improving through their ability to absorb nutrients and secretion of growth promoting metabolites [26]. Auxins, cytokinins, abscisic acid and ethylene are major contributors in plant growth and fitness. Auxin produced by *Trichoderma* spp. enhances during seed germination [27]. IAA is the most abundant auxin in vascular plants, which is known to develop shoot, lateral and adventitious root initiation [29]. *Trichoderma* spp. are responsible for increased production of IAA that promoted plant growth. *T. harzianum* T-78 and *T. virens* promote growth of plant by producing increased level of IAA [30].

Phosphate solubilization

Phosphate solubilization is the ability of microbes to solubilize phosphate by releasing phosphatase enzyme, there by enhancing soil fertility and plant growth. In other study the plant growth was considerably hyperbolic in presence of natural phosphate stirred by *Trichoderma* immunization when compared to plant growth management in absence of *Trichoderma* [28]. Also, organic C, available P and exchangeable K was also improved considerably as compared to the conventional application by the farmers dose burnt rice straw +100% (100N-60P₂O₅-30K₂O Kg ha⁻¹) [29].

IAA Production

Indol-3-acetic acid (IAA) is one of the most common plant hormone that regulates plant growth. The production of microbial IAA commonly depends on the presence of its precursor, L-tryptophan. However, some microorganisms synthesize IAA in amino acid independent pathways. IAA induces longer roots with increased number of root hairs and root laterals which are involved in nutrient uptake [30]. *T. virens*, *T. atroviride* produces IAA, Indol-3-ethanol, Indol-3-acetaldehyde, Indol-3-carboxaldehyde. Many *Trichoderma* spp. were able to produce auxin phytohormone indol-3-acetic acid (IAA), and its production has been suggested to promote root growth [31, 15].

Siderophore production

Siderophores are small iron chelating molecules produced by *Trichoderma* helps in iron uptake and plant growth.

Ferrous form of iron which is easily absorbed by plants is unavailable in environment due to oxic atmosphere and converted into ferric form that is not absorbed by plants. These molecules have higher affinity for ferric ion and convert them to ferrous form by chelating them in cytosol, the ferric iron gets reduced into ferrous iron and becomes accessible to microorganism. Siderophore production by *T. koningii* ST-KKU1 and recombinant *T. harzianum* responsible for plant growth. [32] *Trichoderma harzianum* produce a siderophore called harzianic acid responsible for plant growth promotion [33]. Growth promoting potential of *Trichoderma* spp. under saline stress by producing ferrous ion availability to cucumber plant via siderophore production [35]. A modified chrome azurol S (CAS) agar test is used to detect the siderophore production. One half was CAS blue agar and the other half was iron-free medium in Petri dishes. Production of orange halos around the colonies on blue were indicative of siderophore production. [34]

Trichoderma in Remediation

Trichoderma spp. are present in different environments like decaying wood. Microscopic studies revealed that *T. harzianum* produces and excretes mycolytic enzymes that lyse cell membrane during interaction with other microorganisms [36].

Due to extracellular secretion of 1,3β glucanases, chitinases, cellulases, proteinases facilitated by *T. harzianum* plays a role in biocontrol [37]. *Trichoderma* degrade lignolytic biomass including recalcitrant and highly toxic phenolic compounds, these are peroxidases and oxidases. *T. viride*, *T. reesei* produces cellulases and pectinases and used in waste water treatment [38]. *T. viride*, *T. harzianum* and *T. reesei* being extensively studied to produce extracellular cellulolytic enzymes, these are EGs, endoglucanase, Cello biohydrolase, xylo-glucanases, Glucan endo-1,6 β glucosidase, endochitinase, xylanase and cellobiase which act symbiotically 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 [39].

Different *Trichoderma* strains possess inbred resistance to synthetic chemicals including herbicides, fungicides and pesticides such as DDT, contaminants at different levels [40]. *Trichoderma inhamatum* exhibited a outstanding capacity to reduce Cr (VI) concentration completely as a result myco-remediation initiated in Cr(VI) contaminated waste water. *Trichoderma* species exhibit 100% chromium biosorption in a culture plate [41]. *T. versicolor* degrade lignin by producing lignolytic enzymes and hence produce improved animal feed. These lignolytic enzymes are very useful in biodegradation [42]. Studies revealed that various *Trichoderma* spp contributing to polycyclic aromatic hydrocarbon (PHA) degradation hence affecting native mycorrhizal fungi both positively and/ negatively. Maximum of 75% removal of pyrene (4 ring PHA) at 50 mg/l for uncontaminated cultures of *Trichoderma* spp. Degradation potential of rhizosphere component fungus *Trichoderma* spp against several synthetic dyes, pentachlorophenol and DDT [43]. Hence *Trichoderma* spp have found application in herbicide and pesticide containing soil bioremediation.

Trichoderma Nanoparticals

Nowadays Nanotechnology is a rapidly growing field played effective role in different areas of medical science, cosmetics and agriculture. Nanoparticals are stable under harsh conditions and have several fold high antimicrobial potential [45]. The nanoparticle based formulations might be considered alternative to fungicide and provide an ecofriendly approach for plant disease management and safe to human being.

The antifungal efficiency of silver metal is higher than other metals such as-

$Ag \geq Hg \geq Cu \geq Cd \geq Cr \geq Co \geq Au \geq Zn \geq Fe \geq Mo \geq Sn$ [46].

Trichoderma reesei synthesizes AgNPs by using cell free extract, ion specific of size in the range of 2-11 nm. Silver nanoparticles destabilize the bacterial membrane after its accumulation [47]. *Trichoderma* bio controller based green nano product as a potential template to design novel antifungal agent and overcome the issue of infection in plant fungal diseases [48]. Silver nanoparticles synthesized from *T. viride* is a nanopathogenic, fast growing and environmentally friendly fungus [49]. *T. longibrachiatum* synthesizes AgNPs having biocidal activity against halotolerant sulfate reducing bacteria in mixed culture [50]. *T. harzianum* synthesizes AgNPs showing antifungal activity against *Sclerotinia sclerotium* and *T. harzianum* and *T. reesei* synthesizes ZnOP showing antifungal activity against *Xanthomonas oryzae* [47].

Conclusion and Future perspectives

Salinity is the major drawback in agricultural productivity and hence plays a crucial role in both social and economical development in the entire universe. Agricultural crops expose a spectrum of responses under salt stress. Salinity affects almost all aspects of plant development including: germination and vegetative growth. Soil salinity imposes ion toxicity, oxidative stress, osmotic stress, nutrient (N, Ca, K, Fe, Zn) deficiency and photosynthesis. Other adverse effects of soil salinity include growth of phytopathogens, increase in pollution.

A novel salt tolerant *Trichoderma* spp provide a complete toolbox for new agriculture due its various agronomical applications such as Biocontrol activity, Plant Growth Promotion and soil remediation activity. Nanoparticle formulations of these *Trichoderma* spp. can provide an ecofriendly approach to solve the problems of salinity on agriculture.

In future These salt tolerant Tricho-formulations can be used as-

- Conserve mangrove areas which cover a large area in various parts of world
- Reduce air pollution.
- A large infertile land formed due to high salinity can be converted to fertile.
- Hence contributing in increased crop production.

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