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# Trichoderma in Hydroponic Systems

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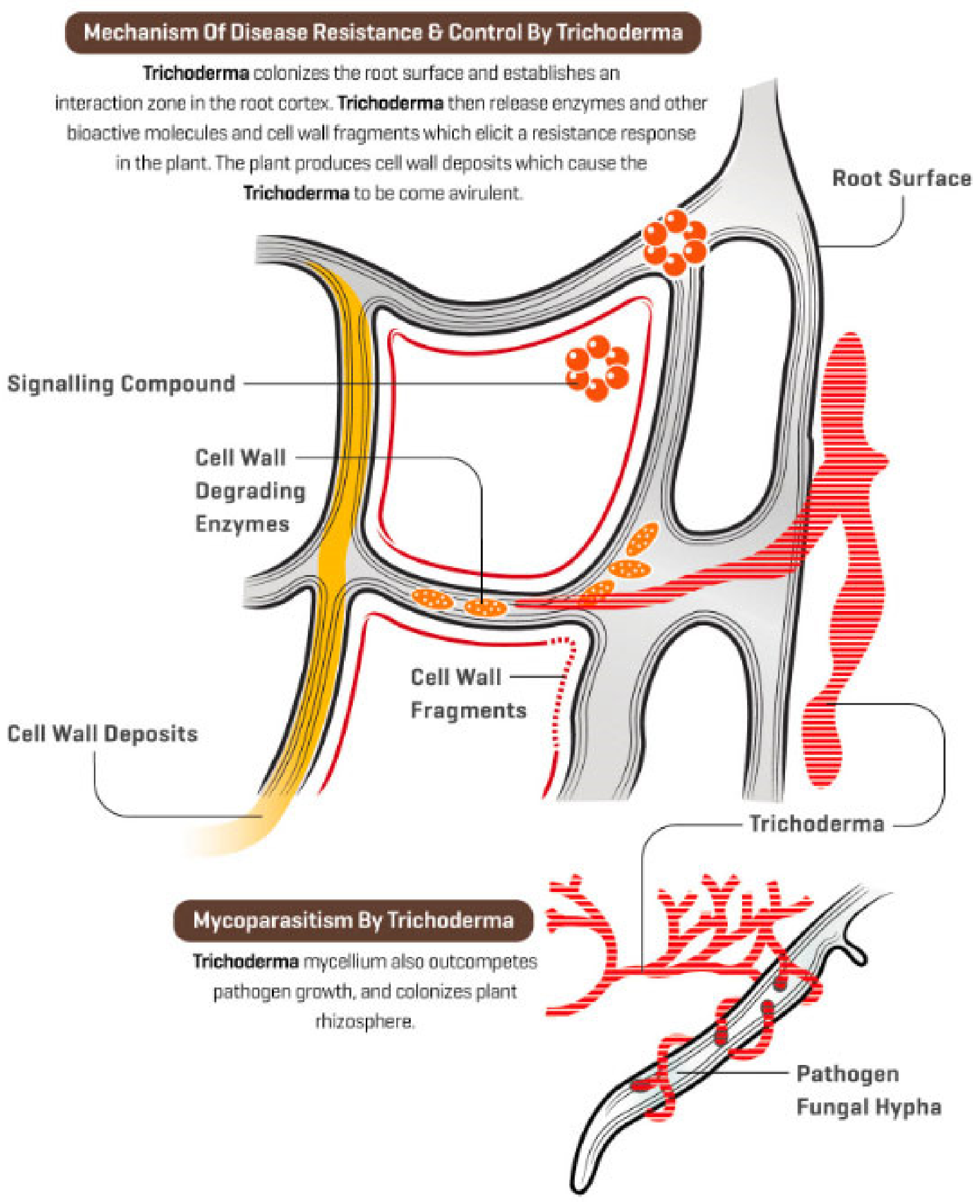
## What is Trichoderma?

*Trichoderma i*s a naturally occurring genus of soil fungi which has been known to possess bio control qualities against a number of plant pathogens since the 1920s. While there are a number of plant-associated microbes, both fungi and bacteria which are strongly beneficial to plants, none has been more intensively studied than *Trichoderma*. Stable and effective preparations of *Trichoderma* have also been formulated into a range of bio control or "effective microorganism" products readily available on the market for both large-scale commercial producers and smaller home gardeners. Although *Trichoderma* is naturally endemic to soil and decomposing organic matter, it is well proven to have significant beneficial effects in soilless systems and formulations have been developed specifically for hydroponic use. While *Trichoderma* can be highly effective as both a pathogen control agent and growth promotant, it is a living organism and as such requires specific conditions for establishment and long term use within a hydroponic system.

## How does Trichoderma operate?

Many species of *Trichoderma*, if given optimal conditions, establish stable and long-lasting colonisations of root surfaces and even penetrate into the epidermis (outer layer of root tissue) and a few cells below this level [1]. This intimate relationship between *Trichoderma* and the host root cells is what induces localized and systemic resistance responses to pathogen attack. Along with root penetration, *Trichoderma* produces a range of antibiotic substances, can strongly compete with other micro organisms for food, and produce enzymes that can degrade cellulose and chitin. *Trichoderma* also has the ability to dissolve the cell wall membranes of pathogenic fungi.




Initially *Trichoderma* species were only thought to have suppressive effects on a small number of plant root pathogens, however as research into the methods of this suppressive effect were studied, it was found that *Trichoderma* had other beneficial properties on plant growth and development. These growth enhancement effects went further than just suppression of pathogen in the root zone allowing a return to normal healthy growth. It has been found that the species *Trichoderma* spp.

increase the uptake and concentration of a variety of nutrients (copper, phosphorus, iron, manganese and sodium) in the roots in hydroponic culture [3]. This increased uptake suggests *Trichoderma* creates an improvement in plant active-uptake mechanisms as well as having been shown to increase root development in numerous plant species. The beneficial effects of *Trichoderma* on plant growth overall has been indicated to be from a combination of reducing damage, even non-visible damage, from plant pathogens, deactivation of toxic compounds in the root zone, increases in nutrient uptake, efficiency of nitrogen use and solubilization of nutrients in soil and organic matter. It is possible *Trichoderma* species release certain molecular elicitors of plant growth promotion in a similar way that growth promotion by certain bacteria is known to occur, however this is still an area of ongoing research and such compounds are as yet unidentified [1]

## Trichoderma and disease control

*Trichoderma* is not just one species of fungi – the genus *Trichoderma* contains many species and strains, of which some are specific to certain pathogenic fungi such as *Pythium* and *Rhizoctonia*. For example, *T. virens* has been found to be specific to certain fungal diseases of field grown cotton, while *T. asperellum* has been found to protect cucumber leaves from *Pseudomonas syringae* when only applied to the root system demonstrating that some *Trichoderma* strains have systemic abilities. Of all the *Trichoderma* species, *T. harzianum*, of which there are several strains, is the most widely commercialised and has been found in scientific studies to be effective against a range of fungal plant pathogens, including *Botrytis, Colletotrichum, Green-mottle mosaic virus, Alternaria solani, Pythium sp., Phytophthora capsici, Rhizoctonia, Fusarium,Sclerotinia* [4] and

One of the most effective methods of pathogenic fungal control exhibited by *Trichoderma* is `mycoparasitism'. In this process the *Trichoderma* first detect other target fungi species and grow towards them, once contact is made, the *Trichoderma* attach and coil around the fungus, then produce several fungitoxic cell-wall degrading enzymes and probably also certain antibiotic compounds. These two activities results in dissolution of the fungal cell walls and parasitism of the target fungus. [1]

Another highly effective mechanism of control by *Trichoderma* is the ability of certain strains to induce phytoalexin defence compounds in plants and seedlings. Phytoalexins are the plant's own natural defense system for fighting off attack by pathogens and although induced resistance systems in plants are complex, they are often highly effective strategies for disease control. The exact nature of resistance system triggering molecules from the *Trichoderma* response are unknown. However it has been proven that applying certain *Trichoderma* strains to the root zone of hydroponically grown plants has given control of certain leaf pathogens (i.e. systemic control) and it is this inducement of the plant's natural defense system by Trichoderma that is likely to be responsible for this effect. Therefore *Trichoderma* has two important modes to action – direct suppression of the pathogen with production of antibiotic substances and enzymes and strongly stimulating the plant's own natural defense mechanism.

## Why do growers love Trichoderma so much?

Apart from pathogen suppression and growth promotant activities, *Trichoderma* has been selected for widespread use in horticulture for a number of other reasons. The spores of *Trichoderma* can be easily formulated into long shelf life products that, upon reactivation, rapidly colonize the growing media under suitable conditions. *Trichoderma* is a strong competitor in the root zone and generally has a good chance of establishment even when there are pre-existing healthy populations of other microbial species. *Trichoderma* has also proven to be compatible with a number of other bio control agents, including beneficial fungi in a number of different studies, so that mixtures of effective microbes can be safely applied. *Trichoderma spp*. In general have also been found to be highly resistant to a variety of toxins including chemical fungicides, heavy metals and antibiotics produced by other microbes [1] . While *Trichoderma* is commonly applied to the root zone or nutrient solution, certain strains have also been applied to fruit, flowers and foliage to control certain plant pathogens and even used to prevent post harvest rot disease. One study found that application of *Trichoderma spp*. on greenhouse strawberries could control post harvest rotting, while several *Trichoderma spp*. have been used to protect fruit such as banana, apple, mango and tomato during post harvest storage [4]. There is evidence to suggest *Trichoderma* assists plant growth and development under `stressful' conditions and the growth promotant potential of *Trichoderma* appears to be stronger in crops growing under less than ideal conditions.

## How to get Trichoderma established in hydroponics

*Trichoderma* is best used as a preventative and since it may take time for complete colonisation of growing substrates, inoculation should be carried out as early in the crop's life as possible. A warm, moist growing media, thoroughly inoculated with *Trichoderma* will rapidly be colonised, and some additional inoculate can then be added directly under the root system of the young transplant. Soaking the root system of transplants or cuttings with *Trichoderma* inoculate can also be helpful to ensure high levels of the microbial product are applied in the right position. While *Trichoderma* should take hold rapidly and colonise the entire growing media, over time the population may decline and fresh inoculation throughout the growing cycle are recommended. Since many pathogens such as *Pythium* which causes `damping off' in seedlings are more prevalent during the sensitive propagation phase, inoculation of seed germination media with *Trichoderma* is particularly important. *Trichoderma* has also been shown to increase the germination percentage of tomato seeds sown in soilless growing media when *Pythium* pathogens were present [5] . Cuttings or clones also benefit from *Trichoderma* application as a preventive for stem rot pathogens and to ensure the new root system is fully colonized and protected by *Trichoderma* before potting on or introducing to a new hydroponic system. Since *Trichoderma* is a living organism, commercially available inoculant products tend to have a limited shelf life, so it is advisable to always check the expiry date and follow usage and storage instructions provided with the product.

## What substrates are best for Trichoderma establishment

Hydroponic systems are generally not sterile environments, however they do tend to contain lower levels and less diversity of micro-organisms compared to soil. Before planting out, sterile growing media, clean and disinfected equipment and a treated water supply provides a clean slate for microbial establishment. For this reason it is considered easier to establish beneficial microbes in hydroponic systems with a new substrate as little competition exists from micro-organism already present, unlike the situation in soil [(6)]. If the system is using synthetic growing media such as rockwool, rather than composted bark, coco fiber or similar substrates, then initially the system is a relatively poor environment for microbial life to take hold and microbe numbers and population diversity have been found to be very low. However once the plants are growing, exudates from the roots and sloughed off root material begin to provide organic substances for microorganisms to grow and population numbers build over time. A substantial part of the food source used by micro flora is derived from plant roots, resulting in high numbers of micro organisms on the surface of plant roots consuming organic compounds such as carbohydrates, mucilage and dead cell material which accumulates over time.

While *Trichoderma* has been shown to establish and proliferate on a range of soilless substrates, there is some evidence that colonization may be greater on certain growing mediums. When coconut fibre (Coir) and rockwool were compared after inoculation with *T. harzianum* it was found that colonization was greater in the coco fiber, with spread through the rockwool substrate being less dense. It was also found that colonization of *Trichoderma* was highest at the site of inoculation suggesting that the initial introduction of *Trichoderma* into a growing medium should be at multiple sites or well mixed through the substrate before planting [(7)] .

## Oxygen and temperature

*Trichoderma,* like many microbial species has temperature optimums for rapid colonization and activity, for most of the commonly applied species this is 77-86 F (25-30$^{o}$ C) [(8)]. If conditions are too cold, the rate of multiplication of the *Trichoderma* will slow and even cease, if too warm, then die back may occur or the *Trichoderma* may become out competed, leaving the way open for other forms of microbial species to take hold.

Another important consideration is oxygen in the root zone – *Trichoderma* and other microbial species require oxygen for healthy functioning and unfortunately oxygen starvation is a common cause of root disease outbreaks in many hydroponic systems. Over watering with either too frequent application of nutrient solution, stagnation and deep ponding in NFT systems, heavy water logged growing media with poor drainage all lead to a lack of oxygen in the root zone which suffocates both root systems and *Trichoderma*. If the root system then becomes damaged due to over watering and a lack of oxygen, this combined with the die back of *Trichoderma* and other beneficial microbes create the ideal situation for opportunist root pathogens such as *Pythium* to take hold.

High levels of oxygenation in the hydroponic root system are relatively easy to maintain with selection of the correct type of growing media for the conditions (coarser and freer draining when it's cooler and growth slower is always advisable to help prevent over watering). Careful control over nutrient application to allow thorough drainage between irrigations which helps draw fresh air through the substrate and replenish oxygen and a nutrient which as some opportunity to re-oxygenate in recirculating systems.

## Trichoderma variability and limitations

While *Trichoderma* has proven to be effective for pathogen control in a wide range of applications, results can sometimes be variable when dealing with biological control systems. Control is dependant on the *Trichoderma* being applied at the correct time (i.e. before levels of pathogens have built to high levels), under the correct conditions of moisture and temperature and of an effective species and strain. Poor control by bio control agents is also attributed to poor distribution in the root zone and growing media and location – *Trichoderma* introduced at a different location to where the pathogen is residing. Initial introductions of *Trichoderma* can be beneficial if applied directly to or under the root system of new transplants as it is likely that any pathogens such as *Pythium* will be introduced to a clean system via infected seedlings. Another limitation is that *Trichoderma* is more specific to fungal pathogen control and may have limited applications for bio control of pathogenic bacteria [(4)] , some of which can cause serious disease outbreaks.

While *Trichoderma* is a popular fungal bio control agent, there are also a number of bacterial `effective microbe (EM)' species (bacteria in the genera *Pseudomonas, Bacillus* and *Streptomyces*) which can also be introduced to the root zone of plants. Often, for unknown reasons, *Trichoderma* may not persist in the root zone long term, thus protection can decline as the crop develops. Re application of *Trichoderma* products on a regular basis is always recommended to ensure population levels don't die out resulting in a lack of pathogen protection in the root zone.

## Trichoderma compatibility with other beneficial fungi

## species

*Trichoderma* are not the only fungi with beneficial effects on plant growth and disease suppression. While there are a vast number of fungal species which may have benefits for crop production, only a small number have been identified and studied. Of these the arbuscular mycorrhizal fungi, *Gliocladium virens*, non pathogenic *F. oxysporum, Paecilomyces lilacinus, Penicillium chrysogenum*, and a number of others have been identified in studies as having an antagonistic effect on pathogenic fungi. In many of these studies it has been discovered that combinations of synergistic fungi species often have a greater effect on disease control than when used singly [(9)].

## Trichoderma compatibility with Mycorrhizal fungi

Arbuscular mycorrhizal (AMF) fungi are another wide spread, naturally occurring soil micro organism which forms a beneficial relationship with the roots of many plant species. Just as with *Trichoderma* species, enhanced growth and disease suppression has been well documented with the use of mycorrhizal fungi inoculated in the root zone of cropping plants [(15)] . Given that *Trichoderma* is such a strong predator and competitor of other species of fungi in the root zone, there has been concern in the past that negative interactions between *Trichoderma* and mycorrhizal inoculants could occur, thus making one or both fungi inactive and therefore incompatible. While numerous scientific studies have been carried out to determine if *Trichoderma* verses mycorrhizal antagonism does exist when both are introduced to the root zone of certain plant species, conflicting results have been reported.

The problem identifying if this sort of interaction does occur is that in biological systems there are multiple factors affecting the result. Not only are there many species of *Trichoderma* with different characteristics and abilities to predate other fungi, but mycorrhizal fungi also contain a number of species including *Glomus claroideum, Glomus mosseae, Glomus intraradicesGlomus geosporum*. Furthermore the conditions in which the fungi are introduced, the crop species tested, growing media, presence of other microbial life and a host of other factors affect the result of fungal interactions. While one study (Green et al, 1999) found that the Mycorrhizal fungi *G. intraradices* had an averse effect on *Trichoderma harzianum*, yet another study (Martinez-Medina et al, 2009) reported that combined inoculation with these two species provided better disease control results and a general synergistic effect than other Mycorrhizal species tested. and

Many other studies have found a synergist effect when *Trichoderma* was use in combination with certain species of Mycorrhizal fungi. It has been reported that dual inoculation of peat substrate with a mixture of 4 species of Mycorrhizal fungi and *Trichoderma harzianum* showed a significant effect on the growth and flowering of cyclamen plants [(12)], while another study found that more plant biomass was produced in a peat-perlite mixture when the mycorrhizal fungus *Glomus mosseaeTrichoderma aureoviridae* [(13)] . Other researchers have also reported that various microbial inoculants such as *Trichoderma* and others showed no negative effects on Mycorrhizal establishment [(14)], while others have reported that combinations of Mycorrhizal fungi species with *Trichoderma harzianum* and other beneficial fungi have a synergistic effect and give greater increases in growth and disease resistance when combined [(15, 16, 17)] . It has been suggested that the differing results reporting the influence of Mycorrhizal fungi on other micro organisms is probably not only due to the combination and species of Mycorrhizal fungi evaluated but also the conditions such as nutrient availability when the studies were carried out [(20)] . was combined with

The bulk of the scientific evidence suggests however that the species of *Trichoderma* and Mycorrhiza commonly used as inoculants in soil and hydroponics are compatible and potentially synergistic when used in combination. *Trichoderma* and Mycorrhiza carry out different but potentially very beneficial roles in the root zone of plants, involving not only protection from many pathogens, but also nutritional and growth benefits.

## Trichoderma Q&A

### What do Trichoderma use as a food source?

Trichoderma release two main types of enzymes in their quest for sustenance – these are different types of cellulases and chitinases. Cellulase enzymes break down cellulose which is a component of plant cells, organic matter and crop residues. Chitinase breaks down Chitin which is a structural component of fungal cell walls (and insect exoskeletons). It is thought that Trichoderma switches the production of these two main enzymes on and off depending on what its main source of food is at the current time. In composts, bark, coconut fiber and other `organic' type substrates there is initially plenty of cellulose to feed on, later on in the crop cycle, plant residues, exudates, dead roots and other organic material are also available for the Trichoderma to digest. Other fungi (certain species of Trichoderma are specific for certain fungi, while others have a wider range of prey) are a easily digested food source through activation of chitinase enzymes and the Trichoderma will actually coil around the host fungi and penetrate the cell walls fairly rapidly

### Will Trichoderma survive in the absence of other fungi to feed from and if so what do they feed on particularly in a hydroponic environment?

Trichoderma not only feed on other fungi, but also on cellulose from various sources of organic matter. We sometimes assume that hydroponic systems are completely `clean', and non-organic and not capable of supporting a diversity of microbial life, but this is rarely the case. Even systems such as rockwool which start out as completely sterile, rapidly develop some forms of microbial life as the warmth, moisture, nutrients and organic matter produced by the plant's root system provide a good environment for microbes. In fact, in hydroponics where there is typically year around heat, plentiful moisture, oxygen and rapid plant growth, microbial growth can be quite plentiful provided the grower is not doing something incompatible such as applying harsh chemical sterilants such as chlorine or hydrogen peroxide to the plants root zone or nutrient solution. Even in solution culture microbial life in the nutrient develops – hopefully the `good' microbes out compete any pathogens and a well oxygenation solution helps with that process. In these cases the food source, if not other fungi, will be organic matter provided by either the substrate or the plant's root system which produce exudates, old root cells which are sloughed off as the root system expands and other debris.

## What do Trichoderma get from root invasion?

Trichoderma penetrate into the cells of the root system – once this occurs, it triggers a response in the plant host which effectively `walls off' the Trichoderma and prevents it getting any further into the living root tissue. In triggering this response, the plants natural system of defence is activated and a systemic resistance is induced. This relationship between Trichoderma and plant roots is termed an `opportunistic avirulent symbiotic relationship' meaning even though the Trichoderma has gained entry to the plant tissue, it does not cause any disease or damage. Symbiotic means both parties benefit, the plant gets protection and the Trichoderma gets a good place to live and also some plant derived sucrose which is an important resource provided to the Trichoderma cells in this association (22).

## How do Trichoderma attack and control pathogens?

Many Trichoderma species are specific for certain pathogens and will predate these if they are present in the same location – this is through a number of different processes. The main method of attack is for the Trichoderma to coil around the pathogenic fungi, release enzymes to break down the cells and consume its prey. It is thought Trichoderma also release a number of antibiotic compounds for direct control. Another method of pathogen control is through inducing systemic resistance in the host plant, Trichoderma does this by invading the plant's root system to the depth of a few cells, which triggers the plant to launch its natural defence mechanism to wall off the Trichoderma, in doing so the systemic resistance spreads through the entire plant so that foliar and fruit diseases may be controlled as well.

## How can Trichoderma products be reactivated and are there any compounds that can be used to help feed or promote Trichoderma.

Generally the manufacturer's instructions should always be carefully followed when reactivating the spores contained in a commercial Trichoderma product as there are a number of different preparations and additives or `carrier agents' used. Some are granules or powers designed to be incorporated directly into growing media, some as a liquid drench. Trichoderma prefers warmth, moisture and oxygen for reactivation, once that occurs a readily available food source is also helpful for rapid development. There has been some evidence that using a growing medium such as composted bark fines, coconut fiber or small volumes of compost/vermicast additions gives faster establishment as it provides a cellulose food source for the Trichoderma in the early stages when the plant root system is still small. However, with hydroponics it's essential to not overload the nutrient solution and system with large volumes of organic matter or additives – in doing so the rapid explosion in many forms of microbial life can rob all oxygen from the root zone creating a situation where roots are suffocated and pathogens flourish under anaerobic conditions.

## Are there upper limits of nutrient solution concentration that Trichoderma can tolerate? Will they survive in high EC solutions and/or do better in low EC solutions?

The range of EC typically used in hydroponics, is actually quite narrow compared to the salinity levels in some soils and the rise in osmotic potential that occurs as soil dries out, so Trichoderma is unlikely to be affected by hydroponic EC levels. Trichoderma `eat' organic matter cellulose and chitin from fungi cells, so unless for some reason the EC is affecting these sources of food, it should have no real influence on the Trichoderma itself. Trichoderma is known to survive and thrive in a diverse range of environments in the presence of toxins, heavy metals and certain chemicals, so EC is unlikely to have any significant effects. Even EC levels high enough to stunt and damage plant growth should have no influence on Trichoderma.

## Why does Trichoderma give greater growth potential to plants growing under stressful conditions?

Largely because there is more potential for growth improvement under less than ideal growing conditions than with plants already at maximum biomass production – the effect is thought to be a combination of both suppression of pathogens, many of which are opportunistic and will attack stressed plants, and by possible production of certain elicitors of plant growth which are as yet unidentified.

## Does coir naturally contain Trichoderma, even after the coir treatment process?

This depends largely on the processes used in the different brands of coir. Some coir is heat treated to kill seeds, insects and pathogen spores, and in this case any naturally occurring Trichoderma will also have been destroyed. Some coir products and other growing mixes on the market are deliberately inoculated with Trichoderma before sale. Coir is typically retted and then composted during its manufacture as a plant growth medium, so during this process it's likely that Trichoderma colonise the fibres and break down some of the cellulose, however that would depend on a number of factors such as the location, if the coir piles are covered or in contact with the soil, the populations of other microbes in the surrounding environment and other factors. Many studies have found naturally occurring Trichoderma (and other beneficial fungi species as well) in a range of coir substrates and it has also been found in some studies that these microbes had disease suppressive qualities (21).

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