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Trichoderma affects plant growth and soil ecological environment: A review

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Abstract

Trichoderma is a genus of widespread filamentous fungi widely used in agriculture as biofungicides for controlling a wide range of plant diseases. *Trichoderma*, as is well known, can not only effectively control crop diseases but also improve soil physico-chemical properties and increase soil productivity. However, the effects of its control on crop growth and the soil's ecological environment are unclear. The results of *Trichoderma* on disease resistance, yield, and crop growth as well as the effects of *Trichoderma* on the soil ecological environment from the standpoint of soil physical, chemical, and microbial properties were therefore reported in this study. Furthermore, this paper highlighted the shortcomings of the existing research on the impact of *Trichoderma* on crop and soil properties and emphasised opportunities to address the gaps in the existing research on the effects of *Trichoderma* on crops and soil attributes.

This review will provide a theoretical foundation for further research and application of *Trichoderma* in agricultural production.

Keywords: crop, functional microbes, soil physico-chemical properties, soil microbial organisms.

Introduction

Unreasonable fertilisation and management practices frequently cause severe damage to the soil ecological environment and degradation of soil functions impeding the sustainability of agricultural production (Hung et al., 2006). The question of how to effectively improve the degraded soil and quickly restore the soil ecological environment has emerged as a pressing issue in agricultural production. To improve degraded soil, physical, chemical, and microbial improvement technologies have been widely used. However, physical and chemical enhancement techniques frequently result in soil nutrient losses and secondary pollution. Microbial improvement technology can improve soil physico-chemical properties and regulate the structure of the soil microbial community via applying a combination of an organic fertiliser and functional microbes to promote the rapid release of soil nutrients, which is beneficial for soil restoration and brings certain ecological and economic benefits. The microbial technique has been commercialised and transformed into a microbial fertiliser and soil enhancer.

Trichoderma has been identified as a common biological bioremediation agent, which widely exists in soil and other settings (Zin, Badaluddin, 2020). *Trichoderma* exhibits a strong colonisation ability in soil, which helps to improve the soil physico-chemical environment, encourage the development and maintenance of advantageous soil microbial communities, increase crop resistance and ultimately foster crop growth, and increase agricultural production (Zin, Badaluddin, 2020; Poveda, 2021). *Trichoderma* thus plays a crucial role in restoring deteriorated soil and is of great significance in promoting the development of sustainable agriculture.

This study systematically expounds on the biological overview of *Trichoderma*, analyses the effects of *Trichoderma* on promoting crop growth and improving soil quality, especially emphasises the contribution of *Trichoderma* to regulating soil microbial community composition, highlights the problems existing in the application of *Trichoderma*, and preliminarily discusses the implications for future research. This review will serve as a resource for the future promotion and application of *Trichoderma* in agricultural production.

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An overview of *Trichoderma*

The life cycle of *Trichoderma* can be divided into two stages: asexual and sexual. Deuteromycotina (subphylum), Hyphomycetes (class), Moniliales (order), Mucedinaceae (family), and *Trichoderma* (genus) are responsible for the asexual stage, while Ascomycotina (subphylum), Sordariomycetidae (class), Hypocreales (order), Hypocreaceae (family), and *Hypocrea* (genus) are responsible for the sexual stage (Waghunde et al., 2016). Nowadays, more than 340 different species of *Trichoderma* are known in world (Wang, Zhuang, 2019). However, only a few of them are applicable in agriculture, which mainly include *T. harzianum*, *T. asperellum*, *T. longibrachiatum*, *T. guizhouense*, and *T. viride*. As a result of the increasingly mature methods of molecular biology, a large number of new *Trichoderma* species have been discovered and identified.

Trichoderma typically produces a variety of secondary metabolites during its growth and reproduction that can weaken the cell walls of pathogenic bacteria and prevent the growth of plant pathogenic bacteria, thereby enhancing plant disease resistance and fostering plant growth (Olowe et al., 2022). Studies have confirmed that *T. viride* and *T. harzianum* can well inhibit 29 species of plant pathogenic fungi belonging to 18 genera (Yedidia et al., 2003). *Trichoderma* has a high adaptability and can grow in a relatively warm and humid environment with a temperature of 20–28°C and an air relative humidity of more than 90% for more conducive to the growth and spore production of *Trichoderma*. *Trichoderma* can grow in acidic, neutral, and alkaline environments but prefers acidic (pH 5.0–5.5) conditions. When incubated in the laboratory, *Trichoderma* colonies in the potato glucose agar medium are dense at first, with no fixed shape and different colours; when spores mature, the colonies gradually turn green or yellowish green in later periods of culture (Hermosa et al., 2000). *T. harzianum*, *T. viride*, *T. koningii*, *T. asperellum*, and *T. longibrachiatum* are currently used in agricultural production (Olowe et al., 2022), of which *T. harzianum* and *T. viride* receiving the most attention in agriculture. *Trichoderma* is often used as a fungal agent and is widely applied for the management of soilborne pathogens to realise the commercial applications in crops such as tomato, cucumber, and sugarcane (Singh et al., 2010; Nawrocka et al., 2019; Rajput et al., 2019). As is known, more than 250 *Trichoderma* agents have been used commercially (Ram et al., 2020). *Trichoderma* agents mainly include ordinary powder, wettable powder, water dispersible granule, liquid fungicide, and organic fertiliser with effective components of *Trichoderma* conidia or conidia and hyphae with the common powder having the highest activity of *Trichoderma* (Hermosa et al., 2000). Beyond all doubt, almost all *Trichoderma* agents can be used to promote crop growth and improve soil ecological environment.

Promotion of *Trichoderma* on crop growth

Trichoderma can be widely used to promote plant growth. At present, *Trichoderma* has been widely used as biocontrol agents to promote crop growth and improve crop yields through different mechanisms (Figure). The growth-promoting mechanism primarily includes the stimulation of *Trichoderma* to plant growth by producing growth regulators, the antibacterial effect of *Trichoderma* metabolites, and the activation of soil nutrients by *Trichoderma*. It has been shown that *Trichoderma* could trigger systemic resistance and enhance root growth and development, crop productivity, resistance to abiotic stresses, and uptake and use of nutrients (Kashyap et al., 2017).

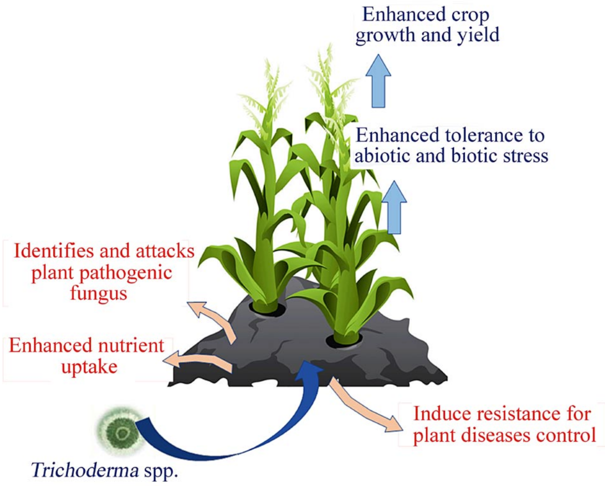

Figure. Mechanisms of *Trichoderma* spp. to enhance crop growth and yield (summarised by Kashyap et al., 2017)

Producing plant growth regulators. Trichoderma spp. synthesises a wide range of compounds (e.g., hormones and plant signals, enzymes, organic acids, siderophores, and secondary metabolites) that have different effects on plants (e.g., disease control and growth stimulation), of which indole-3-acetic acid (IAA) and 6-pentyl-2Hpyran-2-one (6PP) are widely known regulatory compounds (Alfiky, Weisskopf, 2021). *Trichoderma* has a two-way regulatory role, which can alleviate phytotoxicity caused by high plant growth regulators and promote crop growth when the regulators are at low concentrations (Hexon et al., 2009). The increased nodule mass and nitrogenase activity may be indicative of a synergistic effect in response to co-application of rhizobia and *Trichoderma* spp. (Barbosa et al., 2022). *Trichoderma*, by secreting analogues such as ferritin and auxin, can promote seed germination and plant root development and increase crop yield (Valerie et al., 2007).

A lot of evidence indicated that the application of *Trichoderma* spp. to plant rhizosphere promoted plant morphological traits such as root-shoot length, biomass, height, number of leaves, tillers and branches (Halifu et al., 2019). It has been shown that *Trichoderma* can effectively improve the maize root activity and increase the content of soluble sugar and soluble protein in maize, thereby promoting the synthesis of macromolecular substances such as fat and protein in maize and improving the water retention capacity of maize cells (Liu et al., 2021). *T. asperellum* can also improve the photosynthetic characteristics and photosynthetic pigment content of leaves of different genotypes of maize seedlings under saline-alkali stress, increase the ability of cells to scavenge reactive oxygen species, maintain osmotic balance and metabolic homeostasis (Fu et al., 2018), and finally increases the maize yield by more than 10% (Fu et al., 2021). Furthermore, *T. hamatum* application caused increases of 16%, 19%, and 43% in plant height, root length, and dry weight of pepper indicating a significant growth-promoting effect on pepper seedlings (Zhao et al., 2017). As previously described, *Trichoderma* spp. significantly improved both root growth and magnesium (Mg), a key chlorophyll constituent also involved in catalysing enzymatic activity as well as in regulating genes engaged in photosynthesis (Sood et al., 2020). The photosynthetic rate of rice treated with *Trichoderma* was significantly stimulated by three-folds in comparison to plants treated with the classical chemical fertilisation (Doni et al., 2014).

Producing a resistant substance. Since their ability to produce secondary metabolites with antibiotic action is so expressive, *Trichoderma* spp. have aroused interest as a potential fungicide enhancer. Antibiosis occurs due to the release of antistances by *Trichoderma* and by a direct contact when *Trichoderma* hyphae intertwine with pathogenic fungus hyphae and degrade their structures (Barbosa et al., 2022). The addition of *Trichoderma* in a plant's rhizosphere improved plant defence against several pathogenic organisms such as viruses, bacteria, and fungi by stimulating the initiation of different resistance mechanisms mainly encompassing induced systemic resistance, hypersensitive response, and systemic acquired resistance. This has been demonstrated in the control of *Fusarium solani*, *Pythium debaryanum*, *Macrophomina phaseolina*, and *Rhizoctonia solani* (El-Benawy et al., 2020; Ketta et al., 2021). During colonisation, *Trichoderma* can produce volatile or non-volatile antibiotic substances such as pyranones and antimicrobial peptides, thereby inhibiting pathogenic soil bacteria and reducing the harm of pathogenic bacteria to plant roots and promoting crop growth (Zin, Badaluddin, 2020).

Some non-polar compounds (cerinolactone, harzianolide, dehydroharzianolide, T39 butenolide, etc.) with a low molecular weight produced by *Trichoderma* are resistant to *Botrytis cinerea* such as butyrate lactone T39 and harzianolide secreted by *T. harzianum* T39, and azaphilone and harzianopyridone secreted by *T. harzianum* T22 (Vinale et al., 2012). These compounds are also reported to be active against *Gaeumannomyces graminis* var. *tritici* and *R. solani* (Vinale et al., 2012). Piperaibols, for example, polar substances with a high molecular weight, are a class of linear non-ribosomal short peptide chains (less than 25 amino acid residues), which can exert antibacterial activity when *Trichoderma* contacts them. The water lipid amphiphilicity of polar substances allows them to self-associate forming oligomeric ion channels across the width of the lipid bilayer membrane and then causing the leakage of host cytoplasm and death of host cells (Chugh, Wallace, 2001). Hu et al. (2017) found that koninginins molecules produced by *Trichoderma* inhibited the growth of phytopathogens, *Fusarium flocciferum*, and *F. oxysporum*. More recently, Baiyee et al. (2019) collected the extracellular metabolites such as alcohols (ethanol and phenylthyl alcohol), pyran (6-pentyl-2H-pyran-2-one), and other volatile compounds (ethyl 2-methylbutyrate and 2-amylfuran) from *Trichoderma spirale* T76-1 culture filtrates and evaluated their antibiosis against *Corynespora cassiicola* and *Curvularia aeria*. The isolates *T. spirale* T76-1 have produced the above five isolated metabolites that inhibited the growth of *C. cassiicola* and *C. aeria* by 84.68% and 93.03%, respectively. Generally, *Trichoderma* has a broad-spectrum antifungal activity against plant pathogens (Baiyee et al., 2019).

The antibacterial substances (dimethyl disulfide, dibenzofuran, methanethiol, ketones, etc., which were effective ingredients for antagonistic activity) produced by *Trichoderma* can prevent pathogenic microorganisms from colonising the rhizosphere of plants and inhibit pathogenic fungi by competing for nutrition and space, hyperparasitism, bacteriolysis, and the production of antibiotic and secondary metabolites (Chen et al., 2016; Zin, Badaluddin, 2020). Oxygen heterocyclic compounds including poliketides present in *T. atroviride* are another promising molecules to trigger defence response with phenylalanine ammonia-lyase (PAL) expression and introduction of phenolic compounds synthesis (Baker et al., 2012). Harzianolides, harzianopyridone, and pyrones were also potential inducers to have the antifungal and plant growth-promoting effect, while their ability to activate resistance is still needed to be evaluated. Additionally, *Trichoderma* spp. could promote gene expression in plants thus activating defence mechanisms resulting in an indirect control of pathogenic fungi such as *R. solani* and *Sclerotinia sclerotiorum* (Nawrocka et al., 2019; Galletti et al., 2020).

Increasing the rate of nutrient utilisation. *Trichoderma* can promote crop nutrient utilisation by improving the rhizosphere environment increasing plant resistance and encouraging plant growth (Ram et al., 2020). Roots of *Trichoderma*-treated plants have exhibited a higher ability to explore the soil and an improved uptake of minerals. As is well known, nutrient elements in soil exist in an insoluble state and are difficult for crops to absorb; however, *Trichoderma* can improve the ability of crops to absorb the insoluble nutrients. The colonisation of cucumber roots by *T. asperellum* has been shown to enhance the availability of phosphorus (P) with a significant enhancement in plant biomass (Yedidia et al., 2001). Moreover, *T. harzianum* and *T. longibrachiatum* can improve the solubility of P, iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) and reduce the fixation of Fe and Cu in soil (Conte et al., 2022; Tandon et al., 2022). It has been shown that *Trichoderma* spp. strains positively responded to the promotion of soybean growth from 2.1% to 41.1% and promoted the efficiency of soybean P uptake up to 141% (Bononi et al., 2020) thus improving the P utilisation rate. Application of *T. harzianum* formulation at 20 kg ha^{-1} enhanced the availability of primary nutrient nitrogen (N) and P by 27% and 65% in sugarcane production (Singh et al., 2010). Recently, Cai et al. (2015) reported that the 75% chemical fertiliser along with the bio-organic fertiliser promoted tomato to uptake more N, potassium (K), and P at the early stage. Furthermore, the *Trichoderma* spp. enriched biofertiliser enhanced tomato growth, leaf greenness, and mineral contents in tomato roots and produced 12.9% higher yield compared to the recommended doses of chemical fertilisation (Khan et al., 2016).

Effects of *Trichoderma* on soil ecological environment

Soil physico-chemical properties. Most of the nutrients in the soil are either slightly soluble, insoluble, or in the form of compounds, which inhibit the circulation of soil nutrients to some extent (Halifu et al., 2019). Therefore, increasing soil nutrient availability has emerged as a critical strategy for promoting nutrient utilisation and improving soil nutrient conditions (Rashid et al., 2016). *Trichoderma* can generally lower soil pH and activate soil nutrients by secreting organic acids such as gluconic, citric, and fumaric ones (Fu et al., 2019; Poveda, 2021) with the lower soil pH mainly contributing to the improvement of soil nutrient availability. After two years of *Trichoderma* application, the pH of moist oxidised soil with long-term soybean planting decreased by 0.2 unit, while the content of hydrion and aluminium (H+Al) and Mn significantly increased by 5 cmolc dm^{-3} and 28 mg dm^{-3}, respectively (Conte et al., 2022). It has been shown that *Trichoderma* RW309 increased the content of soil mineral N by about 50% compared to that without *Trichoderma* application (Asghar, Kataoka, 2021) and soil available P by 12% improving soil nutrients availability and enhancing soil productivity sustainability (Fu et al., 2019). Moreover, when the maize seedlings were treated with suspension (0.7 g *T. asperellum* powder dissolved in 200 ml water) 15 days and 25 days after the emergence, soil alkali hydrolysable N was significantly increased by about 15% (Fu et al., 2019). Thus, *Trichoderma* can markedly increase the number of available nutrients in the soil. Furthermore, Fu et al. (2019) found that soil organic matter, total N and P increased significantly after the *Trichoderma* agent application in black soil with long-term maize cultivation.

The use of *Trichoderma* as an organic fertiliser caused increases of 52% and 70% in the organic carbon (C) content of aggregates >0.25 mm and the whole soil contributing to the improvement of soil fertility (Zhu et al., 2021). *Trichoderma* can activate not only soil nutrients but also improve soil physical properties. The application of *Trichoderma* biofertiliser significantly increased the content of large aggregates and the stability of aggregates in the soil (Zhu et al., 2021). More recently, Zhu et al. (2022) demonstrated that using the *T. asperellum* biofertiliser as a 20% chemical fertiliser substitution could increase the content of >2 mm aggregates by 40% and the mean weight diameter of soil aggregates by 36%. As is well known, soil moisture is one of the most important factors influencing plant growth and development. Xie et al. (2019) found that after applying *T. harzianum* to the potato-planted soil for four consecutive years, the soil water content and holding capacity increased significantly and the soil water use efficiency increased by 27.2%. In a 9-month incubation experiment, the conidia suspension of *T. atroviride* significantly improved the soil water content (Cordier, Alabouvette, 2009). Therefore, *Trichoderma* can effectively increase the content of large aggregates in soil, increase the soil water holding capacity and improve soil physical properties.

Soil enzyme activity. Soil enzymes are involved in various biochemical processes and nutrient circulation, whose activities can reflect the intensity and direction of soil biochemical processes and objectively indicate soil fertility. *T. hamatum* FB10 significantly increased the soil catalase activity (Baazeem et al., 2021), while *T. harzianum* increased the activities of shikimate dehydrogenase, glucose-6-phosphate dehydrogenase, and polyphenol oxidase in the tomato rhizosphere soil by 53.37%, 69.79%, and 71.71%, respectively (Yan et al., 2021). Thus, *Trichoderma* can slow down the toxic effects of toxic and harmful substances in soil on crops by reducing the accumulation of hydrogen peroxide and phenolic substances in soil.

Trichoderma can also activate soil nutrients and increase the supply capacity of soil nutrients by altering enzyme activities related to nutrient transformation in the soil (Fu et al., 2019). According to Liu et al. (2020), the biofertiliser containing *T. guizhouense* significantly increased the soil urease activity accelerating the transformation of soil organic N and increasing the available N content in the pepper rhizosphere soil, which increased the pepper yield. *Trichoderma* can also increase the soil urease activity and boost the soil alkaline phosphatase activity. Soil phosphatase activity was increased by more than 10% after the inoculation with *Trichoderma* RW309 in a two-month incubation experiment (Asghar, Kataoka, 2021). The inoculation of *Trichoderma* increased the soil phosphatase activity and accelerated the transformation of organic P compounds or inorganic P in the soil. Therefore, *T. harzianum* can significantly improve the soil N and P supply. Furthermore, *Trichoderma* inoculation caused an increase of 45% in the soil invertase activity in an experiment cultivated with Chinese cabbage (Shi et al., 2021), which effectively promoted the soil C turnover and improved the soil ecological environment. Thus, *Trichoderma* can boost the soil enzyme activity related to C, N, and P transformation in soil and improve the soil nutrient supply and crop rhizosphere ecological environment, all of which are conducive to crop growth and yield improvement (Asghar, Kataoka, 2021).

Soil microbial composition and community. A high soil microbial diversity and an appropriate community composition are the main documents to support ecosystem productivity. As a biocontrol agent, *Trichoderma* has fundamental functions in stimulating the plant beneficial microbiome and inhibiting the invading pathogen through different mechanisms. *Trichoderma* can effectively control the diversity and abundance of the soil microbial community. Pang et al. (2017) evaluated the response of resident bacterial community to the *Trichoderma*-enriched organic fertiliser and found a higher number of operational taxonomic units in the soil treated with the *Trichoderma*-enriched organic fertiliser. Moreover, it had the highest Shannon diversity index for the bacterial community after the *Trichoderma* incorporation. When inoculated in the rhizosphere of black pepper (*Piper nigrum* L.), *T. harzianum* MTCC 5179 induced an increase in the alpha diversity of metagenome of 33707 species (Umadevi et al., 2018). A marked difference in the soil bacterial diversity and soil fungal diversity appeared between the treatments with or without *Trichoderma* biofertiliser application (Zhang et al., 2019). *Trichoderma* biofertiliser application significantly increased the bacterial alpha diversity while decreased the fungal alpha diversity and the abundance of the fungal genera *Fusarium*, *Alternaria*, and *Penicillium* (Zhang et al., 2018).

Fu et al. (2019) discovered that each dose of *Trichoderma* application increased the soil bacterial abundance in the soil planted with maize, particularly the abundances of *Nitrospira* and *Sphingomonas*. The relative abundance of *Acidobacteria*, a group of slow-growing ologotrophic bacteria, was also promoted by *Trichoderma* and the improved relative abundance of *Nitrospira* in *Trichoderma* treatment might also be affected by the saline-alkaline soil itself (Fu et al., 2019). *T. harzianum* could also significantly increase the abundances of *Pseudomonas*, *Arthrobacter*, and *Flavobacterium* in the rhizosphere soil of alfalfa (Zhang et al., 2019). Similarly, He et al. (2022) demonstrated that *T. viride* had a greater effect on the bacterial community than on the fungal community and that the combination of *Paraboeremia putaminum*, and *T. viride* exerted a greater impact on the microbiome under drought stress. The relative high abundance of functional bacteria after the *Trichoderma* application might have more abundant reads for disease, virulence, and defence (Umadevi et al., 2018). Whether the change in the abundance of different bacterial groups brought about by *Trichoderma* is related to the function of these bacteria requires further studies.

The inoculation of *T. atroviride* I-1237 resulted in a significant increase in the density of fungal community after three days of inoculation. The structure of fungal community evolved in a similar manner in both control and *T. atroviride* I-1237 inoculated soil (Cordier, Alabouvette, 2009). Zhang et al. (2019) also showed that *T. harzianum* had no effect on the soil fungal abundance compared to the soil without *T. harzianum* application. Since *T. harzianum* ESALQ-1306 and *T. asperellum* BRM-29104 did not affect the abundance of arbuscular mycorrhizal fungi spores, *Trichoderma* spp. may also not affect the fungal species richness diversity or the fungal community composition (Azevedo Solva et al., 2021). This might indicate that *Trichoderma* possibly contributed to the proliferation of existing arbuscular mycorrhizal population but not in enhancing diversity. *Trichoderma* promotes the transformation of soil microorganisms from fungi to bacteria, which helps to maintain the balance of the soil microbial community and thus reduces the occurrence of crop diseases and pests.

Trichoderma agent is a widely used fungicide for controlling soil-borne diseases by attacking and disintegrating plant pathogenic fungi, e.g., *Rhizoctonia solani*, *Alternaria alternata*, *Sclerotinia sclerotiorum*, *Fusarium* spp., *Botrytis cinerea*, etc. (Harwoko et al., 2019; Sood et al., 2020). It has been shown that the *T. brevicrassum* strain TC967 exhibited the highest inhibition rate against *R. solani* (72.14%) followed by *T. longifialidicum* TC463 and TC675, *T. virens* TC702 and TC806, and *T. breve* TC735 (Zhang, Zhuang, 2020). *T. polyspora* effectively inhibited the growth of *Pseudogymnoascus destructans*, and the *T. polyspora*-induced killing of *P. destructans* was highly specific with a minimal to no impact on the indigenous microbes present in the soil (Singh et al., 2018). Azevedo Solva et al. (2021) showed that *Trichoderma* spp. did not significantly affect the metabolic activity of the edaphic microbial community. However, in the antagonistic culture with a soil-borne fungal pathogen, *T. longibrachiatum* EF5 showed the 58% inhibition against *M. phaseolina* by triggering the amino sugar metabolism (Sridharan et al., 2021). Wang et al. (2021) also showed that *T. harzianum* Th62 has an apparent antagonistic ability against soil-borne pathogens, *F. oxysporum* and *A. alternata*. *Trichoderma* also has a clear inhibitory effect on *G. graminis* var. *tritici* in wheat roots (Kang et al., 2019). Hence, *Trichoderma* could be a potential biocontrol agent employed for defence priming and plant growth promotion via regulating soil microbial composition and community.

Conclusions and future prospects

Trichoderma is a vital biocontrol fungus that is widely used in agricultural production. Inoculation of *Trichoderma* spp. can be an environment friendly approach for disease management and soil improvement because of their negative effects on pathogens and positive effects on soil properties and crop growth as compared to those of synthetic pesticides and chemical fertilisers. However, when compared to the chemical control, the biological control effect of *Trichoderma* is relatively slow and requires strict environmental conditions. Farmers are unwilling to bear high costs in preventing and controlling diseases and pests during agricultural management due to the high cost of *Trichoderma* agents. Differences in soil texture, soil type, and hydrothermal conditions in different regions will affect the activity of *Trichoderma* agent applied to the field, limiting its utilisation and field application.

In addition, competition for nutrients might be responsible for alteration in soil microbes. It is challenging to monitor the effect of a bioinoculant on non-target soil microbial communities in rhizosphere; therefore, the current research concerning *Trichoderma* agents is still in the laboratory stage. The rapid advancement of modern biotechnology has created a new avenue for biological control. Scientists, entrepreneurs, and governments in most countries have gradually become interested in the development and research of *Trichoderma* agents. As a result, *Trichoderma* agents have a broader development potential, particularly in the four aspects listed below:

1) creating engineering strains that can withstand environmental stress using modern molecular biology methods such as gene recombination technology;

2) investigating the best culture conditions for *Trichoderma* fermentation, improving the activity and the control effect of *Trichoderma*;

3) improving the soil hydrothermal conditions and nutrient conditions to benefit the growth and reproduction of *Trichoderma*, and thus promoting its colonisation in the soil;

4) in light of plant diseases caused by various pathogenic fungi, different methods for producing *Trichoderma* agents should be used to improve the effectiveness of biological control.

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Trichoderma poveikis augalų augimui ir dirvožemio ekologinei aplinkai: apžvalga

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Santrauka

Trichoderma yra labai paplitusi rūšis fitopatogeninių grybų, žemės ūkyje plačiai naudojamų kaip biofungicidai kovoje su augalų ligomis. Gerai žinoma, kad *Trichoderma* gali ne tik veiksmingai kovoti su augalų ligomis, bet ir pagerinti dirvožemio fizikines bei chemines savybes ir padidinti jo produktyvumą. Šios rūšies atsparumo ligoms poveikis augalų augimui ir dirvožemio ekologinei aplinkai nėra plačiai aprašytas, todėl apžvalgoje pateikti *Trichoderma* atsparumo ligoms, derliui ir augalų augimui rezultatai, taip pat *Trichoderma* įtaka dirvožemio ekologinei aplinkai, t. y. jo fizinėms, cheminėms ir mikrobiologinėms savybėms. *Trichoderma* poveikio augalams ir dirvožemio savybėms tyrimų trūkumas akcentuoja šių tyrimų spragas.
Ši apžvalga suteikia teorinį pagrindą tolesniems *Trichoderma* tyrimams ir jų rezultatų taikymui žemės ūkyje.

Reikšminiai žodžiai: augalų ligos, dirvožemio fizikinės ir cheminės savybės, dirvožemio mikroorganizmai, fitopatogeniniai grybai.