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How Trichoderma Enhances Plant Defense Enzymes in Food Crops: Current Insights and Future Perspectives in Asia

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Abstract

Food crops are plants grown for consumption by humans and animals. These crops face threats from both abiotic and biotic factors. Therefore, environmentally friendly alternative controls, such as enhancing plant resistance using *Trichoderma* spp, are needed. This systematic literature review provides information on the effects of *Trichoderma* spp. application on plant physiology, particularly focusing on defense enzymes in food crops in the Asian region. Articles on the effects of *Trichoderma* application on food crop defense enzymes in Asia were retrieved from PubMed and Scopus. The literature search yielded 3,022 articles from these databases. Four criteria were established for study inclusion: i) studies involving *Trichoderma* spp.; ii) studies using food crops as the subject; iii) studies conducted in Asia; and iv) studies evaluating at least one defense enzyme activity. In this systemic review, we found at least 100 isolates of *Trichoderma* spp. that can increase plant resistance, as indicated by the increase of plant defense enzymes in Asia. The studies were mostly reported in India and China. Rice is the most frequently studied crop. The most frequently used is *T. harzianum*. Meanwhile, the defense enzymes tested are peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, chitinase, and β-1,3-glucanase. The most commonly used inoculation method is seed treatment in a controlled environment such as a greenhouse. More research on changes in plant enzymes due to *Trichoderma* spp. application is recommended to assess its effectiveness in practical, real-world settings, especially in field conditions.

Keywords: Food crops, induce systemic resistance, plant defense enzymes, *Trichoderma* spp.

Introduction

Food crops are essential agricultural commodities grown for human and animal consumption (Aly & Borik, 2023). The growth and production of food crops have become a primary focus in global agriculture due to their crucial role in food security (Guleria et al., 2023). In 2021, corn and rice ranked as the second and third most-produced agricultural commodities worldwide, following sugarcane (Statista, 2023). However, food crops are continuously threatened by various abiotic factors such as water scarcity, soil pollution, and climate change, as well as biotic factors, including pest and disease attacks (Guleria et al., 2023).

Nowadays, the most widely used pest and disease management strategies involve resistant crop varieties and chemical pesticides. However, these methods have limitations. Pests and pathogens are highly adaptable, resilient, and capable of evolving resistance to pesticides, especially under changing climatic conditions (Kaur & Chauhan, 2023). Additionally, excessive pesticide use in agriculture poses significant environmental risks, including soil and water contamination and non-target organism toxicity. The rapid increase in pesticide resistance further exacerbates this issue, reducing the efficacy of previously effective pesticides (Kaur & Chauhan, 2023). Therefore, alternative environmentally friendly control strategies are urgently needed, such as enhancing plant resistance through biological agents like *Trichoderma* spp.

Trichoderma spp. are beneficial microorganisms known for their role in improving soil fertility and plant growth. These fungi establish mutualistic endophytic relationships with various plant species, enhancing host plant development, providing protection against pathogen attacks, and improving nutrient uptake efficiency (Awad-Allah et al., 2023). The effectiveness of *Trichoderma* spp. in mitigating abiotic and biotic stress has been widely documented (Zaidi et al., 2014; Gangwar & Singh, 2018). However, most studies evaluating plant resistance induction by *Trichoderma* spp. focus primarily on visual damage assessments caused by abiotic and biotic stresses. Limited research has explored the physiological mechanisms underlying *Trichoderma*-induced resistance, particularly changes in plant defense enzyme activity.

This literature review aimed to examine the impact of *Trichoderma* spp. application on plant physiology, with a specific focus on the activity of defense enzymes in food crops in Asia. By analyzing the physiological responses of food crops to *Trichoderma* spp., this study seeks to provide deeper insights into the mechanisms of plant resistance induction. The findings are expected to contribute to the development of sustainable agricultural practices and optimize the use of *Trichoderma* spp. as an effective and environmentally friendly biological control agent.

Methods

Database Sources

Articles reviewed on the effect of *Trichoderma* application on food crop defence enzymes in Asia were retrieved from online databases at 21 September 2024. PubMed and Scopus were used as the databases. The search was limited to English-language journal articles with publication dates between 2014 and 2024.

Search Term

The following search strings were utilized in the selection of relevant articles in the title, keywords, or abstract: ("Boost*" OR "Enhanc*" OR "Increas*" OR "Improv*" OR "Stimulat*" OR "Promot*") AND ("Plant* defens* enzyme*" OR" Plant* Enzyme*" OR "Enzyme*") AND ("Trichoderma*") AND ("Agricultural field*" OR "Field*" OR "Farmland*"). The literature search yielded 3022 records from Scopus and Pubmed, which were imported into Rayyan AI (http://rayyan.qcri.org) to manage and screen the data.

Screening and Data Extraction

The screening process removed duplicates, conference proceedings, reviews, book chapters, and editorial material. The remaining records were retrieved in full text and reviewed in detail. Screening was carried out against the inclusion/exclusion criteria. Four criteria were set for study inclusion: i) studies with *Trichoderma* spp.; ii) studies using food crops as an object; iii) studies conducted in Asia; and iv) studies evaluating at least one increasing enzymes defense activity (β-1,3-glucanase, Phenylalanine ammonia-lyase, Peroxidase, Chitinase, Chitosanase, and Polyphenol oxidase). Study exclusion criteria were: i) studies not examine plant defense enzymes; ii) there is no interaction between *Trichoderma* spp. and food crop plants; iii) studies not written in English; iv) Introduction of *Trichoderma* spp. in combination with other microbes (unable to see the effects of *Trichoderma* directly). This systematic review followed the PRISMA statement and checklist guidelines for screening publications (Moher et al., 2009). A checklist for the systematic review is provided in Figure 1.

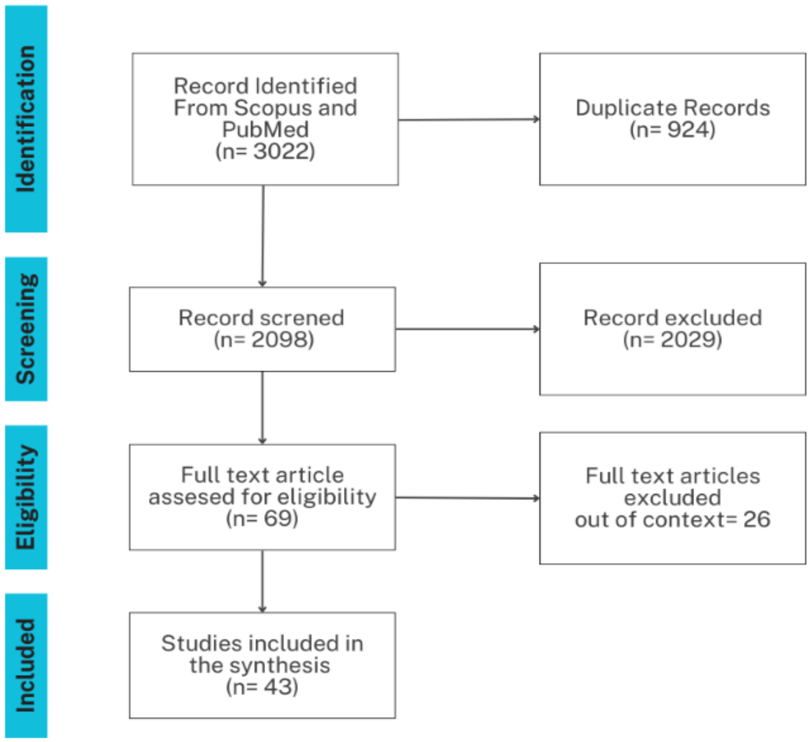

Figure 1. Preferred reporting items for systematic reviews and meta-analysis (PRISMA) diagram of systematic quantitative literature review selection process. Selection criteria are outlined in Section 2.3. represents the number of publications

Potentially relevant articles were downloaded and read in full. Information and data relevant to this review were extracted from eligible articles. The information included the Geographical distribution, the effect of *Trichoderma* sp. on plant defense enzymes, inoculation methods, and the study setting. The study settings used in each article were categorized into controlled and uncontrolled environments (e.g., greenhouse and field). All figures were constructed using Microsoft Excel 2021 and mapchart.net

Results

The geographical distribution of studies measuring the enhancement of defense enzyme activity in food crops using the biocontrol agent *Trichoderma* spp. in Asia reveals that India has conducted the most research on this topic, with a total of 26 studies. This is followed by China, Pakistan, Iraq, Iran, Thailand, and Malaysia (Figure 2). The most common inoculation method is seed treatment (Figure 3)

Figure 2. Geographical distribution of *Trichoderma* spp. application for enhancing food crops defense enzymes in Asia

A total of 100 isolates were identified across 43 reviewed articles. The most frequently used *Trichoderma* species was *T. harzianum*, appearing 43 times. Meanwhile, rice was the most commonly studied crop for enhanced defense enzyme activity. We also found that the defense enzymes tested were peroxidase, polyphenol oxidase, phenyl-alanine ammonia-lyase, chitinase, and β-1,3-glucanase (Table 1).

Table 1. *Trichoderma* species effect on plant defense enzyme

Trichoderma spesies	Plant species	Plant defense enzyme effected	References
T. harzianum T-14	Rice	Increasing 27.07 % POD activity than control	Datta et al., 2022
T. harzianum 94(A)		Increasing 23.29 % POD activity than control	
T. harzianum IRRI-2		Increasing 46.64 % POD activity than control	
T. asperellum OT-3		Increasing 27.30 % POD activity than control	
T. harzianum OT-8		Increasing 27.09 % POD activity than control	
T. harzianum	Chickpea	POD activities were significantly higher than the control	Javaid et al., 2021
T. viride		POD activities were significantly higher than the control	
T. asperellum	Maize	POD activities were significantly higher than the control treatment with meadow soil	Fu et al., 2017

Trichoderma spesies	Plant species	Plant defense enzyme effected	References
T. viride, *T. harzianum,* *T. harzianum* Th14, *T. harzianum* Th19, *T. harzianum* ThR, *T. asperellum* TUK42	Shorgum	POD, PPO, PAL activities were significantly higher than the control	Yadav et al., 2023
T. harzianum	Cowpea	Increasing activity of POD, PPO, and PAL than the control with 41%, 45%, and 39% respectively	Shoaib et al., 2018
T. viride		Increasing activity of POD, PPO, and PAL than the control with 15%, 30%, and 32% respectively	
T. longibrachiatum	Wheat	POD activities were significantly higher than the control	Zhang et al., 2016
T. erinaceum T51 *T. viride* T52	Bean	Significanly Increase activity of PAL after 24, 48, 96 hours after inoculation than the control	Kumar et al., 2024
T. afroharzianum IIPRTh-33	Pigeonpea	POD, PPO, PAL activities were significantly higher than the control	Mishra et al., 2023
T. asperellum IIPRTh-31		POD, PPO, PAL activities were significantly higher than the control	
T. harzianum IIPRTh-10		POD and PAL activities were significantly higher than the control	
T. harzianum IIPRTh-23		PAL activities were significantly higher than the control	
T. harzianum IIPRTh-12		PAL activities were significantly higher than the control	
T. asperellum IIPRTas-9		POD and PAL activities were significantly higher than the control	
T. asperellum IIPRTas-15		POD and PAL activities were significantly higher than the control	
T. asperellum IIPRTas-12		PAL activities were significantly higher than the control	
T. harzianum IIPRTh-38		POD and PAL activities were significantly higher than the control	
T. harzianum IIPRTh-22		PAL activities were significantly higher than the control	
T. asperellum IIPRTas-13		POD and PAL activities were significantly higher than the control	
T. harzianum IIPRTh-3		POD and PAL activities were significantly higher than the control	
T. longibrachiatum IIPRTg-3		PAL activities were significantly higher than the control	
T. asperellum IIPRTas-1		POD and PAL activities were significantly higher than the control	
T. harzianum IIPRTh-39		POD and PAL activities were significantly higher than the control	
T. asperellum T4	Great millet	POD and PPO activities were significantly higher than the control	Manzar et al., 2021
T. harzianum T6		POD and PPO activities were significantly higher than the control	
T. asperellum T19		POD activities were significantly higher than the control	

Trichoderma spesies	Plant species	Plant defense enzyme effected	References
T. asperellum T15		PPO activities were significantly higher than the control	
T. harzianum THU0816 ARS	Bean	POD, PPO, PAL activities were significantly higher than the control	Ram et al., 2015
T. erinaceum	Rice	PPO activities were significantly higher than the control	Shasmita et al., 2019
T. harzianum FCBP-SF-1277	Pea	POD activities were significantly higher with all metabolite concentrations (40, 50, 60%) than the control	Rauf et al., 2024
T. longibrachiatum	Wheat	POD, PPO, PAL activities were significantly higher than the control	Zhang et al., 2014
T. viride *T. harzianum* *T. harzianum* Th14, *T. harzianum* Th19, *T. harzianum* ThR, *T. asperellum* TUK42	Sorghum	POD, PPO, PAL activities were significantly higher than the control	Yadav et al., 2023
T. hamatum UoM 13	Pearl Millet	POD, PPO, PAL, and β -1,3-glucanase activities were significantly higher than the Untreated Plant	Siddaiah et al., 2017
T. harzianum	Broad bean	PAL activities were significantly higher than the control	Al-Ameri, 2023
T. viride BHU-2953	soybean	*T. viride* BHU-2953 with addition of recommendation of fertilizer was significantly increasing the activity of POD enzymes than the control	Paul and Rakshit, 2022
T. harzianum IIPRTh-3	Pigeonpea	POD and PAL activities were significantly higher than the control	Mishra et al., 2024
T. aureoviride FCB 691	Mungbean	Soil application with *T. aureoviride* + biomass of *Coronopus didymus* and inoculated wih *Macrophomina* phaseolina can increased POD, PPO, and PAL significantly than the control	Javaid et al., 2018
T. viride	Potato	POD activities were significantly higher than the control after 72 and 96 hours after pathogen inoculation PPO activities were significantly higher than the control after 48, 72, and 96 hours after pathogen inoculation PAL activities were significantly higher than the control after 48, 72, and 96 hours after pathogen inoculation	Kumar et al., 2023
T. asperellum T42	Rice	POD and PAL activities were significantly higher than the Untreated Plant in Drough or Non-Drought conditions	Singh et al., 2020
T. paraviridescens *T. erinaceum* *T. asperellum*	Rice	PPO activities were significantly higher than the Untreated Plant PPO activities were significantly higher than the Untreated Plant PPO and POD activities were significantly higher than the Untreated Plant	Islam et al., 2023

Trichoderma spesies	Plant species	Plant defense enzyme effected	References
T. harzianum CRRI-T1 *T. erinaceum* CRRI-T2 *T. atroviride* CRRI-T3 *T. atroviride* CRRI-T5 *T. atroviride* CRRI-T9 *T. atroviride* CRRI-T13	rice	PPO activities were significantly higher in shoot and root than the Untreated Plant	Swain et al., 2018
T. harzianum Th9	Potato	Chitinase and β -1,3-glucanase activities were significantly higher than the control	Singh et al., 2020
T. harzianum UPMT1 *T. virens* UPMT2	Rice	POD, PPO, and PAL activities were significantly higher in shoot and root than the Untreated Plant POD, PPO, and PAL activities were significantly higher in shoot and root than the Untreated Plant	Ng et al., 2015
T. harzianum	Maize	PPO activities were significantly higher than the untreated plant	Afrouz et al., 2023
T. harzianum 56 *T. harzianum* 69 *T. harzianum* 75 *T. harzianum* 82 *T. harzianum* 89	Wheat	PAL activities were significantly higher than the untreated plant after 13 days treated with drought stress	Shukla et al., 2014
T. harzianum CRRI-T1 *T. erinaceum* CRRI-T2 *T. artroviride* CRRI-T3 *T. hebeiensis* CRRI-T15 *T. parareesei* CRRI-T16 *T. longibrachiatum* CRRI-T22 *T. reesei* CRRI-T27	Rice	POD and PPO activities were significantly higher than the control	Swain et al., 2021
T. harzianum *T. viride*	Rice	POD activities were significantly higher than the control	Ghosh, 2017
T. asperellum GDFS1009	Maize	POD and PPO activities were significantly higher than the control 0 and 72 hours after inoculation	Batool et al., 2020
T. harzianum	Pea	PAL activities were significantly higher than the control when measured 24 & 48 hours after inoculation PPO activities were significantly higher than the control when measured 96 hours after inoculation POD activities were significantly higher than the control when measured 24 hours after inoculation	Pandey et al., 2021
T. hamatum UoM 13	Pearl Millet	POD, PPO, PAL and β -1,3-glucanase activities were significantly higher than the control	Lavanya et al., 2017
T. harzianum	Wheat	POD activities were significantly higher than the control	Younis et al., 2022
T. artroviride	Pearl Millet	POD activities were significantly higher than the control	Nandini et al., 2017
T. asperellum T42	Pea	PAL activities were significantly higher than the control	Patel et al., 2017

Trichoderma spesies	Plant species	Plant defense enzyme effected	References
T. asperelloides PSU-P1	Rice	POD activities in shoots and roots plant treated with *T. asperelloides* were significantly higher than the control PAL activities in roots plant treated with *T. asperelloides* were significantly higher than the control	Wonglom et al., 2024
T. harzianum UBSTH-501	Wheat	POD and PAL activities were significantly higher than the control	Singh et al., 2019
T. harzianum T891	kidney bean	POD activities were significantly higher than the control	Guo et al., 2024
T. longibrachiatum TG1	Wheat	POD and PAL activities were significantly higher than the control	Boamah et al., 2021
T. longibrachiatum TG1	Wheat	POD and PAL activities were significantly higher than the control	Boamah et al., 2022
Trichoderma CRRIT-5	Rice	POD activities in roots were significantly higher than the control	Sarangi et al., 2021
Trichoderma CRRIT-13		POD activities in shoots and roots were significantly higher than the control	
Trichoderma NRRIT-26		POD activities in shoots and roots were significantly higher than the control	
Trichoderma NRRIT-27		POD activities in shoots and roots were significantly higher than the control	
T. viride	Potato	PAL activities were significantly higher than the control after 0, 24, 48, and 72 hours after pathogen inoculation β -1,3-glucanase activities were significantly higher than the control after 24, 48, and 72 hours after pathogen inoculation	Kumar et al., 2021
T. harzianum		PAL activities were significantly higher than the control after 0, 24, 48, and 72 hours after pathogen inoculation β -1,3-glucanase activities were significantly higher than the control after 0, 24, 48, and 72 hours after pathogen inoculation	
T. reesei	Rice	PPO and PAL activities in shoots and roots were significantly higher than the control	Singh et al., 2019

Note: POD= Peroxidase, PAL= Phenylalanine ammonia lyase, and PPO= Polyphenol oxidase

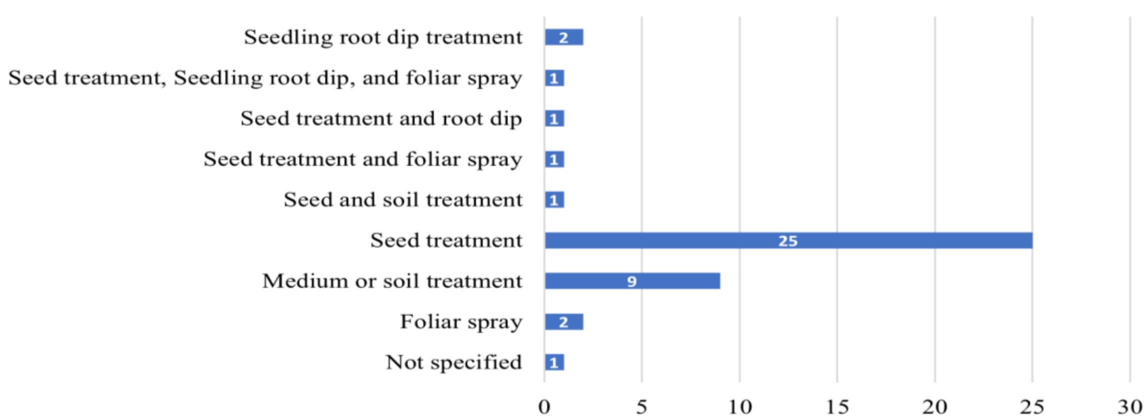

Figure 3. Inoculation methods of *Trichoderma* spp.

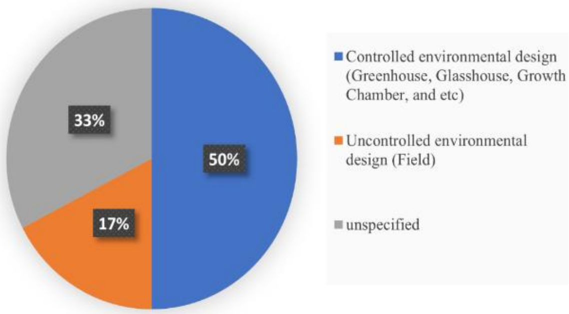

Figure 4. Study setting of *Trichoderma* spp. affecting plant defense enzyme

Discussion

Studies measuring the increase of defense enzyme activity in Asian food crops using *Trichoderma* spp. have been mostly reported in India and China (Figure 2). This is closely related to their superior research capabilities compared to other Asian countries. According to Scimago (2024), data on scientific publications in 2023 show that India and China rank among the top three countries with the highest number of scientific publications worldwide.

Rice is the most frequently studied crop (Table 1). This is linked to the cultural habits of India and China, where rice is a staple food. In 2023–2024, China and India were the largest consumers of rice globally (Statista, 2024). Rice is the most researched commodity and as approximately 90% of global rice production and consumption happens in Asia (Bandumula, 2017).

The most frequently used *Trichoderma* species was *T. harzianum*, appearing 43 times. Meanwhile, defense enzymes tested were peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, chitinase, and β-1,3-glucanase (Table 1). Plant induced resistance is linked to these defense enzymes. Every plant defence enzyme has its own mechanism for enhancing resistance. For example, the enzyme peroxidase. Pathogen or biocontrol agent infection in host plant tissues stimulates peroxidases, a well-known class of PR proteins. They are able to limit the cellular spread of infection by forming structural barriers or by creating highly toxic environments by massive ROS and RNS generation (Appu et al., 2021).

There is a strong correlation between increased plant defense enzyme activity due to *Trichoderma spp.* application (Kumar et al., 2023; Gashash et al., 2023). *Trichoderma* spp. increases plant defence enzymes with its ability to be symbiotic with plants. *Trichoderma* spp. acts as an elicitor that can make plants respond to the stimulus given to them, thus this *Trichoderma* treatment enhances plant defence enzymes that will lead to the formation of jasmonic acid, salicylic acid and other defence metabolites such as phenol, lignin, phytoalexins, and others. Therefore, the plants are more resistant if there is infection from pathogens afterwards (Islam et al., 2023) (Yao et al., 2023).

The most common inoculation method is seed treatment (Figure 3). The method plays a vital role in its effectiveness in influencing plant resistance. It also considers factors such as the type of biocontrol agent, the pathogen, and the specific plant species studied (Lavanya et al., 2017). It is regarded as easier compared to other methods like root soaking or inoculation in the growing medium (Kumar et al., 2014). This suggests that treating seeds with *Trichoderma* spp. can enhance plant resistance, evidenced by increased plant defense enzyme activity. Therefore, for future applications of *Trichoderma* sp. it is highly recommended to apply it to seeds.

Most studies have been conducted in controlled environments such as greenhouse (Figure 4). The place where research is conducted also plays a crucial role in the outcome of the research. Research conducted in a controlled environment tends to provide better results than research in an uncontrolled environment. In addition, data bias is also more common in studies in uncontrolled environments than in controlled environments (Kandi and Vadakedath, 2023). However, research on uncontrolled environments in agriculture must still be conducted by following proper research principles in order to provide many benefits to farmers who generally carry out agricultural practices in the field (Dechassa et al., 2022).

Conclusion

The literature search yielded 3,022 articles from these databases. Four criteria were established for study inclusion: i) studies involving *Trichoderma* spp.; ii) studies using food crops as the subject; iii) studies conducted in Asia; and iv) studies evaluating at least one defense enzyme activity. In this systemic review, we found at least 100 isolates of *Trichoderma* spp. that can increase plant resistance, as indicated by the increase of plant defense enzymes in Asia. The studies were mostly reported in India and China. Rice is the most frequently studied crop. The most frequently used is *T. harzianum*. Meanwhile, the defense enzymes tested are peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, chitinase, and β-1,3-glucanase. The most commonly used inoculation method is seed treatment in a controlled environment such as a greenhouse. More research on changes in plant enzymes due to *Trichoderma* spp. application is recommended to assess its effectiveness in practical, real-world settings, especially in field conditions.

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Declaration

Author contribution

Hasan Albana is the main contributor and corresponding author for this paper. Nurbailis and Darnetty are co-author. All authors read and approved the final paper.

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Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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