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Evaluating trichocompost for disease control and yield improvement in potatoes under tropical dryland conditions in South Central Timor, Indonesia

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Abstract. *Simamora AV, Serangmo DYL, Londingkene JA, Nahas AE, Nenotek PS, Hahuly MV, Kasim M, Mahayasa INW, Gandut YRY, Widinugraheni S, Hosang EY. 2025. Evaluating trichocompost for disease control and yield improvement in potatoes under tropical dryland conditions in South Central Timor, Indonesia. Intl J Trop Drylands 9: 159-168.* Potato (*Solanum tuberosum*) is a key horticultural crop in Indonesia. In tropical dryland areas such as South-Central Timor, Indonesia, potato cultivation faces challenges including limited rainfall, poor soil fertility, and high disease pressure. Late blight caused by *Phytophthora infestans* remains one of the most destructive diseases. This study evaluated the biocontrol efficacy of *Trichoderma harzianum* formulated as trichocompost for disease suppression and yield improvement under dryland conditions. Unlike many previous studies that focused on in vitro or greenhouse testing, this research prioritized native *Trichoderma* isolates adapted to potato rhizosphere soil and validated their performance under harsh Entisol-based dryland field conditions. Five isolates were obtained from the rhizosphere of healthy potato plants and characterized morphologically. Their antagonistic activity against *P. infestans* was assessed using the dual culture method. All isolates inhibited *P. infestans* by more than 70%, with *Trichoderma* 04 showing the highest inhibition. Molecular identification confirmed this isolate as *T. harzianum*, which was selected for field evaluation in four treatments: control, trichocompost applied two weeks before planting (T1), at planting (T2), and two weeks after planting (T3). Data from the dual culture assay and field experiment were analyzed using ANOVA and followed by DMRT at $p<0.05$. Field trials showed that T1 extended the incubation period, substantially reduced disease severity, and increased both tuber number and tuber weight. These results demonstrate the dual function of *T. harzianum* trichocompost as a biocontrol agent and organic soil amendment, supporting sustainable potato production in tropical drylands.

Keywords: Biological control, late blight disease, *Phytophthora infestans*, potato production, *Trichoderma harzianum*

INTRODUCTION

Potato (*Solanum tuberosum*) is a globally important horticultural crop valued for nutritional and economic contributions. In Indonesia, it plays supports food diversification programs, strengthens farmer livelihoods, contributes to non-oil export earnings, and supplies raw material for the processed food industry, underscoring its importance for food security and economic development (Devaux et al. 2020).

East Nusa Tenggara (ENT), particularly South Central Timor (SCT) District, is a notable potato-producing area. However, productivity remains low due to tropical dryland conditions characterized by erratic rainfall, prolonged dry periods, and infertile Entisol soils with poor water retention and nutrient availability. These stresses reduce soil organic matter, limit microbial activity, and exacerbate land degradation. Most farmers depend on low-input production systems with minimal fertilizer or fungicide use due to costs and access constraints. These conditions highlight the need for sustainable, site-specific approaches to soil fertility and disease management (Moata and Takalapeta 2021; Riptanti et al. 2022).

Regional production data further illustrate these challenges. Potato yields in SCT declined from 87.3 quintals per hectare in 2021 to 53.3 in 2022, with only a modest recovery to 59.9 in 2023. By contrast, national yields increased steadily to 196.3 quintals per hectare over the same period (Central Statistics Agency 2024). This disparity indicates SCT's vulnerability and the importance of addressing local production constraints.

Late blight, caused by *P. infestans*, is one of the most destructive constraints in potato systems and cause total crop loss under favorable conditions (Abewoy 2018). Globally, the disease is responsible for annual economic losses of approximately USD 6.7 billion through reduced yield and quality (Liu et al. 2020). Although partial resistance exists, no potato variety is complete immune, leaving the pathogen a persistent threat (Islam et al. 2022). Its adaptability makes control difficult. The pathogen's heterothallic reproductive system and significant genetic variability facilitate swift circumvention of host resistance

(Pazderu and Hamouz 2017). It thrives in highland regions with cool temperatures and high humidity, such as SCT, and can persist in infected tubers, stems, soil, plant debris, and volunteer plants, serving as a source of inoculum for subsequent seasons (Hashemi et al. 2022; Lamichhane et al. 2024). This persistence further complicates its control (Islam et al. 2022; Lamichhane et al. 2024).

Biological control has gained attention as a sustainable alternative. *Trichoderma* species, particularly *T. harzianum*, are effective antagonists that suppress pathogens through mycoparasitism, nutrient competition, enzyme secretion, antibiosis, and induced systemic resistance (Kai et al. 2018; Guo et al. 2022; Tyśkiewicz et al. 2022). These mechanisms support their effectiveness across diverse agroecological conditions, including drylands stress.

Trichoderma can be also formulated into trichocompost, an enriched compost that improves soil microbial activity, organic matter levels, nutrient cycling, and the availability of nitrogen, phosphorus, and potassium. These nutrients are often limited in Entisol soils in SCT (Asghar and Kataoka 2021; Wei et al. 2024). Compost application also increases soil porosity and moisture retention improving crop resilience in low-moisture environments (Hao and Ashley 2021). *Trichoderma*-fortified composts provide the combined benefits of reducing disease incidence and enhancing nutrient mobilization and soil health (Rahman et al. 2024).

Despite these the application of *Trichoderma*-enriched compost in potato systems under naturally infested dryland soils remains underexplored. Existing studies are often limited to in vitro antagonism or greenhouse trials, with few conducted under real field conditions. Addressing this gap is essential for developing sustainable and locally adaptable management strategies in SCT. Therefore, this study aimed to isolate and evaluate native *Trichoderma* species from potato rhizosphere soils for antagonism against *P. infestans* in vitro, and to assess the field efficacy of the most promising isolate (*T. harzianum*) formulated as trichocompost for managing late blight and improving potato productivity under tropical dryland conditions.

We hypothesized that native *Trichoderma* isolates from tropical dryland potato rhizosphere would show strong antagonisms against *P. infestans* and remain effective under challenging field conditions. This study is novel because it uses locally adapted strains and evaluates trichocompost directly in smallholder dryland potato fields with naturally infested soils, limited water availability, and no synthetic inputs, conditions rarely explored in previous *Trichoderma*-potato studies.

MATERIALS AND METHODS

Isolation and identification of *Trichoderma* spp.

Sampling was conducted at a local potato cultivation site in Ayofanu Village, Kie Sub-district, South Central Timor (TTS) District, East Nusa Tenggara, Indonesia. Rhizosphere soil was collected from apparently healthy potato plants situated within a field historically affected by recurring outbreaks of late blight caused by *P. infestans*. The consistent presence of symptom-free plants adjacent to severely infected individuals suggested the potential involvement of protective microbial communities in the root zone. Based on this hypothesis, rhizosphere soils were targeted as potential sources of antagonistic microorganisms, particularly *Trichoderma* spp.

To isolate *Trichoderma* spp. soil samples were processed using the direct planting method. Emerging fungal colonies were cultured on Potato Dextrose Agar (PDA) medium supplemented with 50 ppm chloramphenicol and incubated at room temperature for 7 to 14 days. Following incubation, isolates were characterized based on macroscopic and microscopic features, and taxonomic identification was carried out using morphological criteria described by Watanabe (2010).

All laboratory procedures were performed at the Plant Disease Laboratory, Faculty of Agriculture, Universitas Nusa Cendana. A total of five *Trichoderma* isolates were recovered and evaluated for antagonistic activity against *P. infestans* using in vitro dual culture assays. For the field trial, only one isolate, *Trichoderma* 04 identified as *T. harzianum*, was used because it showed the strongest inhibitory effect.

Pathogen source and maintenance in this study

Phytophthora infestans used in this study was obtained from the culture collection of the Plant Disease Laboratory, Faculty of Agriculture, Universitas Nusa Cendana. This isolate had been previously collected from potato leaves exhibiting typical late blight symptoms in the field and isolated using standard procedures. Briefly, infected leaf segments were placed on Triton Ethanol Agar (TEA) supplemented with 50 ppm chloramphenicol and incubated at room temperature for three days. Colonies displaying typical *P. infestans* morphology were then sub-cultured onto PDA for purification. The identity of the isolate was confirmed using morphological criteria described by Erwin and Ribeiro (1996), and it has since been maintained as part of the laboratory's reference culture collection.

In vitro antagonism assay

A total of five *Trichoderma* isolates obtained from potato rhizosphere soil were tested for antagonistic activity against *P. infestans*. Each isolate was cultured on Potato Dextrose Agar (PDA) medium and incubated at 25 ± 2°C for four days. Mycelial plugs (0.5 cm diameter), taken from the actively growing margins using a sterile cork borer, were placed on one edge of a Petri dish. A similarly sized plug of *P. infestans* was positioned on the opposite edge. The plates were then incubated at 25±2°C for seven days on a laboratory bench to assess antagonistic activity. Each *Trichoderma* isolate was tested in four replicates, and the colony diameter of *P. infestans* was measured daily. The percentage inhibition of pathogen growth was calculated using the formula:

$$\text{Percentage inhibition (\%)} = ((R1 - R2) / R1) \times 100$$

Where, R1 represents the radius of the *P. infestans* colony growing away from the *Trichoderma* isolate, and

R2 represents the radius of the colony growing toward the *Trichoderma* isolate.

Selection of *Trichoderma* isolate for field application

Based on in vitro antagonism tests, the isolate showing the highest inhibition against *P. infestans*, *Trichoderma* 04, was selected for field evaluation. Morphological and molecular analyses confirmed its identity as *T. harzianum*. This isolate, having demonstrated the strongest antagonistic effect, was subsequently incorporated into trichocompost to assess its efficacy under field conditions.

Preparation of trichocompost

Trichocompost was prepared with reference to the protocol outlined by Susanto et al. (2018) with several adjustments to field conditions. *Trichoderma harzianum* was mass-cultured on a corn-based medium. Briefly, 100 g broken corn kernels were sterilized at 121°C and 1 atm for 15 minutes and used as the substrate. After cooling, the corn was placed into heat-resistant plastic bags and re-sterilized under the same conditions. Each cooled bas was then inoculated with five 0.5 cm² mycelial plugs from a 7-day-old PDA culture and incubated at room temperature for 7 days. The resulting actively growing cultures were used as inoculants for the composting process.

The compost mixture comprised 10 kg of chopped straw, 10 kg of cow manure, 50 g of dolomite, and 150 g of *T. harzianum* inoculum grown on broken corn kernels. The process began by moistening half of the chopped straw to a water content of approximately 60-70%. This moistened straw was layered with dolomite and the *T. harzianum* corn-based inoculum, followed by a layer of cow manure. The remaining materials were then added in alternating layers to ensure uniform microbial distribution and efficient decomposition.

All composting activities were carried out on a plastic tarpaulin laid directly on the ground. This setup helped prevent nutrient leaching and minimize contamination from soil-borne organisms. Once assembled, the compost pile was covered with an additional plastic tarpaulin to maintain adequate moisture and temperature. Throughout the composting period, internal temperature and humidity were regularly monitored using a digital thermohygrometer. Water was added as needed to maintain the target moisture range of 60-70%. Compost temperature reached ~70ºC during active fermentation, indicating vigorous microbial activity. To improve aeration and promote uniform breakdown of organic material, the compost was manually turned every 10 days, for a total of three times. After approximately 30-35 days, the compost was fully decomposed, dark brown in color, with a crumbly texture and no unpleasant odor, and was ready for application in the field. Trichocompost viability was confirmed prior to field application by plating representative samples on PDA, where active *T. harzianum* colony growth verified the presence of viable propagules.

Field experiment design and treatments

Field evaluation of *T. harzianum* trichocompost for controlling potato late blight was carried out in a potato farmer's field in Ayofanu Village, Kie Sub-district, SCT District (Latitude: -9.880387; Longitude: 124.600679; elevation: 1,034 meters above sea level), from June to October 2023. The site is classified as an Entisol, characterized by a soil pH of 7.1, organic matter of 3.10%, C-organic of 1.74%, total N of 0.35%, available P of 31 ppm, and exchangeable K of 0.75 me per 100 g soil. Farmers in this area do not use chemical fertilizers or irrigation systems. Water availability is extremely limited due to elevation and the absence of irrigation infrastructure; however, daily dew accumulation provides an important moisture source during the dry season and helps sustain crop growth under rainfed conditions.

Rainfall data from the nearest weather station indicated 6 rainy days totaling in 119 mm in June, 10 rainy days totaling 61 mm in July, 5 rainy days totaling 26 mm in August, and no rainfall in September. During the growing season, minimum air temperatures ranged from 17-23°C and daytime temperatures reached 26-33°C. Relative humidity averaged 60-70% with strong daily fluctuations. Theses cool and dry highland conditions are characteristic of the dry season in Timor Island and support early morning dew formation as a results of significant nighttime cooling. This dew provides a small but meaningful source of moisture for potato plants grown without irrigation.

The experimental field had a documented history of late blight, with confirmed *P. infestans* outbreaks in the previous cropping season, ensuring the natural presence of the pathogen. Although no laboratory soil assay was conducted prior to planting, recurrence of typical late blight symptoms during crop development confirmed active *P. infestans* presence in the field. No artificial inoculation was performed in order to maintain real farmer-field conditions and represent the production context of smallholder systems in the region. Disease pressure was allowed to develop naturally, consistent with established and widely accepted approaches in field epidemiological trials for potato late blight and other foliar pathogens as is commonly practiced in late blight field studies (Mollah and Hassan 2023; Shahni et al. 2023).

The field was plowed to achieve a fine tilth, creating optimal conditions for planting. Healthy, visually uniform seed tubers of a locally grown highland potato cultivar were selected from a farmer's stock. Tubers were screened for health and uniformity, measuring 35-40 mm in diameter and having at least three viable eyes. Trichocompost was applied according to the experimental treatments at a rate of 30 tons ha^{-1}, equivalent to 8.25 kg per plot. The crop was managed following standard local farmers practices to ensure consistency with traditional agricultural productions systems. In accordance with local dryland farming practices specific to this highland area, no irrigation was applied during the cropping period, as potato cultivation here depends on daily dew formation during the cool dry season. No synthetic fertilizers were used, and trichocompost served as the sole soil amendments.

The field experiment followed a RCBD with four treatments and three replicates. Each plot measured 2.5×1.1 m² with 30×40 cm plant spacing. The treatments applied were: T0: No trichocompost (control), T1, trichocompost

applied two weeks before planting; T2, trichocompost applied at planting; T3, trichocompost applied two weeks after planting.

Disease assessment and yield measurement

The study evaluated several parameters to determine the efficacy of trichocompost treatment, including incubation time, disease severity, the Area Under the Disease Progress Curve (AUDPC), number of tubers per plant, and fresh tuber weight. The incubation time was recorded as the period between the last trichocompost application (T3, applied two weeks after planting) and the first appearance of visible late blight symptoms. Disease severity was assessed by examining leaf tissues and estimating the percentage of infected leaf area, with observations conducted weekly over seven intervals starting on day 35 after planting.

Disease severity was determined using the formula proposed by Directorate General of Agricultural Infrastructure and Facilities (2013):

$$DS= (\sum(n\times v)/(N\times Z))\times 100\%$$

Where, DS: Disease severity (%), n: Number of plant leaves in each attack category, v: Scale value for each attack category, N: Total number of leaves observed, and Z: Highest scale value for disease severity

The attack scale values were assigned as follows: 0=no leaf damage, 1=0–10% leaf damage, 2=10–20% leaf damage, 3=20-30% leaf damage, 4=30-50% leaf damage, 5=50-75% leaf damage, 6=>75% leaf damage.

Disease progress was quantified using the Area Under Disease Progress Curve (AUDPC). The AUDPC values were computed in Microsoft Excel using the trapezoidal method applied to weekly disease severity data and were subsequently subjected to ANOVA and DMRT at α=0.05. For clarity, AUDPC results are reported as "disease severity (AUDPC)" in tables and figures.

At 120 days after planting, all plants were harvested, and both the number of tubers and their fresh weight were recorded to assess yield performance. Yield data were collected from all plants except the border plants within each plot. Each plot contained 15 plants, and three replicated plots were used per treatment, resulting in 45 plants per treatment being evaluated. The harvested tubers were then weighed using digital scales to ensure accurate measurement.

Data analysis

The data on percentage inhibition, incubation period, disease severity, number of tubers, and tuber weight were statistically analyzed using Analysis of Variance (ANOVA) based on a Randomized Complete Block Design (RCBD) model. Post hoc comparisons were conducted using Duncan's Multiple Range Test (DMRT) at a 5% significance level. All analyses were performed using SAS software version 9.4 (SAS Institute Inc 2021).

RESULTS AND DISCUSSION

Isolation and identification of *Trichoderma* spp.

Five isolates of *Trichoderma* were obtained from the rhizosphere of healthy potato plants. Their macroscopic and microscopic characteristics are detailed below:

Trichoderma *01*

The colony of *Trichoderma* 01 was circular with a ring-like appearance. Initially, the mycelium was white and gradually turned light green, completely covering the 9 cm Petri dish within five days of cultivation. Microscopically, *Trichoderma* 01 exhibited round conidia, hyaline, branched conidiophores, and short phialides, as displayed in Figure 1.A.

Trichoderma *02*

Characterized by a well-defined circular colony, *Trichoderma* 02 had mycelium that changed from white to green during incubation, reaching the edges of the dish by the fifth day. Under the microscope, this isolate demonstrated grape-like clusters of round conidia with branched conidiophores and thick, short phialides (Figure 1.B).

Trichoderma *03*

The colony of *Trichoderma* 03 exhibited a lateral expansion with a cottony yet slightly rough texture. It filled the Petri dish completely after five days. Microscopically, it was identified by upright, branched conidiophores, short, thick phialides, and oval conidia, as depicted in Figure 1.C.

Trichoderma *04*

Trichoderma 04 formed a circular colony with a ring-like pattern. Initially white, the mycelium turned green as it matured, covering the dish by day five. Microscopically, it displayed hyaline, spherical conidia attached to elongated conidiophores via short phialides (Figure 1.D).

Trichoderma 05

The colony of *Trichoderma* 05 was circular and ring-like, with the mycelium initially appearing white before turning green, dominated by white mycelial strands. It completely covered the Petri dish within five days. Microscopically, *Trichoderma* 05 exhibited upright, branched conidiophores, short and thick phialides, and oval-shaped conidia, as presented in Figure 1.E.

Molecular identification showed that *Trichoderma* 04 formed a well-supported clade with reference sequences of *T. harzianum*, confirming its classification as *T. harzianum* (Figure 2). BLASTn comparison of its ITS revealed 100% identity and full query coverage with *T. harzianum* strain NECC30402 (MH153633.1) and other *T. harzianum* accessions. To further verify its placement, a phylogenetic analysis was performed using the NPGPhylogeni.fr platform (Lemoine et al. 2019), which integrates MAFFT alignment and Maximum Likelihood inference with bootstrap support. This analysis consistently grouped *Trichoderma* 04 within a well-supported *T. harzianum* clade.

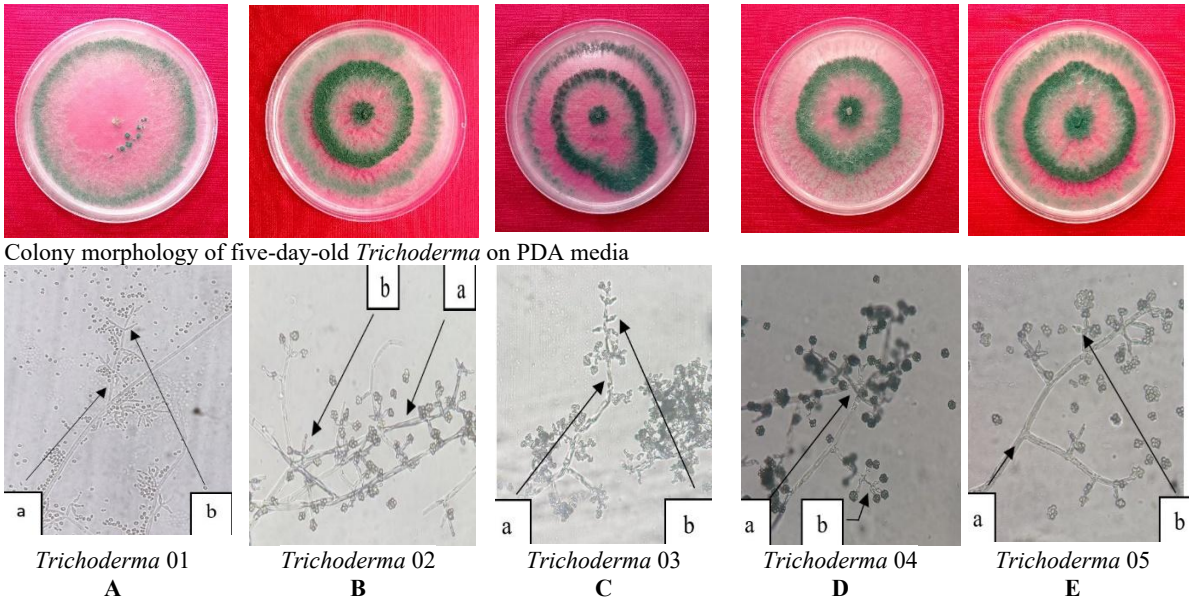

Figure 1. Colony morphology, conidiophore, and phialides of five isolates of *Trichoderma*. a. Conidiophore, b. Phialide

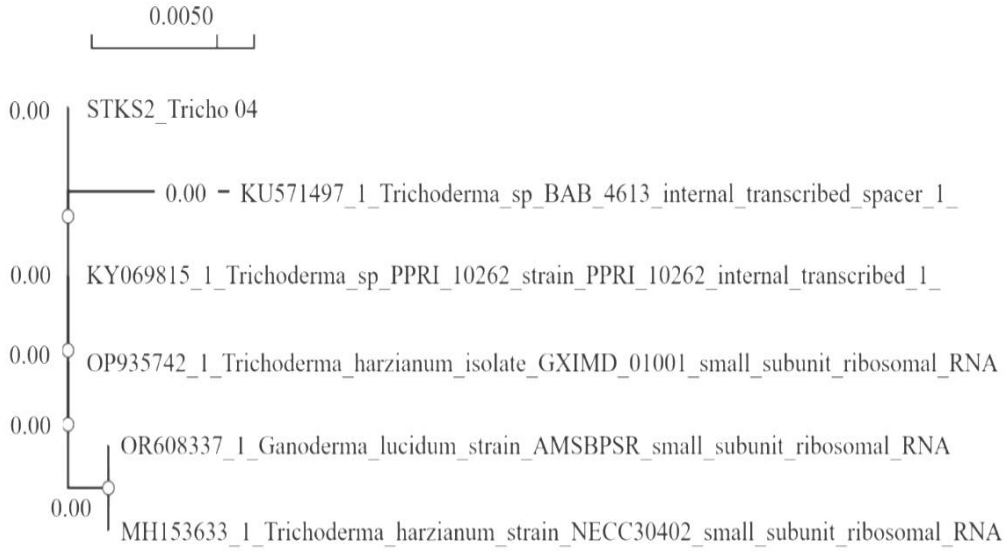

Figure 2. Phylogenetic tree based on ITS-1 rDNA sequences showing the placement of *Trichoderma* 04 (STKS_Tricho 04) within the *T. harzianum* clade. Bootstrap values indicate strong branch support

In vitro antagonism assay

The level of inhibition exerted by *Trichoderma* spp. against *P. infestans* exhibited a highly significant difference. According to the 5% DMRT results, *Trichoderma* 04 demonstrated greater effectiveness, resulting in the highest percentage of inhibition against *P. infestans* (Table 1). The lowest inhibition percentage was achieved by *Trichoderma* 02. However, in general, all *Trichoderma* species assessed had very high antagonistic abilities (above 70%) against *P. infestans*. Visual examination of the dual culture assay showed that all *Trichoderma* isolates inhibited *P. infestans* through competitive interaction. The colonies of *Trichoderma* expanded rapidly toward the pathogen and restricted its radial growth by occupying available space and resources. No lysis zones or clear contact inhibition boundaries were observed, indicating that antagonism occurred primarily through competition. Representative observations from two isolates are presented in Figure 3, as all five isolates exhibited the same competitive inhibition pattern.

Field evaluation of *T. harzianum* trichocompost for controlling potato late blight and enhancing yield

Among the five *Trichoderma* isolates tested in vitro, *Trichoderma* 04 demonstrated the highest inhibition rate against *P. infestans*, achieving 78.2% inhibition. Based on this superior antagonistic activity and subsequent morphological and molecular identification, *Trichoderma* 04 was classified as *T. harzianum*. Therefore, only this isolate was selected for further evaluation under field conditions.

The effectiveness of *T. harzianum*-enriched trichocompost in suppressing late blight disease in potatoes is illustrated in Figures 4.A-B. Application of trichocompost two weeks before planting resulted in the longest incubation period of late blight (17.7 days), significantly higher than the control (7.7 days), application at planting (12.7 days), and application two weeks after planting (9.3 days).The field efficacy of trichocompost in controlling late blight reached 49.18% when applied two weeks before planting (T1), followed by 36.06% at the time of planting (T2), and 24.27% when applied two weeks after planting (T3). These results demonstrate that earlier application leads to stronger disease suppression. In addition to disease suppression, the impact of *T. harzianum* trichocompost on yield parameters, including the number of tubers and average tuber weight, is presented in Table 2.

Table 1. Percentage inhibition (%) of *P. infestans* by *Trichoderma* spp.

No	*Trichoderma* isolates	Percentage inhibition[1)]
1.	*Trichoderma* 01	72.3 a
2.	*Trichoderma* 02	71.5 a
3.	*Trichoderma* 03	76.3 b
4.	*Trichoderma* 04	78.2 c
5.	*Trichoderma* 05	73.1 a

Note: [1)]: Numbers marked by distinct letters differ significantly (P<0.05) according to the DMRT test

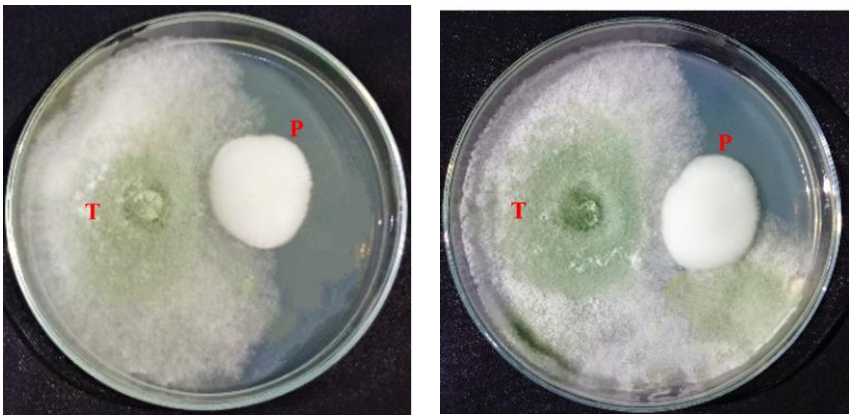

Figure 3. Competitive inhibition of *P. infestans* (P) by *Trichoderma* spp. (T) in dual culture

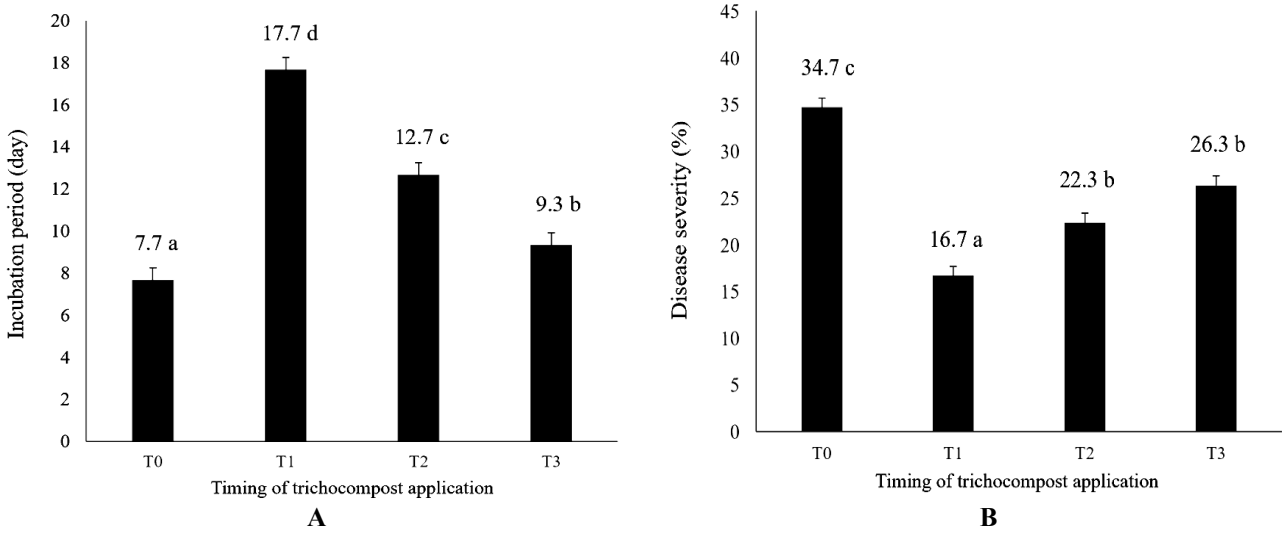

Figure 4. Effect of *T. harzianum* trichocompost on: A. Disease incubation period, B. Disease severity

Table 2. Effect of trichocompost *T. harzianum* on the number of tubers and tuber weight[1)]

Treatments	Number of tubers	Tuber weight (g)
T0: No trichocompost application (control)	5.87±0.12 a	79.00±0.20 a
T1: Application of trichocompost two weeks before planting	7.60±0.17 a	101.67±0.21 b
T2: Application of trichocompost at the time of planting	6.75±0.15 a	85.00±0.20 a
T3: Application of trichocompost two weeks after planting	6.71±0.10 a	84.33±0.25 a

Note: [1)]: Means within the same column followed by different letters are significantly different at P<0.05 according to DMRT

Discussion

The successful isolation of five *Trichoderma* species from the rhizosphere of healthy potato plants indicates that these beneficial fungi are naturally present and well adapted to the soil environment. The variations in their colony color, texture, and conidial form reflect natural diversity among isolates, which often influences their antagonistic ability. This diversity is important because it provides options for selecting strains with the strongest biocontrol potential, as also reported by Bouziane et al. (2016) and Purwantisari et al. (2021).

All five isolates showed strong inhibitory effects against *P. infestans*, with inhibition levels exceeding seventy percent. This result supports previous findings that *Trichoderma* species are effective biological control agents against late blight and other soilborne pathogens. The ability of *Trichoderma* to suppress pathogen growth is generally linked to mechanisms such as mycoparasitism, competition for nutrients, enzyme secretion, and antibiosis (Rokaya et al. 2023).

Among the tested isolates, one consistently produced the highest inhibition rate, showing its potential as a promising candidate for further testing under field conditions. The superior performance of this isolate reflects the well-known variability among *Trichoderma* strains reported in earlier studies. Chen et al. (2024) demonstrated that different *Trichoderma* isolates can display markedly variable antagonistic behaviors against pathogens such as *Pythium* and *Globisporangium*, even when grown under the same laboratory conditions. Stange et al. (2024) also found that the interaction strategies of *Trichoderma*, including active overgrowth and pathogen avoidance, depend strongly on both the strain and the target pathogen. In a similar way, Guzmán-Guzmán et al. (2025) reported that ecological fitness, enzyme production, and biocontrol performance vary widely among strains, particularly under dryland stress. These findings are consistent with the present results and reinforce the importance of selecting and testing local isolates for biological control. The evidence strongly supports the selection of *Trichoderma* 04 as a leading candidate for future field application in late blight management

This field study was conducted in the highland drylands of South-Central Timor, a region characterized by Entisol soils that are inherently infertile and low in organic matter. The agricultural landscape here is marked by sporadic rainfall, limited irrigation infrastructure, and persistent pathogen pressure, making cultivation especially challenging. Most smallholder farmers in the area do not use chemical fertilizers or fungicides due to high costs and poor availability, creating a strong demand for sustainable, low-input alternatives. Despite the absence of rainfall during the latter part of the growing season (September), daily dew in the highlands provided a vital moisture source that helped crops survive without irrigation. Rainfall data further emphasize the environmental constraints: June recorded six rainy days totaling 119 mm, July had ten days with 61 mm, and August had only five days with 26 mm (Central Statistics Agency 2023). This brief and erratic wet season underscores the importance of resilient plant- and soil-health strategies in tropical drylands.

In this study, the application of *T. harzianum* trichocompost produced encouraging results under real farmer field conditions. The T1 treatment, where trichocompost was applied two weeks before planting, proved the most effective. It extended the late blight incubation period from 7.47 days in the control to 17.67 days and reduced disease severity from 34.77% to 17.67%, resulting in an efficacy of 49.18%. Although this value was lower than the 78.2% inhibition observed under laboratory conditions, the field outcome is still meaningful, especially considering the natural variability and challenges present in open field environments (Khatun et al. 2021; Islam et al. 2022). These results show that trichocompost can help slow disease development and lessen symptom severity in a practical production setting. It is important to note that while *T. harzianum* is known in the literature to suppress pathogens through several biological pathways, including competition, antibiosis, and plant defense stimulation (Tyśkiewicz et al. 2022), this study did not measure those mechanisms directly. Therefore, the exact mode of action in this field trial remains unknown and would benefit for further investigation in future work.

Such discrepancies between laboratory and field results are well-documented. They can be attributed to environmental variability, fluctuating soil moisture, and microbial interactions, factors particularly pronounced in Entisol soils, which lack strong structure and retain little water. Despite these limitations, the T1 treatment produced measurable yield benefits. Although the increase in tuber number per plant was not statistically significant, it showed a numerical improvement from 5.87 to 7.60 per plant. In contrast, average tuber weight increased significantly, rising from 79.00 g to 101.67 g. These results highlight the potential dual benefits of trichocompost in suppressing disease and enhancing yield components. Together, the findings indicate a clear relationship between disease suppression and yield performance, where treatments that lowered late blight severity, particularly T1, also produced higher tuber weight and number. Similar positive effects of

Trichoderma-based compost on soil biological function and crop productivity have been reported in previous studies (Asghar and Kataoka 2021; Wei et al. 2024). Further validation with larger plot sizes and increased replication is recommended to strengthen this preliminary observation under dryland field conditions.

Treatments T2 (applied at planting) and T3 (two weeks after planting) also offered improvements, albeit less than T1. This highlights the importance of application timing; early application provides *T. harzianum* more time to colonize the rhizosphere before the onset of pathogen pressure (Mitiku and Eshete 2017). In smallholder systems that depend entirely on organic inputs and ambient moisture, even modest yield increases can significantly improve food security and livelihoods.

Mechanistically, *T. harzianum* suppresses pathogens through multiple modes of action: it competes for nutrients and space (Bae et al. 2017; Naher et al. 2018), produces cell wall–degrading enzymes such as chitinase and glucanase (Adnan et al. 2019), and releases antifungal compounds that inhibit pathogen development (Elsherbiny et al. 2020). Additionally, it parasitizes harmful fungi (Mukhopadhyay and Kumar 2020) and stimulates systemic resistance in host plants, enhancing tolerance to both biotic and abiotic stress (Kai et al. 2018; Guo et al. 2022; Tyśkiewicz et al. 2022).

Beyond disease control, *T. harzianum* contributes to soil fertility by enhancing microbial diversity, accelerating the decomposition of organic matter, and improving nutrient cycling, especially nitrogen, phosphorus, and potassium, which are typically deficient in Entisols (Ahmed et al. 2019; Wang et al. 2019; Mazen 2021; Flores and Leon 2024; Peña et al. 2025). The positive effects of *Trichoderma* spp. on agricultural productivity in arid and semi-arid regions have been well-documented. These fungi enhance crop yields, improve soil structure, and modulate soil microbial communities. For example, *Trichoderma* combined with NPK fertilizers significantly improved mustard yields compared to untreated controls, where biofertilizers alone had minimal effect (Islam et al. 2023). Similar benefits have been reported for other vegetables, including cucumber and tomato, when using *Trichoderma*-enriched biofertilizers (Haque et al. 2012). A review by Zhu et al. (2022) summarized the fungi's capacity to enhance physical, chemical, and biological soil properties, which is particularly valuable in degraded dryland soils. Furthermore, *Trichoderma*'s mycoparasitic behavior supports healthier plant growth by suppressing soil-borne pathogens (La Spada et al. 2020; Abdullah et al. 2021).

To enhance potato productivity in SCT, several strategies should be explored: applying trichocompost at higher doses or more frequently during the crop cycle; combining it with other organic amendments like composted manure or leguminous cover crops; and using *Trichoderma* strains that are locally adapted. Participatory on-farm trials and cost benefit analyses are also essential to promote adoption and inform future policy.

The number of tubers set by a potato plant is largely determined by its genetic makeup, even though environmental and agronomic factors can modulate that potential. In our study, all treatments used the same potato variety, and trichocompost application did not produce a statistically significant difference in tuber number (Table 2). This suggests that genetic factors likely defined the inherent capacity for tuber initiation, which remained relatively stable across treatments. Recent Genome-Wide Association Study research supports this interpretation, showing that specific genomic regions regulate tuber number (Gautam et al. 2024). While potential limits tuber initiation, the improved soil microbial activity and nutrient availability associated with trichocompost likely enhanced tuber bulking rather than tuber set, helping explain the significant increase in tuber weight observed in the T1 treatment. Trichocompost may have contributed to these improvements through microbial enrichment and enhanced nutrient cycling. The activity of *T. harzianum* and associated beneficial microbes accelerates organic matter decomposition and promotes nutrient mineralization, increasing the availability of N, P, and K in nutrient -poor Entisols. These processes are supported by recent evidence showing that Trichoderma strains produce phytohormones and biomolecules that enhance nutrient uptake, root growth, and overall plant vigour (Reghmit 2023). This improved nutrient supply likely supported greater root activity and bulking, contributing to the higher tuber weight recorded in T1 treatment.

In contrast, tuber weight responded significantly to the timing of *T. harzianum* trichocompost application. The T1 treatment, application two weeks before planting, yielded significantly heavier tubers compared to the control and other treatments. This effect is likely due to improved soil structure, enhanced nutrient availability, and beneficial microbial interactions stimulated by the trichocompost. Studies have shown that *Trichoderma*-enriched bioformulations can significantly increase tuber weight and overall yield under stress conditions by improving nutrient uptake and plant resiliency (Ashar et al. 2024; Napolitano et al. 2024).

This study clearly demonstrates that *T. harzianum*-enriched trichocompost is effective in suppressing late blight and improving potato productivity under tropical dryland conditions in SCT. The application of trichocompost at a rate of 30 tons per hectare, particularly when administered two weeks before planting (T1), significantly extended the incubation period of *P. infestans* from 7.47 to 17.67 days, and reduced disease severity from 34.77% to 17.67%. In addition, yield components improved, with tuber number increasing from 5.87 to 7.60 per plant and average tuber weight rising from 79.00 g to 101.67 g compared with the untreated control. These outcomes highlight the dual function of trichocompost as both a biocontrol agent and a soil amendment, offering valuable benefits in Entisol-dominated dryland that are typically low in organic matter and water-holding capacity. Overall, the field results confirm our initial hypothesis that *T. harzianum* trichocompost can suppress late blight and enhance potato yield under the challenging dryland conditions of SCT.

Building on the positive results of this study, the application of *T. harzianum* trichocompost two weeks

before planting shows strong potential for broader adoption in tropical dryland highland regions. This application timing proved particularly effective, offering a practical, affordable, and environmentally sustainable strategy for smallholder farmers who often face challenges in accessing chemical inputs and reliable irrigation. The improvements observed in disease suppression and yield performance underscore the value of trichocompost in enhancing crop resilience under dry and nutrient-poor conditions.

From a practical perspective, the ability of *T. harzianum* trichocompost to prolong disease incubation and enhance tuber yield under-low input conditions has important implications for farmers in tropical drylands. By reducing reliance on synthetic fungicides and external fertilizer, this approach provides a cost-effective and ecologically sustainable option for smallholder farmers. It supports improved soil health, lower production costs, and greater resilience in resource-limited environments, making it particularly valuable for dryland communities that depend on organic inputs and limited water availability.

This study provides initial evidence that *T. harzianum* trichocompost can help reduce late blight and improve potato yields under dryland highland farming conditions in SCT. While promising, these results are from a single site and season, so further trials across different locations and seasons are needed to confirm consistency. Future research should also assess long-term soil health and economic benefits, and explore combining trichocompost with other organic materials to enhance effectiveness. Scaling up this approach will require participatory farmer validation to ensure that technology align with local practices, resource availability, and farmer priorities. Farmer engagement through training and filed demonstrations will be essential for practical adoption. From a policy perspective, integrating trichocompost-based biocontrol into regional agricultural development strategies, such as dryland intensification programs and soil restoration initiatives could support wider implementations. Supporting bio-based soil amendments and community-level composting efforts can strengthen soil health, build climate-resilient production systems, and improve farmer livelihoods in tropical dryland regions. Such integration would also enhance the adaptability and long-term sustainability of dryland farming systems. In summary, *T. harzianum* trichocompost presents a promising strategy to strengthen food production systems in tropical drylands, contributing to both environmental restoration and improved farmer livelihoods.

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