



Sustainable Development of *Trichoderma* sp. Enriched Vermicompost for Enhancing Ginger Seedling Growth

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ABSTRACT

Ginger is a raw material for jamu, traditional herbal medicine, herbal remedies, and bodyrefreshing tonics used to maintain health and treat ailments. The potential for developing the ginger variety faces challenges such as low production and productivity, alongside relatively high production costs. To support sustainable ginger cultivation, environmentally friendly approaches—such as the use of vermicompost enriched with *Trichoderma* sp. Fungi are necessary. Treatment T5 (250 g *Trichoderma* sp + 3 kg vermicompost per plot) yielded the greatest plant height (61.67 cm), the highest number of leaves (37.67), and the highest number of shoots (5.33); thus, it can be concluded that higher dosages of *Trichoderma* sp result in improved growing medium conditions and better shoot development in ginger seedlings.

Keywords: vermicompost, ginger, *trichoderma* sp



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INTRODUCTION

Ginger (*Zingiber officinale*) is an important medicinal and culinary plant that is widely utilized as a raw material for jamu, traditional herbal medicines, herbal preparations, and health-promoting beverages. Its bioactive secondary metabolites, including zingiberene, zingiberol, and oleoresin, contribute to its various pharmacological properties and have been associated with potential benefits such as alleviating fever, supporting physical stamina, improving blood circulation, and providing anticancer activity (Khoiriyah & Heriyanto, 2021). The Sari Jahe Mas Farmer Group in Tiga Village comprises farmers who are primarily engaged in ginger cultivation. In 2022, the group recorded an average ginger productivity of approximately 28.7 tons ha⁻¹. However, the farm-gate price during this period ranged from IDR 5,000 to 7,000 kg⁻¹, representing a substantial decrease compared with the previous year, when ginger prices reached approximately IDR 10,000–25,000 kg⁻¹. The higher prices in the preceding year were

associated with increased market demand for ginger as a raw material for herbal products and medicinal preparations, particularly during the COVID-19 pandemic (Utami & Darmawan, 2025).

The decline in ginger production in Tiga Village, Susut District, Bangli Regency, may be associated with several constraints, including inadequate land preparation, insufficient availability and application of high-quality fertilizers, and the occurrence of plant diseases. Among the major fungal pathogens affecting agricultural crops, the genus *Fusarium* is considered particularly important due to its widespread distribution and ability to infect numerous plant species. *Fusarium* spp. are commonly found in soil and may occur in association with plant roots as either saprophytic or pathogenic organisms. Their broad host range and worldwide distribution make *Fusarium* a significant concern in crop production systems (Yadav et al., 2025).

The development of ginger production in the study area is therefore constrained by low yield and productivity, as well as relatively high production costs. One of the factors contributing to low productivity is the limited use of fertilizers by farmers, which may restrict nutrient availability and consequently hinder plant growth and development. At the same time, the high cost of production, particularly expenditure on fertilizers, presents an additional challenge for farmers. This constraint can potentially be reduced through the utilization of locally available organic materials as alternative sources of plant nutrients and soil amendments. The incorporation of organic inputs may provide a more economical and environmentally sustainable approach to improving soil fertility and supporting ginger productivity.

An environmentally sustainable approach for improving crop productivity and managing soil-borne diseases involves the use of beneficial microorganisms, particularly *Trichoderma* spp. These fungi are widely recognized as important biological control agents because they can suppress plant pathogens through several complementary mechanisms, including mycoparasitism, competition for nutrients and ecological niches, antibiosis, production of hydrolytic enzymes, and activation of plant defense responses (Pandit et al., 2022). *Trichoderma* spp. can also establish beneficial interactions with plant roots and stimulate plant growth through mechanisms associated with nutrient mobilization and uptake, root development, phytohormone regulation, and the production of bioactive metabolites. Recent evidence indicates that *Trichoderma* can enhance the acquisition of both macro- and micronutrients and improve plant performance under different environmental conditions (Mishra et al., 2022). These characteristics make *Trichoderma* a promising component of integrated and environmentally sustainable crop management systems.

Vermicompost is an organic amendment produced through the biological transformation of organic materials by earthworms and associated microorganisms. It contains organic matter, mineral nutrients, beneficial microorganisms, and biologically active compounds that can contribute to improved soil fertility and plant development. The application of vermicompost can improve soil physical properties, including aeration, porosity, water retention, and bulk density, while also influencing chemical and biological

properties of the soil (Lim et al., 2015). A meta-analysis by Blouin et al. (2019) demonstrated that vermicompost application generally has positive effects on plant growth, including increases in total biomass, shoot biomass, root biomass, and crop yield. Vermicompost may therefore serve not only as a source of nutrients but also as a biologically active soil amendment that supports a favorable rhizosphere environment.

The benefits of vermicompost may be further enhanced through the incorporation of beneficial microorganisms. Microbial enrichment of organic amendments can contribute to nutrient cycling, improve nutrient availability, and enhance the suppressive capacity of the growing medium against soil-borne pathogens. In particular, the addition of *Trichoderma* to organic amendments has been reported as a promising strategy for combining the nutritional and soil-conditioning functions of organic matter with the biological control and plant-growth-promoting properties of beneficial fungi (Mishra et al., 2022). Studies on fortified vermicompost have also indicated that microbial supplementation can improve plant growth and nutrient status while contributing to the suppression of plant diseases (Joshi et al., 2020).

The interaction between *Trichoderma* sp. and vermicompost is therefore potentially important for developing an integrated organic input for sustainable ginger production. Vermicompost can provide organic matter and nutrients while creating a favorable substrate for beneficial microbial activity, whereas *Trichoderma* sp. may contribute to pathogen suppression, nutrient mobilization, root development, and plant-growth promotion. Experimental evidence also indicates that *Trichoderma* strains can accelerate the stabilization of organic materials and increase phosphorus availability during vermicomposting, suggesting that microbial enrichment may improve the functional quality of the resulting organic amendment (Busato et al., 2021). Accordingly, vermicompost enriched with *Trichoderma* sp. has the potential to provide broader agronomic benefits than vermicompost alone by integrating nutrient supply, soil-quality improvement, microbial activity, and biological protection against soil-borne pathogens. This approach may represent a practical and environmentally sustainable strategy for supporting the growth and health of ginger (*Zingiber officinale*) plants.

Although the individual benefits of vermicompost and *Trichoderma* spp. have been widely reported, information regarding the optimum dose of *Trichoderma* sp. enriched vermicompost for ginger seedling production under local cultivation conditions remains limited. Therefore, this study evaluated different doses of *Trichoderma* sp. incorporated into vermicompost to determine their effects on ginger seedling growth and to identify a practical dosage for sustainable cultivation.

RESEARCH METHOD

This study was conducted on agricultural land belonging to Mr. I Nyoman Subamia in Tiga Village, Susut District, Bangli Regency, Bali, Indonesia, from December 2025 to March 2026. The equipment used in the study consisted of a stove, hoe, shovel, planting pots, Bunsen burner, graduated cylinder, analytical balance, spatula, and tweezers. The

materials included a *Trichoderma* sp. isolate, water, Potato Dextrose Agar (PDA) medium, earthworms (*Lumbricus rubellus*), and ginger (*Zingiber officinale*) seedlings.

The research procedures were conducted through a series of experimental stages, beginning with the preparation of the materials and biological agents, followed by the preparation of vermicompost, enrichment with *Trichoderma* sp., and application to ginger seedlings. The experimental procedures were carried out sequentially as described below:

1) Preparation and Propagation of *Trichoderma* sp.

The propagation of *Trichoderma* sp. was performed under aseptic conditions to minimize the possibility of microbial contamination. Prior to the procedure, the working surface was disinfected with 70% ethanol, and gloves and a face mask were worn during the preparation process. Metal instruments, including the spatula and tweezers, were sterilized by flame sterilization using a Bunsen burner before being used (Novianti, 2018).

Rice was selected as the solid substrate for *Trichoderma* sp. propagation. A total of 100 g of rice was washed thoroughly and soaked in hot water for approximately 15 min. The rice was subsequently steamed for 30 min until sufficiently cooked and then allowed to cool to room temperature. The cooled rice was aseptically transferred into a sterile zip-lock plastic bag. The substrate was then inoculated with 1 mL of *Trichoderma* sp. suspension and incubated under appropriate conditions (Haristia et al., 2021).

Inoculum characterization, Prior to application, the *Trichoderma* sp. inoculum was incubated for 10–14 days until active sporulation occurred. The inoculum used in this study was standardized as a mature, fully colonized rice-based inoculum. Direct measurements of spore density (CFU or spores mL⁻¹) were not available and should be considered a limitation of the study.

The rice substrate was monitored periodically during incubation. The culture was considered suitable for subsequent use when the substrate was extensively colonized by *Trichoderma* sp. and developed a characteristic green coloration, indicating active growth and sporulation of the fungus. The use of rice as a propagation substrate is supported by previous studies demonstrating its suitability for the growth and multiplication of *Trichoderma* spp. and for the production of fungal conidia (Irianti et al., 2025).

2) Vermicompost was produced by first preparing all required materials and equipment.

Coffee husks were thoroughly mixed with spent mushroom substrate (baglog waste) to obtain a homogeneous substrate. Water was then added gradually until the moisture content reached an adequate level, approximately equivalent to field capacity. The mixture was subsequently allowed to undergo a preliminary decomposition process for approximately one week.

Following the pre-decomposition period, *Lumbricus rubellus* earthworms were introduced into the prepared substrate. The moisture condition of the vermicomposting medium was monitored weekly and maintained at a level suitable for earthworm activity and decomposition. The vermicomposting process was continued for several weeks until the organic material reached a mature and stable condition.

Vermicompost was harvested at the end of the incubation period when the substrate exhibited characteristics of maturity, including a pH approaching neutral conditions

(approximately 7.0) and a temperature below 30°C. The mature vermicompost was then collected and prepared for subsequent application in the experiment.

3) Preparation of the Planting Medium

The planting area was initially cleared of weeds and other unwanted vegetation. Subsequently, planting beds measuring 1 m × 1 m were prepared. Ginger seedlings were planted at a spacing of 30 cm × 30 cm, resulting in a total of nine plants per planting bed.

4) Seed Selection

High-quality ginger seed rhizomes were selected from superior and genetically uniform varieties with a well-documented origin. The seed material was obtained from healthy and vigorous parent plants harvested at 8–10 months of age. Selection criteria included rhizomes with a fibrous texture when broken, firm and non-easily peeling skin, and a shiny, plump appearance. Each seed rhizome weighed approximately 20–60 g and possessed 2–3 viable buds. Rhizomes showing physical damage, deformities, or other visible defects were excluded from the planting material (Latifah *et al.*, 2022).

5) The sprouting process was initiated by preparing a suitable propagation medium consisting of straw or rice husks. The medium was arranged in four layers, each approximately 5 cm thick, resulting in a total medium thickness of 20–25 cm. Moisture was maintained by lightly spraying the medium with water once or twice a week, while excessive watering or waterlogging was avoided.

Healthy ginger rhizomes selected for sprouting were sun-dried for approximately 1–2 days and were required to have 2–3 viable buds. Prior to planting, the rhizomes were immersed in a solution containing a disinfectant and plant growth regulator for approximately 1 min to reduce the risk of microbial contamination and support bud development. The treated rhizomes were subsequently placed in the prepared sprouting medium and covered with a thin layer of kitchen ash or rice husks.

The sprouting process was maintained for approximately two weeks until the rhizomes produced visible and healthy shoots suitable for subsequent planting.

6) Transplanting

Planting involves placing healthy, sprouted ginger rhizomes into a properly prepared growing medium to promote rapid emergence and uniform plant establishment. The rhizomes should be placed in shallow planting holes at an appropriate depth, with the viable buds oriented upward, and then covered and gently firmed with soil to ensure adequate contact between the rhizome and the growing medium. Proper planting depth and bud orientation are important factors affecting ginger emergence, establishment, and subsequent rhizome development (Kandiannan *et al.*, 2010; Ravindran *et al.*, 2005).

7) Crop Maintenance

Crop maintenance practices consisted of irrigation, weed management, and organic fertilization. Ginger requires adequate soil moisture for optimal growth, but excessive water should be avoided because prolonged water saturation may adversely affect root and rhizome development. Therefore, irrigation was adjusted according to rainfall and soil moisture conditions, with planting preferably scheduled at the beginning of the rainy season.

Weed control was conducted manually to minimize competition between weeds and ginger plants for water, nutrients, light, and growing space. The first weeding was performed when the plants were approximately 2–4 weeks after planting, followed by subsequent weeding at intervals of approximately 3–6 weeks, depending on weed growth. Weeding was also integrated with earthing-up activities, which help maintain soil structure, improve root aeration, suppress weed growth, and provide sufficient soil volume for rhizome development (Verma et al., 2019).

Fertilization was managed using organic inputs in accordance with the organic cultivation approach. Vermicompost enriched with *Trichoderma* sp. was used as the primary organic amendment to provide nutrients and organic matter while supporting beneficial microbial activity in the growing medium. The use of vermicompost and *Trichoderma* in ginger cultivation is consistent with established organic production practices, in which organic manure and microbial inoculants are incorporated to support plant growth and nutrient management (Sarathambal et al., 2024).

Organic fertilizer was applied at planting and subsequently as supplementary applications during crop development. Fertilizer was distributed evenly around the plants within the active root zone to facilitate uniform nutrient availability. Additional compost or vermicompost was applied following weeding and incorporated into the soil during earthing-up. This practice allows the organic amendment to become more effectively integrated into the root-zone environment while simultaneously supporting soil moisture conservation, nutrient availability, and rhizome development (Nair, 2013).

8) Observation

Observations were carried out according to predetermined response variables. Plant height and leaf number were assessed at two-week intervals throughout the experimental period, whereas shoot number, total fresh plant weight, and total dry plant weight were measured at the end of the experiment.

The variables evaluated in this study included plant height, leaf number, and shoot number. The collected data were subjected to statistical analysis using Analysis of Variance (ANOVA) to determine the effects of the treatments. When significant differences were detected, mean comparisons were performed using Duncan's New Multiple Range Test (DNMRT) at the 5% significance level.

RESULTS AND DISCUSSION

The statistical analysis revealed that the application of different doses of *Trichoderma* sp. incorporated into vermicompost had a highly significant effect on all measured growth parameters of ginger (*Zingiber officinale*) seedlings, including plant height, leaf number, shoot number, total fresh weight, and total oven-dry weight. Overall, the response of the seedlings showed an increasing tendency with increasing doses of *Trichoderma* sp. Treatment T5, consisting of 250 g of *Trichoderma* sp. combined with 3 kg of vermicompost per plot, consistently produced the highest values for all growth parameters, whereas the control treatment (T0) recorded the lowest values.

Treatment T5 consistently produced the highest mean values for plant height, leaf number, and shoot number. Treatment differences were evaluated using ANOVA followed by Duncan's New Multiple Range Test (DNMRT) at the 5% significance level. Future studies are encouraged to present complete statistical tables including standard errors and grouping letters to improve result interpretation.

The improved growth performance observed under the *Trichoderma*-enriched vermicompost treatments may be associated with the complementary functions of both components. Vermicompost provides organic matter and plant-available nutrients that support plant growth, while *Trichoderma* spp. can contribute to the decomposition and transformation of organic substrates, enhance microbial activity in the rhizosphere, and facilitate nutrient acquisition by plants. The interaction between these biological processes can create a more favorable root-zone environment, thereby supporting vegetative development and biomass accumulation. Previous studies have demonstrated that *Trichoderma*-based biostimulants can improve nutrient-use efficiency, root development, and overall plant growth, while vermicompost can enhance soil fertility and provide nutrients in forms that are more accessible to plants (Fiorentino et al., 2018; Mishra et al., 2022; Sánchez-Montesinos et al., 2020).

The consistently superior performance of T5 suggests that the combination of 250 g of *Trichoderma* sp. with 3 kg of vermicompost per plot provided the most favorable conditions for ginger seedling growth under the conditions of this experiment. However, the increasing trend should not necessarily be interpreted as a linear dose-response relationship unless supported by the statistical analysis. Overall, the results indicate that integrating *Trichoderma* sp. with vermicompost has considerable potential as an environmentally friendly approach for improving the early growth and biomass production of ginger seedlings.

Plant height (cm)

The analysis of variance showed that the application of different doses of *Trichoderma* sp. incorporated into vermicompost had a highly significant effect on leaf production in ginger (*Zingiber officinale*) seedlings. Among the treatments, T5, consisting of 250 g of *Trichoderma* sp. combined with 3 kg of vermicompost per plot, produced the highest average number of leaves (37.67), and this value was significantly different from those of the other treatments. In contrast, the control treatment (T0) resulted in the lowest average number of leaves, with 25.50 leaves.

The greater leaf production observed in the treated plants suggests that the application of *Trichoderma* sp.-enriched vermicompost provided more favorable conditions for vegetative growth. This response may be related to improved nutrient availability and nutrient uptake, particularly nitrogen, which is an essential element for the development of leaves and other vegetative organs. *Trichoderma* spp. can promote plant growth by improving root development, enhancing nutrient acquisition, and modifying nutrient availability within the rhizosphere (Fiorentino et al., 2018; Mishra et al., 2022).

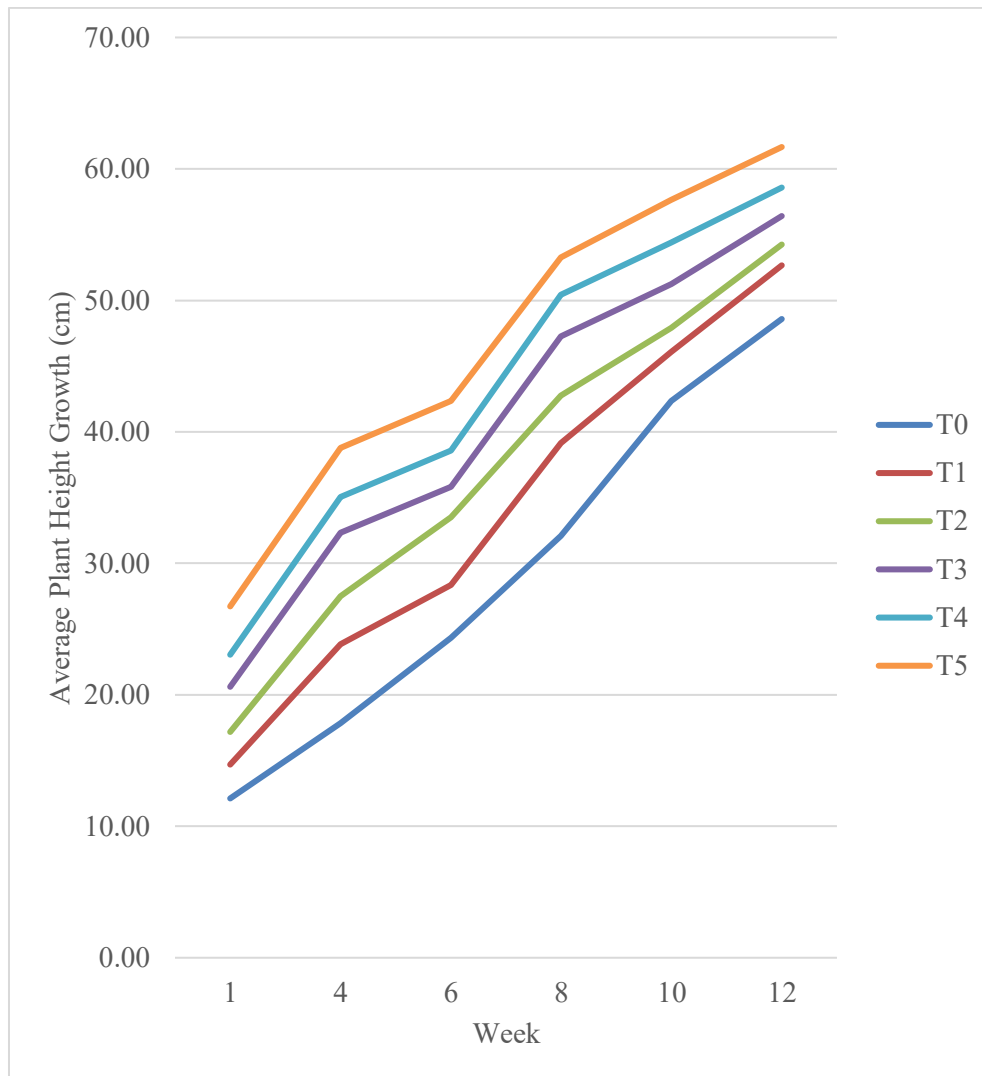


Figure 1. Average Height Growth of Ginger Seedlings.

The increase in leaf number may also contribute to greater photosynthetic potential because leaves serve as the primary photosynthetic organs of plants. A more developed leaf canopy can increase the plant's capacity to capture light and produce photosynthates, which are subsequently utilized to support vegetative growth and biomass accumulation. Previous studies have demonstrated that *Trichoderma* spp. can act as plant-growth-promoting microorganisms by influencing nutrient uptake, root development, and physiological processes associated with plant growth (Sánchez-Montesinos et al., 2020). Therefore, the superior performance observed in treatment T5 may be attributed to the complementary effects of vermicompost as a source of organic nutrients and *Trichoderma* sp. as a biological growth-promoting agent. Nevertheless, because nutrient uptake and photosynthetic activity were not directly measured in the present study, these mechanisms should be regarded as potential explanations for the observed increase in leaf number.

Number of leaves

The analysis of variance demonstrated that the application of different doses of *Trichoderma* sp. incorporated into vermicompost had a highly significant effect on the number of leaves produced by ginger (*Zingiber officinale*) seedlings. Treatment T5, consisting of 250 g of *Trichoderma* sp. combined with 3 kg of vermicompost per plot, resulted in the highest average number of leaves (37.67), which was significantly greater than those observed in the other treatments. In contrast, the control treatment (T0) produced the lowest average number of leaves (25.50).

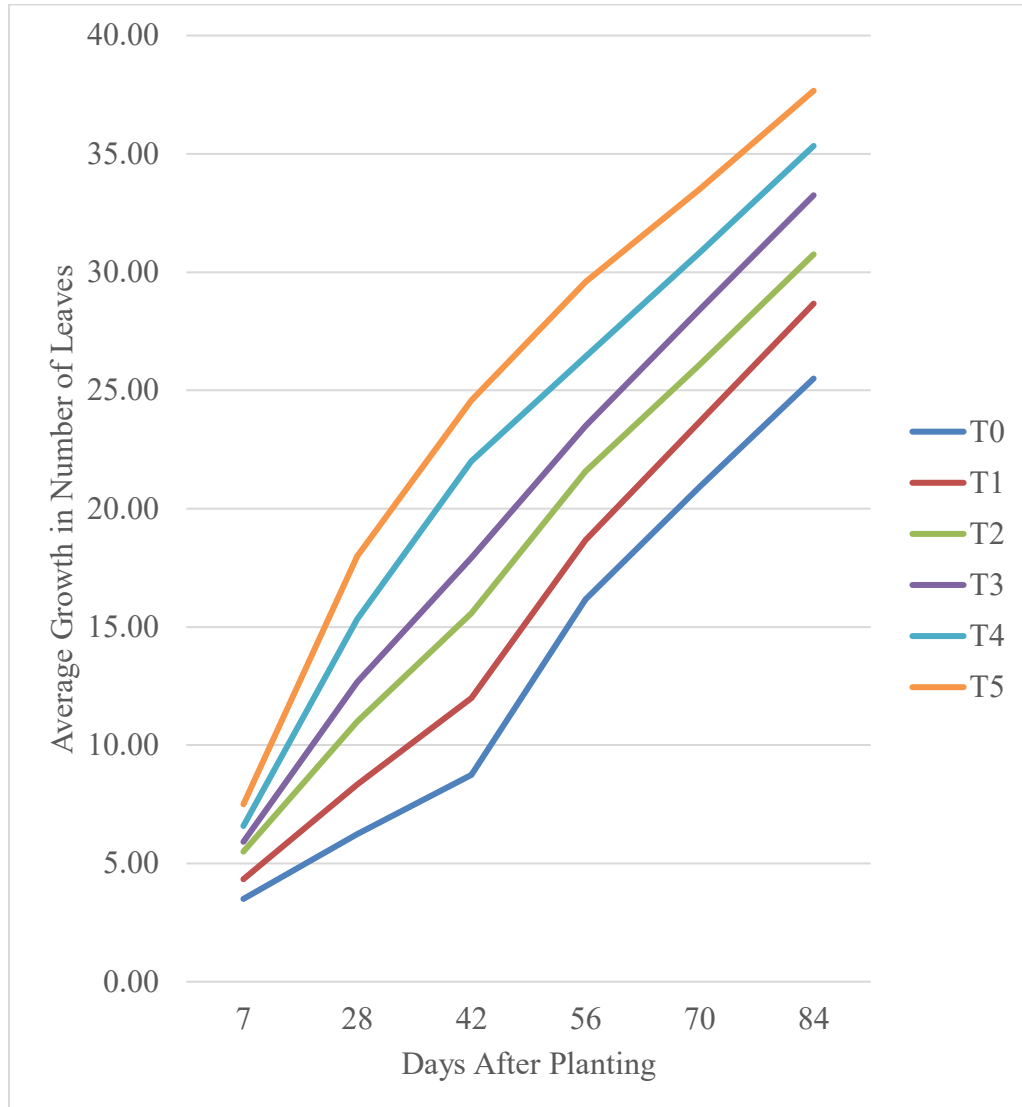


Figure 2. Average Leaf Number Growth and Development of Ginger Seedlings.

The greater number of leaves observed in the *Trichoderma*-enriched vermicompost treatments indicates that the growing conditions were more favorable for vegetative development (Sutarman, 2019). This response may be associated with improved nutrient availability and uptake, particularly nitrogen, which plays an essential role in leaf formation and vegetative growth (Mishra et al., 2022). *Trichoderma* spp. have been

reported to improve nutrient acquisition by promoting root development and increasing the availability and uptake of essential nutrients, including nitrogen and phosphorus. These effects may subsequently support the formation and expansion of vegetative organs (Fiorentino et al., 2018).

An increase in leaf number is also important because leaves constitute the major photosynthetic organs of plants. A greater leaf area and more abundant foliage can increase the plant's photosynthetic capacity, thereby supporting the production of assimilates required for subsequent vegetative growth and biomass accumulation. Recent evidence indicates that *Trichoderma* can contribute to improved photosynthetic performance through enhanced nutrient acquisition, chlorophyll accumulation, and modulation of plant physiological processes (Fiorentino et al., 2018). Therefore, the superior leaf production observed in T5 may reflect the complementary effects of vermicompost as a source of organic nutrients and *Trichoderma* sp. as a plant-growth-promoting microorganism. However, because nutrient concentrations and photosynthetic activity were not directly measured in this study, these mechanisms should be interpreted as possible explanations rather than direct evidence of causality (Sánchez-Montesinos et al., 2020).

Number of Shoots

The analysis of variance revealed that the application of different doses of *Trichoderma* sp. in combination with vermicompost had a highly significant effect on shoot production in ginger (*Zingiber officinale*) seedlings. Among the treatments, T5, consisting of 250 g of *Trichoderma* sp. combined with 3 kg of vermicompost per plot, produced the highest average number of shoots (5.33), which was significantly higher than those recorded in the other treatments. In contrast, the control treatment (T0) resulted in the lowest average number of shoots, at 1.50 shoots per plant.

The increase in shoot production following the application of *Trichoderma* sp.-enriched vermicompost suggests that the treatment created more favorable conditions for vegetative development and the formation of new shoots in ginger seedlings (Lincy & Sasikumar, 2010). This response may be associated with the ability of *Trichoderma* spp. to improve nutrient availability, stimulate root development, and promote physiological processes associated with plant growth. Previous studies have reported that *Trichoderma* can enhance nutrient acquisition and modify root system architecture, thereby increasing the capacity of plants to absorb water and nutrients (Fiorentino et al., 2018). In addition, *Trichoderma* is recognized as a plant-growth-promoting fungus capable of producing or modulating growth-related compounds and improving nutrient mobilization in the rhizosphere (Sánchez-Montesinos et al., 2020).

The present findings are also consistent with the concept of *Trichoderma* as a microbial biostimulant. Its beneficial interaction with plants may involve root colonization, nutrient solubilization, phytohormonal regulation, and stimulation of plant growth. Such mechanisms can contribute to improved vegetative growth and biomass accumulation. Therefore, the higher shoot number observed at T5 may reflect the

combined contribution of vermicompost as an organic nutrient source and *Trichoderma* sp. as a plant-growth-promoting microorganism (Mishra et al., 2022). However, because nutrient availability, root development, and phytohormonal responses were not directly measured in this study, these mechanisms should be considered possible explanations rather than direct causal evidence (Rojas et al., 2026).

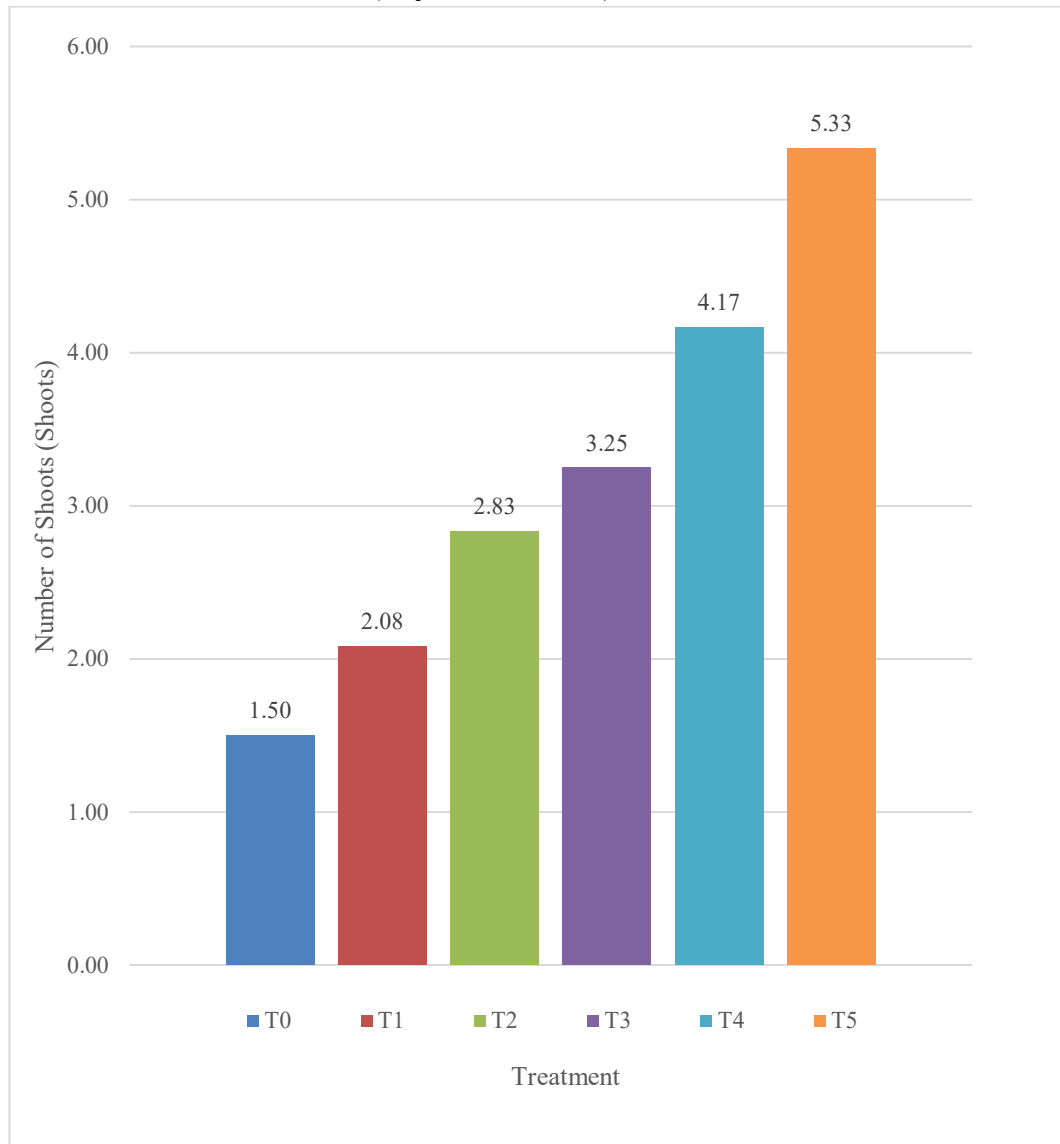


Figure 3. Comparison of Shoot Number in Ginger Seedlings

The use of *Trichoderma* sp.-enriched vermicompost supports sustainable agricultural development by reducing dependence on synthetic fertilizers, promoting the utilization of locally available organic wastes, and improving soil biological activity. Integrating beneficial microorganisms with organic amendments may enhance nutrient-use efficiency while maintaining environmentally friendly cultivation practices. Therefore, this technology has potential to contribute to more resilient and sustainable ginger production systems.

Overall, the results indicate that the application of vermicompost enriched with *Trichoderma* sp. had a positive and consistent effect on the growth performance of ginger seedlings. Among the treatments tested, T5 showed the most favorable response, producing the highest values for all observed growth parameters. The superior performance of this treatment suggests that the combined contribution of vermicompost as a source of organic matter and *Trichoderma* sp. as a beneficial biological agent may improve nutrient availability and create more favorable conditions for early plant growth. These findings demonstrate the potential of *Trichoderma* sp.-enriched vermicompost as an environmentally friendly cultivation practice for enhancing seedling establishment and supporting sustainable ginger production.

CONCLUSION

The incorporation of *Trichoderma* sp. enriched vermicompost resulted in a significant improvement in the growth performance of ginger (*Zingiber officinale* Rosc.) seedlings, particularly in terms of plant height, number of leaves, and number of shoots.

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