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Potential of Trichocompost to improve organic garlic production in *Fusarium* wilt–endemic fields in Tawangmangu, Central Java

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Abstract
Garlic is a high-value commodity in Tawangmangu, major production centers in Central Java. However, productivity in this region is seriously affected by *Fusarium*, the pathogen causes basal rot and wilting in the upper parts of the plant. The disease known as basal rot or *Fusarium* wilt, with the disease intensity in the field can exceed 60%. Currently, chemical control remains the primary management strategies, which in organic farming, this practice is not acceptable. Therefore, environmentally alternatives are required, such as organic fertilizers, biological control agent like *Trichoderma*. *Trichoderma* is known as a cellulolytic microbe, which enhance the composting process and produce improved *Trichocompost*This study aimed to evaluate the effectiveness of *Trichocompost* in suppressing *Fusarium* wilt while enhancing garlic growth under field conditions. A field experiment was conducted in a *Fusarium* wilt-endemic area in Tawangmangu using a randomized complete block design (RCBD) with 5 treatments, *Trichocompost* (TC), compost (C), *Trichoderma* (T), untreated control, and farmers' practices to assess disease severity, control effectiveness, plant dry weight, yield, and soil nutrient. The results indicated that *Trichocompost* (TC) performed better compared to compost (C), *Trichoderma* (T), or untreated treatment. *Trichocompost* reduced disease incidence from 27.03% to 13.41% and wilting intensity from 14.30% to 3.18%, with a control effectiveness of 77.76%, comparable to farmers' practices. Garlic treated with *Trichocompost* showed better growth as indicated by increased plant dry weight (18.58 g) and yield (10.72 $t.ha^{-1}$). Therefore, there is an indication that improved plant growth contributes to reduced the intensity of *Fusarium* wilt in garlic.

Keywords: *Allium sativum*, compost, endemic, *Fusarium oxysporum, Trichoderma*.

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Introduction

Tawangmangu, a district in Central Java and one of the garlic production centers in Indonesia, has struggled with *Fusarium* wilt since the early 2000s. The outbreak of *Fusarium* wilt, caused by *Fusarium oxysporum* f. sp. *cepae*, became a crucial problem for garlic farmers in Tawangmangu. According to Hadiwiyono (1), *Fusarium* wilt has been endemic in the area since the 2000s, with its incidence recorded at more than 60%. This disease is difficult to control because the pathogen can persist in the soil for a very long time by forming chlamydospores, which allows the clamydospores to survive or a long periods even without a host plant (2). Furthermore, as stated also by Hadiwiyono et al. (3), this pathogen is seed-borne with a very high infection index exceeding 80%, making it difficult to obtain pathogen-free seeds. Such conditions lead a continuous reinfection cycle each planting season, leading to worsening disease severity over time (4). In addition, an important characteristic of *Fusarium* is that it is categorized as a weak pathogen and a hemibiotroph, in which, in normal healthy plants, disease symptoms do not appear, but they emerge when the plant is weakened, leading to necrotrophic damage in plants with advanced symptoms.

Control of weak and hemibiotrophic parasites like *Fusarium* can be done by mantaning the cultivation of physiologically healthy plants. Healthy plants will be resistant to weak pathogens like *Fusarium*. Plant growth can be enhanced with either biotically or abiotic approach. Biotic growth enhancement involves applying plants with growth-promoting agents *Trichoderma*, which support plant growth through direct and also indirect mechanims, such as mycoparatism (5), antibiosis, lytic enzymes (6), competition for space (7). Abiotic enhancement, on the other hand, can be achieved through fertilization, such as using organic amendments, which can improve nutrient availability, soil structure and microbial activity (8).

This manuscript reports the results of research on the effect of *Trichoderma* and organic fertilizers (compost and rice husk charcoal) on the control of *Fusarium* wilt in garlic. the study highights the performances of *Trichoderma* and organic inputs in enhancing plant health and affecting soil environment. This research particularly aims to investigate how biological agents and amandements can enhance the plant growth, improve soil chemical properties and suppress *Fusarium* wilt.

Materials and Methods

The experiment was conducted in the *Fusarium* wilt-endemic garlic area in Tawangmangu, Karanganyar, at an altitude 1000 m a.s.l. The experiment used a a randomized complete block design (RCBD) with three replications (blocks) to account for field heterogeneity. The experimental unit within wcah block composted of a garlic bed measuring 1 × 8 m^2, planted with the Tawangmangu Baru variety at a spacing of 10 × 15 cm. All tested treatments were included in each block, and treatments were randomly assigned to beds within each block. The primary treatment tested was *Trichocompost* (TC), which is near-mature compost amended with a *Trichoderma* starter at a density of 10^3 conidia.g^{-1} applied two weeks before use. As a comparison, the treatments are compost (C), *Trichoderma* (T), control (untreated), and garlic cultivation using traditional farming practice (application of synthetic NPK fertilizers and chemical fungicides).. Disease variables observed were *Fusarium* wilt intensity and control effectiveness. While the growth and production variables consisted of dry matter yield and bulb yield. The disease intensity was observed using the following formula.

$$DI = \frac{\sum_{i=0}^{n}(n.v)}{N.Z} 100\%$$

Where IP = disease intensity; n = the number of plants with a specific score; v = disease score of category; N = the total number of sample plants; and Z = the highest disease score. The disease scoring used is based on this: 0=asymptomatic; 1= slight wilting (1–25%); 2= moderate wilting (26–50%); 3= severe wilting (51–75%); 4= extensive wilting greater than 75%. Disease intensity is assessed using 10 sample plants selected systematically. The effectiveness of control was calculated based on the yield of the untreated control minus the yield of the treated crop, multiplied by 100%. Similarly, growth improvement was calculated by subtracting the yield of the treated crop from the yield of the untreated control without treatment then multiplied by 100%. All data were analyzed using analysis of variance (ANOVA) according to a randomized complete block design. Significant differences among treatment means were further compared using Duncan's multiple range test (DMRT) at $p \leq 0.05$.

Results and Discussion

The research results show that *Trichocompost* is effective in reducing the incidence and severity of *Fusarium* wilt (Table 1). Based on the analysis of variance, both incidence and wilting intensity, were significantly different among treatments; *Trichocompost* was significantly different from the control (untreated), and not significantly different from the farmers' practices that intensively used synthetic NPK fertilizers and chemical fungicides.

Table 1. Effects of *Trichoderma* and Organic Fertilizers on Disease Incidence, Wilting Intensity, and Control Effectiveness of Garlic Compared to the Untreated Control

Treatment	Disease Incidence (%)		Wilting Intensity		Control Effectiveness (%)
Untreated	27.03±1,04	c	14.30±0,22	c	-
Compost (C)	18.09±1,12	b	5.83±0,08	b	59.23
Trichoderma sp. (T)	18.40±1,1 6	b	5.15±0,95	b	63.99
Trichocompost (TC)	13.41±1,12	a	3.18±1,30	a	77.76
Farmer practice	18.42±1,21	b	3.17±1,60	a	77.83
Sig.	0.0001		0.0001		-
CV (%)	5.93		16.13		-

Note: Values followed by the same letter within a column are not significantly different according to DMRT at p≤0.05.

Trichocompost treatment reduced disease incidence from 27.03% in the control treatment to 13.41% and also decreased wilt intensity from 14.30% to 3.18%. In terms of effectiveness, *Trichocompost* (TC) outperformed both compost (C) and *Trichoderma* (T). *Trichocompost* showed an effectiveness of 77.76%, higher than compost (59.23%) or *Trichoderma* (63.99%), and was close to the farmers' practices, which had an effectiveness of 77.83%. The coefficient of variation (CV) for disease incidence across the five treatments was 5.93%, demonstrating low variability and high experimental precision, whereas the CV for control effectiveness was 16.13%, indicating moderate but acceptable variability for a derived parameter under field conditions. These CV values indicate that the observed treatment effects were consistent and reliable.

These result indicate that *Trichocompost* outperformed compared to compost or *Trichoderma* is associated with an integrated disease suppression effect rather than a single mechanism. The simultaneous reduction in disease incidence and wilting intensity explain that *Trichocompost* is effective in suppressing the pathogen establishment and disease progression under field condition. Based on disease parameters, the integrated suppression effect may involve two sequential processes. First, *Trichocompost* suppresses pathogen establishment at the early stage of rhizosphere, as reflected by the reduced disease incidence. Second, the lower wilting intensity suggests that disease development was restricted after the pathogen had entered the plant, indicating an effect on disease progression during later stages.

This integrated suppression effect demonstrates that *Trichocompost* functions not only as an organic amendment but also as an effective medium for *Trichoderma*. The organic matter in compost creates a favorable environment that enhances *Trichoderma* persistence, thereby restricting pathogen establishment at early infection stages (9)(10). Early dominance of *Trichoderma* in the rhizosphere limits *Fusarium* establishment through competition for space and nutrients, thereby reducing disease incidence at the initial stage of infection (11)(12).

According to Awal et al. (13), through mechanism of space and nutrient competition, systemic resistance induction, hyphal parasitism, and the formation of antimicrobial metabolites, *Trichoderma* sp. have demonstrated efficacy as a biological control agent against *Fusarium* infections. Consistent with the observed reduction in wilting intensity, the disease suppression appears to extend beyond early pathogen establishment. Plants treated with *Trichocompost* exhibited lower wilting intensity during later stages of infection, indicating that *Trichoderma* activity extends to restricting pathogen development as the disease progresses. Earlier studies suggest that *Trichoderma* can interfere *Fusarium* within host vascular tissues by direct antagonistic interactions, particularly through mycoparasitism and the production of antifungal metabolites (14)(15). *Trichoderma* has also been reported to induce plant defense responses, which may increase host tolerance to vascular diseases caused by *Fusarium* sp. (16)(17).

Trichocompost performed the best compared to compost or *Trichoderma* applied as a single treatment, reflects the advantages of combining organic amendment with biological control in agricultural approach. Compost alone primarily improves soil physical and biological properties, while *Trichoderma* applied alone may experience limited persistence under field conditions (18). Their integration in *Trichocompost* enables prolonged biological activity, enhanced nutrient availability, and continuous antagonistic pressure against *Fusarium*, resulting in more stable and consistent disease suppression in the field (19).

In addition, *Trichoderma* is commonly used as a decomposer in composting and has been demonstrated to enhance compost quality. *Trichoderma* sp. are frequently used as decomposer agents in composting because of their capability to produce cellulolytic and hemicellulolytic enzymes (β-glucanase, endoglucanase, and xylanase) as catalysts for lignocellulose degradation and humification (20). Based on the statements of Heng et al. (21), who also report that *Trichoderma* species, such as *T. harzianum* and *T. reesei*, can secrete several amounts of cellulolytic enzymes, which play a crucial role in the bioconversion of organic biomass.

Compost in this study also showed significant results in controlling *Fusarium* wilt, with an effectiveness of 59.23%. This figure is meaningful and shows only a small difference compared to the farmers' practice, which achieves 77.83% effectiveness. This finding is consistent with various previous studies on shallots. Compost has been reported to reduce *F. oxysporum* disease by restructuring the microbial community in the rhizosphere (22). In Additionally to microbial community changes, as reported by Blaya et al. (23), enzymatic analysis of compost showed that enzyme activity (protease and chitinase) were also correlated with the level of suppression against *Fusarium* sp.

Compost is the product of the biological decomposition of organic matter, a process that can be catalyzed by various types of microbes under warm and humid conditions, whether in aerobic or anaerobic environments (24). This process can be accelerated by adding biological agents such as *Trichoderma* sp., *Aspergillus* sp., *Rhizobium* sp., or others that act as biological activators (25). These biological agents break down lignocellulose using cellulolytic and lignocellulolytic enzymes, catalizing the compost mature and stable faster (2).

Trichocompost is a composting method that is formed by combining organic materials with *Trichoderma*. This compost is formed through the decomposition of organic materials enriched with *Trichoderma*, which accelerates decomposition process and prevents soil-borne pathogen (27). As highlighted by Talukdar et al. (28), *Trichoderma*-fortified compost also demonstrated superior effects in enhancing various plant growth parameters. regarding disease control, *Trichocompost* performs a dual function: it enhances compost quality and also acting as a biological control agent *Trichoderma*.

Conceptually, the effectiveness of *Trichocompost* in controlling *Fusarium* wilt can be attributed to two main mechanisms. First, the compost promotes plant growth, enhancing resistance to weak pathogens like *Fusarium*. The intensity of *Fusarium* wilt tends to be lower in plants with high growth vigor due to more optimal nutrient availability and optimal plant health resistance. Several studies have demonstrated the correlation between plant vigor and disease expressions. Plants usually perform better physiologically at higher levels of soil fertility, with more organic matter, which reduces the development of *Fusarium* wilt. Sufficient nutrient supply and root activity allow it to promote plant tolerance with soil-borne pathogens by stimulating host plant defense and reducing stress-induced susceptibility (29). In addition, organic amendments are commonly associated with disease-suppressive soil by improving soil structure, nutrient cycling, and beneficial microbial activity, which support vigorous plant growth and reduce disease severity (30). This result also correspond with the findings of Azizah and Advinda (31), which also indicate that *Fusarium* is a weak pathogen, and its severity tends to decrease in plants exhibiting high growth vigor. Second, mechanism involves using a compost as a carrier for biological control agents. Compost acts as an effective substrate for carrying and delivering *Trichoderma*. Following the results of Akter et al. (32), rice straw and water hyacinth (*Eichhornia crassipes*) can sustain the population of *Trichoderma* sp. spores, making it an effective medium for biological agent propagation. Furthermore, findings from Amaria et al. (33) indicate that compost used as a carrier keeps *T. harzianum* viable, acting as both a nutritional medium and an inoculum storage.

The mechanism of reduced *Fusarium* wilt intensity by increased plant growth is demonstrated by the results of dry weight and yield measurements. Garlic treated with *Trichocompost* showed increased growth, represented by dry weight and garlic yield (Table 2).

Table 2. Effects of Compost, *Trichoderma*, and *Trichocompost* on Dry Weight and Yield of Garlic

Treatment	Dry Weight (g)		Yield ($t.ha^{-1}$)	
Untreated	11.09±1,16	c	6.93±0,16	b
Compost (C)	14.84±1,17	b	7.20±0,72	b
Trichoderma sp. (T)	14.20±2,28	b	7.11±1,33	b
Trichocompost (TC)	18.58±3,73	a	10.72±0,94	a
Farmer practice	18.32±2,39	a	10.74±1,63	a
Sig.	0.0001		0.0001	
CV (%)	15.37		12.26	

Note: Values followed by the same letter in the same column are not significantly different according to DMRT at 5%

Trichocompost treatment characterised by a dry weight of 18.58 g and a yield of 10.72 $t.ha^{-1}$. This value is not significantly different from those obtained under farmers' practice (18.32 g and a yield of 10.74 $t.ha^{-1}$). These increase in garlic dry weight and yield indicate that *Trichocompost* can contribute to reducing the intensity of *Fusarium* wilt by improving the plant's vigour.

Several studies reported that *Trichocompost* can increase the biomass across various crop commodities. According to Ahmad et al. (34), there was a significant increase in the number of onion bulbs after application with compost-enriched with minerals and the biological agent *Trichoderma*. Moreover, as explained by Sutriana et al. (35), the application of *Trichocompost* can improve soil water availability, hence increasing bulb yield in onion plants.

Increased plant growth in the *Trichocompost* treatment is related with improved soil nutrient status, as shown in (Table 3), where the application of *Trichocompost* increased organic matter content (2.30%), available Nitrogen (2.74%), and C/N ratio (0.48%), which were higher than the untreated control.

Table 3. Effects of Compost, *Trichoderma*, and *Trichocompost* on Nutrient Content of Andisol Soil in Tawangmangu

Treatment	pH	Organic C (%)	Organic Matter (%)	Available P (Ppm)	Total N (%)	Available K (cmol/kg)	C/N Ratio
Untreated	5.47	1.00	1.72	0.87	2.13	0.02	0.46
Compost (C)	5.84	1.35	2.33	1.52	2.44	0.04	0.55
Trichoderma sp. (T)	5.72	1.61	1.78	1.05	2.05	0.04	0.78
Trichocompost (TC)	5.65	1.33	2.30	1.60	2.74	0.04	0.48
Farmer practice	5.74	1.29	1.73	4.92	2.77	0.08	0.47

Trichocompost increases nitrogen availability because the presence of *Trichoderma* in the compost accelerates N mineralisation and enhances plant growth (36). According to Kalen et al. (37), higher amounts of *Trichocompost*, the greater the population of Tricoderma within it, which contributes to increased the organic matter and enrich nutrients availability for plants. The addition of *Trichoderma* to compost also attributes the C/N ratio in the soil, which acts a critical role in plant growth. The higher the C/N ratio, the slower the composting process. If the C/N ratio is low, can result in nitrogen loss through oxidation, hence inhibiting plant growth (38)

Conclusions

Trichocompost is effective in reducing *Fusarium* wilt and improving the growth and yield of garlic compared to other treatments and also showing result comparable to farmers' practices. Due to its dual mechanisms as a nutrient source and a carrier of *Trichoderma*, *Trichocompost* offers practical and sustainable approach for disease management. It is highly recommended that farmers apply *Trichocompost* during land preparation to improve soil health and plant resistance, and future optimization of dosage and formulation will be optimized for wider use.

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District, Karanganyar, Central Java, on organic garlic cultivation.

Conflict of Interest

There are no conflicts of interest associated with this publication.

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