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The Potential of Banana Peel Waste Compost Enriched with Trichoderma sp. as a Disease Suppressant Agent in Pakcoy *(Brassica rapa L.)* Cultivation

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Abstract: Pakchoy *(Brassica rapa L.)* is a leafy vegetable commodity whose productivity is often hampered by soil-borne and leaf-borne diseases, while control with synthetic fungicides carries the risk of residue generation and environmental impacts. Experimental research on banana peel waste compost enriched with Trichoderma sp. on pakchoy plants very significant effect on plant height and a significant effect on leaf number and fresh weight, with a combination of 300 g compost and 10-15 g Trichoderma sp. per polybag as the best treatment. However, this study only observed growth variables and did not measure disease variables, so its effectiveness in suppressing disease growth rates cannot be directly concluded from these data. This article presents a narrative literature review that synthesizes scientific evidence regarding pakchoy's susceptibility to major diseases, the content of antimicrobial bioactive compounds in banana peels, and the biocontrol mechanisms of Trichoderma sp. (mycoparasitism, antibiosis, competition, and induction of systemic resistance), empirical evidence from other horticultural commodities showing that the combination of organic compost and Trichoderma sp. is able to suppress soil-borne diseases by 51-69%, challenges in the formulation and viability of biological agents at the farmer scale, and its relevance to the principles of a circular economy and sustainable agriculture. Based on this synthesis, the combination of banana peel compost and Trichoderma sp. theoretically has strong potential as a disease suppressant agent in bok choy, but direct proof requires further experimental research with pathogen inoculation and measurement of incidence, severity, and disease development rate (AUDPC). This article concludes with a proposed further research design to address these gaps.

Keywords: Banana peel compost; Bok choy; Biocontrol agent; Plant disease; Trichoderma sp

Introduction

Indonesia is an agricultural country with a horticultural sector, including leafy vegetables such as bok choy *(Brassica rapa L.)*, which contributes significantly to food security. Data from the West Nusa Tenggara Central Statistics Agency (BPS) recorded fluctuating productivity of mustard greens, from 10.83 tons/ha (2018), to 8.5 tons/ha (2019), and then rising to 13.11 tons/ha (2020), indicating the need for continuous improvement in cultivation techniques (BPS NTB, 2018, 2019, 2020). One of the main obstacles to bok choy cultivation is the pressure of plant pests, including soil-borne diseases such as clubroot caused by Plasmodiophora brassicae, with a reported infestation rate of 26.6% in production centers in West Java (Pratama et al., 2022), as well as stem rot and damping-off diseases, which commonly affect the Brassicaceae family and other leafy vegetables, caused by Rhizoctonia solani, Sclerotium rolfsii, and Fusarium spp.

Conventional plant disease control still relies on synthetic fungicides, which, while effective in the short term, risk leaving chemical residues, degrading soil quality, and disrupting the balance of soil microbiota in the long term (Aqualdo et al., 2015). Sinambela (2024) reports that approximately 80% of sprayed pesticides ultimately fall and accumulate in the soil, reducing fertility and disrupting beneficial non-target organisms

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such as natural predators and soil microorganisms. Residues carried by surface runoff also pollute water bodies.

Regarding health, the same study noted that the majority of farmers routinely exposed to pesticides report health complaints such as nausea, dizziness, and skin irritation, in addition to long-term risks such as resistance to pathogens and target pests, which forces increased dosages and constant changes in active ingredients (Sinambela, 2024). This situation reinforces the urgency of developing more environmentally friendly alternatives for controlling plant diseases, including the use of biological agents and composted organic materials. Furthermore, the abundant banana peel waste from banana consumption and processing centers in Indonesia is largely underutilized and has the potential to cause environmental pollution if left to accumulate without processing (Kusna, 2022). Kepok banana peel is known to contain high levels of nitrogen, phosphorus, and potassium (Zega et al., 2023) as well as secondary metabolite compounds such as flavonoids, alkaloids, tannins, saponins, and triterpenoids that have antimicrobial activity (Ariani et al., 2024; Lumowa & Bardin, 2018), so it has the potential to double as a source of nutrients and a plant protective agent when processed into compost.

To optimize this potential, banana peel waste compost can be enriched with the biological agent Trichoderma sp., a soil saprophytic fungus that has been widely reported to play a dual role as a biodecomposer, plant growth promoter, and biocontrol agent against various soil-borne pathogenic fungi, including Rigidiporus lignosus, Fusarium oxysporum, Rhizoctonia solani, and Sclerotium rolfsii (Guzmán-Guzmán et al., 2025; Ningrum et al., 2026). Situmorang & Santri (2025) tested the combination of banana peel compost and Trichoderma sp. doses on the growth of bok choy plants through a two-factorial Completely Randomized Design experiment in a greenhouse, and found that the combination of 300 g of compost with 10-15 g of Trichoderma sp. per polybag provided the best growth in plant height, number of leaves, and fresh weight. The study also noted that the experimental plants relatively did not require additional treatment for leaf blight because they had been given Trichoderma sp. as a biological agent, but these notes are observational and not the result of systematic measurements of disease variables (incidence, severity, or rate of disease progression).

This gap is the basis for writing this article. Rather than claiming disease suppression effectiveness based on unavailable data, this article aims to compile a narrative literature review that honestly maps: (1) the susceptibility profile of bok choy to major diseases; (2) the scientific basis for the antimicrobial potential of banana peel compost; (3) the biocontrol mechanisms of Trichoderma sp. that have been demonstrated in various pathosystems; (4) empirical evidence from other horticultural crops that strengthens the plausibility of the disease suppression hypothesis; and (5) the design of further experimental studies needed to directly demonstrate the effectiveness of the combination of banana peel compost and Trichoderma sp. in suppressing disease growth rates in bok choy.

Method

This article was prepared using a narrative literature review approach. A literature search was carried out on the Google Scholar, ScienceDirect, MDPI, PMC/PubMed, Frontiers, DOAJ, AGRIS FAO databases, as well as the final project repositories of universities in Indonesia, using a combination of the keywords "Trichoderma sp.", "biocontrol/biological agents", "banana peel compost", "plant disease", "Brassica rapa/pakcoy", and "disease suppression". Sources included include national and international indexed journal articles, seminar proceedings, and theses that explicitly report quantitative data related to biocontrol mechanisms or disease suppression results. Primary data from research on the growth of pak choy on various doses of banana peel compost and Trichoderma sp. Situmorang & Santri (2025) is used as a case study and supporting context, not as a source of disease data, considering that this variable was not measured in the original research. Synthesis is carried out thematically to build coherent arguments from molecular/biological mechanisms to empirical evidence in plants, as well as to identify relevant research gaps.

Result and Discussion

Vulnerability of Pakcoy Plants to Major Diseases

Pakcoy *(Brassica rapa L.)* is a plant in the Brassicaceae family whose cultivation is susceptible to a number of diseases, both soil-borne and airborne. One of the most detrimental soil-borne diseases in Brassicaceae is clubroot, caused by Plasmodiophora brassicae, characterized by symptoms of wilting, stunted growth, and root swelling. In the pakcoy production center in the Cianjur agropolitan area, West Java, the attack intensity was recorded at 26.6% and is associated with production factors such as land area, seed use, organic fertilizer, and pesticides (Pratama et al., 2022). Furthermore, leafy vegetables of the same family and close relatives as bok choy are commonly reported to be susceptible to damping-off and stem rot caused by Rhizoctonia solani and Sclerotium rolfsii, and wilt caused by Fusarium spp., all of which are soil-borne pathogens with root-

borne infection (Ningrum et al., 2026; Taufik, 2008). In Situmorang & Santri (2025) research maintenance notes, control of late blight (Phytophthora sp.) is explicitly stated as unnecessary due to the use of Trichoderma sp. as a biological agent, a qualitative observation consistent with the biocontrol potential of Trichoderma sp. but lacking quantitative evidence.

Banana Peel Waste Compost: A Source of Nutrients and Antimicrobial Bioactive Compounds

Banana peels, particularly those from the kepok variety (Musa paradisiaca/Musa balbisiana), contain relatively high levels of macronutrients, including 3.44% nitrogen, 0.35% phosphorus, and 9.85% potassium (Zega et al., 2023), making them a potential composting material for supporting plant vegetative growth. Beyond their nutritional value, kepok banana peels also contain secondary metabolites such as flavonoids, alkaloids, tannins, and saponins, which have been shown to have antimicrobial activity against Staphylococcus aureus bacteria in vitro, with inhibition zones increasing with increasing extract concentration (Ariani et al., 2024). Other phytochemical studies on kepok banana peels have also reported flavonoids, alkaloids, tannins, saponins, and triterpenoids, which are reported to be able to suppress plant-disturbing organisms (Lumowa & Bardin, 2018). These phenolic and terpenoid compounds generally work by disrupting the integrity of cell membranes and disrupting the metabolic processes of target microorganisms. Although this antimicrobial evidence has so far been largely tested against bacteria and microbes in clinical trials (in vitro), its presence in compost feedstock provides a plausible biochemical basis for the contribution of banana peel compost to suppressing harmful microorganisms in the rhizosphere. Direct evidence on target plant pathogens is still limited and requires further testing.

Biocontrol Mechanisms of Trichoderma sp. against Plant Pathogens

Trichoderma sp. is one of the most widely studied and applied biological control agents in agriculture due to its ability to suppress the growth of pathogenic fungi through several mechanisms that can work simultaneously (Guzmán-Guzmán et al., 2025; Hadiwiyono, 2008). First, mycoparasitism, which is the ability of Trichoderma sp. hyphae to recognize, coil around, and penetrate target pathogen hyphae with the aid of extracellular lytic enzymes such as chitinase, β-1,3-glucanase, protease, cellulase, and lipase, which degrade the pathogen's cell wall (Iqbal et al., 2024). Second, antibiosis, which is the production of antibiotic secondary metabolites such as trichodermin and viridin, which are toxic to other fungi (Hadiwiyono, 2008). Third, competition for growth space and nutrients, where fast-growing and aggressive Trichoderma sp. dominates the rhizosphere, thereby limiting the space for pathogen colonization (Setyadi et al., 2017). Fourth, induction of systemic resistance (induced systemic resistance/ISR), which is the ability of Trichoderma sp. to trigger the host plant's defense pathways, making the plant more resistant to subsequent pathogen attacks (Guzmán-Guzmán et al., 2025). Beyond these four antagonistic mechanisms, Trichoderma sp. also acts as a plant growth promoter through phosphate solubilization and increasing nutrient bioavailability in the root area (Guzmán-Guzmán et al., 2025; Zendrato & Lase, 2025), so that the host plant grows more vigorously and has the potential to be more tolerant to biotic stress. Trichoderma species and isolates that have been reported to be effective in suppressing soil-borne pathogens relevant to leafy vegetables include T. harzianum, T. viride, and T. koningii, with target pathogens including Rhizoctonia solani, Sclerotium rolfsii, and Fusarium oxysporum (Iqbal et al., 2024).

Empirical Evidence of the Synergy of Compost and Trichoderma sp. in Suppressing Diseases in Other Horticultural Crops

The concept of compost enriched with antagonistic agents is in line with the suppressive soil theory, which states that soil conditions that naturally or through organic amendments are able to suppress the development of soil-borne pathogens by increasing the population of antagonistic microorganisms (Hadiwiyono, 2008). Several empirical studies on other horticultural crops support the plausibility of this mechanism. Talukdar et al. (2017) reported that compost enriched with Trichoderma harzianum isolate Co-7 was able to reduce the mortality of chickpea (Cicer arietinum) seedlings by 69.31%, reduce the incidence of Fusarium oxysporum by 63.7%, Sclerotium rolfsii by 64.1%, and Rhizoctonia solani by 51.4%, with a reduction in disease severity ranging from 64.9-67.8% and an increase in seed yield of up to 50% compared to the control. In lettuce (Lactuca sativa), the application of Trichoderma harzianum has been reported to reduce the intensity of stem rot disease caused by Rhizoctonia solani. In chili plants, the application of Trichoderma sp., either through seed coating or soil application, has been reported to suppress the incidence of damping-off disease caused by Rhizoctonia solani and Sclerotium rolfsii, while compost enriched with antagonistic microbes has also been reported to suppress the pathogenicity of Ralstonia solanacearum, which causes bacterial wilt in red chilies. In tomato plants, liquid organic fertilizer based on banana peels with added bioactivators has been reported to play a role in controlling Fusarium wilt disease. A summary of the empirical evidence is presented in Table 1.

Table 1. Summary of empirical evidence of disease suppression by Trichoderma sp. and/or organic compost on various horticultural crops

Host Plant	Target Pathogen	Treatment	Disease Suppression Results	Sources
Chickpeas (Cicer arietinum)	Fusarium oxysporum, Rhizoctonia solani, Sclerotium rolfsii	Poultry manure compost enriched with Trichoderma harzianum isolate Co-7	Incidence decreased by 51.4-69.3%; severity decreased by 67.8%; grain yield increased by ~50%	(Talukdar et al., 2017)
Lettuce (Lactuca sativa)	Rhizoctonia solani (stem rot)	Application of Trichoderma harzianum	Reduction in the intensity of stem rot disease	Prosiding Semnas UIN Sunan Gunung Djati (2019)
Chili (Capsicum spp.)	Rhizoctonia solani, Sclerotium rolfsii (damping-off)	Seed coating / soil application with Trichoderma sp.	Decreased incidence of damping off compared to control	Jurnal Fitopatologi Indonesia; Jurnal HPT UB
Red chili (Capsicum annuum)	Ralstonia solanacearum (bacterial wilt)	Compost enriched with antagonistic microbes	Suppression of pathogenicity in crops	Repositori UGM (etd.repository.ugm.ac.id)
Tomato (Solanum lycopersicum)	Fusarium oxysporum f. sp. lycopersici (Fusarium wilt)	Liquid organic fertilizer from banana peel + bioactivator	Reported to suppress the development of Fusarium wilt disease	Research Gate (2023)

The similarity of the patterns in Table 1 strengthens the argument that the combination of composted organic matter and Trichoderma sp. consistently suppresses soil-borne pathogens that are also major threats to bok choy, namely Rhizoctonia solani, Sclerotium rolfsii, and Fusarium spp. However, all of this evidence comes from commodities other than bok choy, so direct generalization to bok choy requires separate testing, as each pathosystem (host-pathogen-environment combination) may respond differently.

Relationship with Bok Choy Growth Data from Initial Research

Bok choy plant growth data from Situmorang & Santri (2025) study are summarized in Table 2. The combination of 300 g of banana peel compost and 10 g of Trichoderma sp. per polybag (P3T2) produced the highest plant height, fresh weight, and root length, while the combination of 300 g of compost and 15 g of Trichoderma sp. (P3T3) produced the highest number of leaves and dry weight. The control treatment without compost and without Trichoderma sp. (P0T0) or low dose of compost without Trichoderma sp. (P1T0) consistently produced the lowest values for all growth parameters.

Table 2. Summary of the results of the effect of banana peel compost and Trichoderma sp. doses on the growth parameters of bok choy at 4 weeks after planting

Parameters	The best treatment	Average	Lowest treatment	Average	Significance (ANOVA)
Plant height (cm)	P3T2 (kompos 300 g + Trichoderma 10 g)	20.33	P1T0 (100 g compost, without Trichoderma)	13.50	Very real
Number of leaves	P3T3 (kompos 300 g + Trichoderma 15 g)	16.00	P1T0 (100 g compost, without Trichoderma)	10.00	Real
Fresh weight (g)	P3T2 (kompos 300 g + Trichoderma 10 g)	41.10	P0T0 (Control)	16.07	Real (p=0,014)*
Dry weight (g)	P3T3 (kompos 300 g + Trichoderma 15 g)	3.40	P0T0 (Control)	1.47	Not real (p=0,333)
Root length (cm)	P3T2 (kompos 300 g + Trichoderma 10 g)	33.00	P0T2 (without compost + 10 g Trichoderma)	22.80	Not real (p=0,248)

The higher vegetative growth patterns and biomass weights in the treatments with the highest compost and Trichoderma sp. doses are indirectly related to the plant's potential for disease resistance, as plants with better nutrient status and more developed root systems generally have greater energy reserves and

physiological capacity to respond to biotic stresses (Campbell et al., 2018; Lana et al., 2021). However, this relationship is associative and cannot be interpreted as evidence of disease suppression, as Situmorang & Santri (2025) study was conducted in a greenhouse without pathogen introduction and without measuring any disease variables. Therefore, the arguments in this section should be understood as hypotheses indirectly supported by growth data and by established Trichoderma sp. biocontrol mechanisms in the literature (sections 3.3 and 3.4), rather than as proven conclusions.

Formulation Challenges, Viability, and Practical Application at the Farmer Level

The biological effectiveness of Trichoderma sp. in the laboratory or greenhouse does not necessarily guarantee success in the field, because propagules' viability and colonization ability are greatly influenced by production, packaging, and storage methods before application. Ratnawati et al. (2023) evaluated the shelf life of Trichoderma asperellum TR3 in three types of packaging (aluminum foil, plastic, and bottles) for ten months of storage and found that aluminum foil packaging was relatively better at maintaining fungal viability and growth capacity than plastic or bottle packaging at the end of the observation period. This finding is relevant for the application of banana peel compost containing Trichoderma sp. on a farmer scale, because compost produced independently is generally stored in non-sterile conditions with uncontrolled temperature and humidity fluctuations, so that the active propagule population has the potential to decrease over time before application to the field. In addition to packaging aspects, the success of field application also depends on the timing and method of application; Trichoderma sp. Generally, it requires a period of adaptation in the rhizosphere before it can effectively dominate and suppress pathogens (Zendrato & Lase, 2025), so application early in the soil or nursery, rather than after disease symptoms appear, is agronomically preferable. Therefore, successfully replicating the benefits of banana peel-Trichoderma sp. compost from a controlled research scale to a real-life farming scale requires consistent production standards, packaging, and application timing, not just the optimum dosage as shown in Table 2.

Circular Economy Principles and Implications for Sustainable Agriculture

Utilizing banana peel waste as a raw material for Trichoderma sp.-enriched compost aligns with the principles of a circular economy in agriculture, namely converting organic waste streams that are currently wasted and potentially polluting the environment into value-added production inputs (Kusna, 2022). This approach offers benefits in three dimensions simultaneously: the environmental dimension, by reducing the volume of organic waste ending up in landfills and reducing dependence on synthetic fertilizers and fungicides and their associated environmental risks (Sinambela, 2024). The economic dimension, as banana peel waste is essentially an abundant, low-cost raw material, potentially reducing input costs for small- and medium-scale farmers in bok choy (pak choy) cultivation (Aqualdo et al., 2015), and the social dimension, as it raises public awareness about the productive management of household and agro-industrial organic waste. If the disease suppression hypothesis outlined in sections 3.1-3.5 is proven experimentally in bok choy, banana peel-Trichoderma sp. compost has the potential to become a model for appropriate technology aligned with the sustainable agriculture agenda, particularly for banana production centers that also serve as centers for leafy vegetable horticulture, such as those found in West Nusa Tenggara and other regions in Indonesia.

Research Gaps and Proposed Advanced Test Designs

To directly demonstrate the effectiveness of banana peel waste compost with the addition of Trichoderma sp. in suppressing the growth rate of diseases in bok choy, further experimental research is needed with the following design elements. First, the determination of relevant and representative target pathogens, for example Rhizoctonia solani (damping-off/stem rot) or Plasmodiophora brassicae (clubroot), which are selected based on epidemiological risks at the research site. Second, artificial inoculation of the pathogen into the growing media or seedlings with a standardized inoculum density, accompanied by positive controls (without biological agents) and negative controls (without pathogen inoculation). Third, a factorial experimental design (compost dose × Trichoderma sp. dose × pathogen inoculation status) using a Completely Randomized Design or Randomized Block Design with adequate replications. Fourth, systematic measurement of disease variables, including incubation period, disease incidence (percentage of infected plants), disease severity (scoring scale based on the area of infected tissue), and disease progression rate, which can be represented by disease progression curves and area under the disease progression curve (AUDPC) values to compare infection rates between treatments over time. Fifth, confirmation of Koch's postulates and re-isolation of the pathogen from infected plant tissue to ensure the validity of the diagnosis. This design will allow quantitative testing of the hypotheses developed in this review and can form the basis for recommendations on optimal application doses of banana peel-Trichoderma

sp. compost, both for growth and protection of bok choy plants from disease.

Several limitations should be considered when interpreting the synthesis in this article. First, this review is narrative in nature, not a systematic review with standardized search protocols and study quality assessments (e.g., following the PRISMA framework), potentially subject to literature selection bias, despite the search being conducted across multiple databases. Second, the evidence for disease suppression in Table 1 comes entirely from commodities other than bok choy (chickpeas, lettuce, chili peppers, tomatoes) with different environmental conditions, soil types, and pathogen pressures. Therefore, direct extrapolation to bok choy carries reasonable uncertainty given the specificity of host-pathogen-environment interactions in each pathosystem. Third, the growth data in Table 2 are sourced from a single study Situmorang & Santri (2025) conducted at a greenhouse scale with a single cropping cycle, and therefore do not represent seasonal variation, location, or natural disease pressure in the field. Fourth, some of the secondary sources cited are seminar proceedings, theses, or institutional repositories that have not necessarily undergone the same comprehensive peer review process as reputable international journals. Therefore, readers are advised to independently examine primary sources if they intend to use the quantitative figures in their technical decision-making. These limitations do not diminish the validity of the conceptual argument.

Conclusion

This literature review demonstrates that the combination of banana peel waste compost and Trichoderma sp. has a strong scientific basis for functioning as a disease suppressant agent in bok choy, based on four lines of evidence: (1) the nutrient content and antimicrobial bioactive compounds in banana peels; (2) the widely proven biocontrol mechanisms of Trichoderma sp. (mycoparasitism, antibiosis, competition, and induction of systemic resistance); (3) empirical evidence from various other horticultural crops showing 51-69% suppression of soil-borne diseases by the combination of compost and Trichoderma sp.; and (4) circular economy principles and practical formulation considerations that support the feasibility of its application at the farmer level. Therefore, the claim of the effectiveness of banana peel waste compost with the addition of Trichoderma sp. in suppressing disease growth in bok choy currently remains a hypothesis supported by the literature, not a proven empirical finding in this commodity. Further experimental research with controlled pathogen inoculation and measurements of disease incidence, severity, and progression rate (AUDPC) as described in section 3.8 is needed to directly test this hypothesis and generate optimal application dose recommendations for bok choy farmers.

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The authors declare that there is no conflict of interest in this study.

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