**Composted plant residue amendments in integration with Trichoderma asperellum suppresses above-ground diseases and improves the growth of cacao (*Theobroma cacao* L.)**

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ABSTRACT

Cacao (*Theobroma cacao* L.) suffers severe losses due to infectious and non-infectious diseases. This work reports the potential of three formulations of plant residues compost in integration with *Trichoderma asperellum* to reduce these cacao diseases. All formula consisted of gliricidia and rice straw. In addition, the first compost contained empty stalks of oil palm fruit, the second contained billygoat weed, and the third compost had coconut husks. These three composts formula plus *T. asperellum* were applied through soil amendment. Then, their impact was evaluated on significant above-ground diseases, specifically VSD (vascular streak dieback) and (PPR Phytophthora pod rot), NPK availability for the plant, and decreased Ni content in the plant. The efficacy of first, second, and third compost plus *T. asperelum* in controlling VSD was 73%, 68%, 72%, and PPR 65%, 51%, and 59%, respectively five months post-application in the first year. In the second year, the efficacy against the disease was higher than in the first year. It was 83%, 75%, and 58% for VSD and 69%, 61%, and 78% for PPR, respectively. Moreover, the treatments increased pod production and P content in the leaves, while N and K content rose just in treating the second and third compost plus *Trichoderma*. Ni content only decreased in the treatment of the first compost plus *Trichoderma*. These data showed that especially first compost in integration with *T. asperellum* treatment suppressed above ground diseases and increased cacao pod production. Therefore, disease management and cacao growth on a bigger scale could potentially use the *Trichoderma* integrated-composted plant residues.

Keywords: Cacao, compost, nutrient, Phytophthora pod rot, Soil amendment, Trichoderma, vascular streak dieback

# INTRODUCTION

Cacao, the source of chocolate, is a perennial tropical crop typically grown by small-holder farmers. In Sulawesi-Indonesia, currently, this crop suffers severe losses due to biotic and or abiotic stress factors. Among these factors, Phytophthora pod rot (PPR), vascular streak dieback (VSD), nutrition deficiency, and heavy metal toxicity are worth mentioning. The PPR caused by *Phytophthora palmivora* is found throughout the island of Sulawesi and is responsible for decreasing cacao pod production by 60 to 70% (Sriwati et al. 2015). Management of the disease is difficult, especially in high rainfall areas, favoring the pathogen (Vanegtern et al. 2015). VSD caused by fungus *Ceratobasidium theobromae*, was first noticed in the early 2000s in South and West Sulawesi’s border and has become widespread in the region (Rosmana et al*.* 2016). Infection of soft young leaves at the branch tips by air-borne fungal spores is followed by colonization of leaf and branch by the fungal hyphae, ultimately causing the death of shoot apex and, the pathogen can kill mature trees of susceptible cacao clones (Asman et al. 2021; McMahon et al. 2018). Production losses due to VSD can reach 100% in untreated plantations (Gusli et al. 2008). In addition to infectious diseases, in many Sulawesi areas, continuous cropping of cacao and other crops cause a decrease in soil fertility (van Vliet et al. 2015). Continuously cropped soils shallow in organic C and nitrogen, below 2.0% and 0.2%, respectively (Mulia et al. 2017; Rosmana et al. 2019a). Also, heavy metals are a concern as many cacao plantations are close to nickel mining, covering approximately 127,000 ha (Erfina and Sjarmidi 2019; Vale 2019). Soil pH < 5 is found in many cacao farms, and Ni’s plant content can reach about 14 mg kg-1 (Mulia et al. 2017; Rosmana et al. 2019a). This element is essential for plants at around 0.1– 10 mg kg-1,andbeyond this concentration can be toxic (Li et al. 2011; Harasim and Filipek 2015). The pH affects the toxicity of Ni to plants; higher toxicity occurs when the pH lower (Li et al. 2011).

Compost application can improve soil fertility, production quality, and disease control by direct and indirect modes of action (Segarra et al. 2013; Rosmana et al. 2019b). The soil organic matter of compost origin provides a crucial reservoir of macronutrients such as N, P, and S, essential for growth and pod production (van Vliet et al. 2015; Scotti et al. 2015). Additionally, compost plays a critical role in nutrient availability by providing exchange sites and mobilization by microorganisms, thus preventing rapid leaching and improving the availability of nutrients to plants by gradual release in the rhizosphere (Scotti et al. 2015). Several recent studies showed that the amendment of composted and non-composted plant residues could control soil-borne pathogens by releasing antifungal compounds (Pane et al. 2013). This ability is related to direct compost action by producing fungi toxic compounds and indirect action by enhancing an antagonistic microorganism’s development (Bellini et al. 2020). The compost may also improve plant defence response called systemic acquired resistance (SAR). This response is believed to be associated with resistance to pathogens infecting above ground, such as Botrytis cinerea, Ceratobasidium theobromae, Tomato spotted wilt virus (TSWV) (Segarra et al. 2013; Rosmana et al. 2019b; Bonanomi et al. 2020).

From the perspective of integrated pest management, the integration of compost with the application of known microorganisms, such as *Trichoderma,* may have a synergistic impact in strengthening disease reduction and enhancing plant growth (Hermosa et al. 2012). The fungus plays a vital role in ecology by taking part in the decomposition of plant residues. *Trichoderma* functions as an antagonist of fungal plant disease agents and acts in the degradation of human-made chemicals and inhibiting the accumulation of various metals from wastewater and soil (Kacprzak et al. 2013; Lopezet al. 2015). As a biological agent in cacao, *Trichoderma* can effectively control *Phytophthora palmivora* and *C. theobromae*, the causal agents of Phytophthora pod rot and vascular streak dieback diseases, respectively (Sriwati et al. 2015; Rosmana et al. 2016; Rosmana et al. 2019b). Also, a combination of composted plant residues and *Trichoderma* provides higher inhibition of VSD and enhancement of growth than compost and *Trichoderma* alone (Rosmana et al. 2019a; Rosmana et al. 2019b). Sources of plant residues are present in large quantities in the field, but their occurrence depends on location. Therefore, the use of the various formulations of plant residues in integration with the application of *Trichoderma* both for disease control and growth support of cacao is planned.

The research was done in two years to see the impact of plant residues compost and *T. asperellum* integration in the short-and medium-term. In this time frame, the study aimed to characterize composted material with *Trichoderma* and evaluate its efficacy to control VSD and PPR diseases in the farm, improve nutrient uptake, reduce heavy metal, especially Ni uptake, and increase cacao production.

# MATHERIALS AND METHODS

Preparation of composted plant residues and Trichoderma asperellum production

Plant residues, consisting of coconut (*Cocos nucifera* L.) husks, rice (*Oryza sativa* L.) straws, gliricidia [*Gliricidia sepium* (Jacq.) steud*.*] leaves, billygoat (*Ageratum conyzoides* L*.*) weed, and empty stalks of decayed oil palm (*Elaeis guineensis* Jacq.) fruit, were collected from fields near the research sites. Three formulations were made from these plant residues: the first compost consisted of gliricidia, rice straw, and empty stalks of oil palm fruit; the second consisted of gliricidia, rice straw, and billygoat weed; and the third consisted of gliricidia, rice straw, and coconut husks. Composting was carried out by incubating these plant residues for 30 days at ambient temperature (28ºC to 31ºC) in plastic sacks (50 cm wide and 80 cm high, aerated by 20 holes). According to the previous study (Rosmana et al. 2018b), these composts support the growth and development of *T. asperellum*. The *T. asperellum* strain used was ART-4/G.J.S. 09-1559, isolated from cacao pod in Sulawesi, Indonesia, and characterized as an endophyte (Rosmana et al. 2015). Their mass production for field experiments was done by using the rice grain medium reported in a previous study (Rosmana et al. 2016).

Field assessment

The field trial was located on a farm dominantly cultivated with cacao clone MCC 02 of six years old and infested by PPR, VSD, and soil nickel of 23 mg kg-1. The experiment was established with a randomized block design with three treatments: first compost and T. asperellum, second compost and T. asperellum, and third compost and T. asperellum. Four trees with four repetitions in each treatment provided 64 trees, including the control. A line of untreated cacao trees separated the plot and block of treatments. One kilogram of compost formula was mixed with four grams of *T. asperellum* powder immediately before application. In each, one gram of *Trichoderma* consisted of around 5 x 108 spores. Each tree treated was amended with 10 kg of this compost and the fungus combination placed in four holes measuring 30 cm x 30 cm x 30 cm, respectively. These holes were aligned in East-West and North-South direction, approximately 60 cm from the cacao tree’s basal stem. Cacao leaves litter was used as mulch to cover treated holes and the cacao basal stem area to maintain humidity. The application of compost and *T. asperellum* was occurred two times, one time per year.

The experiment observed PPR incidence, VSD incidence, nickel (Ni), nitrogen (N), phosphorous (P), and potassium (K) uptake. Ten pods of the two-week-old per plot were selected for measuring PPR incidence and observed for disease presence periodically until harvest. This incidence was calculated using the formula of Inc = n/N x 100%, where Inc is the incidence, n is the number of pods infected by PPR and N, is the total of pods observed. Then, in the second year or ten months after treatment, the same formula was used for calculating PPR incidence. However, n is the number of pods infected per tree and N, is the total number of pods found in the tree. The incidence of VSD was observed monthly for over five months. Two branches per tree were sampled, and the incidence of VSD was determined by using the formula of I = x/y x 100%, where I is the incidence, x is the number of leaves showing VSD symptoms, and y is the total of leaves observed in one branch. The same sample branches were used for counting the VSD incidence in the second year at 15 months after the first application or five months after the second application.

In evaluating Ni uptake, the third and fourth leaves of cacao were sampled ten months after treatment. These leaves were oven-dried at 60°C for 48 hours and then ground into a fine powder using a mortar. After digestion of this powder with 65% HNO3 and 95% H2SO4, the samples were cooled for 30 minutes. Then, the clear solutions were filtered and brought at 50 mL with distilled deionized water. The total content of Ni was measured and then analyzed by Atomic Absorption Spectrophotometer (AAS). Samples were analyzed in triplicate, and the concentration of Ni was reported in mg kg-1 of the dry weight.

Analyses of N, P, and K content were also from the third and fourth leaves. The total N content was measured following the Kjeldahl method (Bremner 1996). The total P content was determined according to the NaOBr method (Dick and Tabatabai 1977). While K content was measured using the same manner as for nickel. All measurements were in triplicate, and concentrations are reported as a percentage.

Statistical analysis

PPR and VSD incidence in the plant, N, P, K, and Ni content in leaves and pod number per tree were analyzed using analysis of variance (ANOVA). The analysis utilized MS Excel 2013, and the data was not transformed after testing for normality using skewness and kurtosis. The least significant difference (LSD) was then used in evaluating significant differences (*P* ≤ 0.05) among the treatment means.

# RESULTS AND DISCUSSION

Impact of treatments on incidence of VSD and PPR

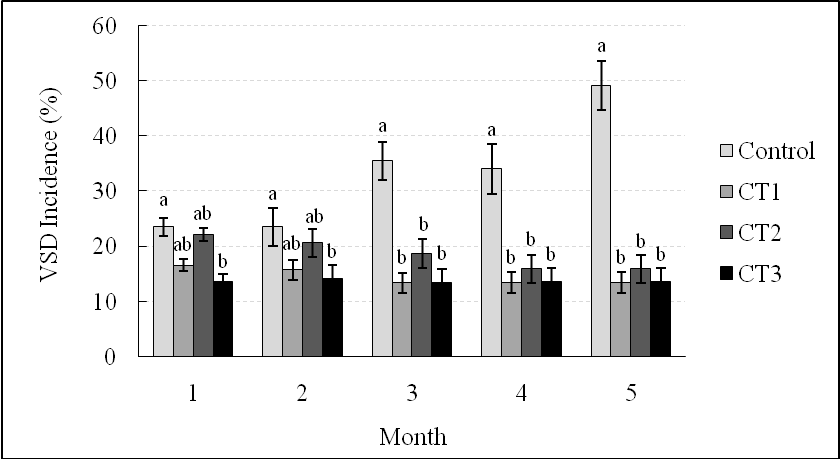
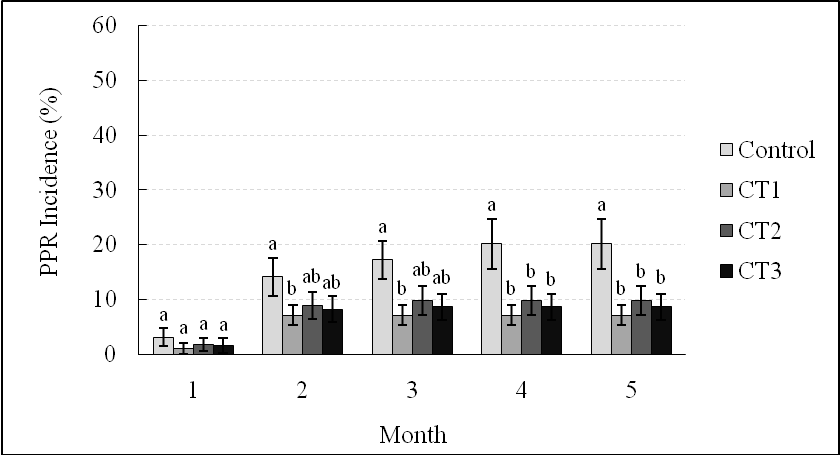
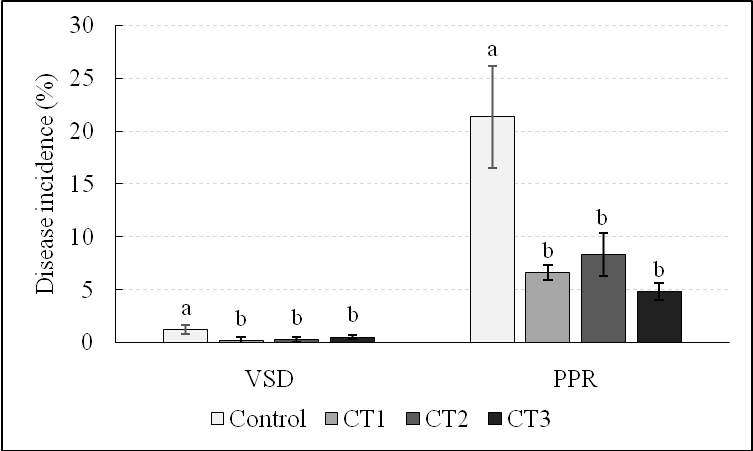
Three compost formula were made from plant residues found in the research area in Luwu Timur Regency. The first compost was formulated from leaves of gliricidia, empty stalks of the oil palm fruit, and rice straw. The second from gliricidia leaves, billygoat weed, and rice straw. While the third from gliricidia leaves, coconut husk, and rice straw. Amendments of these three composts formula plus *Trichoderma asperellum* in the field produced an effect on reducing VSD and PPR incidence. In the non-treated trees, VSD incidence was 23.5% one month and 49.2% five months post-treatment. Contrarily the incidence in the treated trees by first, second, and third compost plus *T. asperellum* was 16.6%, 22.1%, and 13,6% at one month and 13.4%, 15.9%, 13.7%, respectively at five months after treatment. At this last observation, the three treatments were significantly different (P ≤ 0.05) from the control, while each treatment was not entirely different (Figure 1). Therefore, the three composts formula’s efficacy against VSD disease at five months after application in the first year was 72.8%, 67.7%, and 72.2%, respectively.

Figure 1. Vascular streak dieback disease incidence on cacao one to five months post-treatment in the first year with composted plant residues applied to soil combined with *Trichoderma asperellum*. CT1 = first compost consisted of gliricidia leaves, empty stalks of oil palm, and rice straw plus *T. asperellum*, CT2 = second compost consisted of gliricidia leaves, billygoat weed, and rice straw plus *T. asperellum*, CT3 = third compost consisted of gliricidia leaves, coconut husk, and rice straw plus *T. asperellum*. The incidence means per month followed by the same letter are not significantly different according to the LSD (p ≤ 0.05). Vertical bars show standard errors of means.

The results also observed the exact impact of compost formula plus T. asperellum on decreasing PPR incidence. In non-treated cacao, the incidence was 3.1% one month and 20.1% five months post-application. Whereas the incidence on treated trees with first, second, and third compost plus *T. asperellum* was 1.0%, 1.8%, and 1.6% at one month and 7.1%, 9.8%, and 8.6%, respectively at five months after treatment (Figure 2). By comparing the control in the last observation, the three treatments were significantly different (p ≤ 0.05), and the treatment efficacy was 64.7%, 51.2%, and 59.2%, respectively. There was no significant difference in the incidence between each treatment.

Figure 2. Phytophthora pod rot disease incidence on cacao one to five months post-treatment with composted plant residues combined with *Trichoderma asperellum* applied through soil amendment in the first year. CT1 = first compost consisted of gliricidia leaves, empty stalk of oil palm, and rice straw plus *T. asperellum*, CT2 = second compost consisted of gliricidia leaves, billygoat weed, and rice straw plus *T. asperellum*, CT3 = third compost consisted of gliricidia leaves, coconut husk, and rice straw plus *T. asperellum*. The incidence means per month followed by the same letter are not significantly different according to the LSD (p ≤ 0.05). Vertical bars show standard errors of means.

In the second year or 15 months after the first treatment, VSD incidence reduced dramatically both untreated and treated. In the untreated was 1.2% and in the treated cacao was 0.2%. 0.3%. and 0.5% (Figure 3), resulting an efficacy of 83.3%, 75.0%, and 58.3%, respectively. Control and treatments were not significantly different (P ≤ 0.05), except for the first treatment. While, PPR incidence on the control in the second year or ten months post-first application remained at ca. 21.3%, unchanged from the first year. However, on the treated trees, PPR incidence was 6.6%, 8.3%, and 4.8%, with a resulting efficacy of 69.0%, 61.0%, and 77.5%, respectively. This efficacy was higher than that in the first year (Figure 3). The control and the treatments were significantly different, whereas each treatment was not significantly different.

Figure 3. Vascular streak dieback and Phytophthora pod rot disease incidence on cacao after treatment with the integration of composted plant residues and *Trichoderma asperellum* applied through soil amendment in the second year. CT1 = first compost consisted of gliricidia leaves, empty stalks of oil palm, and rice straw plus *T. asperellum*, CT2 = second compost consisted of gliricidia leaves, billygoat weed, and rice straw plus T. asperellum, CT3 = third compost consisted of gliricidia leaves, coconut husk, and rice straw plus *T. asperellum*. Each disease incidence means followed by the same letter are not significantly different according to the LSD (p ≤ 0.05). Vertical bars show standard errors of means.

Impact on availability of nitrogen, phosphorus, potassium, and nickel in plants

The observation of nitrogen (N), phosphorus (P), and potassium (K) at ten months after treatments showed that the content of these elements in the third and fourth leaves of untreated trees were 0.72%, 0.06%, and 0.30%, respectively. Whereas the N content in plants treated with the first, second, and third composts plus *T. asperellum* was 0.93%, 0.90%, and 0.84%. Therefore, there was a respective increase of 29.2%, 25.0%, and 16.7% by comparing to the control. The P content was 0.07%. 0.06%, and 0.06%, or an increase of 16.7%, 0.0%, and 0.0%. Further, the K content was 0.36%, 0.38%, and 0.38%, an increase by 20.0%, 26.7%, and 26.7%, respectively. Statistically, the increase of these nutrients following treatment was significantly different (*p* ≤ 0.05) with the control, just for N, whereas for P and K was not different (Table 1).

Nickel (Ni) content was detected at a concentration of 18.6 mg kg-1 in leaves of untreated cacao. In contrast, its content in cacao treated with the three compost formulations plus *T. asperellum* was 11.4 mg kg-1, 16.8 mg kg-1, and 17.1 mg kg-1, a decrease of 38.7%, 9.7%, and 8.1%, respectively (Figure 4). Only the first compost formula plus *T. asperellum* was statistically different from the control (*P* ≤ 0.05).

Impact on cacao pod production

Pod production increased after treatment with three formulations of composted plant residues plus *T. asperellum*. After a full season, the average number of pods produced on the untreated trees were 19.8 pods. Whereas in cacao trees treated the first, second, and third composts plus *T. asperellum* individual trees averaged 33.9 pods, 30.2 pods, and 28.3 pods, an increase of 71.2%, 52.5%, and 42.9%, respectively (Figure 5). All these treatments were significantly different (*p* ≤ 0.05) from the control, while the treatment each other were not significantly different.

Table 1. Content of nitrogen, phosphorus, and potassium in leaves of cacao clone MCC 02 ten months after the first treatment with three formulations of composted plant residues plus Trichoderma asperellum

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment and control | Content in leaves | | |
| Nitrogen | Phosphorus | Potassium |
| Control | 0.72 a | 0.06 a | 0.30 a |
| Fist compost + *T. asperellum* | 0.93 c | 0.07 a | 0.36 a |
| Second compost + *T. asperellum* | 0.90 bc | 0.06 a | 0.38 a |
| Third compost + *T. asperellum* | 0.84 b | 0,06 a | 0.38 a |

Each element content means followed by the same letter are not significantly different according to the LSD (*p* ≤ 0.05).

Figure 4. Content of nickel in leaves of cacao clone MCC 02 ten months after the first treatment with three formulations of composted plant residues plus *Trichoderma asperellum*. CT1 = first compost consisted of gliricidia leaves, empty stalks of oil palm, and rice straw plus *T. asperellum*, CT2 = second compost consisted of gliricidia leaves, billygoat weed, and rice straw plus *T. asperellum*, CT3 = third compost consisted of gliricidia leaves, coconut husk, and rice straw plus *T. asperellum*. The Ni content means followed by the same letter are not significantly different according to the LSD (p ≤ 0.05). Vertical bars show standard errors of means.

Figure 5. The average number of pods produced per cacao tree during the second year, ten months post-treatment with three formulations of composted plant residue formula and *Trichoderma. asperellum*. CT1 = first compost consisted of gliricidia leaves, empty stalks of oil palm, and rice straw plus *T. asperellum*, CT2 = second compost consisted of gliricidia leaves, billygoat weed, and rice straw plus *T. asperellum*, CT3 = third compost consisted of gliricidia leaves, coconut husk, and rice straw plus *T. asperellum*. The pod number means followed by the same letter are not significantly different according to the LSD (p ≤ 0.05). Vertical bars show standard errors of means.

Discussion

The work showed that the compost and *Trichoderma* combination, applied to the soil under field conditions, can reduce VSD and PPR diseases incidence. These applications also decrease the uptake of nickel (Ni) and increase uptake of nitrogen (N), phosphorus (P), and potassium (K) while increasing the production of cacao pods. Previous work has proven that the combination may diminish VSD (Rosmana et al. 2019b), however in this trial, the application gave impressive results, far greater disease suppression. Within the same period as we used here, and a compost comprising gliricidia leaves, rice straw, and billygoat added in combination with *Trichoderma*on cacao of Jalani clone, the VSD reduction was 18.3% in the first year and 26.5% in the second year (Rosmana et al., 2019b). Using the exact composition of compost plus *T. asperellum* on MCC 02 clone in this trial, the disease reduction was 67.7% and 75.0% in the first and second year, respectively. The clone MCC 02 is moderately resistant to VSD (McMahon et al. 2018; Nurlaila et al. 2020), and Jalani is highly susceptible to VSD disease. The different degrees of VSD suppression by a mixture of compost and *T. asperellum* have also been shown on clones S1, MCC 02, AP, THR, and RB (Nurlaila et al. 2020). This disparity is likely related to the interaction between host, pathogen, *Trichoderma*, and compost (Hoitink et al. 2006). We found that the first compost application, which consisted of gliricidia leaves, rice straw, and empty stalks of oil palm fruit plus *Trichoderma,*tended to reduce VSD incidence than the second and third composts plus *Trichoderma*. With high VSD suppression on treated trees, the inoculum source in the area would be minimized and consequently reduce new infections even in untreated trees. Therefore, it is likely that this disease could be eliminated from a tree or field.

Besides showing efficacy against VSD disease infecting cacao leaves and branches, the combination of compost and *T. asperellum* could reduce disease infecting pods, PPR. This disease is the most significant cause of loss in cacao production in Sulawesi, sometimes resulting in annual losses of up to 90% of pod production (Vanegtern et al. 2015). In previous work, the application of *Trichoderma* for controlling PPR was made by frequently spraying onto the pod (Hakkar et al. 2014; Sriwati et al. 2015). In this trial, we discovered that a single application of *Trichoderma* integrated-plant residues compost through soil application could control the disease significantly in a short time. The first formulation tended to offer more reduction in PPR incidence than the two others, indicating that plant residues’ composition in compost affects their activity against this disease. They consider success in controlling the two essential diseases, VSD and PPR, the possibility of general control of these diseases in reach.

The disease suppression could be due to compost alone, *Trichoderma* itself, or synergism of the two. The impact of compost application on aerial plant diseases has been shown by using olive marc and olive tree leaves to reduce foliar disease caused by *Botrytis cinerea* in Arabidopsis plants (Segarra et al. 2013). They are also, using olive marc on decreasing symptoms caused by *B. cinerea* in tomato (Fernandez et al. 2014). At the same time, Rosmana et al. (2018a; 2019b) showed that by amendment of compost consisting of gliricidia, billygoat, and rice straw can reduce VSD incidence caused by *Ceratobasidium theobromae* infecting cacao leaves and branches in the field. Numerous studies demonstrate that disease reduction following pathogen inoculation in plants treated with compost is associated with increased plant defence responses that share molecular features most similar to systemic acquired resistance (SAR) (Segarra et al. 2013; Bonanomi et al. 2020). The control capability of *T. asperellum* alone against infection of above-ground plant parts of cacao in the field has been investigated (Rosmana et al*.* 2016; Rosmana et al*.* 2019b). The stimulation of induced systemic resistance (ISR) by the fungus occurs from interaction with plant roots, as described by many researchers (Bae et al. 2011; Harman et al. 2012; Hermosa et al. 2013; Saravanakumar et al. 2016; Yuan et al*.* 2019). It has been suggested that *T. asperellum* could also act directly against the pathogen at the infection site in aerial parts by colonizing infection sites in the stem, branches, and leaf tissues (Rosmana et al. 2018b; Rosmana et al. 2019b).

*Trichoderma* integrated-compost always provides more significant disease suppression than either compost or *Trichoderma* alone (Ros et al*.* 2017; Rosmana et al. 2018a). This synergistic impact is possibly due to the stimulation of resistance through SAR and ISR simultaneously, better growth and development of *T. asperellum* in compost medium, and a better supply of nutrition for the plant. Through compost, plants employ SAR to restrict pathogen expansion in tissues by inducing necrosis at the local site upon primary infection (Segarra et al. 2013; Fernandez et al. 2014). This defence is typically characterized by the activation of SA-related genes and pathogenesis-related proteins (Segarra et al. 2013; Mehta et al. 2014). In the presence of *Trichoderma*, ISR is not only induced by colonization and the interaction with this fungus but is also initiated by pathogens (Saravanakumar et al., 2016). *Trichoderma* populations are often abundant in compost (Mehta et al. 2014; Ros et al. 2017). A high community permits *Trichoderma* to penetrate and interact continuously with the cacao tree for disease protection.

A plant’s nutrition determines in small measure its susceptibility to disease, its morphological structure, and the pathogen’s capability to survive (Schumann et al 2017). *Trichoderma* has shown useful as an activator in composted rice straw residues by enhancing the compost’s nutrient content, especially NPK (Lopez et al. 2015). Here, in the treated trees, leaf content of N, P, and K mounted. P is part of many organic molecules, including DNA, RNA, ATP, and phospholipids. In general, the increase in P can reduce plant disease incidence (Dong et al. 2019). Whereas the rise of K up to the optimal level for growth may decrease the host plant’s susceptibility to disease (Schumann et al. 2017). Contrarily, Ni content was reduced in treated trees. Nickel plays a role as an essential element, but excessive Ni can be toxic to plants. Excess Ni impairs photosynthesis and nutrient balance, resulting in the disorder of cell membrane functions and obstruction of plant growth and development (Fabiano et al. 2015). Since the tolerable limit of nickel content in cacao is around 13 mg kg-1(Kohiyama et al. 1992), we suggest decreasing nickel content in leaves from 19 mg kg-1 to 11-17 mg kg-1 could reduce its excess. Therefore, it supports plant health by diminishing Ni toxicity and cacao susceptibility to diseases (Nyczepir and Wood 2012).

The increase in cacao pod production was related to the role of growth stimulation offered by compost formula plus *T. asperellum* and decreased disease incidence. Several studies indicate that *Trichoderma* may promote plants’ growth responses by producing indole acetic acid (IAA). This hormone is responsible for lateral root development and stimulation of ethylene (ET) biosynthesis via amino cyclopropane carboxylic acid (ACC) synthase. In turn, the latter triggers an increase in abscisic acid (ABA) biosynthesis, commonly associated with plant development (Hermosa et al. 2013). A previous study on side-graft cacao shows that the application of *Trichoderma* can increase the number of shoots and branches (Rosmana et al*.* 2016). With the first compost formula, pod production tends to be higher than the second and the third formula. This difference indicated the role of compost in growth stimulation, besides *Trichoderma*.

In conclusion, composted plant residue amendments added to soil in combination with *T. asperellum* were able to suppress important above-ground diseases of cacao, VSD and PPR. With the compost composition of gliricidia leaves, empty stalks of oil palm, and rice straw, this suppression could reach 83% for VSD and 69% for PPR, and cacao pod production could increase 71%. Therefore, the treatment can be categorized as highly effective against disease and could support cacao growth.

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