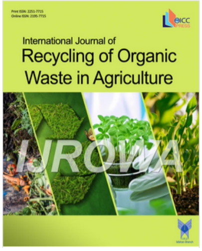

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Efficacy of bio-compost from pineapple waste coupled with indigenous fungi strains *Trichoderma* spp. on soil fertility, nutrients uptake, growth, and yield of *Ananas comosus* (L.) Merr

Nguyen Quoc Khuong[1], Truong Thi Kim Chung[1], Le Thi My Thu[1], Tran Chi Nhan[2], Lieu Mong Ca[1], Le Thanh Quang[1], Ly Ngoc Thanh Xuan[2], Ngo Thanh Phong[3,*]

[1]*Faculty of Crop Science, College of Agriculture, Can Tho University, Can Tho, Vietnam.*
[2]*Experimental and Practical Area, An Giang University, An Giang, Vietnam; Vietnam National University, Ho Chi Minh City, Vietnam.*
[3]*Department of Biology, College of Natural Sciences, Can Tho University, Can Tho, Vietnam.*

[*]**Corresponding author:** ngophong@ctu.edu.vn

Original Research

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Abstract:

Purpose: The current study aimed to figure out the types and dosages of bio-composts supplied with cellulose degrading *Trichoderma* strains for ameliorating soil properties, and the growth and yield of pineapple.
Method: The experiment with two factors followed a completely randomized block design, including 20 treatments (4 replications). The first factor (A) was the types of bio-composts inoculated with different *Trichoderma* spp., which were (i) the bio-compost supplied with the commercial *Trichoderma* (the *Trichoderma* of Can Tho University) as the positive control treatment, and the bio-compost supplied with *Trichoderma* strains of (ii) TC1 (TC1 bio-compost), (iii) TC2 (TC2 bio-compost), (iv) TC3 (TC3 bio-compost), and (v) TC1, TC2, and TC3 (TC123 bio-compost). The second factor (B) was rates of bio-compost used (t ha^{-1}) as follows: (i) 1, (ii) 2, (iii) 3, and (iv) 4.
Results: The application of TC123 bio-compost at 4 t ha^{-1} contributed to the greatest available N, soluble P, concentrations, and N, P, and K uptake values. The treatments with the TC123 bio-compost correspondingly increased plant height, leaf number, D-leaf length, peduncle height, fruit length, and fruit width by 1.9, 31.8, 16.7, 5.4, 7.8, and 12.1%, in comparison with the treatments with the positive control. The TC123 bio-compost fertilization increased fruit size, resulting in enhanced pineapple yield by 9.80% in comparison with the commercial bio-compost fertilization.
Conclusion: The TC123 bio-compost surpassed the commercial one in enhancing the characteristics of pineapples (*Ananas comosus* (L.) Merr). At 4 t.ha^{-1}, this bio-compost performed the greatest.

Keywords: Acid sulfate soil; Bio-compost; Pineapple; *Trichoderma*

1. Introduction

Pineapple (*Ananas comosus*) is a tropical plant with a short stem, long hard leaves, and above-average fruit size, which can be consumed directly or processed into various products (Hikal et al., 2021). Each hectare of pineapple annually provides roughly 188.0 tons and 270.6 tons of dry stem and leaf biomass, respectively. Thus, making use of those by-products is vital for organic cultivation and sustainable agriculture (Souza et al., 2019). In addition, chemical fertilizers provide essential nutrients for crops, which negatively affects the chemical and physiological properties of soils

(Liu et al., 2010). Moreover, long-term fertilization with chemical fertilizers changes the microbial community and the availability of nutrients, and causes other environmental issues (Guo et al., 2019). In the meantime, a tremendous number of by-products in agriculture are abandoned, while nutrient concentrations in these wastes, such as stems, leaves, and slips of pineapples, are fairly rich (Moreira et al., 2022). In particular, the nutritional concentrations of K, N, Ca, P, Mg, and S provided by pineapple shoots are 2.426, 480, 147, 101, 67, and 45 kg ha^{-1}, respectively (Souza et al., 2019). The *Trichoderma* fungi can perform cellulose degradation, biological antagonism, plant growth stimulation, and fungi elimination, which contribute to not only protecting crops from fungal pathogens but also providing nutrients for crops (Asghar and Kataoka, 2021; Kusumawati et al., 2021). Therefore, these fungi should be used to make compost from pineapple waste. Bio-composts can enhance soil fertility, provide macro- and micronutrients for crops, and promote the bacteria community in soil (Ahmad et al., 2021). The application of bio-compost improves nutrient uptake in pineapples and boosts efficiency and income for farmers (Awasthi et al., 2022). Furthermore, fertilizing bio-composts containing species of *Trichoderma* fungi is a sustainable and environmentally friendly approach that increases nutrient uptake and crop productivity (Abdullah et al., 2021). Besides, the bio-compost application can reduce chemical fertilizers used and control diseases, which results in high-quality agricultural products and reductions in environmental contamination (Hariharan et al., 2022). Bhandari et al. (2021) assume that *Trichoderma* spp. fungi are environmentally safe to control pathogens due to their minor effects on crops, soil, and human health as compared to chemical methods. That is why the study was conducted to (i) detect the best type of bio-compost containing new cellulose-degrading *Trichoderma* strains to improve the growth, and yield of pineapple as compared to a commercial *Trichoderma* product, and (ii) determine an appropriate dosage of bio-composts for improving soil characteristics, growth and yield of pineapple.

2. Materials and methods

A field experiment was carried out in Vi Thanh City, Hau Giang Province, from September 2019 to February 2021. The initial characteristics of the soil for the "Queen" pineapple cultivar (the pineapple of specialty in Hau Giang province, Vietnam) are presented in Table 1. The *Trichoderma* TC1, TC2, and TC3 strains were selected from pineapple cultivating regions in Tan Tien, Hoa Tien (Vi Thanh city), and Vinh Vien A communes, Vinh Vien town (Long My district), Hau Giang province, and stored in the Faculty of Crop Science, College of Agriculture, Can Tho University. The commercial *Trichoderma* product is the Tricho-DHCT of Can Tho University, Vietnam.

Fertilizers: Bio-composts were incubated from pineapple stems and leaves with strains of *Trichoderma* with a density of 10^8 CFU per gram of bio-compost. In particular, pineapple raw materials were collected in Hau Giang, chopped into smaller pieces, and packed into 1-ton cubes. Then, after being added with a thin layer of CaO powder, the cubes were poured with a liquid of the tested *Trichoderma* sp. and covered with a tarpaulin for 30 days (Thuy et al., 2022). The characteristics of bio-composts are included in Table 1. Bio-compost produced gradually more nutrients for plants, so they absorbed the greater nutrients, which contributed to greater nutrition accumulation as compared to conventional practices. Chemical fertilizers used consisted of Phu My nitrogen fertilizer (46% N), Long Thanh superphosphate fertilizer (16% P_2O_5), and potassium chloride (60% K_2O). The bio-compost and the chemical fertilizers were applied separately throughout the cultivation of pineapples, in which bio-compost was applied as a basal 4 days before planting the pineapple.

Procedure: The field experiment was conducted in Tan Tien commune, Vi Thanh City, Hau Giang province. The bed-to-drain ratio was 6: 4. The surface of the beds was cleaned, plowed, and fertilized with all of the bio-composts containing the *Trichoderma* strains that had been completely incubated. Pineapples were grown in queues with a distance of 0.60×0.45 m in a 5.0×5.0 m plot, with a 1.0 m distance between plots.

Experimental design: The two-factorial experiment was conducted in a completely randomized block design with 20 treatments and 4 replications each. In detail, the first factor (A) was the bio-compost incubated with *Trichoderma* spp. strains, including (i) the commercial *Trichoderma* (Tricho-DHCT) as the positive control, (ii) the *Trichoderma* sp. TC1 (TC1 bio-compost), (iii) TC2 (TC2 bio-compost), (iv) TC3 (TC3 bio-compost), and (v) the mixture of the three *Trichoderma* spp. TC1, TC2, and TC3 isolates (TC123 bio-compost). The other factor (B) was the amount of bio-compost applied (t ha^{-1}), including (i) 1, (ii) 2, (iii) 3, and (iv) 4.

Components of chemical fertilizers: The recommended formula of chemical fertilizer for pineapples in the Mekong Delta, Vietnam, was 10 g N, 9 g P_2O_5, and 8 g K_2O per plant. The fertilizer application was divided into equal 6 times and stopped one month before flowering.

Methods for analyzing soil samples

Soil samples at a depth of $0 - 20$ cm were analyzed before the plantation and at harvesting. The soil samples were collected at five sites following a diagonal cross and naturally dried at room temperature. Subsequently, samples were crushed via a 0.5- and 2.0- mm strainer to analyze parameters such as pH_{H_2O}, pH_{KCl}, EC, N_{total}, NH_4^+, P_{total}, $P_{soluble}$, Al-P, Fe-P, Ca-P, $Al_{exchangeablei}$, Fe^{2+}, Fe_2O_3, organic matter (OM), titratable acidity, and exchangeable cations (K^+, Na^+, Ca^{2+}, and Mg^{2+}), according to the soil analytic methods by Sparks et al. (1996). Particularly, the pH_{H_2O} and EC were measured with a soil-water ratio of 1: 2.5 by a pH meter. The pH_{KCl} was extracted by KCl 1.0 N at the soil-KCl ratio of 1:2.5 and measured by a pH meter. The soil titratable acidity was determined by the soil

Table 1. Initial properties of acid sulfate soil and bio-compost for cultivating pineapple.

Subject	Properties (unit)	Value
Acid sulfate soil	pH_{H_2O}	2.62
	pH_{KCl}	2.56
	$Acidity_{total}$ (meq H^+ 100 g^{-1})	18.3
	EC (mS cm^{-1})	0.64
	Fe_2O_3 (%)	0.94
	Al^{3+} (meq 100 g^{-1})	13.3
	P_{total} (%)	0.145
	$P_{available}$ (mg P kg^{-1})	5.24
	OM (%C)	3.58
	N_{total} (%)	0.221
	NH_4^+ (mg NH_4^+ kg^{-1})	78. 5
	NO_3^- (mg NO_3^- kg^{-1})	21.7
	Ca^{2+} (meq Ca^{2+} 100 g^{-1})	1.45
	Mg^{2+} (meq Mg^{2+} 100 g^{-1})	2.62
	K^+ (meq K^+ 100 g^{-1})	0.14
	Na^+ (meq Na^+ 100 g^{-1})	0.28
	Al-P (mg P kg^{-1})	37.7
	Fe-P (mg P kg^{-1})	206.8
	Ca-P (mg P kg^{-1})	33.5
Trichoderma bio-compost Can Tho University (positive control)	Total nitrogen (%)	1.65
	Total phosphorus (%)	1.72
	Total potassium (%)	1.69
	Organic matter (C%)	47.5
	C/N ratio	28.8
	Bacterial density (CFU/g)	4.25×10^5
Trichoderma bio-compost TC_1 strain	Total nitrogen (%)	1.86
	Total phosphorus (%)	1.62
	Total potassium (%)	1.44
	Organic matter (C%)	48.7
	C/N ratio	26.2
	Bacterial density (CFU/g)	4.11×10^6
Trichoderma bio-compost TC_2 strain	Total nitrogen (%)	1.76
	Total phosphorus (%)	1.82
	Total potassium (%)	1.51
	Organic matter (C%)	44.9
	C/N ratio	25.5
	Bacterial density (CFU/g)	4.27×10^6
Trichoderma bio-compost TC_3 strain	Total nitrogen (%)	1.79
	Total phosphorus (%)	1.63
	Total potassium (%)	1.66
	Organic matter (C%)	49.2
	C/N ratio	27.5
	Bacterial density (CFU/g)	3.97×10^6
Trichoderma bio-compost Mixture of TC_1, TC_2 and TC_3 strains	Total nitrogen (%)	1.92
	Total phosphorus (%)	1.76
	Total potassium (%)	1.53
	Organic matter (C%)	43.3
	C/N ratio	22.6
	Bacterial density (CFU/g)	4.62×10^6

Values are the mean of three replications.

extraction method, in which soils were extracted by KCl 1.0 M with a soil-KCl 1.0 M ratio of 1:12.5, and titrated by the color indicator, phenolphthalein 1%, and NaOH 0.01 N until the solution turned stable pink for 1 min. The N_{total} content was determined by the Kjeldahl distilling method. The NH_4^+ concentration was determined by the colorimetric comparison method by a spectrometer at the 650 nm wavelength. The P_{total} content was colorized by the acid ascorbic reduction and measured by a spectrometer at the 880 nm wavelength after soil samples were digested by a mixture of perchloric acid and $H_2SO_{4\ saturated}$. The $P_{soluble}$ concentration was determined by the Bray 2 method. The fractions of $P_{insoluble}$ (Al-P, Fe-P, and Ca-P) were extracted by NH_4F 0.5 M, NaOH 0.1 M, and H_2SO_4 0.25 M, respectively. To determine the $Al_{exchangeable}$ concentration, soils were extracted by KCl 1 N, colorized by a mixture of 8-hydroxyquinoline 1%, hydroxylamine hydrochloride, sodium acetate 1 M, phenanthroline 0.2%, and butyl acetate, and measured by a spectrometer at the 395 nm wavelength. The Fe^{2+} concentration was extracted by KCl 1 M with a soil-KCl 1 N ratio of 10:25, colorized by a mixture of ammonia acetate-acetic acid, hydroxylamine chloride 10%, and octophenoltroline 0.25%, and measured by the colorimetric comparison method at the 520 nm wavelength. The free Fe_2O_3 content was determined by the reaction with the sodium dithionite reductant, $Na_2S_2O_4$, which made a complex with H4-EDTA at a soil-solution ratio of 0.5:25, and measured by an atomic absorption spectrometer (ASS) at the 248.3 nm wavelength. The OM content was determined according to the Walkley-Black method, in which samples were oxidized by a mixture of $H_2SO_{4\ saturated}$ - $K_2Cr_2O_7$, and titrated by $FeSO_4$. The cation exchange capacity (CEC) was extracted by $BaCl_2$ 0.1 M, and titrated by EDTA 0.01 M. The K^+, Ca^{2+}, and Mg^{2+} concentrations from the CEC extract were measured by an ASS at the respective wavelengths of 766.5, 422.7, and 285.2 nm.

Methods for analyzing plant samples: Each plant part was dried at 70° C for 48 h. Dry samples were ground through a 0.5 mm sieve by a plant grinding machine. The N nutritional content was determined according to the Kjeldahl distilling method, the P nutritional content was determined by the ascorbic acid method at the 880 nm wavelength, and the K nutritional content was determined by an ASS at the 766.5 nm wavelength.

Plant growth: Plant heights (cm), leaf numbers (leaves/plant), D-leaf lengths, and D-leaf widths (cm) were determined after 420 days after plantation (DAP).

Yield components: Fruit diameters, fruit lengths, peduncle heights, crown lengths, and crown widths (cm) were determined at harvesting.

Yield: The yield per 5 m^2 was weighed in each 25 m^2 treatment at harvesting, and converted into t ha^{-1}.

Fruit quality: The titratable acidity (TA) and vitamin C concentration in fruit flesh were determined according to the method of the Association of Official Analytical Chemists (AOAC, 1990).

Dry biomass (kg ha^{-1}): Parts of pineapple plants and fruits, including crown, flesh, core, shell, slip, peduncle, butt, and leaf, were dried continuously at 70° C until the weight remained.

The formula for calculating N, P, and K uptake (kg ha^{-1}): N uptake = dry biomass (kg ha^{-1}) in each plant part x the N nutritional content (%) in that part. Similar calculations were applied to the P and K uptake values.

Statistical analysis: The data were processed by Microsoft Excel 2010. Statistical analysis was processed by SPSS 13.0. The ANOVA was tested by Duncan's test at the 5% significance level to evaluate differences between means of different treatments.

3. Results and discussion

Effects of *Trichoderma* bio-compost on acid sulfate soil fertility

The area of acid sulfate soil is made from the sulfidation and sulfurization of iron and aluminum ions (Fanning et al., 2017), so the toxic concentrations of Al^{3+} and Fe^{2+} are high and the nutritious contents of N and P are low, inhibiting farming (Ng et al., 2022). This indicated that concentrations of nutrients and toxins are correlated with pH values. Thus, an approach to improving the soil pH to increase nutritious availability and decrease toxic solubility is needed. As reported by Wang et al. (2019), applying inorganic fertilizers results in a decreased soil pH average of 0.07 annually, but combining the application of both organic and inorganic fertilizers increases the soil pH roughly by 0.04, contributing to enhancing the nutritional availability in acid sulfate soil. In the current study, the supplementation of bio-composts improved the pH_{H_2O} values. To be more specific, the treatments with the TC1, TC2, TC3, and TC123 bio-composts resulted in greater pH_{H_2O} values (3.15 – 3.25) than the positive control with the commercial bio-compost (3.09). The OM, NH_4^+, Al^{3+}, and Fe^{2+} concentrations of the treatment with the TC123 bio-compost and the positive control were equivalent. The bio-composts made of different types of *Trichoderma* spp. featured with the NPK contents of 1.65 – 1.92%, 1.62 – 1.82%, and 1.44 – 1.69%, the organic matter of 43.3 – 49.2 C% and the bacterial density of $3.97 \times 10^6 - 4.62 \times 10^6$ (Table 1). These results are greater than bio-composts degraded by different *Trichoderma* strains in the study by Jahangir et al. (2021) on cattle manure. However, the bacterial density in the current bio-composts was lower than that in the study by Thuy et al. (2022) on bio-composts degraded by *Trichoderma* reesei, though the total N of the current bio-composts was superior. This could be due to the difference among the strains themselves, which led to different properties of bio-compost. On the other hand, this could be due to the differences in the material used for the composting. Therefore, the three *Trichoderma* strains TC1, TC2, and TC3, and their mixture should be further tested on different types of local substrates. Moreover, the TC123 bio-compost showed a greater amount of N, and P nutrients than the positive control one. This explained why the treatment with the TC123 bio-compost had the soil NO_3^- concentration and $P_{soluble}$ content valued at 42.5 and 28.7 mg kg^{-1}, which were greater than those in the positive control treatment

Table 2. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on the fertility of acid sulfate soil (in a depth of 0 – 20 cm) cultivated pineapple.

Factor		pH_{H_2O} -	OM (%C)	NO_3^- (mg kg^{-1})	NH_4^+ (mg kg^{-1})	$P_{soluble}$ (mg kg^{-1})	K^+ (meq 100 g^{-1})	Al^{3+} (meq 100 g^{-1})	Fe^{2+} (mg kg^{-1})
Bio-compost containing fungi strain *Trichoderma* sp. (A)	Control	3.09^b	4.82^{ab}	36.6^d	36.7^a	20.5^b	0.152	5.55^d	303.7^{ab}
	TC_1	3.25^a	4.90^a	36.1^d	29.3^b	19.1^c	0.184	6.43^c	249.8^c
	TC_2	3.21^a	4.73^b	39.9^b	34.7^a	17.1^d	0.196	6.76^b	273.6^{bc}
	TC_3	3.15^{ab}	1.58^c	38.0^c	29.3^b	17.4^d	0.179	7.45^a	288.9^{ab}
	TC_{123}	3.19^a	4.81^{ab}	42.5^a	34.4^a	28.7^a	0.169	5.60^d	316.1^a
Bio-compost level (t ha^{-1}) (B)	1	3.18	4.59^c	31.9^d	28.8^c	17.6^d	0.167	6.73^a	274.4
	2	3.18	4.58^c	37.1^c	31.0^{bc}	18.7^c	0.183	6.55^{ab}	295.1
	3	3.20	4.82^b	40.7^b	34.0^b	21.6^b	0.166	6.32^b	279.2
	4	3.15	5.08^a	44.7^a	37.6^a	24.2^a	0.186	5.82^c	297.0
Significant differences	F (A)	*	**	**	**	**	ns	**	**
	F (B)	ns	**	**	**	**	ns	**	ns
	F (A x B)	ns	**	**	ns	**	ns	ns	**
CV (%)		4.08	4.05	4.44	15.3	6.67	29.4	7.39	16.3

In a column, the different superscripts indicate significant differences at 5% significance (*) or at 1% significance (**), and without a letter, there is no significant difference according to Duncan's post-hoc test at the 5% level (ns).

(36.6 and 20.5 mg kg^{-1}, respectively). Moreover, the Al^{3+} concentrations in the soil went on a downward trend during the treatments with bio-compost and fluctuated from 5.55 to 7.45 meq 100 g^{-1}, when compared to that in the soil at the beginning of the crop, whose value was 13.3 meq 100 g^{-1} (Table 2). However, only in the treatment with the TC123 bio-compost, the Al^{3+} concentration was not statistically different from that in the positive control, which was all lower than those in the treatments with each *Trichoderma* strain (Table 2).

Among the amounts of bio-compost at 1, 2, 3, and 4 t ha^{-1}, the pH_{H_2O} values, K^+, and Fe^{2+} concentrations did not significantly change, and fluctuated from 3.15 to 3.20, from 0.166 to 0.186 meq 100 g^{-1}, and from 274.4 to 297.0 mg kg^{-1}, respectively. The OM, NO_3^-, NH_4^+, and $P_{soluble}$ contents gradually increased following 1, 2, 3, and 4 t ha^{-1}. Between amounts of bio-composts containing *Trichoderma* strains, there were interactions in OM, NO_3^-, $P_{soluble}$, and Fe^{2+} concentrations (Table 2). Besides, the difference between the C/N ratio of the different bio-composts is also important. The suitable ratio of C/N for a good bio-compost is roughly 20 – 30 (Ji et al., 2023; Li et al., 2022). This is consistent with the current study, where the C/N ratio among bio-composts was 22.6 – 28.8. The C/N ratio can show the process of degradation in compost. The C/N ratio reduces when organic materials are degraded along the N fixation by microbes (Biruntha et al., 2020; Sharma et al., 2023). In other words, the lower the C/N ratio in bio-compost is, the better it can be (Biruntha et al., 2020). Thereby, the lowest C/N ratio was found in the TC123 bio-compost (22.6), which can be considered the best bio-compost in the current study. This could be due to the synergistic interactions between the TC1, TC2, and TC3 strains. As can be seen in Table 1, the TC1 bio-compost showed great N content, while the TC2 bio-compost resulted in great P content, and great K content was found in the TC3 bio-compost. The synergy of *Trichoderma* spp. with other species has also been found in some previous studies (Batool et al., 2020; Poveda and Eugui, 2022). Ultimately, because the TC123 bio-compost showed better properties than the positive control one, applying the TC123 bio-compost increased pH_{H_2O}, NO_3^-, and $P_{soluble}$ by 3.24, 16.12, and 40.00%, respectively in comparison with the positive control. Therein, applying bio-composts at 4 t ha^{-1} enhanced OM, NO_3^-, NH_4^+, and $P_{soluble}$ by 10.68, 40.13, 30.56, and 37.50%, respectively, and the Al^{3+} concentration was reduced by 13.52% in comparison with the treatment with bio-composts at 1 t ha^{-1}. This result was in accordance with the study by Moyin-Jesu (2018), which found that applying organic fertilizers increases pH_{H_2O} by 29.41 – 40.00% in comparison with the treatment with only chemical fertilizers on pineapple soil. In addition, applying bio-compost resulted in a pH of 7.14, which was greater than that of the treatment with only inorganic fertilizers, at 5.10 (Moyin-Jesu, 2018).

Effects of *Trichoderma* bio-compost on biomass, and N, P and K uptakes of pineapple plants

Effects of bio-composts on the biomass of pineapples in acid sulfate soil

Trichoderma fungi are capable of degrading plant residues and promoting plant growth (Kusumawati et al., 2021). Thus, the balance of fertilization between organic and inorganic fertilizers contributes to providing macro- and micronutrients in sufficient amounts for crops, which, thereby, increases the efficiency of using nutrients and the yield of the crops (Rothe et al., 2019). Soil nutrients originate from the process of mineralizing OM via the activities of microbes that decompose organic polymers to provide nutrients for roots to absorb (Dhaliwal et al., 2019), leading to greater biomass within the crops. The treatments with the bio-compost-TC123 resulted in greater

Table 3. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on biomass parts of pineapple cultivated on acid sulfate soil at harvest.

Factor		Biomass (kg ha^{-1})							
		Crown	Flesh	Core	Shell	Slips and suckers	Peduncle	Butt	Leaf
Bio-compost containing fungi strain *Trichoderma* sp. (A)	Control	462.5^{b}	1083.8^{c}	298.1^{c}	1021.6^{c}	893.3^{c}	302.9^{bc}	1060.5^{a}	5517.5^{d}
	TC_1	404.4^{d}	1122.2^{b}	280.3^{d}	913.5^{d}	991.6^{b}	311.6^{b}	835.3^{d}	5310.2^{e}
	TC_2	375.7^{e}	1096.5^{c}	322.0^{b}	1009.1^{c}	904.0^{c}	338.1^{a}	952.4^{b}	5961.7^{b}
	TC_3	444.0^{c}	1007.1^{d}	284.0^{d}	1048.4^{b}	721.9^{d}	296.9^{c}	920.2^{c}	5690.0^{c}
	TC_{123}	487.7^{a}	1331.5^{a}	333.3^{a}	1215.4^{a}	1024.5^{a}	342.8^{a}	1072.9^{a}	6588.1^{a}
Bio-compost level (t ha^{-1}) (B)	1	369.0^{d}	1026.1^{d}	269.0^{d}	947.7^{d}	764.9^{d}	283.3^{d}	837.5^{d}	5218.9^{d}
	2	438.5^{c}	1102.9^{c}	293.5^{c}	1021.5^{c}	877.0^{c}	309.2^{c}	947.5^{c}	5657.7^{c}
	3	450.3^{b}	1151.3^{b}	315.5^{b}	1072.3^{b}	960.7^{b}	333.1^{b}	1027.1^{b}	6022.7^{b}
	4	481.6^{a}	1232.6^{a}	336.2^{a}	1125.0^{a}	1024.6^{a}	348.3^{a}	1060.9^{a}	6354.7^{a}
Significant differences	F (A)	**	**	**	**	**	**	**	**
	F (B)	**	**	**	**	**	**	**	**
	F (A x B)	**	**	**	**	**	**	**	**
CV (%)		4.00	2.31	2.54	1.73	2.93	4.31	4.07	4.17

In a column, the different superscripts indicate significant differences at 5% significance (*) or at 1% significance (**), and without a letter, there is no significant difference according to Duncan's post-hoc test at 5% level (ns). Butt (stem with leaves stripped off); suckers: arial suckers and ground suckers.

biomass in the crown, flesh, core, slip, peduncle, butt, and leaf of pineapples at 5% significance than those resulted from the treatments with TC1, TC2, or TC3 bio-compost and the positive control. Furthermore, the treatment with the TC123 bio-compost resulted in the greatest biomass in crown, flesh, core, slip, peduncle, and leaf, which were 487.7, 1331.5, 333.3, 1215.4, 1024.5, 342.8, and 6588.1 kg ha^{-1}, respectively. Exceptionally, biomass in the peduncle of the treatment with the TC123 bio-compost was 342.8 kg ha^{-1}, which was equivalent to that of the treatment with the TC2 bio-compost (338.1 kg ha^{-1}). In butt, the biomass of the treatment with TC123 bio-compost and the positive control was equivalent, with 1072.9 and 1060.5 kg ha^{-1}, respectively (Table 3). Increasing the dosage of bio-compost resulted in increased dry biomass in pineapple. Applying bio-compost at 4 t ha^{-1} resulted in the greatest biomass in

Table 4. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on N uptake in parts of pineapple cultivated on acid sulfate soil at harvest.

Factor		N uptake (kg ha^{-1})							
		Crown	Flesh	Core	Shell	Slips and suckers	Peduncle	Butt	Leaf
Bio-compost containing fungi strain *Trichoderma* sp. (A)	Control	4.81^{a}	12.0^{c}	3.24^{b}	11.7^{b}	8.07^{c}	2.91^{b}	17.9^{c}	63.7^{c}
	TC_1	4.50^{b}	12.8^{b}	2.71^{c}	9.36^{d}	8.48^{c}	2.84^{b}	14.8^{d}	62.9^{c}
	TC_2	4.17^{c}	12.6^{bc}	3.14^{b}	10.4^{c}	9.41^{b}	3.24^{a}	19.6^{b}	72.9^{b}
	TC_3	4.62^{ab}	12.4^{bc}	3.31^{b}	11.5^{b}	7.31^{d}	2.30^{c}	20.0^{b}	63.4^{c}
	TC_{123}	4.73^{ab}	16.7^{a}	3.72^{a}	14.0^{a}	11.2^{a}	3.43^{a}	27.8^{a}	78.5^{a}
Bio-compost level (t ha^{-1}) (B)	1	3.63^{d}	11.0^{d}	2.50^{d}	9.65^{d}	6.76^{d}	2.12^{d}	15.2^{c}	57.2^{d}
	2	4.48^{c}	12.9^{c}	3.06^{c}	11.3^{c}	8.55^{c}	2.86^{c}	19.4^{b}	66.3^{c}
	3	4.70^{b}	14.2^{b}	3.39^{b}	11.9^{b}	9.38^{b}	3.09^{b}	21.6^{a}	71.1^{b}
	4	5.44^{a}	15.1^{a}	3.96^{a}	12.9^{a}	10.9^{a}	3.15^{a}	22.2^{a}	78.6^{a}
Significant differences	F (A)	**	**	**	**	**	**	**	**
	F (B)	**	**	**	**	**	**	**	**
	F (A x B)	**	**	**	ns	**	**	**	**
CV (%)		0.32	0.93	0.26	0.77	0.84	0.35	1.59	5.45

In a column, the different superscripts indicate significant differences at 5% significance (*) or at 1% significance (**), and without a letter, there is no significant difference according to Duncan's post-hoc test at the 5% level (ns). Butt (stem with leaves stripped off); suckers: arial suckers and ground suckers.

the crown, flesh, core, shell, slip, peduncle, butt, and leaf, whose values were 481.6, 1232.6, 336.2, 1125.0, 1024.6, 348.3, 1060.9, and 6354.7 kg ha^{-1}, respectively, while the lowest result was found in the treatment with 1 t ha^{-1} of bio-compost, with 369.0, 1026.1, 269.0, 947.7, 764.9, 283.3, 837.5, and 5218.9 kg ha^{-1}, respectively. There was an interaction between types and dosages of bio-compost in all of the pineapple parts (Table 3). Ultimately, Table 3 illustrated that dry biomass values in crown, flesh, core, shell, slip, peduncle, and leaf in pineapple treated with the TC123 bio-compost increased from 5.4 to 22.9% in comparison with the positive control. Moreover, with the aspect of bio-compost dose, applying bio-compost at 4 t ha^{-1} increased dry biomass by 18.7 – 34.0% in comparison with the treatment with bio-compost at 1 t ha^{-1}.

Effects of bio-composts on N, P, and K uptake of pineapples in acid sulfate soil

Tables 4, 5, and 6 showed that N, P, and K uptakes in flesh, core, shell, slip, peduncle, butt, and leaf of the treatment with the TC123 bio-compost increased by 13.5 – 55.3% N, 8.7 – 71.4% P and 21.2 – 80.0% K in comparison with the positive control. In addition, applying bio-composts at 4 t ha^{-1} contributed to increasing N content in the crown, flesh, core, shell, slip, peduncle, butt, and leaf in pineapples, whose results were 37.3 – 61.2% N, 13.7 – 45.5% P, and 43.9 – 73.3% K in comparison with the treatment with bio-composts at 1 t ha^{-1}.

To be more specific, applying the TC123 bio-compost resulted in the greatest N uptake values in flesh, core, shell, slip, butt, and leaf, and valued at 16.7, 3.72, 14.0, 11.2, 27.8, and 78.5 kg ha^{-1}, respectively. In addition, the N uptake value in the crown of the treatment with the TC123 bio-compost was 4.73 kg ha^{-1} which was equivalent to the positive control (4.81 kg ha^{-1}), and the treatment with the TC3 bio-compost (4.62 kg ha^{-1}), but greater than the treatments with the TC1 or TC2 bio-composts (4.50 and 4.17 kg ha^{-1}, respectively). Likewise, the N uptake value in the peduncle of the treatment with the TC123 bio-compost was 3.43 kg ha^{-1}, equivalent to the treatment with the TC2 bio-compost (3.24 kg ha^{-1}), and greater than the positive control (2.91 kg ha^{-1}) (Table 4). The greatest N uptake values were found in the crown, flesh, core, shell, slip, peduncle, butt, and leaf in the treatment with bio-composts at 4 t ha^{-1}, and the lowest ones were in the treatment with bio-composts at 1 t ha^{-1}. Between types and dosages of bio-composts, there was an interaction at 1% significance in the N uptake in every pineapple part, except for the shell.

Applying the TC123 bio-compost resulted in the greatest P uptake values in crown, flesh, core, shell, slip, butt, and leaf, with 1.53, 4.33, 0.650, 3.50, 3.31, 3.29, and 16.9 kg ha^{-1}, respectively. The P uptake values in crown, flesh, shell, peduncle, and butt of the treatment with bio-composts at 4 t ha^{-1} were 1.41, 3.48, 3.25, 0.558, and 2.55 kg ha^{-1}, equivalent to the treatment with bio-composts at 3 t ha^{-1} (1.38, 3.45, 3.19, 0.540, and 2.44 kg ha^{-1}, respectively) (Table 5). These two bio-compost levels resulted in greater P uptake values in the crown, flesh, shell, peduncle, and butt in the treatments with bio-composts at 2 or 1 t ha^{-1}. Between types and dosages of bio-composts, there was an interaction at the 1% significance level in the P uptake in the crown, flesh, core, shell, slip, butt, and leaf of pineapples (Table 5).

The K uptake values in parts of pineapple of the treatments with TC123, TC1, TC2, or TC3 bio-compost in core, peduncle, and leaf fluctuated roughly 4.31 – 5.00, 8.80 – 12.2, and 100.0 – 154.6 kg ha^{-1}, and were greater

Table 5. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on P uptake in parts of pineapple cultivated on acid sulfate soil at harvest.

Factor		P uptake (kg ha^{-1})							
		Crown	Flesh	Core	Shell	Slips and suckers	Peduncle	Butt	Leaf
Bio-compost containing fungi strain *Trichoderma* sp. (A)	Control	1.31^{c}	3.17^{b}	0.523^{c}	3.22^{b}	2.53^{cd}	0.381^{e}	1.92^{c}	12.1^{c}
	TC_1	1.06^{d}	2.68^{d}	0.401^{d}	2.44^{d}	2.65^{c}	0.478^{c}	1.29^{e}	9.90^{e}
	TC_2	1.09^{d}	2.97^{c}	0.556^{b}	2.78^{c}	2.85^{b}	0.585^{a}	2.93^{b}	11.2^{d}
	TC_3	1.40^{b}	3.12^{bc}	0.544^{bc}	3.32^{b}	2.40^{d}	0.418^{d}	1.53^{d}	14.0^{b}
	TC_{123}	1.53^{a}	4.33^{a}	0.650^{a}	3.50^{a}	3.31^{a}	0.552^{b}	3.29^{a}	16.9^{a}
Bio-compost level (t ha^{-1}) (B)	1	1.01^{c}	3.06^{b}	0.479^{c}	2.74^{c}	2.20^{d}	0.388^{c}	1.84^{b}	11.4^{e}
	2	1.31^{b}	3.04^{b}	0.530^{b}	3.02^{b}	2.65^{c}	0.446^{b}	1.95^{b}	12.0^{c}
	3	1.38^{a}	3.45^{a}	0.537^{b}	3.19^{a}	2.94^{b}	0.540^{a}	2.44^{a}	13.2^{b}
	4	1.41^{a}	3.48^{a}	0.593^{a}	3.25^{a}	3.20^{a}	0.558^{a}	2.55^{a}	14.7^{a}
Significant differences	F (A)	**	**	**	**	**	**	**	**
	F (B)	**	**	**	**	**	**	**	**
	F (A x B)	**	**	**	**	**	**	**	**
CV (%)		6.86	7.13	6.97	6.43	8.04	8.69	11.0	7.22

In a column, the different superscripts indicate significant differences at 5% significance (*) or at 1% significance (**), and without a letter. there is no significant difference according to Duncan's post-hoc test at 5% level (ns). Butt (stem with leaves stripped off); suckers: arial suckers and ground suckers.

than the positive control, with 3.80, 8.25, and 85.9 kg ha^{-1}, respectively. In addition, the treatment with TC123 resulted in the greatest K uptake values in flesh, shell, slip, peduncle, and butt, with 23.1, 20.0, 43.1, and 50.9 kg ha^{-1}, respectively. The K uptake values in the crown between the treatment with the TC123 bio-compost and the positive control were equivalent to each other (Table 6). The K uptake in parts of pineapple planted in AS soils rose according to the amounts of bio-compost from 1 to 4 t ha^{-1}. The greatest K uptake values in crown, flesh, core, shell, slip, peduncle, butt, and leaf resulted from the treatment with bio-composts at 4 t ha^{-1}, with 15.0, 20.5, 5.31, 17.6, 33.1, 11.6, 50.3, and 133.5 kg ha^{-1}, while the treatment with bio-composts at 1 t ha^{-1} resulted in the lowest K uptake values, with 9.62, 12.8, 3.43, 11.8, 19.1, 8.05, 31.4, and 92.8 kg ha^{-1}, respectively. There was an interaction between types and amounts of bio-compost for K uptake values in every pineapple part, except for the leaf (Table 6).

Effects of bio-composts on total N, P and K uptake of pineapples on acid sulfate soil

From the uptakes in part of the pineapples, the total uptake values of N, P, and K of the treatment with the TC123 bio-compost at 4 t ha^{-1} were the greatest (Figs. 1, 2, 3).

The greatest total N uptake in pineapples was found in the treatment with the TC123 bio-compost at 4 t ha^{-1} (176.1 kg N ha^{-1}); the second greatest was at 2 and 3 t ha^{-1} treatments, where the total N uptake values were equivalently 162.3 and 164.3 kg N ha^{-1}, which were all greater than the results of the positive control and the treatments with TC1, TC2, or TC3 bio-composts at the same dosage at 2, 3 and 4 t ha^{-1}, i.e. their values were 118.9, 131.6, 150.0 kg N ha^{-1}; 118.5, 119.0, 138.1 kg N ha^{-1}; 130.9, 144.0, 153.4 kg N ha^{-1}; and 113.8, 137.3, 145.7 kg N ha^{-1}, respectively (Fig. 1). Simultaneously, at the same bio-compost dosage of 1 t ha^{-1}, the treatment with the TC123 bio-compost resulted in a total N uptake value of 129.4 kg N ha^{-1}, which was greater than that of the positive control (97.6 kg N ha^{-1}) and the treatments with the TC1, TC2, or TC3 bio-compost, whose results were 98.1, 113.5, and 102.3 kg N ha^{-1}, respectively. Increasing the rate of bio-compost from 1, 2, 3, and 4 t ha^{-1} resulted in increased total N uptake values in pineapples. In particular, when the bio-compost rose from 1 to 4 t ha^{-1}, the total N uptake increased from 129.4 to 176.1 kg N ha^{-1} in the treatment with the TC123 bio-compost, from 113.5 to 153.4 kg N ha^{-1} in the treatment with the TC2 bio-compost, from 98.1 to 138.1 kg N ha^{-1} in the treatment with the TC1 bio-compost, from 102.3 to 145.7 kg N ha^{-1} in the treatment with the TC3 bio-compost, and from 97.6 to 150.0 kg N ha^{-1} in the positive control.

The treatment with the TC123 bio-compost at 4 t ha^{-1} resulted in the greatest total P uptake value of 37.3 kg P ha^{-1}. The second greatest total P uptake belonged to the treatment with the TC123 bio-compost at 3 t ha^{-1} (35.5 kg P ha^{-1}), which was greater than the positive control and the treatments with TC1, TC2, or TC3 bio-compost at the same 3 t ha^{-1} and even 4 t ha^{-1}, whose results were 25.9, 28.2 kg P ha^{-1}; 21.9, 23.1 kg P ha^{-1}; 27.4, 28.5 kg P ha^{-1}, and 27.6, 31.7 kg P ha^{-1}, respectively. The treatment with the TC123 bio-compost at 1 or 2 t ha^{-1} resulted in equivalent total P uptake values (31.4 and 32.0 kg P ha^{-1}) to the treatment with the TC3 bio-compost at 4 t ha^{-1} (31.7 kg P ha^{-1}), which was greater than those of the positive control and the treatments with TC1 or TC2 bio-compost at the dosage from 1 to 4 t ha^{-1}. Increasing the dosage of

Table 6. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on K uptake in parts of pineapple cultivated on acid sulfate soil at harvest.

Factor		K uptake (kg ha^{-1}) Crown	Flesh	Core	Shell	Slips and suckers	Peduncle	Butt	Leaf
Bio-compost containing fungi strain *Trichoderma* sp. (A)	Control	16.4^a	15.3^c	3.80^c	12.3^c	24.6^b	8.25^d	42.0^b	85.9^e
	TC_1	10.4^b	17.9^b	4.32^b	12.1^c	25.2^b	8.80^c	38.1^d	107.7^c
	TC_2	10.0^b	13.7^d	5.00^a	15.8^b	19.7^c	10.5^b	40.0^c	128.9^b
	TC_3	10.1^b	13.8^d	4.31^b	15.0^b	19.1^c	10.1^b	36.7^d	100.0^d
	TC_{123}	16.5^a	23.1^a	4.95^a	20.0^a	43.1^a	12.2^a	50.9^a	154.6^a
Bio-compost level (t ha^{-1}) (B)	1	9.62^d	12.8^d	3.43^d	11.8^d	19.1^d	8.05^d	31.4^d	92.8^d
	2	12.5^c	16.3^c	4.37^c	14.6^c	24.9^c	9.65^c	39.7^c	109.6^c
	3	13.6^b	17.4^b	4.79^b	16.1^b	28.2^b	10.5^b	44.7^b	125.8^b
	4	15.0^a	20.5^a	5.31^a	17.6^a	33.1^a	11.6^a	50.3^a	133.5^a
Significant differences	F (A)	**	**	**	**	**	**	**	**
	F (B)	**	**	**	**	**	**	**	**
	F (A x B)	**	**	**	*	**	**	**	ns
CV (%)		7.88	9.11	8.05	9.93	6.16	5.63	5.85	8.10

In a column, the different superscripts indicate significant differences at 5% significance (*) or at 1% significance (**), and without a letter, there is no significant difference according to Duncan's post-hoc test at 5% level (ns). Butt (stem with leaves stripped off); suckers: arial suckers and ground suckers.

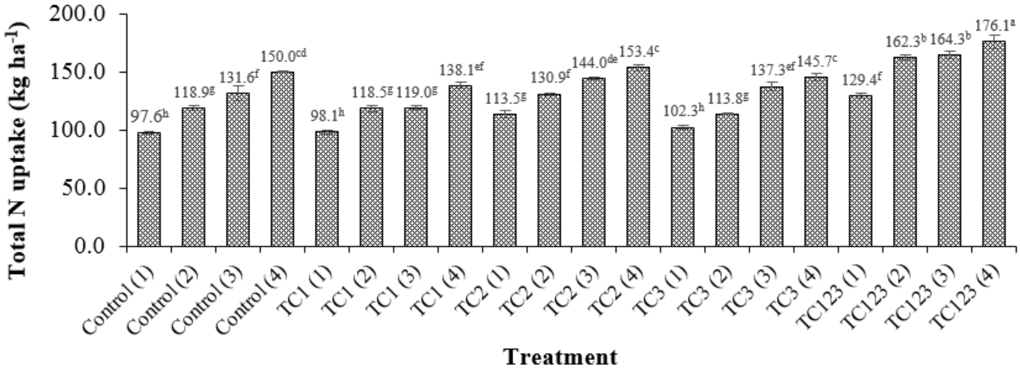

Figure 1. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on total N uptake of pineapple cultivated on acid sulfate soil at harvest.
The mean of four replications and its standard deviation are presented; while different letters above the bars reveal significant differences at $P < 0.05$; ns is for no significant difference at $P > 0.05$. The numbers within the parentheses indicate the amount of bio-compost applied (t ha^{-1}).

bio-compost from 1, 2, 3, to 4 t ha^{-1} enhanced the total P uptake in pineapple. In detail, the total P uptake rose when the bio-compost rate went up from 1 to 4 t ha^{-1} in the treatment with the bio-compost TC123 and valued from 31.4 to 37.3 kg P ha^{-1}, from 24.1 to 31.7 kg P ha^{-1} in the treatment with the TC3 bio-compost, from 20.8 to 28.5 kg P ha^{-1} in the treatment with the TC2 bio-compost, from 17.3 to 23.1 kg P ha^{-1} in the treatment with the TC1 bio-compost, and from 22.0 to 28.2 kg P ha^{-1} in the positive control (Fig. 2).

The greatest total K uptake value in pineapples was found in the treatment with the TC123 bio-compost at 4 t ha^{-1} and valued at 374.0 kg K ha^{-1}; the second greatest was at the 3 t ha^{-1} level for the total K uptake of 355.9 kg K ha^{-1}; and the third greatest was in the treatment with 2 t ha^{-1} and resulted in 314.0 kg K ha^{-1}, which were all greater than the positive control and treatments with individual TC1, TC2, or TC3 bio-compost at the bio-compost level of 4 t ha^{-1}, whose results were 256.4, 265.4, 284.6, and 252.2 kg K ha^{-1}, respectively. Increasing the bio-compost level from 1 to 4 t ha^{-1} resulted in increased total K uptake values in pineapples. In other words, the total K uptake peaked in the treatment with bio-composts at 4 t ha^{-1} and bottomed in the treatment with bio-composts at only 1 t ha^{-1} (Fig. 3).

Ultimately, an improvement in nutrient uptake resulted from applying *Trichoderma* in addition to organic fertilizers (Kamal et al., 2018). *Trichoderma* helps to ameliorate soil chemical characteristics (Asghar and Kataoka, 2021). According to Khan et al. (2017), applying inorganic fertilizers in addition to cellulose-degrading *Trichoderma* sp. contributes to providing organic matter for plants, leading to increased nutrient uptake in the plants because the *Trichoderma* can decompose organic complex substances in the soil (Wahyuni and Nasution, 2019).

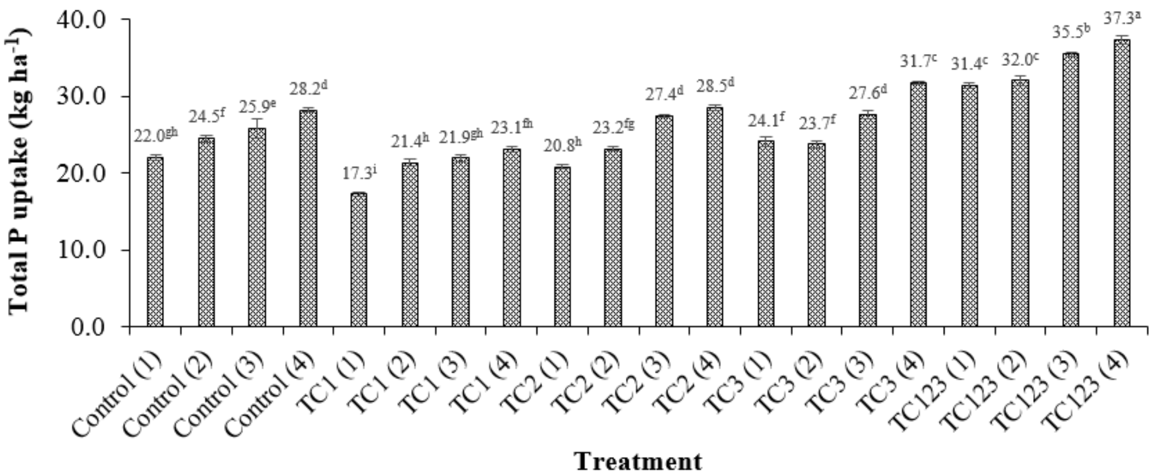

Figure 2. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on total P uptake of pineapple cultivated on acid sulfate soil at harvest.
The mean of four replications and its standard deviation are presented, while different letters above the bars reveal significant differences at $P < 0.05$; ns is for no significant difference at $P > 0.05$. The numbers within the parentheses indicate the amount of bio-compost applied (t ha^{-1}).

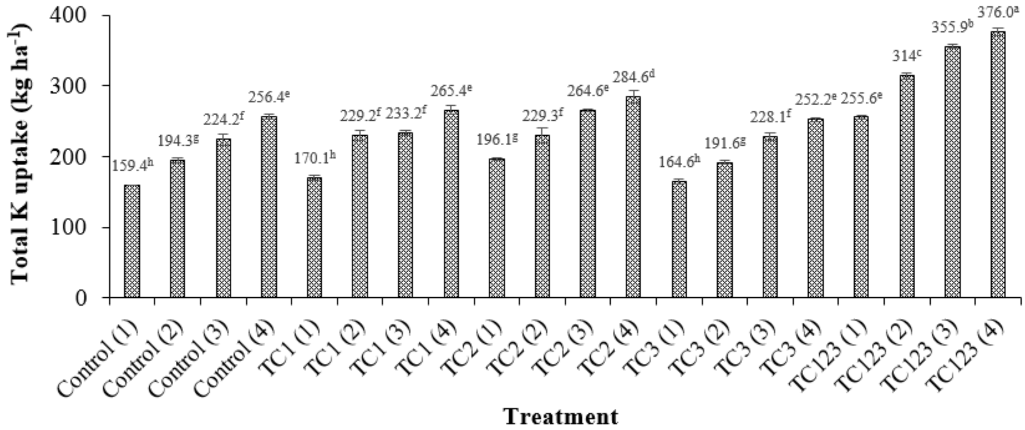

Figure 3. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on total K uptake of pineapple at harvest cultivated on acid sulfate soil.
The mean of four replications and its standard deviation are presented, while different letters above the bars reveal significant differences at $P < 0.05$; ns is for no significant difference at $P > 0.05$. The numbers within the parentheses indicate the amount of bio-compost applied (t ha^{-1}).

Effects of *Trichoderma* bio-compost on growth, yield components, and yield of pineapple plants

Effects of bio-compost on the growth of pineapples in acid sulfate soil

Applying the TC123 bio-compost increased by 1.9, 31.8, 16.7, 5.4, 7.8, and 12.1% in plant height, leaf number, D-leaf length, peduncle height, fruit length, and fruit diameter, respectively, in comparison with the positive control (Table 7). In detail, the treatment with the TC123 bio-compost resulted in greater plant height (81.6 cm), number of leaves (36.5 leaves), D-leaf length (32.8 cm), and peduncle height (17.3 cm) than the uptake positive control, whose results were 80.1 cm, 27.7 leaves, 28.1 cm, and 16.4 cm, in the same order. Furthermore, the treatment with the TC123 bio-compost also had a greater plant height than the treatments with the TC1, TC2, or TC3 bio-compost. In the study by Moyin-Jesu (2018), applying organic fertilizers resulted in greater plant height, longer D-leaf length, and a larger leaf surface than those of the treatment with only inorganic fertilizers. However, for the leaf number, leaf length, and peduncle height, there were variations between the treatment with the TC123 bio-compost and the ones with TC1, TC2, or

Table 7. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on the growth of pineapple cultivated on acid sulfate soil at harvest.

Factor		Plant height (cm)	Numbers of leaf (leaves)	D-leaf length (cm)	Leaf width (cm)	Peduncle Height (cm)	Crown Height (cm)	Crown Width (cm)	Fruit Height (cm)	Fruit Width (cm)
Bio-compost containing fungi strain *Trichoderma* sp. (A)	Control	80.1^{b}	27.7^{c}	28.1^{b}	3.09	16.4^{c}	18.1^{a}	13.1^{a}	15.3^{c}	10.7^{c}
	TC_1	80.3^{b}	32.1^{b}	30.4^{ab}	3.27	16.9^{abc}	17.4^{b}	12.7^{ab}	16.0^{ab}	11.2^{b}
	TC_2	79.1^{c}	32.0^{b}	29.6^{b}	3.20	16.6^{bc}	16.7^{c}	12.5^{bc}	15.7^{bc}	10.9^{bc}
	TC_3	79.6^{bc}	34.6^{ab}	29.1^{b}	3.19	17.1^{ab}	16.9^{bc}	12.2^{c}	16.2^{ab}	11.3^{b}
	TC_{123}	81.6^{a}	36.5^{a}	32.8^{a}	3.15	17.3^{a}	17.1^{bc}	12.7^{b}	16.5^{a}	12.0^{a}
Bio-compost level (t ha^{-1}) (B)	1	79.0^{c}	32.5	28.8	2.95^{c}	16.5	16.9	12.5	15.5^{b}	11.2
	2	79.9^{bc}	31.7	29.4	3.25^{ab}	16.7	17.4	12.7	15.8^{ab}	11.2
	3	80.5^{ab}	32.7	30.5	3.08^{bc}	17.0	17.3	12.7	16.1^{a}	11.2
	4	81.3^{a}	33.6	31.3	3.42^{a}	17.2	17.3	12.8	16.3^{a}	11.4
Significant differences	F (A)	**	**	*	ns	*	**	**	**	**
	F (B)	**	ns	ns	**	ns	ns	ns	*	ns
	F (A x B)	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)		1.7	10.8	14.4	14.4	5.75	3.90	4.90	5.33	4.59

In a column, the different superscripts indicate significant differences at 5% significance (*) or at 1% significance (**), and without a letter, there is no significant difference according to Duncan's post-hoc test at the 5% level (ns).

TC3 bio-compost. Particularly, the leaf number of the treatment with the TC123 bio-compost was greater than the treatments with the TC1 or TC2 bio-compost but equivalent to the one with the TC3 bio-compost. The leaf length of the treatment with the TC123 bio-compost was longer than the treatments with the TC2 or TC3 bio-compost but insignificantly different from the treatment with the TC1 bio-compost. The peduncle height of the treatment with the TC123 bio-compost was greater than the treatment with the TC2 bio-compost but equivalent to those of the treatments with the TC1 or TC3 bio-compost. For the leaf width, differences between treatments were insignificant. This can be inferred that the TC1 and TC3 strains contributed to plant growth more than the TC2 strain. According to Mahmud et al. (2018), the treatment with vermicompost, a type of organic fertilizer, led to increases of 4.33, 4.76, 2.52, and 3.85% in plant height, leaf number, D-leaf length, and D-leaf width, in comparison with the treatment with inorganic fertilizers on the MD2 pineapple cultivar. Crown lengths and diameters were the greatest in the positive control with 18.1 and 13.1 cm, respectively, while the treatments with the TC1, TC2, TC3, or TC123 bio-compost resulted in 16.7 – 17.4 cm in length and 12.2 – 12.7 cm in diameter. (Table 7). In addition, the treatment with organic fertilizers resulted in fruit weight, fruit length, and fruit diameter of 91.4 – 126.2 t ha^{-1}, 15.0 – 19.0, and 35.1 – 38.0 cm, in comparison with the treatment with only inorganic fertilizers, with 88.3 t ha^{-1}, 13.5, and 34.7 cm. As reported by Trejo et al. (Trejo et al., 2021), supplying bio-compost along with 50% inorganic fertilizers for the Cayenne pineapple cultivar resulted in the greatest fruit weight, fruit length, and fruit diameter, with 2.70 kg, 21.46 cm, and 12.9 cm, respectively.

The factor of the applied level of bio-compost had a significant difference at 1% in plant height and leaf width (Table 7). The treatment with bio-composts at 4 t ha^{-1} resulted in plant height and leaf width of 81.3 cm and 3.42 cm, respectively, and was different at 1% significance from the treatment with bio-composts at 1 t ha^{-1}, with 79.0 cm and 2.95 cm, respectively. For leaf number, leaf length, peduncle height, crown height, and crown width, results were equivalent between rates of bio-compost. Interactions of all growth parameters were insignificant between types and dosages of bio-compost.

Effects of bio-compost on yield components and yield of pineapples in acid sulfate soil

Mahmud et al. assume that applying organic fertilizers results in pineapple plants with excellent growth but at a cheaper cost in comparison with the treatment with inorganic fertilizers (Mahmud et al., 2018). However, this organic fertilizer is not suggested with a single application, but this is promising in maintaining soil quality and obtaining sustainable agriculture (Mahmud et al., 2018). The yield in the treatment with the TC123 bio-compost increased by 9.80% in comparison with the positive control. In addition, the treatments with bio-compost at 3 – 4 t ha^{-1} resulted in increases in yield of 20.9 – 24.0% in comparison with the treatment with bio-compost at 1 t ha^{-1} (Table 8). In detail, the treatments with TC1, TC3, or TC123 bio-compost resulted in greater fruit height and fruit diameter than the positive control, and the treatment with the TC2 bio-compost, i.e., values of the fruit height and fruit diameter were up to 16.0 – 16.5 and 11.2 – 12.0 cm in the treatments with TC1, TC3, or TC123 bio-compost and only 15.3 – 15.7 and 10.7 – 10.9 cm in the positive control and the treatment with the TC2 bio-compost, respectively. Moreover, applying bio-composts from 3 to 4 t ha^{-1} resulted in greater fruit height (16.1 – 16.3 cm) than the one with bio-composts at 1 t ha^{-1} (15.5 cm), but the fruit diameter was equivalent between dosages of bio-compost (Table 7). In the study by Liu et al. (2013), applying organic fertilizers resulted in a greater pineapple yield of 47.9% in comparison with control without fertilizers.

The values of pineapple fruit yield of the treatment with TC2 or TC123 bio-compost were 26.0 and 26.9 t ha^{-1}, which were greater than that of the positive control (24.5

Table 8. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on the yield of pineapple cultivated on fields in Tan Tien commune, Vi Thanh City, Hau Giang Province.

Types of bio-composts applied with *Trichoderma* spp. (A)	Dosage of bio-composts (B) (t ha^{-1})				Mean (A)
	1	2	3	4	
Control	21.9^{c}	22.0^{c}	27.3^{ab}	27.0^{ab}	24.5^{C}
TC_1	21.3^{c}	25.8^{b}	26.7^{ab}	28.2^{ab}	25.5^{BC}
TC_2	21.7^{c}	26.9^{ab}	27.5^{ab}	28.0^{ab}	26.0^{AB}
TC_3	22.5^{c}	26.2^{b}	26.6^{ab}	27.1^{ab}	25.6^{BC}
TC_{123}	25.4^{b}	25.4^{b}	27.9^{ab}	29.1^{a}	26.9^{A}
Mean (B)	22.5^{C}	25.3^{B}	27.2^{A}	27.9^{A}	
Significance level (A)					**
Significance level (B)					**
Significance level (A*B)					*

Note: The different lower-case superscripts indicate significant differences between values in both rows and columns, while the different upper-case ones indicate significant differences between values in either the row or the column (**: different at 1% significance; *: different at 5% significance).

Table 9. Effects of bio-compost from pineapple waste containing indigenous fungi strains *Trichoderma* spp. on the fruit quality of pineapple cultivated on acid sulfate soil at harvest.

Factor		Water content (mL)	Brix (%)	Vitamin C (mg 100 g^{-1})	TTA (mL L^{-1})	Color L*	Color a*	Color b*	Flesh/Shell
Bio-compost containing fungi strain *Trichoderma* sp. (A)	Control	169.5^b	11.4^b	13.0	116.6	44.4^{ab}	9.27	13.1^{ab}	1.06^c
	TC_1	210.3^a	12.1^a	12.8	110.0	41.6^c	10.5	13.8^a	1.23^a
	TC_2	180.8^b	11.7^{ab}	14.1	99.4	46.0^a	9.68	13.6^a	1.09^b
	TC_3	196.2^a	12.0^a	12.4	84.7	44.2^b	9.35	12.0^{bc}	0.96^d
	TC_{123}	202.6^a	11.9^a	13.5	67.1	43.9^b	9.55	11.4^c	1.10^b
Bio-compost level (t ha^{-1}) (B)	1	179.5^c	11.9	13.3	100.0	42.3^c	9.70	13.1	1.09
	2	188.0^{bc}	11.6	12.7	98.6	43.6^{bc}	9.77	12.7	1.08
	3	197.1^{ab}	11.9	12.8	82.1	45.6^a	10.2	12.9	1.08
	4	203.0^a	11.9	13.9	101.5	44.6^{ab}	9.07	12.4	1.10
Significant differences	F (A)	**	*	ns	ns	**	ns	**	**
	F (B)	**	ns	ns	ns	**	ns	ns	ns
	F (A x B)	ns	**	**	ns	**	ns	**	**
CV (%)		11.3	4.88	18.7	56.3	5.09	20.1	12.5	2.26

In a column, the different superscripts indicate significant differences at 5% significance (*) or at 1% significance (**), and without a letter, there is no significant difference according to Duncan's post-hoc test at the 5% level (ns). TTA: Total titratable acidity = g of citric acid per kg of pulp. Vitamin C: mg of ascorbic acid per kg of pulp. °Brix: Total soluble solids.

t ha^{-1}), and the treatments with either TC1 (25.5 t ha^{-1}) or TC3 (25.6 t ha^{-1}) bio-compost. Moreover, pineapple yields of the treatments with bio-composts from 4, 3, 2 to 1 t ha^{-1} gradually reduced to 27.9 $\sim$ 27.2 > 25.3 > 22.5 t ha^{-1}. The two factors of types and dosages of bio-compost interacted at 5% significance. The interactive result showed that applying TC123 bio-compost at 1 t ha^{-1} or TC1, TC2, or TC3 bio-compost at 2 t ha^{-1} was equivalent to that of the positive control at 4 t ha^{-1} (Table 8). This is in accordance with the study by Sudantha and Suwardji (2021), where shallot growth and yield were improved by a bio-compost degraded by *Trichoderma* species.

Effects of *Trichoderma* bio-compost on the fruit quality of pineapple plants

Table 9 indicated that the treatment with the TC123 bio-compost helped to increase water content and degree Brix by 19.53 and 4.39%, respectively, in comparison with the positive control. The water content in fruits of the treatment with the TC123, TC1, or TC3 bio-compost was 196.2 – 210.3 mL, which was greater than that of the positive control and the treatment with the TC2 bio-compost, whose results ranged from 169.5 to 180.8 mL. At the same time, applying bio-compost at 3 – 4 t ha^{-1} resulted in a greater volume of water (197.1 – 203.0 mL) than applying at 1 t ha^{-1} (179.5 mL) by 9.8 – 13.1%. The flesh-to-shell ratio of the treatments with TC1, TC2, TC3, or TC123 bio-compost was greater than that of the positive control. Degrees Brix of the treatments with TC1, TC3, or TC123 bio-compost were correspondingly 11.9 – 12.1%, which was greater than those of the positive control (11.4%). As reported by Trejo et al. (2021), the treatment with 50% inorganic fertilizers in addition to bio-compost resulted in a greater degree of Brix (15.97%) than the treatment with 100% chemical fertilizers (7.86%). The treatments with bio-composts containing indigenous *Trichoderma* spp. contributed to increasing the water content in fruit and degree Brix due to the metabolisms of microorganisms that stimulate plant growth and assimilate essential nutrients, promoting the synthesis of enzymes that reduce sugar contents in the cell walls of fruits and increase mono-carbohydrate compounds, from which the degree Brix rises during fruit ripening (Molla et al., 2012; Lombardi et al., 2020). In the meantime, the b* values of fruit colors of the treatments with the TC123 bio-compost (11.4) were lower than that of the positive control (13.1). Nevertheless, degrees Brix, ratios of flesh-to-shell, and b* values of fruit colors were equivalent between dosages of bio-compost, with 11.6 – 11.9, 1.08 – 1.10, and 12.4 – 13.1%, respectively. The vitamin C content, titratable acidity in fruits, and a* values were not significantly different between treatments, with ranges of 12.4 – 14.1 mg 100 g^{-1}, 67.1 – 116.6 mL, and 9.07 – 10.5, respectively. The values of L* colors of the shell of only the treatment with TC1 bio-compost were lower than that of the positive control, with 41.6 compared to 44.4, respectively, but the treatments with TC2, TC3, or TC123 bio-compost resulted in equivalent results to the positive control. However, the treatments with bio-compost at 3 – 4 t ha^{-1} resulted in significantly greater L* values (44.6 – 45.6) at 1% significance than those of the treatments at 1 t ha^{-1} (42.3). The interactive analysis between the types and dosages of bio-composts revealed that there were differences at 5% significance in parameters of degree Brix, vitamin C, L*color, b* color, and flesh-to-shell ratio (Table 9).

4. Conclusion

In the current study, the TC123 bio-compost can be considered the best bio-compost for pineapple cultivation in acid sulfate soil. Applying the TC123 bio-compost at 4 t ha^{-1} contributed to increasing contents of $P_{soluble}$ and $N_{available}$ and obtained the greatest N, P, and K uptake. The treatments with the TC123 bio-compost resulted in plant height, leaf number, D-leaf length, peduncle height, fruit length, and fruit width that increased by 1.9, 31.8, 16.7, 5.4, 7.8, and 12.1%, respectively, in comparison with the treatment with the commercial bio-compost. Applying the TC123 bio-compost increased pineapple fruit yield by 9.80% in comparison with the treatment with the commercial bio-compost. From there, the bio-compost combined with chemical fertilizers should be further applied on a larger scale. Thereby, the local farmers should be transferred with this way of fertilization to make use of the local waste, increase income, and ultimately enhance their livelihood.

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Ethical approval
This manuscript does not report on or involve the use of any animal or human data or tissue. So the ethical approval is not applicable.

Author contribution
The authors confirm the study conception and design: N.Q. Khuong, T.T.K. Chung; data collection: L.T.M. Thu, T.C. Nhan, L.M. Ca; analysis and interpretation of results: L.T. Quang, L.N.T. Xuan; draft manuscript preparation: N.Q. Khuong, T.T.K. Chung. The results were evaluated by all authors, and the final version of the manuscript was approved.

Availability of data and materials
Data presented in the manuscript are available via request.

Conflict of interest statement
The authors declare that they are no conflict of interest associated with this study.

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