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The enhancement of soil fertility and baby maize output by *Streptomyces panayensis* and vermicompost

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Abstract

Gradual reduction to chemical fertilizer application by adopting sustainable alternatives that naturally harness, nutritional sources from endophytic *actinobacteria processes* in combination with vermicompost (VP) is capable of improving the available nutrients of farmland and baby maize (BM) output. This field research observed the combined efficiency of *Streptomyces panayensis* (*S. panayensis)* inoculum and three VP rates on available nutrients and BM productivity. it was carried out by mean of two factors, consisting of factor 1: three VP levels (0, 4 and 8 t ha^{-1}) in a combination with factor 2 (supplementation and no supplementation of *S. panayensis*) on the BM variety "SG-7", utilizing a completely random block with six experimental plots with four replications. All plots of both *S. panayensis* and VP supplementation raised soil nutrients and ear number, weights of fresh ear and plant biomass compared to those with no *S. panayensis* and VP supplementation. The research emphasizes the supplementation of *S. panayensis* and VP application to increase availably nutritional concentrations in soil and augment BM productivity. The results of the research showed a 50% reduction in VP supplementation that could maintain productivity and soil fertility. These findings provide valuable insights for sustainable agriculture, presenting a promising approach to increase BM production, improve soil fertility, and protect the environment. The combination of endophytic actinobacteria inoculation and organic manure management in this integrated approach is proven to be a right pathway in modern agriculture, enhancing both soil health and biomass yields.

Keywords: Actinobacteria, addition, animal manures, cob yield, nutrition, output

Introduction

Exploring the innovative natural fertilizer options to replace chemical pesticides and inorganic fertilizers purposely is to obtain environmentally friendly agricultural practices to increase quality, yield, and crop protection. In agricultural cultivation, Actinobacteria (especially *Streptomyces* spp.) are the great option related to plant growth and protection (Kunova et al., 2016). Plant diseases coupled with nutrient deficiencies are the significantly contributing factors in the decrease of crop yields. Ameliorating this issue through the application of chemical fertilizers is not a sustainable or efficacious approach. Utilizing *Streptomyces* spp. in disease management, along with their contribution to the decomposition of organic matter into bioavailable nutrients for soil and plants, represents a necessary alternative strategy to address the challenges associated with chemical inputs. *Streptomyces*, a gram-positive saprophytic actinobacterium, exhibits a remarkable efficacy in combating phytopathogens that produce a diverse array of bioactive antimicrobial metabolites and enzymes that are capable of exterminating or inhibiting the proliferation of plant pathogens (Adhilakshmi et al., 2014). *Streptomyces* species are ubiquitous in natural environments, but are particularly abundant in the rhizosphere and endosphere. They can be employed as biocontrol agents to protect crops from diseases. Beyond their antagonistic potential against pathogens. *Streptomyces* can promote plant growth through various mechanisms. They synthesize plant growth-promoting substances,

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such as indole-3-acetic acid (IAA), cytokinins, and siderophores. Also, *Streptomyces* can suppress diseases via antibiosis, mycoparasitism, and nutrient competition. Furthermore, they are able to provide plants with essential minerals, including iron, copper, phosphorus, and sulfur. Therefore, it can be stated that *Streptomyces* spp. can serve as a viable alternative to chemical agents for controlling plant diseases (Al Hamad et al., 2021). The well known antibiotics have been produced by biology in which 80 % of the metabolites with biological activity in the total yield of actinomycetes are produced by *Streptomyces* genera (Barka et al., 2016). The scientists have identified up to 5,000 bioactive compounds created by the *Streptomyces* sp. *Streptomyces* isolated from the soil and plant, could inhibit the phytopathogen growth and degrade the soil organic matter (Kaur et al., 2019). *Streptomyces* genera that could promote plant growth and prevent root pathogens can also inhibit fungal pathogens. They produce degradative enzymes and antifungal agents to protect plant roots. Further, *Streptomyces* genera are capable of producing the siderophore or IAA to promote plant development playing a key role in the interactions of bacteria-actinobacteria and plant-microorganisms. These characteristics allow these microorganisms to be the promising agents as both biofertilizers and bio-pesticides (Bonaldi et al., 2014). Furthermore, several genera of *Streptomyces* could protect plant from diseased root fungus by producing degradative enzymes and antifungal agents, and soil organic matter (SOM) metabolites. They additionally can enhance available nutrients, and the ability of highly saline adaptation, drought and contaminated farmland. The positive efficiency of *Streptomyces* species has been proven for increasing plant output and decreasing the usage of inorganic fertilizers and pesticides, proven as an eco-friendly approach for agricultural cultivation (Jog et al., 2016; Tyc et al., 2017; Nazari et al., 2023). The application of 10t VP ha^{-1} or 50% N fertilizer combined with endophytic bacteria inoculation attained the maximum groundnut yield (Chuong, 2024, Chuong et al., 2024). Organic manure remarkably affected seed and stem yield. The amendment of animal manures brings the positive efficiency to raise the physical and chemical properties of soil, water holding ability, and soil microbial population in the climate change conditions (Chen et al., 2019; Bhanwaria et a., 2022). In dealing with the integrated nutrient management, it is suggested to use microbial inoculations in combination with organic manure addition to reduce the amount of chemical fertilizers applied. The prior researches have proven that the inefficiency of inorganic fertilizers could be decreased by amending endophytic microorganism in association with organic manure addition that are capable of enhancing availably nutrient uptake efficiency and plant growth promotion while decreasing inorganic fertilizer application by up to 50% without reducing any crop output loss compared to the fully applied control (Thuc et al., 2022; Chuong, 2023)

The BM (baby maize) contains high nutritional compositions. The application of endophytic microorganisms combined with organic manures can prevent pests and diseases for BM plants. This technology that has been used by biological methods for increasing the soil fertility and BM yield, is deemed critical (Kumar et al., 2014; Humaun et al., 2021). A study by Chuong (2024) showed that the inoculation of endophytic bacterium (K. quasipneumoniae) in BM seeds could reduce 50% nitrogen fertilizer application and increase total N concentration in soil and yield and cob quality traits. The BM cultivation has faced a number of serious diseases, generated by nematodes, fungi, bacteria, viruses, and insects. 110 different diseases are found to increasingly affect corn plants (Lv et al., 2020; Xu et al., 2021). Recently, endophytic *Streptomyces* spp. have been discovered for their disease resistance ability (Nazari et al., 2023). They filamentous allowing them to adapt during disadvantageous time. For this reason, they are able to adapt more effectively against other soil bacteria. *Streptomyces* spp. can create differently lytic enzymes, which can degrade organic matter, and break them to provide sucrose for being transformed and absorbed by plants (Vurukonda et al., 2018). The research aim is to assess the efficiency of S. panayensis with three vermicompost (VP) rates on soil fertility, and the output of BM cobs.

Material and Methods

Streptomyces panayensis selection

Streptomyces panayensis was firtly isolated from BM roots on CGA medium (Casein Glycerol Agar). Results described that organisms had the highest percent identity (99.78%) with sample sequence. The accession number in GenBank of *S. panayensis* species was MF462923.1 with sequence length at 1450 bp; closest type strain of *Streptomyces panayensis* strain 21; and identity at 99.78% to the previously known *S. panayensis*.

Experimental site and time

The field plots were carried out in the AGU Research Center from 1st May to 20th June, 2024. To determine the soil traits of the experimental location, initial farmland samples were taken from the depth of 0- 20 cm and certain physicochemical properties of the selected samples were determined using the methodology of

Carter and Gregoric (2007). The two factors included six treatments labeled BR0 (0.0t VP ha^{-1}+ no *S. panayensis* inoculation), BR1 (0.0t VP ha^{-1}+ *S. panayensis* inoculation), BR2 (4.0t VP ha^{-1}+ no *S. panayensis* inoculation), BR3 (4.0t VP ha^{-1}+ S. panayensis inoculation), BR4 (8.0t VP ha-1+ no *S. panayensis* inoculation), and BR5 (8.0t VP ha^{-1}+ *S. panayensis* inoculation), with four replications. All treatments were applied with a similar chemical fertilizer level (165 Urea – 370 P_2O_5 – 80 KCl kg per ha). The planting distances concluded the holes spaced at 30 cm x 20 cm, each of which was sowed with 02 seeds. The " SG-7" variety of BM was used during the experiment. Furthermore, the total research area covered 480 m2 (1 m x 20 m x 4 replicates x 6 treatments). The pure VP was collected and composted from local farms, containing 59.1% C, 2.30% N, 1.80% P_2O_5, 0.820 % K_2O, aerobic bacteria (2.0 x 10^8 CFU g^{-1}), phosphorus-solubilizing bacteria (10^7 CFU g^{-1}), and nitrogen fixing bacteria (10^7 CFU g^{-1}).

S. panayensis inoculation and seed sowing

The *S. panayensis* was increased to a density of 10^8 CFU mL^{-1} on CGA medium. The BM seeds of SG7 variety were collected from the Southern Breed Company, Vietnam, in which they had high-yielding, high-quality baby corn variety with disease resistance and able to be cultivated year-round. The *S. panayensis* was well sprayed on BM seeds and was amended to BM seeds for the treatments of BR1, BR3 and BR5 (except for BR0, BR2 and BR4).

Calculation and observation of growth and yield traits

The tassel removal became an important stage executed at 50 DAS. It helped a main process in rousing the BM growth to produce more BM ears and increase output and nutritional concentration. The agronomy characteristics, yield components, and edible corn cob yield were systematically evaluated from 15 DAS until harvest time. The growth traits consisting of height, leaf number per plant, weight of plant biomass, fresh pod, silk, husk, tassel, cob length and diameter, were determinated at harvest (45 DAS). After the BM matured, 10 uniformly grown plants were selected from each treatment for harvest and assessment of the number of marketable ears, yield, ear length, ear diameter, fresh ear weight, and yield calculation. Furthermore, all BM traits that were counted based upon the methodology as outlined by Jones (2001),

Soil physicochemical analysis

All soil samples were taken in the initial and the end of period of experiment (Exp) from all treatments to define the influences engendered by the amended plots on farmland physicochemical traits. A pH meter here was used to determine pH (soil/H_20:1/2.5) values. Meanwhile, mineral nitrogen (MN) concentration was determined by using Kjeldahl methodology. The soluble P (SP) utilized by the Bray II methodology, was used by extracting 0.1N HCl and 0.03N NH_4F with a ratio of 1 soil: 7 water (w/v). A spectrophotometer was utilized to determine SP (880 nm). The analysis method of SOM analyzed according to Sparks et al. (1996), used $K_2Cr_2O_7$ to oxidize organic compositions and 0.5 N $FeSO_4$ using the redundant $K_2Cr_2O_7$ concentration (Carter and Gregoric, 2007).

Statistical Data

To compare differences, the analysis of variance (ANOVA) was conducted, followed by Duncan's multiple range test at a 5% significance level, using Statgraphics software version XVIII. Here, data processing was carried out by the help of Microsoft Excel 2013.

Results

Effects of the association of VP addition and *S. panayensis* inoculation on the soil properties

Under the influences of both *S. panayensis* inoculation and VP addition, the concentrations of soil pH, SOM, MN, and SP in the initial experiment changed insufficient at the level of 5%. However, as shown in Table 1, both *S. panayensis* inoculation and VP addition presented changed sufficiently at the level of 5 and 1% in the Exp end (Except SP in factor B of the last experiment). The results in the initial and last soil pH of factor A and B ranged from 7.01 to 7.04 and from 6.75 to 7.296, respectively. Similarly, the influences of both *S. panayensis* inoculation and VP addition on soil nutrient properties, consisted of the SOM valued from 1.52 to 1.54 (initial Exp), 1.42 to 1.77% (Exp end), MN from 0.067 to 0.069% (initial Exp), 0.062 to 0.082% (Exp end), SP from 0.047 to 0.051% (initial Exp), 0.033 to 0.058% (Exp end), respectively. As shown in Table 1, all soil nutrient concentrations such as pH, SOM, MN and SP in the initial Exp had no significant differences in the plots of both *S. panayensis* inoculation and VP addition. In contrast, the treatments at harvest season with VP (4 or 8 t ha^{-1}) showed significantly higher pH, SOM, MN, and SP compared to the initially experimental soil and the control treatment (no inoculation or no VP application) at the end of Exp. The interactions (**$P<0.01$) between two factors led to significant differences for increasing the soil nutrition uptake such as SOM, MN and SP concentration

Table 1. Effects of Streptomyces and VP on soil chemical properties before and after the exp.

Factors		pH		SOM (%)		MN (%)		SP (%)	
		Initiation	Harvest	Initiation	Harvest	Initiation	Harvest	Initiation	Harvest
S.panayensis (A)	No	7.01 ±0.08	6.75±0.09b	1.52±0.02	1.45±0.02b	0.068±0.02	0.062±0.00c	0.048±0.0	0.033±0.0c
	Yes	7.05 ±0.08	7.29 ±0.09a	1.54±0.02	1.75±0.02a	0.069±0.02	0.075±0.00a	0.050±0.0	0.058±0.0a
VP (t ha^{-1}) (B)	0.0	7.01 ±0.08	6.93±0.09b	1.52±0.02	1.42±0.02b	0.069±0.02	0.047±0.00c	0.051±0.0	0.043±0.0
	4.0	7.04 ±0.08	7.17±0.09ab	1.53±0.02	1.75±0.02a	0.068±0.02	0.078±0.00b	0.049±0.0	0.043±0.0
	8.0	7.04 ±0.08	7.26 ±0.09a	1.54±0.02	1.77±0.02a	0.067±0.02	0.082±0.00a	0.047±0.0	0.045±0.0
F_{test}	F (A)	ns	**	ns	**	ns	**	ns	**
	F (B)	ns	*	ns	**	ns	**	ns	ns
	F (AxB)	ns	ns	ns	**	*	**	ns	**

Note: No: no *S. panayensis* inoculation; Yes: *S. panayensis* inoculation; ns: insufficient difference (P>0.05); *, ** = sufficient difference (P≤ 0.05 and ≤0.01, respectively); Sign (±): the standard deviation of 4 replications.

During the growth period of 15, 30 and 45 DAS, the plant height was significantly affected at 5% and 1% by the addition of VP levels and *S. panayensis*. However, the leaf number of BM was significantly affected at 5% (except for factor B at 15 DAS and 45 DAS). As shown in Table 2, plant height and the leaf number raised during the growth period of 15, 30 and 45 DAS that belonged to the following increase of VP levels. The plots at both factors with *S. panayensis* amendment and VP levels (4 or 8 t ha^{-1}) were significantly higher than those of the initial experiment for soil and the control treatment (no inoculation or no VP application) at the end of Exp. The interaction of two factors showed several significant differences at level of 5 and 1% (except for plant height at 30 DAS and leaf number at 45 DAS) (See Table 2)

Table 2. Effects of Streptomyces and VP on height and leaf number of BM plants

Factors		Plant heights			Leaf number (Leaves plant^{-1})		
		Days after sowing (DAS)					
		15	30	45	15	30	45
S. panayensis (A)	No	17.1±0.272b	68.5±1.592b	142±2.17b	5.0±0.035	8,4±0.148	11.9±0.095
	Yes	19.3±0.272a	73.4±1.592a	156±2.17a	5.0±0.035	8,8±0.148	12.1±0.095
VP (t ha^{-1}) (B)	0.0	16.2±0.333c	53.1±1.95b	130±2.658c	4.8±0.043b	8,4±0.181	11.5±0.116b
	4.0	17.7±0.333b	77.2±1.95a	150±2.658b	5.1±0.043a	8.8±0.181	12.1±0.116a
	8.0	20.8±0.333a	82.5±1.95a	168±2.658a	5.1±0.043a	8.6±0.,181	12.4±0.116a
F_{test}	F (A)	**	*	**	ns	ns	ns
	F (B)	**	**	**	**	ns	**
	F (AxB)	**	ns	**	*	*	ns

Note: No: no *S. panayensis* inoculation; Yes: *S. panayensis* inoculation; ns: insufficient difference (P>0.05); *,** = sufficient difference (P≤ 0.05 and ≤0.01, respectively); Sign (±) : the standard deviation of 4 replications.

As shown in Table 3, ear number per plant and fresh ear weight (ear, silk, husk and tassel) differed sufficiently at 5% and 1% under the influences of different VP rates and *S. panayensis* supplementation. At 50% and 100% addition of VP and *S. panayensis* inoculation, the ear number per plant and weight of ear, silk, husk and tassel were found more than those of no *S. panayensis* supplementation and no VP addition. The treatment added to 8.0 t VP ha^{-1}, which obtained the highest values of ear number per plant and fresh ear weight, followed by 4.0 tVP ha^{-1}, and the lowest results were no VP addition treatments. In the case of *S. panayensis* inoculation in seeds, the ear number per plant and fresh ear weight of BM, statistically was found higher than that of without the *S. panayensis*. There were no interactions between different VP application levels and *S. panayensis* inoculation (Except for ear number).

Table 3. Effects of Streptomyces and VP on on ear number, fresh ear weight and tassel of BM plants

Factors		Ear number (ears plant^{-1})	Fresh ear weight (t ha^{-1})			
			Ear	Silk	Husk	Tassel
S. panayensis (A)	No	2.6±0.021b	6.1±0.168b	1.0±0.039b	4.1±0.147b	4.3±0.113b
	Yes	2.8±0.021a	7.1±0.168a	1.2±0.039a	4.7±0.147a	4.8±0.113a
VP (t ha^{-1}) (B)	0.0	2.0±0.026b	5.1±0.206c	0.9±0.048b	3.3±0.180c	3,3±0,139c
	4.0	3.1±0.026a	6.9±0.206b	1.1±0.048a	4.7±0.180b	4,6±0,139b
	8.0	3.1±0.026a	7.8±0.206a	1.2±0.048a	5.3±0.180a	5,7±0,139a
F_{test}	F (A)	**	**	**	*	**
	F (B)	**	**	**	**	**
	F (AxB)	**	ns	ns	ns	ns

Note: No: no *S. panayensis* inoculation; Yes: *S. panayensis* inoculation; ns: insufficient difference (P>0.05); *, ** = sufficient difference (P≤ 0.05 and ≤0.01, respectively); Sign (±) : the standard deviation of 4 replications.

Table 4 shows that cob length, cob diameter, plant biomass and edible cobs differed sufficiently at 1% level under the influences of varying VP rates and *S. panayensis* amendment. At 4.0% and 8.0% of VP and *S. panayensis* inoculation, the values of cob length, cob diameter, plant biomass and edible cobs were found higher than those of no *S. panayensis* inoculation and no VP addition. While, the treatment fertilized to 4.0 t VP ha^{-1}, obtained the similar values of cob length, cob diameter, plant biomass and edible cobs compared to the addition of 8.0 tVP ha^{-1}, and the lowest results were found in the no VP addition treatments. Further, the cob output in the treatments with 100% VP addition was found insufficient differences with 50% VP in case of no *S. panayensis* inoculation. Productivity increased remarkably for the *S. panayensis* inoculation at these VP levels. This showed that potential output could have the higher plots of *S. panayensis* inoculation compared to chemical fertilizers alone. In brief, the inoculation of *S. panayensis* in combination with VP amendment was efficient in increasing soil fertility and BM yield. Here, there were no interactions between different VP application ratios and *S. panayensis* inoculation in the values of cob length, plant biomass and edible cobs (Except for cob diameter).

Table 4. Effects of Streptomyces and VP on plant biomass, edible cobs, the length and diameter of BM

Factors		Cob length (cm)	Cob diameter (cm)	Plant biomass (t ha^{-1})	Edible cobs (t ha^{-1})
S. panayensis (A)	No	47.7±0.817b	2.6±0.021b	47.7±0.817b	1.0±0.034b
	Yes	53.1±0.817a	2.8±0.021a	53.1±0.817a	1.2±0.034a
VP (t ha^{-1}) (B)	0.0	43.1±1.001b	2.0±0.026b	43.1±1.001b	0.9±0.041c
	4.0	52,6±1.001a	3.1±0.026a	52,6±1.001a	1.29±0.041a
	8.0	55,5±1.001a	3.1±0.026a	55,5±1.001a	1.30±0.041a
F_{test}	F (A)	**	**	**	**
	F (B)	**	**	**	**
	F (AxB)	ns	**	ns	ns

Note: No: no *S. panayensis* inoculation; Yes: *S. panayensis* inoculation; ns: insufficient difference (P>0.05); *, ** = sufficient difference (P≤ 0.05 and ≤0.01, respectively); Sign (±): the standard deviation of 4 replications.

Discussion

Endophytic microorganisms have been presenting in the plant roots and stems, protecting and promoting plant growth and yield to cope with many diseases and environmental stresses (Ahemad, 2014; Hayat, 2010). Furthermore, the long-term use of chemical fertilizers can lead to soil hardening, decreased soil fertility, water and soil pollution, and depletion of crucial soil nutrients and minerals, thereby posing a threat to the environment (Lin et al., 2019). Therefore, applying organic fertilizers in conjunction with *Streptomyces* sp. can enhance the availability of readily decomposable organic matter, transforming it into soluble nutrients for plants. *Streptomyces* sp. has a high adaption to survive in harsh environments such as salty and droughty conditions (Shaffique et al., 2022). They promotionally help the crop growth in combination with biocontrol ability (Sadeghi et al., 2017; Shaffique et al., 2022). High organic matter fertilization allows plants to thrive within a wider pH range. This promotes both the growth of Streptomyces and the formation of larger spores. From this enhanced population density in the nutrient-rich environment, they stimulate roots to exude more secretions to resist pathogens and secrete more H^+, leading to a decrease in soil pH after planting (Doolotkeldieva et al., 2015). A research demonstrated that *Streptomyces saraceticus* used as soil addition could decrease soil disease pathogens and raise plant yields. Moreover, this research discovered that *S. panayensis* that has an ability on biological control could be appropriate for organic cultivation (Wu et al., 2021). In repulsing soil-borne diseases and chemical fertilizer use in the reduction in organic farming, the application of animal manures combined with endophytic microorganisms could bring cost savings as well as and an increase for farmers' income (Nguyen, 2023; Chuong et al., 2024). The inorganic fertilizers could rapidly increase the crop output, but they harm soil health and agricultural product quality. In contrast, the use of endophytic microorganism inoculants has been a right option for a strategy to improve soil nutrients and plant yields (Vurukonda et al., 2018; Nguyen et al., 2024). *Streptomyces* addition attained the highest quality of cucumbers and reduced the nitrate and soluble sugar concentration in fruits. The quality compositions raised the antioxidant content and firm level compared to no *Streptomyces* addition. Streptomyces addition could reduce 25% of inorganic fertilizer during the plant period (Orouji et al., 2023). The inorganic fertilizers, could increase crop outputs; however, their excessive negative impacts on the environment, such as soil degradation and loss of nutrients, have been previously studied (Cai et al., 2015).

As shown in Tables 1, there were sufficient differences from soils, amended by *S. panayensis* and VP amendment treatments at differently added conditions at harvest season. The pH, SOM, MN and SP were positively determined by the soil fertility of experimental end. This was a cause of the addition of endophytic actinobacteria and animal manures by *S. panayensis and* VP, which could enhance nutrition from this combination. When added to the farmland, VP could raise the available nutrients and increase an availably nutrient uptake of plant (Mitter et al., 2021; Chuong, 2023; Sudaryati et al., 2024). Soil *Streptomyces* trains have an ability to survival and adapt in any harshly environmental conditions, and could cure themselves in case a damage or destructibility (Wang et al., 2019). St. supplementary is an enrichment process of N, P, K, and SOM in soils. When positive microorganisms are applied with a native soil microorganism, an ecological relationship will be formed through their competition (Haiming et al., 2020; Kamei-Ishikawa, 2020). The recent researches showed that animal manure amendment could increase the organically nutrient concentrations of microorganism such as biomass P, natural N and others (Manna et al., 2005). The addition of maize cob organic manure (12.5 t ha^{-1}) attained the maximum concentrations of total chlorophyll, root length, MN and SP uptake. The uptake of SP and EK is related to the biomass and root length of plants. Therefore, this studied results suggest that application of organic manure may increase the output and availably nutritional uptake of low nutrient soils (Budiastuti et al., 2023).

In the growth period of BM, both plant height and leaf number were positively affected by the added treatments *S. panayensis* and VP in which they obtained the higher values compared to control (no addition of *S. panayensis* and VP) (Table 2). The combination of newly discovered strains with organic fertilizers is increasingly being applied by researchers in limited areas within agriculture. Broadening their application in production through products such as biofertilizers and biological plant protection agents aims to directly or indirectly harness the positive effects of endophytic actinobacteria (Olanrewaju and Babalola, 2019; Asfaw, 2022; Chuong, 2024). The treatments of endophytic bacteria have significantly proven the same or higher MN and SP use efficiencies compared to full inorganic fertilizer application. These discoveries proved the reduction of 50% in the amounts of N and P fertilizers through the fertilization in combination with endophytic microorganisms (Thuc et al., 2022; Nguyen et al., 2024)

These endophytic microorganisms could form a positive relation with crop roots, raising the uptake of the micro-nutrients and micro-nutrients to promote the growth and yield of plants (Tang et al., 2020; Van and Tri, 2024).

As shown in Table 3 and 4, *S. panayensis* isolated and identified from BM roots, were completely tested both increased yield traits and promoted the edible cob yield compared to control. Treatments of *S. panayensis* addition reduced significantly on the deleterious diseases to plant growth. It is worth present that SP had a positive species on growth and yield of BM.

In this research, it was monitored that the supplementation of VP and/or *S. panayensis* at different levels to farmland, in conjunction with chemical fertilizers, increased either the pH, SOM, MN or SP concentration of the soil fertility and the productivity traits and productivity of BM (Table 1-4), alike prior discoveries (Samsami, 2016 Tran et al., 2021; Teka et al., 2024; Chuong, 2024). This was mainly due to separate SOM into its constituent parts in the combined supplementation of inorganic fertilizers, animal manures and endophytic microorganism inoculation, causing an increase in microbial density and an activity of endophytic microorganism (Abbasi et al., 2019; Tan et al., 2021; Chuong et al., 2024). The combined supplementation was more efficient in satisfying the nutrient demands of BM plants sufficiently, taking high yields. Furthermore, *S. panayensis* aids in SOM decomposition and diseased protection. From above results, the supplementation of VP and/or *S. panayensis* raised soil fertility and BM yield (Vergnes et al., 2020; Zhu et al., 2020; Chuong and Tri, 2024; Chuong, 2024).

Conclusion

The supplementation of *S. panayensis* co-ordinated with VP amendment had a positive efficacy at augmenting the fertility of highly sandy soils. Regarding the concentrations of SOM, MN, and SP, pH value significantly ameliorated soil structures, the physicochemical and biological properties of farmlands, and the bioavailability of solute nutrition in the crop soils. For the plant height and leaf number per plant, the productivity traits and output of BM rose in the plots amended with 4.0 and 8.0 t VP ha^{-1} P in a combination with *S. panayensis* addition compared to those in the treatments with no both *S. panayensis* inoculation and VP addition. Meanwhile, baby maize plants amended with 4.0 t ha $^{-1}$ of VP increased edible cob yield similar with the one in the plots applied with 8.0 t VP ha-1(1.29 and 1.3 t ha^{-1}of BM cob yield, respectively). The *S. panayensis* inoculation raised the higher yield (6.7%) compared to control treatment without any S. *panayensis* supplementation. The BM yield in the treatments supplemented with 4.0 tVP ha^{-1} and/or a S. *panayensis* inoculation increased the yield equivalently or even higher compared to the treatment with 8.0 t VP ha^{-1} and/or a *S. panayensis* inoculation. The new findings revealed a significant correlation between VP and *S. panayensis*. These substances demonstrated the remarkable effects on improving soil health, yield parameters, and the edible corm yield of BM. A 50% reduction in VP application in combination with *S. panayensis* resulted in a more increase by 16.7% compared to the control and no significant difference in the edible corm yield of BM compared to the recommended 100% VP application. This new discovery is a crucial point in sustainable agricultural cultivation, opening a new technology for producing safe food and protecting environment. Therefore, the research positions the combination of S. panayensis inoculation with VP reduction as a potential strategy in a new agricultural background.

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