

***Bacillus* Consortium Functions to Reduce the Nitrogen-Phosphorus-Potassium Compound Fertilizer Dose in Potted Choy Sum**

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ABSTRAK/ABSTRACT

Peran konsorsium *Bacillus* dalam mengurangi dosis pupuk majemuk NPK pada tanaman caisim dalam pot

Kata Kunci:
Biomassa tanaman,
Fosfor tanah, Pupuk
hayati konsorsium,
Pupuk NPK

Peningkatan produktivitas caisim (*Brassica rapa* subsp. chinensis var. parachinensis) dapat dicapai melalui penggunaan pupuk organik dan anorganik yang tepat. Penelitian ini bertujuan untuk mengetahui pengaruh kombinasi pupuk NPK 16-16-16 dengan pupuk hayati *Bacillus* spp. 0,5% terhadap pertumbuhan dan hasil tanaman caisim. Penelitian ini menggunakan rancangan acak kelompok dengan enam perlakuan, yaitu kontrol (P₀), NPK 50 kg/ha (P₁), *Bacillus* spp. 0,5% (P₂), kombinasi *Bacillus* spp. 0,5% dengan NPK 50 kg/ha (P₃), kombinasi *Bacillus* spp. 0,5% dengan NPK 100 kg/ha (P₄), dan kombinasi *Bacillus* spp. 0,5% dengan NPK 150 kg/ha (P₅). Hasil penelitian menunjukkan bahwa tanaman yang diberi perlakuan *Bacillus* yang dikombinasikan dengan semua dosis NPK menunjukkan tinggi tanaman, jumlah dan lebar daun, serta ketebalan batang yang lebih besar. Berat akar segar tidak dipengaruhi oleh perlakuan. Kombinasi *Bacillus* spp. 0,5% dengan 50 kg/ha NPK menghasilkan berat kering tertinggi sebesar 10,9 g, sedangkan berat akar kering tertinggi diperoleh dari tanaman yang diberi perlakuan *Bacillus* pada semua dosis NPK. Tingkat keasaman dan total N pada media tanam tidak berubah secara signifikan, namun kadar P tersedia meningkat seiring dengan peningkatan dosis NPK, bukan akibat inokulasi *Bacillus*. Penelitian ini menunjukkan bahwa *Bacillus* merupakan pupuk hayati yang efektif sebagai input pelengkap untuk meningkatkan kinerja tanaman dalam kondisi penggunaan pupuk kimia yang dikurangi.

Keywords:
Consortium
biofertilizer,
fertilizer,
biomass,
phosphorus

NPK
Plant
Soil

Increasing the productivity of choy sum (*Brassica rapa* subsp. chinensis var. parachinensis) can be achieved by using organic and inorganic fertilizers properly. This study aimed to determine the effect of combining NPK 16-16-16 fertilizer with 0,5% *Bacillus* spp. biofertilizer on the growth and yield of choy sum plants. The study used a randomized block design with six treatments, namely control (P₀), NPK 50 kg/ha (P₁), *Bacillus* spp. 0.5% (P₂), a combination of *Bacillus* spp. 0,5% with NPK 50 kg/ha (P₃), a combination of *Bacillus* spp. 0,5% with NPK 100 kg/ha (P₄), and a combination of *Bacillus* spp. 0,5% with NPK 150 kg/ha (P₅). Plants treated with *Bacillus* combined with all NPK doses showed greater plant height, leaf number and width, and stem thickness. Fresh root weight was not affected by the treatment. The combination of *Bacillus* spp.

0.5% with 50 kg/ha of NPK produced the highest dry weight of 10.9 g, whereas the highest dry root weight was obtained from plants treated with *Bacillus* at all doses of NPK. The acidity and total N of the planting medium did not change significantly, but available P increased with higher NPK doses rather than *Bacillus* inoculation. This study shows that *Bacillus* is an effective biofertilizer as a complementary input that improves plant performance under reduced chemical fertilizer.

INTRODUCTION

Eco-friendly agriculture requires a balanced use of chemical, organic, and biofertilizers. The right fertilizer mix can reduce chemical fertilizer use and improve its effectiveness. Biofertilizers are recommended as nutrient sources for crop production because they supply nitrogen (N) and phosphorus (P). Additionally, biofertilizers serve as biostimulants, producing phytohormones such as auxins (usually indole-3-acetic acid), gibberellins, and cytokinins, which are essential for regulating plant growth, development, and reproduction (Mahendhiran et al., 2024).

Volcanic-tropical soils such as Inceptisols naturally have low levels of carbon, available phosphorus (P), and nitrogen (Elfarisna et al., 2024; Rahmayuni et al., 2023; Sara et al., 2025). Therefore, using both chemical and organic fertilizers is recommended. The macronutrients N and P are vital for the growth of leafy vegetables such as Chinese cabbage and choy sum. Nitrogen is essential for protein synthesis and overall plant growth, while phosphorus plays a key role in energy metabolism and transfer (Farhan et al., 2024). Phosphorus is essential for the synthesis and activation of enzymes involved in nutrient acquisition and transport, such as N, K, and Ca, and it alters root architecture, reduces stem elongation, and increases shoot biomass (Tariq et al., 2023).

Choy sum is an important vegetable crop in Indonesia; its production reached 712,000 kg in 2023 and 710,000 kg in 2024 (Badan Pusat Statistik, 2024). Currently, leafy vegetable cultivation consistently uses a NPK compound fertilizer and organic matter as nutrient sources to maintain plant productivity at 250 kg/ha (Widowati, 2024). In Inceptisol soil, beds that received 70 kg N/ha of urea produced higher yields (Hindersah et al., 2023). Nonetheless, in Malaysia, the recommended dose of inorganic fertilizer is much lower, at 34 kg N/ha in Oxisol, to achieve the highest vegetative growth and yield (Khairun et al., 2016).

A sustainable way to improve the efficiency of inorganic fertilizer use in leafy vegetable cultivation is biofertilizer inoculation. The use of biofertilizers containing active, beneficial microbes has not been widely adopted in Indonesia, even though field research demonstrated the biofertilizers' effectiveness in reducing NPK compound fertilizer as well as increasing plant growth and yield of important agricultural commodities (Hindersah et al., 2023; Ikhwan et al., 2024; Puspitawati et al., 2013).

Commonly developed biofertilizers in Indonesia include nitrogen-fixing bacteria and phosphate-solubilizing microbes such as endospore-forming *Bacillus* that can resist the abiotic stress. The phosphate-solubilizing *Bacillus* has been used in biofertilizer formulations because it primarily solubilizes inorganic P and K with organic acids and produces phytohormones such as auxin, CK, and GA (Handayani & Mirawanty, 2023; Rabari et al., 2025; Risanti et al., 2024). They inherited the *nif* gene, which encodes N₂ fixation (Jain et al., 2021), which catalyzes the N₂ conversion into NH₃, which is then enzymatically nitrified to nitrate (NO₃⁻) that is available to plants (Ayiti & Babalola, 2022). Auxin regulates cell division and elongation, which are essential for leaf formation and vegetative plant growth (Kiba & Krapp, 2016).

Therefore, *Bacillus* inoculants, as biofertilizers, have the potential to reduce NPK fertilizer requirements, including for leafy vegetable crops. *Bacillus*-based biofertilizer application should be combined with an organic matter amendment, since heterotrophic *Bacillus* require organic C as an energy and carbon source. Organic matter also improves soil structure, mainly porosity, and provides macronutrients N, P, and K through decomposition (Gerke, 2022). Therefore, for short-term cultivation of leafy vegetables, NPK fertilizer, along with organic matter and biofertilizers, could reduce chemical fertilizer use. A previous pot experiment on mineral soil showed that the yield (shoot plant weight) and dry weight of choy sum treated with 75 and 150 kg/ha NPK fertilizer (16-16-

16) plus biofertilizer consortia up to 10^6 CFU/g soil were comparable to those treated with 225–300 kg/ha (Hindersah et al., 2021). Meanwhile, residual soil N was similar across treatments. Reducing the NPK dose to 50 kg/ha may support the scientific idea that biofertilizer can minimize the use of chemical fertilizers.

A *Bacillus*-based biofertilizer composed of *Bacillus subtilis* and *B. cereus* has been developed, but its effectiveness on plants has not been studied. The novelty of a mixed-strain *Bacillus* biofertilizer over a single-strain inoculant lies in its functional multiplicity and diverse mechanisms for promoting plant growth. The aim of this research was to examine the effect of *Bacillus* spp. combined with different levels of NPK 16-16-16 on the growth and biomass of choy sum, the *Bacillus* count, and N and P levels in the soil to identify the best combination of *Bacillus* spp. biofertilizer and NPK 16-16-16 doses that enhance choy sum yield. The experiment also observed plant growth and yield at a lower NPK level than the Indonesian recommended dose, which can show fertilizer substitution to maintain comparable growth and yield.

MATERIALS AND METHODS

Research Location and Duration

The greenhouse experiment was conducted at the Ciparanje Greenhouse, Faculty of Agriculture, Universitas Padjadjaran, Jatinangor, Sumedang Regency, West Java Province, from October to December 2024. The research location is at an altitude of ± 752 meters above sea level, with rainfall type C (Schmidt & Ferguson, 1951). The pot experiment was conducted using Jatinangor Inceptisols soil mixed with cow manure. The soil acidity was 6.45, with organic carbon of 1.09% (low), total nitrogen of 0.12 (low), and a C/N ratio of 9 (low), available phosphorus of 5.89 mg/kg (low), potential phosphorus of 19.23 mg/100 g (low), potential potassium of 7.53 mg/100 (low), and a *Bacillus* count of approximately 10^5 CFU/g. The manure contained 41.09% organic carbon, 2.06% total nitrogen, a C/N ratio of 19.95, potential phosphorus of 0.56%, and potential potassium of 0.29%, with acidity and water content of 6.05% and 19.03%, respectively. Liquid biofertilizer composed of *Bacillus cereus* and *B. subtilis* was formulated in an organic liquid medium enriched with 0.1% KH_2PO_4 . The initial concentration of each species was 1%, with a balanced composition. The culture was incubated for

72 hours at room temperature on a gyratory shaker at 115 rpm to obtain a *Bacillus* density of approximately 10^7 CFU/mL.

Experimental Design

The experiment was designed in a Completely Randomized Block Design with 6 mixed treatments of biofertilizer and NPK, as follows:

A: Negative control: without NPK and *Bacillus*

B: Positive control: NPK 50 kg/ha

C: Positive control: *Bacillus*

D: *Bacillus* and NPK 50 kg/ha

E: *Bacillus* and NPK 100 kg/ha

F: *Bacillus* and NPK 150 kg/ha

Each treatment was repeated four times. The compound fertilizer had an NPK composition of 16-16-16 (%). The *Bacillus* liquid inoculant dose was 0.5%, equivalent to 5 mL per pot. The population of mixed biofertilizer before application was 10^9 CFU/mL. Therefore, 5 mL biofertilizer contained 5×10^9 CFU of microbes, equal to 10^6 CFU/g in soil. This concentration is the average of *Bacillus* counts in soil, 10^5 – 10^7 CFU/g (Wardani et al., 2018; Mawarda et al., 2022).

Experimental Establishment

The seeds of choy sum cv Shinta were planted in nursery trays with 3 cm x 3 cm holes, filled with a mixture of Inceptisol and cow manure (1:1, v/v). The soil was cleared of any debris before being mixed with cow manure in a 70:30 volume ratio. One kilogram of the planting medium was transferred into 20 x 20 cm polybags and watered with groundwater to field capacity.

One week before planting, the *Bacillus* consortium biofertilizer was evenly sprayed onto the media surface after being diluted with 20 mL of water. A single 14-day-old transplant was placed into a polybag at a depth of 3 cm. The biofertilizer and NPK were applied in split doses once a week for 1 to 4 weeks after planting. The NPK fertilizer was applied one day after the *Bacillus* application by placing it in the planting hole, 3 cm from the stem, at a depth of 3–5 cm.

Watering was performed twice daily, in the morning and evening, with the water volume adjusted to the field capacity of 170 mL. Weeding was carried out by carefully removing weeds to avoid damaging the plants, at daily intervals throughout the four-week trial period.

Parameters and Data Analysis

Plant height, leaf width, number of leaves, and stem diameter were measured at weekly intervals over the four-week period. The wet and dry weights of the plant shoots and roots were measured at harvest (28 days after planting). The crown and roots were separated, soil was removed, and they were dried at 70 °C for 48 hours to determine dry weight. The *Bacillus* population in the growing medium after harvest was also measured.

At the end of the experiment, soil pH and total nitrogen content were measured using the Kjeldahl method, and soil available phosphorus was determined using spectrophotometry refers to the method of AOAC (Latimer Jr, 2019). *Bacillus* populations were counted using the serial dilution plate method on TSA media (Bağcıoğlu et al., 2019; Risanti et al., 2024).

All data were analyzed using analysis of variance (F test) at $p < 0.05$. If the F test indicated a significant effect on a parameter, Duncan's Multiple

Range Test (DMRT) was conducted. The statistical analysis was performed using IBM SPSS version 27.

RESULTS AND DISCUSSION

Growth Traits

Fertilizer treatment enhanced growth traits, including plant height, leaf number, leaf diameter, and stem thickness. At the end of the experiment, *Bacillus* alone did not increase all traits (Tables 1, 2, 3, 4) compared with the negative control. At three and four weeks, choy sum was significantly taller when combined with *Bacillus*, regardless of the NPK fertilizer dose (Table 1). The *Bacillus*-inoculated plants were comparable in height to the control plants, but both were shorter than the NPK-treated plants. At four weeks, NPK at 50 kg/ha increased plant height and leaf number by 47.5% and 28%, respectively, compared with the control. The combination of all NPK fertilizer doses with *Bacillus* did not improve these two parameters compared with NPK at 50 kg/ha alone.

Table 1. The influence of different NPK fertilizers combined with *Bacillus*-based biofertilizer on plant height of choy sum

Fertilizer treatments	Plant height (cm) of choy sum up to 4 weeks			
	Week 1	Week 2	Week 3	Week 4
A: Negative control	13.8 c	21.8 a	26.0 a	28.0 a
B: NPK 50 kg/ha	12.3 ab	21.5 a	31.5 b	41.3 b
C: <i>Bacillus</i>	11.8 a	21.3 a	26.3 a	30.8 a
D: <i>Bacillus</i> , NPK 50 kg/ha	11.8 a	20.5 a	33.8 b	46.3 b
E: <i>Bacillus</i> , NPK 100 kg/ha	13.5 c	21.0 a	33.0 b	44.0 b
F: <i>Bacillus</i> , NPK 150 kg/ha	13.3 bc	20.0 a	32.5 b	42.8 b

Numbers followed by similar letters are not significantly different according to DMRT, with $p < 0.05$.

Based on ANOVA, plants receiving combined NPK and *Bacillus* treatments had higher leaf numbers at each measurement week than the control (Table 2). However, plants with *Bacillus* inoculation alone had

a leaf number similar to that of the control plant. No difference in leaf number was observed in NPK + *Bacillus*-treated plants.

Table 2. The influence of different NPK fertilizer combined with *Bacillus*-based biofertilizer on leaf number of choy sum

Fertilizer treatments	Leaf number of choy sum up to 4 weeks			
	Week 1	Week 2	Week 3	Week 4
A: Negative control	4.0 a	7.0 a	9.0 a	10.0 a
B: NPK 50 kg/ha	5.0 c	8.3 c	10.8 c	12.8 b
C: <i>Bacillus</i>	4.3 ab	7.3 ab	9.5 ab	11.0 a
D: <i>Bacillus</i> , NPK 50 kg/ha	5.0 c	9.0 d	11.0 c	13.5 b
E: <i>Bacillus</i> , NPK 100 kg/ha	4.8 bc	7.8 bc	10.0 b	13.0 b
F: <i>Bacillus</i> , NPK 150 kg/ha	4.5 abc	7.5 ab	9.8 b	12.5 b

Numbers followed by similar letters are not significantly different according to DMRT with $p < 0.05$

In the first and second weeks, the plants treated with NPK and biofertilizer had smaller leaf diameters than the control and the *Bacillus*-only-treated plants (Table 3). However, at harvest (4 weeks), any NPK dose combined with *Bacillus* increased leaf width compared with the negative

control and *Bacillus* alone. The widest leaves were observed in plants with 50 kg/ha with *Bacillus*, which is slightly higher than 50 kg/ha without *Bacillus* and 100 kg/ha NPK with *Bacillus* (7.8% and 5%, respectively).

Table 3. The influence of different NPK fertilizers combined with *Bacillus*-based biofertilizer on the leaf diameter of choy sum

Fertilizer treatments	Leaf width (cm) up to 4 weeks			
	Week 1	Week 2	Week 3	Week 4
A: Negative control	4.5 c	8.3 ab	10.3 a	12.3 a
B: NPK 50 kg/ha	4.5 c	8.5 b	13.8 b	16.5 bc
C: <i>Bacillus</i>	3.0 a	7.5 a	10.0 a	12.5 a
D: <i>Bacillus</i> , NPK 50 kg/ha	3.7 b	7.5 a	14.0 b	17.8 c
E: <i>Bacillus</i> , NPK 100 kg/ha	4.2 bc	7.5 a	13.8 b	16.8 bc
F: <i>Bacillus</i> , NPK 150 kg/ha	3.7 b	7.5 a	13.5 b	16.3 b

Numbers followed by similar letters are not significantly different according to DMRT, with $p < 0.5\%$.

Table 4 shows that the treatments did not affect stem thickness in the first weeks after transplanting, but, consistent with other plant growth parameters, stem thickness increased after NPK and *Bacillus* treatments in subsequent weeks. At 3 and 4 weeks, the plant receiving NPK at 50 kg/ha, combined with *Bacillus*, had a higher stem diameter

than the *Bacillus*-treated and control plants. A significant increase in stem thickness of up to 31% was observed in plants with 50 kg/ha NPK + *Bacillus* compared to NPK 50 kg/ha. Both higher dose of NPK with biofertilizer reduced the stem thickness significantly.

Table 4. The influence of different NPK fertilizers combined with *Bacillus*-based biofertilizer on the stem thickness of choy sum

Fertilizer treatments	Stem thickness (mm) up to 4 weeks			
	Week 1	Week 2	Week 3	Week 4
A: Negative control	2.0 a	4.6 a	8.2 a	8.5 a
B: NPK 50 kg/ha	2.0 a	4.7 a	9.6 b	10.9 b
C: <i>Bacillus</i>	2.0 a	4.6 a	8.5 a	8.9 a
D: <i>Bacillus</i> , NPK 50 kg/ha	2.0 a	4.9 b	10.0 c	14.3 d
E: <i>Bacillus</i> , NPK 100 kg/ha	2.0 a	4.8 ab	9.6 bc	13.3 c
F: <i>Bacillus</i> , NPK 150 kg/ha	1.9 a	4.7 a	9.4 b	13.1 c

Numbers followed by similar letters are not significantly different according to DMRT, with $p < 0.5\%$.

Tables 1 to 4 indicated that 50 kg NPK/ha + *Bacillus* outperformed higher NPK rates, suggesting improved nutrient-use efficiency through complementary mineral fertilizer–*Bacillus* interactions rather than a simple response to increased fertilizer supply. At harvest, *Bacillus* plus NPK produced the highest shoot, more leaves, widest leaves, and stem thickness at the 50 kg dose, while raising NPK from 50 to 150 kg/ha reduced leaf width and stem thickness. This pattern indicates that *Bacillus* inoculation may have improved fertilizer

efficiency by enhancing the acquisition and utilization of nutrients supplied by the lower NPK dose (Sales & Rigobelo, 2024).

Overall, the plants were healthy throughout the experiment, with no significant pest or disease attacks (Figure 1). The performance of plants was relatively comparable by day 14, but at day 28, the plants receiving NPK 50 kg/ha (B), and *Bacillus* with NPK at the rate of 50, 100, and 150 kg/ha (D, E, and F, respectively) had better growth performance.



Figure 1. Choy sum grown in potted Inceptisol soil at 14 days (a) and 28 days (b) after transplanting. A: negative control, B: NPK 50 kg/ha, C: *Bacillus*, D: *Bacillus* and NPK 50 kg/ha, E: *Bacillus* and NPK 100 kg/ha, F: *Bacillus* and NPK 150 kg/ha.

This study showed that the *Bacillus*-based biofertilizer's effectiveness depended strongly on the presence of inorganic fertilizer. While *Bacillus* alone produced growth and biomass comparable to the unfertilized control, combining it with NPK fertilizer significantly enhanced choy sum's vegetative growth and yield. These findings suggest that the bacterial consortium serves better as a complementary biofertilizer—improving nutrient utilization—rather than as a full substitute for mineral fertilizers in low-N soil.

Biofertilizers increased plant growth, possibly by enhancing microbial functions that reduce dependence on chemical fertilizers. The *Bacillus* strains used in this experiment produce phosphatases essential for P solubilization and synthesize the phytohormones IAA, cytokinins, and gibberellins (Hindersah et al., 2020). These results align with the effectiveness of *Bacillus subtilis* for lettuce under low N fertilizer levels (Venancio et al., 2019). The P are the backbone of DNA and RNA, and are essential in energy storage and transfer during metabolism, including photosynthesis. Phytohormones also play a significant role in regulating plant growth. Stem thickness (secondary growth) is promoted by cambial activity and cell division in lateral meristems that

regulate by phytohormon (Peng et al., 2024). Shoot growth is determined by indigenous cytokinin, but cytokinin produced by PGPR in the rhizosphere contributes to the CK levels required for plant growth (Chieb & Gachomo, 2023).

Plant Biomass

Bacillus alone was unable to increase plant biomass; shoot and root biomass were influenced by the NPK and NPK-plus-*Bacillus* treatments (Table 5). The shoot fresh weight of plants receiving any dose of NPK combined with *Bacillus* was statistically similar to that of 50 kg/ha NPK without *Bacillus*. Shoot fresh weight is the principal economic yield of leafy vegetables. Plants receiving 50 kg/ha NPK with *Bacillus* showed an increase in yield of up to 14%, but this increment was not statistically significant at higher NPK doses. This indicates that *Bacillus* can maintain yield at a lower NPK dose (50 kg/ha). Biomass production data further support the positive interaction between mineral fertilizer and *Bacillus*. The lowest fresh and dry shoot biomass was observed in the control and *Bacillus*-only treatment groups.

The S/R ratio of plants receiving NPK with *Bacillus*-based biofertilizer was higher than that of the control and *Bacillus*-only treatments, indicating

that mixed fertilization promotes shoot growth, which is economically essential for leafy vegetables. This may be due to higher cytokinin synthesis by *Bacillus*, since CK is essential for shoot growth over auxin. Previous experiments reported that the ratio of CK-to-auxin of *B. cereus* (formerly *B. megaterium*) and *B. subtilis* were 3.6 and 5.3 respectively (Hindersah et al., 2020).

Table 5. The influence of different NPK fertilizers combined with *Bacillus*-based biofertilizer on the shoot and root biomass of 4-week-old choy sum

Fertilizer treatments	Wet weight (g)		Dry weight (g)		S/R*
	Shoots	Roots	Shoots	Roots	
A: Negative control	50.0 a	6.3 a	4.2 a	0.4 a	9.4 a
B: NPK 50 kg/ha	151.5 b	9.5 a	7.8 b	0.6 c	12.2 b
C: <i>Bacillus</i>	60.5 a	7.0 a	4.8 a	0.5 b	8.8 a
D: <i>Bacillus</i> , NPK 50 kg/ha	174.5 b	10.5 a	10.9 c	0.7 d	14.3 c
E: <i>Bacillus</i> , NPK 100 kg/ha	172.3 b	9.3 a	10.6 c	0.7 d	14.1 c
F: <i>Bacillus</i> , NPK 150 kg/ha	172.0 b	9.0 a	10.2 c	0.7 d	14.1 c

Numbers followed by similar letters are not significantly different according to DMRT, with $p < 0.5\%$.

Soil Characteristics

Table 6 shows that various doses of NPK fertilizer combined with 0.5% and *Bacillus* spp. did not affect total soil N but increased available P. Total N after growing choy sum was higher than before the experiment (0.12%), which inhibited biological nitrogen fixation (Cabeza et al., 2024). Available P increased in the unfertilized control and at NPK 50 kg/ha, while *Bacillus* alone gave the lowest concentration (1.92 mg/kg). Because available P was similar with and without *Bacillus* at NPK 50 kg/ha, the higher available P at higher NPK rates was likely

due to greater P input from fertilizer rather than *Bacillus*-mediated solubilization. This suggests that *Bacillus* may not contribute to enhancing available P in soil. Fertilizer treatments influenced soil available-P concentration,

Fertilizer treatments did not affect soil acidity or *Bacillus* population; pH was approximately 7, higher than before the experiment (6.45). A modest increase in *Bacillus* counts was observed in the rhizosphere of choy sum with NPK, *Bacillus*, and their combination, although these increases were not statistically significant compared to the control.

Table 6. The effect of various combinations of *Bacillus* and NPK on total N, available P, and pH of soil, and *Bacillus* count in the rhizosphere of choy sum.

Fertilizer treatments	Total N (%)	Available P (mg/kg)	Media acidity	<i>Bacillus</i> counts 10 ⁶ CFU/mL
A: Negative Control	0.36 a	3.66 a	7.50 a	1.80 a
B: NPK 50 kg/ha	0.52 a	5.72 ab	7.20 a	2.25 a
C: <i>Bacillus</i>	0.42 a	1.92 a	7.20 a	2.18 a
D: <i>Bacillus</i> , NPK 50 kg/ha	0.46 a	6.9 ab	7.10 a	2.60 a
E: <i>Bacillus</i> , NPK 100 kg/ha	0.54 a	10.37 bc	7.23 a	2.65 a
F: <i>Bacillus</i> , NPK 150 kg/ha	0.47 a	13.48 c	7.20 a	2.53 a

Numbers followed by similar letters are not significantly different according to DMRT, with $p < 0.5\%$.

In this experiment, low available P in the soil (5.89 mg/kg) before the experiment may induce P solubilization by *Bacillus*. The research indicated that all fertilizer combinations are safe to use without risking excessive changes in acidity, thereby not disrupting nutrient availability for choy sum plants. A similar *Bacillus* population suggests that the interaction between indigenous and exogenous

Bacillus in the soil may be mutualistic, which enriches *Bacillus* in the soil (Zhang et al., 2023).

The consistent presence of *Bacillus* across treatments indicates that soil conditions support its proliferation. The results indicated that the *Bacillus* consortium primarily enhanced plant growth through phytohormone mechanisms, since the higher available P in the soil was likely caused by NPK fertilization. The contribution of *Bacillus* to P

mobilization was confounded with the effect of the NPK. *Bacillus* counts on TSA could not distinguish native (endogenous) from introduced (exogenous) *Bacillus* cells. Consequently, they may have contributed to increased plant growth. However, further research using molecular markers is needed to determine whether exogenous *Bacillus* is present among the *Bacillus* species.

Although the role of *Bacillus* in P mobilization remains unclear, this finding indicated that higher levels of NPK fertilizer were unnecessary for short-growing leafy vegetables. After the experiment, soil still contained low levels of available P but high levels of total N. Reducing P fertilizer levels while maintaining N fertilizer is required to increase P solubilization by *Bacillus*, since high available P inhibits the gene function responsible for this physiological activity (Sun et al., 2022).

CONCLUSION

Inoculating choy sum with a *Bacillus* consortium at various NPK fertilizer doses increased growth, biomass, the S/R ratio, and available soil P. This study indicated that combining *Bacillus* with 50 kg/ha of NPK increased choy sum growth without significantly affecting pH or total N. However, higher NPK doses, rather than *Bacillus* inoculation, strongly increased available soil P. Yields from plants receiving higher and lower NPK doses were similar, indicating that maintaining plant biomass at a reduced NPK dose is possible. *Bacillus* alone resulted in plant growth and soil properties similar to the unfertilized control, showing that *Bacillus* is an effective biofertilizer as a complementary input that improves plant performance at reduced chemical fertilizer, mainly P. Further research is needed to compare leafy vegetable responses to lower P doses with and without *Bacillus* inoculation, and to analyze exogenous *Bacillus* counts in soil using molecular markers.

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