INTRODUCING MICROBIAL-COATED FERTILIZER TO INCREASE THE YIELD AND QUALITY OF BROCCOLI IN A POT EXPERIMENT

PENERAPAN PUPUK BERSALUT MIKROBA UNTUK MENINGKATKAN PRODUKTIVITAS DAN KUALITAS TANAMAN BROKOLI PADA PERCOBAAN POT

Reginawanti Hindersah[1*], Mieke Rochimi Setiawati[1], Rara Rahmatika Risanti[2], Fasa Aditya[3], Gita Bina Nugraha[3]

[1]Department of Soil Science, Faculty of Agriculture, Universitas Padjadjaran, Jl. Raya Bandung Sumedang Km. 21, Sumedang 45363, Indonesia
[2]Fellow researcher at The Soil Biology Laboratory, Universitas Padjadjaran, Jl. Raya Bandung Sumedang Km. 21, Sumedang 45363, Indonesia
[3]Indonesian Fertilizer Research Institute, PT. Pupuk Indonesia, Jl. Taman Anggrek No.2, Kemanggisan Jakarta Barat 11480, Indonesia

*Correspondence: reginawanti@unpad.ac.id

Accepted: 20 October 2025 / Revised: 30 October 2025 / Approved: 18 December 2025

ABSTRACT

Increasing broccoli yield and quality is essential to meet consumer expectations for nutrient-rich vegetables. Implementing a balanced mix of chemical fertilizers and biofertilizers may support this goal. A greenhouse experiment was conducted to examine the effect of Bacillus-coated NPK combined fertilizer (BCN) on the growth, nutrient uptake, yield, and vitamin content of broccoli heads. The experiment was arranged in a Randomized Block Design with seven treatments and four replications. These treatments included different combinations of BCN type and dose, two levels of NPK, and a control without fertilizer. Results showed that BCN did not affect plant growth or N, P, and K content in the soil, but it increased the chlorophyll content index, nutrient uptake, and the shoot-to-root ratio. Although BCN did not influence yield, it enhanced Vitamin B-complex and K levels in the broccoli heads. The study concluded that in this short-term experiment, BCN improved N, P, and K levels in the shoots and increased the nutritional value of broccoli heads.

Keywords: Bacillus, Biofertilizer, NPK macronutrient, Vitamin

ABSTRAK

Peningkatan hasil dan kualitas brokoli merupakan salah satu cara untuk memenuhi harapan konsumen akan sayuran bernilai gizi tinggi. Penerapan pupuk berimbang antara pupuk kimia dan pupuk hayati dapat mendukung harapan tersebut. Percobaan di rumah kaca dilakukan untuk mengamati pengaruh pupuk kombinasi NPK berlapis *Bacillus* (NBB) terhadap pertumbuhan, penyerapan hara, hasil, dan kandungan vitamin pada bonggol brokoli. Percobaan disusun dalam Rancangan Acak Kelompok, terdiri dari tujuh perlakuan dan empat ulangan. Perlakuan tersebut terdiri dari kombinasi jenis dan dosis NBB, dua dosis NPK, dan satu perlakuan kontrol tanpa

Cite this as: Hindersah, R., Setiawati, M. R., Risanti, R. R., Aditya, F. & Nugraha, B. N. (2025). Introducing microbial-coated fertilizer to increase the yield and quality of broccoli in a pot experiment. *Jurnal Agro*, *12*(2), 275-288. https://doi.org/10.15575/j.agro.51511

pupuk. Hasil penelitian menunjukkan bahwa NBB tidak memengaruhi pertumbuhan tanaman dan kandungan N, P, dan K dalam tanah, tetapi meningkatkan indeks kandungan klorofil, penyerapan hara, dan rasio pucuk terhadap akar. Meskipun tidak mempengaruhi hasil panen, NBB meningkatkan vitamin B kompleks dan K di bunga brokoli. Penelitian ini menyimpulkan bahwa dalam percobaan jangka pendek, NBB meningkatkan nutrisi N, P, dan K pada tajuk serta nilai gizi bunga brokoli.

Kata kunci: *Bacillus*, Pupuk hayati, Unsur hara makro NPK, Vitamin

INTRODUCTION

Broccoli (*Brassica oleracea* var. *italica*) is widely grown for its nutritional value since it is rich in vitamins (C, B1, B9, K), calcium, and potassium (Syed et al., 2023; Majkowska-Gadomska et al., 2024). Despite its subtropical origin, broccoli is consumed in tropical countries, particularly by middle- to high-income societies. In the tropics, heat-tolerant broccoli grows best in high-altitude regions where the average temperature ranges from 18 to 27 °C. The crown initiation of broccoli occurs more rapidly at higher altitudes than at lower altitudes (Astarini et al., 2020). The challenge of cultivating broccoli in Indonesia lies in the quality of the soil. The soil in Indonesia's high-altitude areas is typically volcanic, including Inceptisols and Andisols.

Inceptisols exhibit soil textures predominantly of clay, clay loam, and sandy loam (Muslim et al., 2020) and poor chemical properties that hinder optimal growth and yield. Clay soil can impede vegetable root expansion by limiting airflow and water penetration and increasing physical resistance (Abuarab et al., 2019). The natural Inceptisols show low pH, organic matter, total nitrogen (N), and available phosphorus (P) but high cation exchange capacity (Muslim et al., 2020). Usually, growers fertilize their broccoli field with chemical fertilizer. The application of 600 and 800 kg NPK ha^{-1} resulted in higher broccoli head weight and diameter (Amina & Sudiarso, 2020).

The broccoli roots are adaptable to clay soils, and chemical fertilizers enhance nutrient availability, allowing local farmers to cultivate broccoli in high-altitude areas (Astarini et al., 2020). However, the chemical fertilizer use efficiency is low, and might reduce plant productivity. Introducing biofertilizers is a way to maintain nutrient availability and stimulate plant growth while reducing the NPK fertilizer dose.

Bacillus is a plant growth-promoting rhizobacteria commonly used in biofertilizer formulations. Under harsh conditions, *Bacillus* forms dormant endospores that increase resistance and can regenerate into vegetative cells when conditions become more favourable (Bressuire-Isoard et al., 2018). The *Bacillus* species enhance plant growth and yield through various mechanisms. They release organic acids to convert insoluble inorganic phosphate into available ones and produce phosphatases to decompose organic phosphorus into soluble forms (Setiawati et al., 2020); fix nitrogen to convert inert dinitrogen into ammonia (Miljaković et al., 2020), which is subsequently transformed into available nitrate through nitrification (Beeckman et al., 2018); and produce phytohormones auxins, cytokinins, and gibberellins (Basu et al., 2022) to promote various aspects of plant development.

While biofertilizers are essential in agriculture, their adoption remains limited in many areas. Combining chemical fertilizers with spore-forming *Bacillus* improves adoption by providing beneficial microbes and nutrients to the root zone. Research on these microbial-coated fertilizers is still limited, and application effects may differ by crop, region, and soil. A granular fertilizer coated with microbial inoculants increased potato yield in the Saint-Thomas region of Quebec, Canada (Overbeek et al., 2021). *Bacillus* and compost coating on DAP and urea granules enhanced wheat growth and yield by 20% (Ahmad et al., 2017). In a previous research, a reduced dose of BCN yielded similar biomass to conventional NPK 16-16-16 fertilizer for tomato plants grown in Andisol (Hindersah et al., 2025). The effect of *Bacillus*-coated NPK fertilizer on broccoli in Inceptisols is currently unexplored. This study aims to determine the impact of two types of BCN (BCN-C and BCN-G) on the growth, nutrient uptake, yield, and vitamin content of broccoli heads grown in potted Inceptisols.

MATERIALS AND METHODS

A pot experiment was carried out from February to May 2021 in a farmer's greenhouse at Mekarwangi, Parongpong District, Bandung Barat Regency, at an elevation of 1,260 m, with an annual temperature range of 17-28°C. The soil was classified as Inceptisols, with a pH of 6.9, low organic carbon content (1.83%), moderate total nitrogen (0.22%), low C/N ratio (8.31), moderate potential P_2O_5 (38.31 mg/100 g), high available P_2O_5 (14.37 mg kg^{-1}), and moderate potential K_2O (23.57 mg/100 g). The soil's cation exchange capacity was 34.29 cmol/kg (high), and base saturation was 49.75% (moderate). The soil texture was clay, consisting of 7% sand, 30% silt, and 63% clay.

The liquid culture of a bacterial consortium composed of *Bacillus safensis* B1, *B. subtilis* B14, *B. altitudinis* D2, and *Bacillus* sp. E2, which were isolated from the rhizosphere of various vegetable crops. Two types of *Bacillus*-coated NPK fertilizer, BCN-C and BCN-G, were formulated using different concentrations of *Bacillus* consortia liquid inoculant and zeolite. The BCN-C was produced using 0.2% liquid inoculant and 0.4% zeolite, while BCN-G contained 0.4% liquid inoculant and 0.2% zeolite.

Experimental Design

The pot experiment was designed using a Randomized Block Design, consisting of seven treatments with four replications. The treatments included a combination of two dosage levels (50 and 100% recommended dose) and compound fertilizer (NPK fertilizer, BCN formula C, and BCN formula G). The control treatment excluded fertilizer. The formulation of BCN-C and BCN-G was distinguished based of zeolite and inoculant concentrations. Two sets of experimental pots were used, one for assessing plant and soil parameters and another for evaluating the yield.

Experimental Establishment

Twenty-one-day-old seedlings were transplanted into 40×40 cm polybags containing 10 kg of substrate composed of soil and cow manure, with a volume ratio of 2:1 due to the high clay content in the soil. All polybags were placed 30 cm apart on the ground of a UV-plastic-covered area (Figure 1). NPK fertilizer and BCN were applied to the soil twice, at 7 and 21 days after planting, each 5 g plant^{-1} (equivalent to 600 kg ha^{-1}). The fertilizers were placed in a ring 2 cm from the plant stem and then covered with substrate. Dursban insecticide, with the active ingredient chlorpyrifos, was sprayed in the third and sixth weeks after planting. Intensive weeding was performed until the shoots covered the ground.

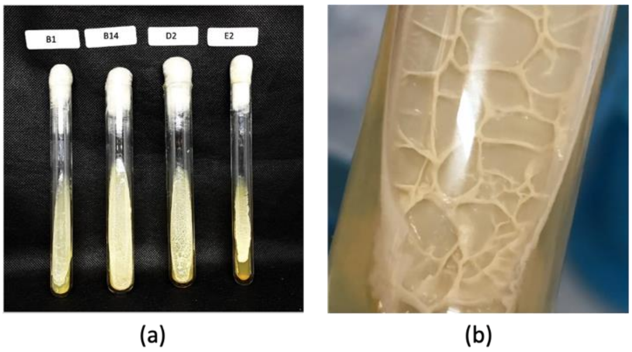

Figure 1. a. Pure cultures of four selected isolates (B1, B14, D2, and E2) on nutrient agar slants, and b. Colony morphology of a *Bacillus* isolate showing characteristic wrinkled surface structure.

Parameters and Chemical Analysis

The shoot height, along with leaf number and length, were measured weekly at two and four weeks after transplanting. At week four, the chlorophyll index of three fully expanded leaves was analyzed using the SPAD device, and the levels of N, P, and K in the soil were examined by soil chemical analysis (AOAC, 2017). Simultaneously, the fresh and dry weights of shoots and roots were recorded to calculate the shoot-to-root dry weight ratio (S/R). At 10 weeks after planting, the fresh weight and diameter of the flower head were measured, and the content of vitamins B-complex and K was analyzed.

Broccoli leaves were dried at 60°C until reaching a constant weight before measuring nitrogen (N) content using the Kjeldahl method, and the phosphorus (P) and potassium (K) contents were determined by spectrophotometry (AOAC, 2017). The N, P, and K uptake were calculated based on the shoot dry weight and its N, P, and K contents. The analysis of vitamins B-complex and K was performed using HPLC (Mozumder et al., 2019; Otles & Cagindi, 2007).

All data were analyzed using analysis of variance (ANOVA, F-test) at $p < 0.05$ to assess the effects of different treatments on the parameters. When a significant F-test was found, the Duncan Multiple Range Test at $p < 0.05$ was applied. Statistical analysis was conducted with SPSS version 25.

RESULTS AND DISCUSSION

Growth of Broccoli Plant

The plants showed no signs of nutrient deficiency or disease from the early vegetative to the flowering stages (Figures 2). The ANOVA indicated that the fertilizer treatments only increased the height of 2-week-old plants and had no significant impact on leaf number (Table 1).

Figure 2. a. The 14-day-old potted broccoli grown under the shaded area and b. Head initiation stage at day 50

This short-term experiment showed that the shoot height of 4-week-old plants and leaf number of fertilizer-treated plants was similar to that of plants without fertilizer. The significant increase in shoot height observed at 2 weeks but not at 4 weeks suggests that early vegetative growth responded temporarily to nutrient addition. However, as the soil had relatively high natural fertility and the experiment duration was short, this early advantage diminished by week four.

Table 1. Effect of *Bacillus*-coated NPK fertilizer on shoot height and number of leaves at 2 and 4 weeks after planting

Fertilizer treatments	Shoot height (cm)		Leaf number	
	2 weeks	4 weeks	2 weeks	4 weeks
Control	12.50 a	36.12 a	3.80 a	7.80 a
100% NPK	14.70 b	35.80 a	4.60 a	8.20 a
50% NPK	15.10 bc	31.92 a	4.20 a	7.60 a
100% BCN-C	16.10 bc	36.04 a	4.40 a	8.00 a
50% BCN-C	16.38 c	37.96 a	4.60 a	7.80 a
100% BCN-G	14.22 b	33.20 a	4.20 a	7.80 a
50% BCN-G	16.06 bc	38.52 a	4.80 a	7.60 a

Numbers followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

The soil was quite fertile, with average levels of nitrogen (N) and potassium (K), and it was even high in available phosphorus (P). The soil might supply enough essential macronutrients for plant growth. Neutral pH, high cation exchange capacity (CEC), and an average base saturation support nutrient availability in the soil. Additionally, applying cow manure before the experiment probably increased the organic carbon from low to average levels and reduced the high clay content in the soil; this could raise the Carbon-to-Nitrogen ratio and promote root development. The absence of a detectable fertilizer effect on shoot height and leaf number at week four may be associated with the naturally fertile soil used in the experiment, and the relatively low fertilizer dose applied, which may not have generated further growth differentiation once plants progressed to later vegetative stages.

At four weeks, the fertilizer did not affect the fresh and dry weights of shoots and roots, but it improved the leaf chlorophyll content index (CCI) and the shoot-to-root ratio (Table 2). The CCI of plants treated with a single dose of BCN-C and BCN-G increased significantly by approximately 60% and 48%, respectively, compared to the control and a 100% NPK treatment. The higher S/R was observed in plants treated with any dose of BCN; overall, a 31% increase in S/R was recorded in plants with BCN. However, the application of 100% NPK also increased the S/R compared to the control.

Although single doses of BCN-C and BCN-G significantly increased the chlorophyll content index (CCI), this increase did not result in higher shoot or root biomass. Increased chlorophyll often reflects improved physiological status, rather than direct biomass accumulation (Wang & Grimm, 2021). In short-term experiments, increases in nutrient assimilation or chlorophyll synthesis may occur more rapidly than measurable changes in plant mass (Hu et al., 2026). Furthermore, broccoli biomass is strongly influenced by soil physical constraints, and clay-dominated substrates may have limited root expansion despite increased chlorophyll content.

The BCN-C and BCN-G significantly increased the S/R ratio, where root growth is more prominent than shoot growth. The enhancement of the root system may include increased root hair size, which indicates the plant's ability to absorb soil water and nutrients, including N, that play a significant role in Chlorophyll content.

Table 2. Effect of *Bacillus*-coated NPK fertilizer on chlorophyll index and biomass of broccoli at 4 weeks after planting

Fertilizer treatments	Chlorophyll (CCI)*	Fresh weight (g)		Dry weight (g)		Shoot-to-root ratio
		Shoot	Root	Shoot	Root	
Control	7.98 a	33.29 a	3.02 a	1.95 a	0.64 a	3.05 a
100% NPK	8.46 a	37.04 a	2.20 a	2.17 a	0.51 a	4.25 b
50% NPK	8.26 a	32.06 a	2.45 a	1.73 a	0.59 a	2.93 a
100% BCN-C	12.54 b	36.69 a	2.91 a	2.25 a	0.53 a	4.25 b
50% BCN-C	9.80 a	42.03 a	2.85 a	2.49 a	0.61 a	4.08 b
100% BCN-G	12.58 b	28.94 a	2.11 a	1.67 a	0.47 a	3.55 ab
50% BCN-G	8.90 a	43.13 a	3.09 a	2.56 a	0.61 a	4.20 b

Numbers followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$. *Chlorophyll content index

The four *Bacillus* species produced more IAA than cytokinin in the previous in vitro study, resulting in significant root growth (Hu et al., 2021). Although plants produce their own phytohormones, their roots can also absorb phytohormones from the growth substrate (Anfang & Shani, 2021). Moreover, the ability of *Bacillus* to support root system development has been documented (Raimam et al., 2024).

The Macronutrient in the Soil

The fertilizer treatments had a minor effect on total P in the soil but did not alter the total N and K significantly based on statistical analysis (Table 3). Surprisingly, soil P levels in in treatments receiving the 50% NPK were higher than in the control and 100% NPK. Additionally, 100% BCN treatments resulted in lower P levels compared to 50% BCN. In general, the effect of NPK as well as BNC on N, P, and K content in soil was not pronounced at the end of the vegetative stadia. This implies that rather than accumulating in the soil, the applied nutrients were likely absorbed by the plants during growth, which aligns with the higher nutrient uptake values observed in the shoot analysis.

Table 3. The effect of *Bacillus*-coated NPK fertilizer on total N, P, and K in soil grown with broccoli at 4 weeks after transplanting

Fertilizer treatments	N (%)	P (mg/100g)	K (mg/100g)
Control	0.49 a	1.88 a	0.13 a
100% NPK	0.57 a	1.78 ab	0.17 a
50% NPK	0.65 a	2.04 b	0.18 a
100% BCN-C	0.55 a	1.54 a	0.12 a
50% BCN-C	0.43 a	1.67 ab	0.18 a
100% BCN-G	0.46 a	1.56 a	0.12 a
50% BCN-G	0.43 a	1.67 ab	0.13 a

Numbers followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

The Macronutrient Content and Uptake in Shoots

Table 4 shows that BCN type and dose significantly affected shoot P concentration but did not influence N or K levels. However, the half dose of BCN enhanced N, P, and K uptake. Half doses of BCN-C and BCN-G increased the N uptake up to 33.6% and 59.7 % respectively, compared to one dose of BCN-C and BCN-G. The increment of P and K uptake of plants treated with a half dose of BCN-G was more pronounced than that of BCN-C. Approximately 77% and 56% increase in P and K uptake was demonstrated following application of a 50% BCN-G compared to one dose.

The rise in the S/R ratio of plants treated with BCN (Table 2) may contribute to higher nutrient uptake in the shoot, as the improved root system can supply nutrients more consistently. This aligns with the increased macronutrient uptake observed in vegetable leaves after beneficial bacteria inoculation, including *Bacillus* (Santander et al., 2024). BCN is designed to release nutrients more slowly than conventional NPK fertilizers, providing a steadier supply of N, P, and K to plant roots and minimizing nutrient loss. An increase in nutrient use efficiency has been reported for various coated fertilizers (Himmah et al., 2018; Kassem et al., 2024).

Unchanged levels of three macronutrients in soil (Table 3) were followed by different levels of their uptake in broccoli leaves. The study only measured total N, P, and K in soil rather than their availability for plant uptake. An increase in N, P, and K uptake by plants with half the dose of both BCN formulas confirms that *Bacillus* contributes to providing available macronutrients, particularly phosphorus and nitrogen. Each *Bacillus* species formulated in this coated NPK was proven to synthesize phosphatase and a specific organic acid (Risanti et al., 2025), which induces P solubilization in soil. In the previous assay, all *Bacillus* species showed nitrogenase activity and released nitrate in the N-free broth, which is related to N_2 fixation. The nitrogenase activity that catalysed N_2 fixation in the *Paenibacillus* and *Bacillus genera* has been reported (Wang et al., 2025). This suggests that the four *Bacillus isolates* provide available N, P and K to promote N and P uptake for chlorophyll synthesis, as shown by the increase in CCI in leaves treated with BCN (Table 2).

Table 4. Nitrogen, phosphorus, and potassium content and uptake in broccoli shoots 4 weeks after transplanting

Fertilizer treatments	Nutrient content (%)			Nutrient uptake (mg g^{-1})		
	N	P	K	N	P	K
Control	5.72 a	2.12 b	3.47 a	11.13 bc	4.13 b	6.75 b
100% NPK	5.95 a	1.38 a	3.22 a	12.86 d	2.99 a	6.96 b
50% NPK	5.46 a	1.74 ab	3.42 a	9.44 a	3.01 a	5.92 a
100% BCN-C	5.08 a	2.12 bc	3.19 a	11.43 c	4.77 c	7.17 b
50% BCN-C	6.12 a	2.39 c	3.39 a	15.28 e	5.95 d	8.39 c
100% BCN-G	5.92 a	1.92 abc	3.25 a	9.92 ab	3.21 a	5.42 a
50% BCN-G	6.20 a	2.20 bc	3.31 a	15.85 e	5.69 e	8.48 d

Numbers followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

Biomass and Yield of Broccoli

The results indicated that applying NPK and BCN at any dose did not alter the yield compared to no fertilizer (Table 5). The experiment, conducted in relatively fertile Inceptisols, showed that the NPK and BCN doses can be decreased by 50% without reducing broccoli yield, as shown by no significant effect on the yield of plants that received half the dose of fertilizer. However, the one dose of fertilizer used in this research (5 g $plant^{-1}$) might be too low to boost plant growth and yield.

The existing nutrients in the soil might have compensated for the NPK and bacterial-coated NPK fertilizers in each treatment. Ollio et al., (2024) tested different formulations of plant growth-promoting microbes and observed no significant effect on broccoli yield. The absence of a significant yield response does not necessarily indicate incompatibility between broccoli and the *Bacillus* strains. Instead, it may reflect the short duration of the experiment, the fertile soil conditions, and the relatively low fertilizer dose, all of which may limit detectable yield differences despite observed improvements in physiological traits and nutrient uptake. Additionally, the method of application, doses, and inoculation frequency of the fertilizer can influence the yield.

Table 5. Effect of *Bacillus*-coated NPK on the biomass and yield of broccoli at 10 weeks after planting

Fertilizer treatments	Head weight (g)	Head Diameter (cm)
Control	108.6 a	11.9 a
100% NPK	122.6 a	12.5 a
50% NPK	124.3 a	12.4 a
100% BCN-C	194.8 a	14.8 a
50% BCN-C	129.2 a	12.5 a
100% BCN-G	116.5 a	13.9 a
50% BCN-G	136.3 a	13.7 a

Numbers followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

Vitamins in a Broccoli Head

The fertilizer treatments affected the concentrations of vitamins B-complex and K in the broccoli heads (Table 6). Excluding half the BCN-G dose, the BCN treatment caused a significant increase in vitamin B-complex by 29.2% and 24.5% compared to the control and NPK fertilizer. Overall, all BCN applications increased the Vitamin K content by up to 14.4% and 21.8% compared to the control and NPK fertilizer, respectively. This result showed that a dose and a half of BCN is more effective for achieving high levels of vitamins B and K in the head compared to NPK fertilizer.

Table 6. The vitamins B and K in broccoli heads

Fertilizer treatments	Vitamin B-complex (mg/100 g)	Vitamin K (μg/100g)
Control	1.06 a	99.08 b
100% NPK	1.14 a	97.03 b
50% NPK	1.07 a	89.07 a
100% BCN-C	1.48 b	119.15 d
50% BCN-C	1.33 b	116.44 d
100% BCN-G	1.32 b	109.74 c
50% BCN-G	0.98 a	108.28 c

Numbers followed by the same letter in each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

Despite the absence of the BCN effect on yield, any dose and type of BCN increased both vitamin B-complex and K in broccoli heads. Phosphorus and nitrogen play essential roles in vitamin biosynthesis in plants. Increased N and P uptake may be linked to the vitamin increase in the broccoli heads. The vitamin synthesis pathways involve the chemical energy adenosine triphosphate, which is produced from adenosine monophosphate. Amino acids serve as precursors in the biosynthesis of most B vitamins in plants (Miret & Munné-Bosch, 2014). Specific wild types of *Bacillus* are known to produce Vitamins B and K (Abdel-Baki et al., 2024; Kang et al., 2022), although the *Bacillus* used in this experiment has not been tested for its ability to produce these vitamins.

This finding confirms that in short-term broccoli cultivation, BCN can decrease NPK application by 50% to gain a similar yield of plants grown with conventional NPK while enhancing the nutrient content of the broccoli heads. In vitro and in planta tests are necessary to examine *Bacillus*'s role in vitamin synthesis. More research is needed to explore the long-term effects of reduced doses of *Bacillus*-coated NPK fertilizer, especially regarding its compatibility with broccoli. This is because nutrient depletion may occur after planting broccoli for a specific period, possibly limiting nutrient uptake if fertilizers are not applied.

CONCLUSION

Neither the dose nor the type of BCN affected plant growth, biomass, and yield of broccoli. However, BCN increased the shoot-to-root ratio and chlorophyll content. Despite no effect of BCL on total N, P, and K in soil, any dose and type of BCN increased their uptake in the shoot. The BCN treatments also enhanced the vitamin B and K content of broccoli heads. In this short-term pot experiment, the BCN had an comparable ability to conventional NPK fertilizer in maintaining broccoli growth, biomass, and yield. The similar yield suggests that the doses of both fertilizers could be reduced by up to 50%. This experiment verified that growing broccoli in quite fertile potted soil resulted in no observed effect of BCN on yield. Nonetheless, *Bacillus*-coated NPK fertilizers are promising for increasing the nutritional value of broccoli heads, as they contribute to higher vitamin content. Further experiment to enhance the dose of BCN as well as NPK fertilizer is required to boost plant growth and yield.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to PT Pupuk Kujang Indonesia for the financial and technical support provided for this research.

REFERENCES

Abdel-Baki, R. M. M., Ahmed, M. N., Barakat, O. S., & Khalafalla, G. M. (2024). Enhanced vitamin B12 production by isolated *Bacillus* strains with the application of response surface methodology. *BMC Biotechnology*, *24*(1). https://doi.org/10.1186/s12896-024-00919-5

Abuarab, M. E., El-Mogy, M. M., Hassan, A. M., Abdeldaym, E. A., Abdelkader, N. H., & El-Sawy, M. B. I. (2019). The effects of root aeration and different soil conditioners on the nutritional values, yield, and water productivity of potato in clay loam soil. *Agronomy*, *9*(8). https://doi.org/10.3390/agronomy9080418

Ahmad, S., Imran, M., Hussain, S., Mahmood, S., Hussain, A., & Hasnain, M. (2017). Bacterial impregnation of mineral fertilizers improves yield and nutrient use efficiency of wheat. *Journal of the Science of Food and Agriculture*, *97*(11), 3685–3690. https://doi.org/10.1002/jsfa.8228

Anfang, M., & Shani, E. (2021). Transport mechanisms of plant hormones. In

Current Opinion in Plant Biology (Vol. 63). Elsevier Ltd. https://doi.org/10.1016/j.pbi.2021.102055

Astarini, I. A., Defiani, M. R., Suriani, N. L., Griffiths, P. D., Stefanova, K., & Siddique, K. H. M. (2020). Adaptation of broccoli (*Brassica oleracea* var. italica l.) to high and low altitudes in Bali, Indonesia. *Biodiversitas*, *21*(11), 5263–5269. https://doi.org/10.13057/biodiv/d211129

Basu, S., Priyadarshini, P., Prasad, R., & Kumar, G. (2022). Effects of Microbial Signaling in Plant Growth and Development. In: Prasad, R., Zhang, SH. (eds) Beneficial Microorganisms in Agriculture. *Environmental and Microbial Biotechnology*.

Beeckman, F., Motte, H., & Beeckman, T. (2018). Nitrification in agricultural soils: impact, actors and mitigation. In *Current Opinion in Biotechnology* (Vol. 50, pp. 166–173). Elsevier Ltd. https://doi.org/10.1016/j.copbio.2018.01.014

Bressuire-Isoard, C., Broussolle, V., & Carlin, F. (2018). Sporulation environment influences spore properties in *Bacillus*: Evidence and insights on underlying molecular and physiological mechanisms. In *FEMS Microbiology Reviews* (Vol. 42, Issue 5, pp. 614–626). Oxford University Press. https://doi.org/10.1093/femsre/fuy021

Candra Amina, M., & Sudiarso. (2020). Pengaruh Pemberian Kompos Sampah Kota dan Pupuk NPK terhadap Pertumbuhan dan Hasil The Effect of Municipal Solid Compost Waste and NPK Fertilizer on The Growth and Yield of on Broccoli Plant (*Brassica oleracea* L. var. Italica). *Jurnal Produksi Tanaman*, *8*(9), 840–847.

Himmah, N. I. F., Djajakirana, G., & Darmawan, D. (2018). Nutrient Release Performance of Starch Coated NPK Fertilizers and Their Effects on Corn Growth. *SAINS TANAH - Journal of Soil Science and Agroclimatology*, *15*(2), 104. https://doi.org/10.15608/stjssa.v15i2.19694

Hindersah, R., Fitriatin, B. N., Setiawati, M. R., Suryatmana1, P., Risanti, R. R., Yeni, D., & Dewi, W. (2025). Enhancing Tomato (Lycopersicon esculentum Mill.) Growth in a Greenhouse Using NPK Fertilizer Coated with Endospore-Forming *Bacillus*. *Jurnal Agrikultura*, *2025*(1), 128–137.

Hu, J., Xiong, J., Zhao, Z., & Wang, X. (2026). Carbon dots promote plant growth via coordinated regulation of nutrient uptake and photosynthesis: Evidence from multivariate modeling. *Bioresource Technology*, *440*. https://doi.org/10.1016/j.biortech.2025.133515

Hu, Y., Omary, M., Hu, Y., Doron, O., Hoermayer, L., Chen, Q., Megides, O., Chekli, O., Ding, Z., Friml, J., Zhao, Y., Tsarfaty, I., & Shani, E. (2021). Cell kinetics of auxin transport and activity in Arabidopsis root growth and skewing. *Nature*

Communications, *12*(1). https://doi.org/10.1038/s41467-021-21802-3

Kang, M. J., Baek, K. R., Lee, Y. R., Kim, G. H., & Seo, S. O. (2022). Production of Vitamin K by Wild-Type and Engineered Microorganisms. In *Microorganisms* (Vol. 10, Issue 3). MDPI. https://doi.org/10.3390/microorganisms10030554

Kassem, I., Ablouh, E. H., El Bouchtaoui, F. Z., Jaouahar, M., & El Achaby, M. (2024). Polymer coated slow/ controlled release granular fertilizers: Fundamentals and research trends. In *Progress in Materials Science* (Vol. 144). Elsevier Ltd. https://doi.org/10.1016/j.pmatsci.2024.101269

Miljaković, D., Marinković, J., & Balešević-Tubić, S. (2020). The significance of *Bacillus* spp. In disease suppression and growth promotion of field and vegetable crops. In *Microorganisms* (Vol. 8, Issue 7, pp. 1–19). MDPI AG. https://doi.org/10.3390/microorganisms8071037

Miret, J. A., & Munné-Bosch, S. (2014). Plant amino acid-derived vitamins: Biosynthesis and function. In *Amino Acids* (Vol. 46, Issue 4, pp. 809–824). Springer-Verlag Wien. https://doi.org/10.1007/s00726-013-1653-3

Mozumder, N. H. M. R., Akhter, Most. J., Khatun, A. A., Rokibuzzaman, M., & Akhtaruzzaman, M. (2019). Estimation of Water-Soluble Vitamin B-Complex in Selected Leafy and Non-Leafy Vegetables by HPLC Method. *Oriental Journal Of Chemistry*, *35*(4), 1344–1351. https://doi.org/10.13005/ojc/350414

Muslim, R. Q., Kricella, P., Pratamaningsih, M. M., Purwanto, S., Suryani, E., & Ritung, S. (2020). Characteristics of Inceptisols derived from basaltic andesite from several locations in volcanic landform. *Sains Tanah*, *17*(2), 115–121. https://doi.org/10.20961/STJSSA.V17I2.38221

Ollio, I., Santás-Miguel, V., Gómez, D. S., Lloret, E., Sánchez-Navarro, V., Martínez-Martínez, S., Egea-Gilabert, C., Fernández, J. A., Calviño, D. F., & Zornoza, R. (2024). Effect of Biofertilizers on Broccoli Yield and Soil Quality Indicators. *Horticulturae*, *10*(1). https://doi.org/10.3390/horticulturae10010042

Otles, S., & Cagindi, O. (2007). Determination of vitamin K1 content in olive oil, chard and human plasma by RP-HPLC method with UV-Vis detection. *Food Chemistry*, *100*(3), 1220–1222. https://doi.org/10.1016/j.foodchem.2005.12.003

Overbeek, W., Jeanne, T., Hogue, R., & Smith, D. L. (2021). Effects of Microbial Consortia, Applied as Fertilizer Coating, on Soil and Rhizosphere Microbial Communities and Potato Yield. *Frontiers in Agronomy*, *3*. https://doi.org/10.3389/fagro.2021.714700

Raimam, M. P., de Castro, G. L. S., Rodrigues, G. R., de Moraes, A. J. G., & da Silva, G. B. (2024). Inoculation of *Bacillus* sp. improves root architecture, gas exchange and efficiency of nutrient use in Corymbia seedlings. *Scientia Horticulturae*, *338*. https://doi.org/10.1016/j.scienta.2024.113756

Risanti, R. R., Hindersah, R., Fitriatin, B. N., Suryatmana, P., Maksum, I. P., Setiawati, M. R., Hanindipto, F. A., & Nugraha, G. B. (2025). Exploring the *Bacillus* from vegetable rhizosphere for plant growth. *Journal of Ecological Engineering*, *26*(1), 109–120. https://doi.org/10.12911/22998993/195286

Santander, C., González, F., Pérez, U., Ruiz, A., Aroca, R., Santos, C., Cornejo, P., & Vidal, G. (2024). Enhancing Water Status and Nutrient Uptake in Drought-Stressed Lettuce Plants (*Lactuca sativa* L.) via Inoculation with Different *Bacillus* spp. Isolated from the Atacama Desert. *Plants*, *13*(2). https://doi.org/10.3390/plants13020158

Setiawati, T. C., Pandutama, M. H., Mandala, M., & Arta, C. (2020). The Capacity of Soil Bacteria, *Bacillus* sprifand *Pseudomonas* sprif, in solubilizing Soil Phosphate and Potassium. *IOP Conference Series: Earth and Environmental Science*, *583*(1). https://doi.org/10.1088/1755-1315/583/1/012040

Syed, R. U., Moni, S. S., Break, M. K. Bin, Khojali, W. M. A., Jafar, M., Alshammari, M. D., Abdelsalam, K., Taymour, S., Alreshidi, K. S. M., Elhassan Taha, M. M., & Mohan, S. (2023). Broccoli: A Multi-Faceted Vegetable for Health: An In-Depth Review of Its Nutritional Attributes, Antimicrobial Abilities, and Anti-inflammatory Properties. In *Antibiotics* (Vol. 12, Issue 7). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/antibiotics12071157

Wang, P., & Grimm, B. (2021). Connecting Chlorophyll Metabolism with Accumulation of the Photosynthetic Apparatus. In *Trends in Plant Science* (Vol. 26, Issue 5, pp. 484–495). Elsevier Ltd. https://doi.org/10.1016/j.tplants.2020.12.005

Wang, X., Gao, S., Fu, J., & Li, R. (2025). Heterologous Expression of the Nitrogen-Fixing Gene Cluster from Paeni*Bacillus* polymyxa in *Bacillus subtilis*. *Microorganisms*, *13*(6). https://doi.org/10.3390/microorganisms13061320