



Research Article

Physiological and Yield Response of Cabbage (*Brassica oleracea* var. *capitata*) to Bio-Inoculation and Integrated Fertilization in Calcareous Soils

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Abstract | This study aimed to evaluate the effect of phosphate-solubilizing bacteria (PSB), liquid organic fertilization (Bio-60), and triple superphosphate mineral fertilization (TSP), and the overlaps between them in improving some of the growth and productivity indicators of the plant growth (*Brassica oleracea* var. *capitata*). A field trial was conducted in autumn 2025 at the Faculty of Agriculture/University of Wasit fields, utilizing the Randomized Complete Block Design (RCBD) and in a three-factor design with three replicates. The 12 treatments were created by interaction PSB inoculation, liquid organic fertilizer, and triple superphosphate. Measurements included chlorophyll index (SPAD), head radius, marketable head weight, and stem diameter as the heads matured. The results showed significant differences between the treatments at a probability level ($P \leq 0.05$), as the treatment inoculated with phosphate-solubilizing bacteria (PSB) outperformed the uninoculated control treatment. The enhancement of all assessed characteristics was also achieved through the use of both organic and mineral fertilizers. Three-factor interaction treatment (A1O1M2) recorded the highest values, reaching 111.8 SPAD units for chlorophyll index, 10.10 cm for head radius, 3.268 kg for marketable head weight, and 3.37 cm for stem diameter. The enhanced effectiveness is because of the synergistic impact of factors that raise phosphorus availability and improve nutrient uptake. This showed the high efficiency of photosynthesis, as well as vegetative and cumulative growth. Using organic and mineral fertilizers that integrate with biological components is a successful and sustainable way to boost cabbage growth and yield while decreasing chemical fertilizer use in calcareous soils.

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Keywords | Cabbage, Phosphorus soluble bacteria, Liquid organic fertilizer, Superphosphate triple, Growth, Productivity



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Introduction

Brassica oleracea var. *capitata* is one of the main winter crops of economic importance, as it belongs to the Cruciferous family (Brassicaceae), which is

characterized by its high health and nutritional value. This is due to the fact that they contain a group of active biological compounds, such as vitamins, especially vitamin C, in addition to phenolic compounds and glucosinolates that contribute to enhancing the

nutritional and functional value of this crop (Shikano *et al.*, 2025). The varieties of cabbage also show a clear variation in their morphological and productivity qualities according to the difference in mineral feeding systems and environmental conditions, which is reflected in their productivity and the quality of their heads in marketing terms (Zeb *et al.*, 2022; Yan *et al.*, 2025).

Phosphorus is one of the major nutrients essential for plant growth. It has a pivotal role in the processes of energy transfer, cell division, and the formation of nucleic acids and biological compounds associated with growth. However, phosphorus availability is often limited in the soil, especially in calcareous soils, because of its fixation or deposition in insoluble forms, which leads to a decrease in the efficiency of its use by the plant and an increase in toxic losses (Alkarawi and Zotz, 2014; Delgado and Gómez, 2024).

FAO reports have indicated that the actual utilization rate of composted phosphorus is low in many agricultural systems, which calls for the search for more efficient alternatives and strategies in phosphorus management (FAO, 2018). Despite the widespread reliance on mineral phosphate fertilizers, such as tsp, because of its high solubility, the efficiency of its use remains limited in calcareous soils, which imposes the need to combine mineral fertilization and biofertilization for the purpose of raising the availability of phosphorus and raising the efficiency of its absorption by the plant (FAO, 2018; Delgado and Gómez, 2024).

In this context, PSB emerged as one of the components of biofertilization because of its ability to dissolve unavailable phosphates through the secretion of organic acids and phosphatase enzymes and convert them into plant absorbable forms, as well as its role in improving the efficiency of nutrient use and supporting the sustainability of agricultural systems (Pan *et al.*, 2023; Silva *et al.*, 2023; Alori *et al.*, 2017). Recent studies also indicate that the adoption of integrated nutrient management through the integration of biofertilization with organic and mineral fertilization, as it is one of the most successful methods to improve soil fertility and raise the efficiency of nutrient absorption, as this integration contributes to improving the physical and chemical properties of the soil, activating microorganisms in the root zone and reducing dependence on traditional

chemical fertilizers, which positively reflects on crop growth and productivity (Yasir *et al.*, 2025; Calvo *et al.*, 2014). Therefore, we aim to identify the most effective integrated approach for improving cabbage growth and yield in calcareous soil by employing fertilization methods with liquid organic fertilizer, triple superphosphate, and phosphate-solubilizing bacteria.

Materials and Methods

Experimental site

The field experiment was carried out in the fall 2025 season in the fields of the Faculty of Agriculture, University of Wasit in Wasit Governorate (32.497105° N, 45.842733° E), using the seedlings of Club Star, where the planting took place on 12.09.2025 and the harvest took place on 20.12.2025. All agricultural operations were carried out according to the scientific principles followed to cultivate the yield of the cultivar. Surface irrigation was relied upon, while manual control of the weed was carried out when needed.

Soil sample and analysis

A soil sample representative of the experiment site was taken before planting at a depth of 0-30 cm, then it was air dried, ground and sieved with a sieve with a diameter of 2 mm. The sample was used to estimate some physical and chemical characteristics of the soil, which included soil texture, Particle and bulk density, soil PH, electrical conductivity EC, cationic exchange capacity CEC, base elements (Ca, Mg, Na), anions (CL, SO_4^{-2} , CO_3^{-2} , HCO_3^{-}), ready-made nutrients (NPK), microelements (Fe, Cu, Zn) and organic matter (Table 1), as explained by Black (1965).

Design of experiment

The experiment was laid out as a RCBD with three replicates in a 2×2×3 factorial arrangement (12 treatments): A: PSB inoculation (0- or 12-mL plant⁻¹), O: Bio-60 (0- or 5-mL plant⁻¹), and M: TSP (0, 50, or 100 kg ha⁻¹). Plots were 3×3 m (20 plants; 75×50 cm spacing), with measurements taken from five plants per plot at maturity (720 plants total).

Fertilization and bacterial vaccine

Used a commercial liquid biofertilizer BactoFeed (Green Tech America Inc., Miami, FL, USA) containing phosphorus soluble bacterial strains of the genus *Bacillus* spp. They included *Bacillus subtilis*, *Bacillus megaterium*, and *Bacillus amyloliquefaciens*, and

at a total bioconcentration of 1×10^8 colony-forming unit/ml (CFU/ml). The bacterial vaccine was added once when planting by direct injection into the soil near the root zone and at a rate of 12 ml plant⁻¹

Table 1: *The chemical and physical properties of the soil of the field before planting.*

Capacity	Value	Measurement unit
Soil (pH)	7.8	
Electrical Conductivity (EC)	2.62	dS m ⁻¹
Cation Exchange Capacity (CEC)	12.7	Centimole kg ⁻¹ soil
Ca ²⁺	6.43	m mol.L ⁻¹
Mg ²⁺	4.02	m mol.L ⁻¹
K ⁺	1.04	
Na ⁺	4.70	
Cl ⁻	7.91	
SO ₄ ²⁻	8.55	
CO ₃ ²⁻	Nil	
HCO ₃ ⁻	0.91	
Soil organic matter (S.O.M.)	8.03	g kg ⁻¹ soil
Bulk density	1.19	Mg.m ⁻³
Particle Density	2.56	
Available nitrogen	36.33	mg kg Soil ⁻¹
Available phosphorus	13.8	
Available Potassium	76.7	
Iron	0.68	mg kg Soil ⁻¹
Copper	0.17	
Zinc	0.25	
Soil texture	Sandy loam	

Liquid organic fertilizer Bio60 containing 50% organic matter was also used, and it was added once when planting to the soil near the roots and at a rate of 5ml plant⁻¹. Triple superphosphate (TSP) fertilizer was added in one batch when planting at the levels specified for the treatment. Nitrogen fertilizer in the form of urea (46% N) was added in two equal batches for all treatment, the first at planting and the second 30 days after the first addition.

Farm operations

All the agricultural service operations necessary for the plants were carried out throughout the experiment, as the weed was controlled manually when needed, and surface irrigation was adopted, where the plants were irrigated when about 50% of the ready water was drained into the soil with moisture being delivered to the level of field capacity, to ensure appropriate conditions for plant growth.

Measured growth traits

The growth traits were estimated at the maturity of the heads, based on five plants represented by each experimental unit, and the measurements included the following:

1. Chlorophyll index (SPAD value):
2. The chlorophyll index was measured using a chlorophyll meter (SPAD meter), by taking five readings from five representative leaves for each plant and then calculating the average.
3. Marketable head weight (kg):
4. The weight of the head was measured after the removal of the non-marketable outer leaves using a digital scale, and the results were expressed in kilograms.
5. Radius of the head (cm): The circumference of the head was measured using a flexible measuring tape, and then the radius of the head was calculated according to the following equation: $r = C / 2\pi$ as r represents the radius of the head (cm), and C is the circumference of the head (cm), and the value of $\pi = 3.14$ was adopted
6. Stem diameter (cm): The stem diameter of the plant was measured using a vernier caliper a few centimeters above the soil surface, and the results were expressed in cm.

Statistical analysis

The data were analyzed statistically according to the RCBD design in a three-factor order, and the averages were compared using the LSD test at a probability level of 0.05 using the [SAS Program \(2018\)](#).

Results and Discussion

Chlorophyll index (SPAD)

The results of the study showed that there are clear significant differences in the chlorophyll index between different treatments at a probability level ($P \leq 0.05$), ([Table 2](#)), and the uninoculated and unfertilized control treatment ($A_0O_0M_0$) recorded the lowest value of 63.10 SPAD units, reflecting the limited phosphorus availability in the absence of fertilizer additives. This trend is consistent with what ([FAO, 2018](#); [Wang et al., 2022](#)) indicated regarding the low efficiency of phosphorus absorption in calcareous soils. On the other hand, the inoculated treatments were superior to the phosphate-solubilizing bacteria (PSB), especially the triple interference treatment ($A_1O_1M_2$), as it recorded the highest value of 111.8 SPAD units with a smaller difference (LSD= 15.80),

and this is in line with what was mentioned by [Yasir et al. \(2025\)](#) that integrated bio inoculation improves the nutritional efficiency of the plant, which reflects positively on the efficiency of photosynthesis and chlorophyll index, which is also consistent with the results of [Habeeb et al. \(2023\)](#). Those who pointed out that improving the mobility and phosphorus availability in the soil contributes to enhancing the physiological processes of the plant. This superiority is attributed to biological activity in the root zone, as explained by [Habeeb et al. \(2023\)](#) that the biological interactions between roots and soil affect the dynamics of nutrients, which is reflected positively on the efficiency of photosynthesis and increase the index of chlorophyll, which is consistent with what [Sharma et al.\(2023\)](#). On the role of phosphorus soluble bacteria in raising the availability of phosphorus and the efficiency of photosynthesis.

Table 2: *Effect of biofertilizer, organic and mineral fertilization on chlorophyll index (SPAD) unit.*

PSB inoculation	Organic	Mineral fertilization			Mean
A	O	M0	M1	M2	A * O
	O ₀	63.10	85.40	87.90	78.80
A ₀	O ₁	90.50	94.14	103.33	95.98
	O ₀	98.70	98.20	95.13	97.34
A ₁	O ₁	99.16	107	111.80	106.09
LSD0.05		7.09			10.49
M*A					
		M0	M1	M2	Mean A
A ₀		76.80	89.76	95.61	87.39
A ₁		98.93	102.75	103.46	101.72
LSD0.05		14.23			6.45
M *O					
		M0	M1	M2	Mean O
O ₀		80.90	91.80	91.51	88.07
O ₁		94.83	100.71	107.56	101.04
Mean M		87.86	96.25	99.54	
LSD0.05		14.23			6.45

Head radius (cm)

The results of the head radius ([Table 3](#)) indicate that there are significant differences between the treatment at the level of probability ($P \leq 0.05$). The control treatment (A₀O₀M₀) recorded the lowest value of 8.71 cm, while the three-factor interaction (A₁O₁M₂) recorded the highest value of 10.10 cm. This was attributed to the more efficient absorption of phosphorus and other nutrients, which cabbage

vegetative growth and the formation of larger heads. These findings are consistent with [Zeb et el. \(2022\)](#). He pointed out that the improvement of mineral nutrition is reflected positively in the morphological and marketing qualities of the population.

Table 3: *Effect of biofertilizer, organic and mineral fertilization on head radius (cm).*

PSB inoculation	Organic	Mineral fertilization			Mean
A	O	M0	M1	M2	A * O
	O ₀	8.71	8.83	8.98	8.84
A ₀	O ₁	9.11	9.24	9.38	9.25
	O ₀	9.34	9.39	9.55	9.43
A ₁	O ₁	9.47	9.91	10.10	9.83
LSD0.05		0.023			0.169
M*A					
		M0	M1	M2	Mean A
A ₀		8.91	9.03	9.18	9.04
A ₁		9.72	9.43	9.73	9.63
LSD0.05		0.287			0.019
M *O					
		M0	M1	M2	Mean O
O ₀		9.02	9.11	9.27	9.14
O ₁		9.29	9.58	9.54	9.54
Mean M		9.16	9.34	9.51	
LSD0.05		0.287			0.019

Marketable head weight (kg)

The results of the marketable head weight ([Table 4](#)) showed that there were significant differences between the treatment at a probability level ($P \leq 0.05$). The control treatment (A₀O₀M₀) recorded the lowest weight of 2.06 kg, while the three-factor interaction (A₁O₁M₂) recorded the highest significant value of 3.268 with a significant difference exceeding the LSD value of 0.337. This superiority is attributed to the improved efficiency of phosphorus use as a result of integrated nutrient management, which has led to increased dry matter accumulation and improved production and marketing qualities of heads. These findings are consistent with those of [Alori et al. \(2017\)](#) and [Lei et al. \(2025\)](#) on the role of phosphorus-soluble microorganisms in improving crop productivity.

Stem diameter (cm)

The results of the stem diameter ([Table 5](#)) showed that there are clear significant differences between the treatment at a probability level of ($P \leq 0.05$), as the control treatment (A₀O₀M₀) recorded the lowest

value of 1.14 cm, while the three-factor interaction (A1O1M2) recorded the highest value of 3.37 cm.

Table 4: *Effect of biofertilizer, organic and mineral fertilization on marketable head weight (kg).*

PSB inoculation	Organic	Mineral fertilization			Mean
A	O	M0	M1	M2	A * O
A ₀	O ₀	2.06	2.32	2.54	2.31
	O ₁	2.61	2.67	2.69	2.66
	O ₀	2.80	2.63	2.83	2.75
A ₁	O ₁	2.88	3.10	3.26	3.08
LSD0.05		0.081			0.162
M*A					
		M0	M1	M2	Mean A
A ₀		2.33	2.49	2.62	2.48
A ₁		2.84	2.87	3.05	2.92
LSD0.05		0.273			0.066
M *O					
		M0	M1	M2	Mean O
O ₀		2.43	2.48	2.68	2.53
O ₁		2.75	2.88	2.98	2.87
Mean M		2.59	2.68	2.83	
LSD0.05		0.273			0.066

Table 5: *Effect of biofertilizer, organic and mineral fertilization on stem diameter (cm).*

PSB inoculation	Organic	Mineral fertilization			Mean
A	O	M0	M1	M2	A * O
A ₀	O ₀	1.14	1.32	2.14	1.53
	O ₁	2.48	2.73	2.70	2.64
	O ₀	3.13	2.90	2.92	2.99
A ₁	O ₁	3.04	3.13	3.37	3.18
LSD0.05		0.137			0.286
M*A					
		M0	M1	M2	Mean A
A ₀		1.81	2.02	2.42	2.09
A ₁		3.08	3.02	3.14	3.08
LSD0.05		0.596			0.112
M *O					
		M0	M1	M2	Mean O
O ₀		2.13	2.12	2.53	2.26
O ₁		2.76	2.93	3.03	2.91
Mean M		2.45	2.52	2.78	
LSD0.05		0.596			0.112

This superiority reflects the improved strength of the plant and its ability to support vegetative and cumulative growth because of improved nutrition

efficiency, especially phosphorus. These findings are consistent with what [Delgado and Gómez \(2024\)](#) said about the role of phosphorus in plant tissue formation, and with what [Sharma et al. \(2023\)](#) that biofertilization contributes to improving the balanced growth of the plant and increasing the efficiency of nutrient absorption.

Conclusions

PSB inoculation led to significant improvements in cabbage growth and productivity under calcareous soil, showing better P availability and uptake. Using PSB, Bio-60, and TSP together produced a clear synergistic effect, yielding better SPAD chlorophyll index, head radius, marketable head weight, and stem diameter than when used alone or in pairs. Across all measured traits, the three-factor interaction treatment showed the highest values, indicating it was the most effective approach for balanced vegetative and head development. The rise in SPAD values with integrated treatments shows enhanced photosynthetic efficiency, correlating with increased dry-matter accumulation, larger head size, and improved marketable yield. Bio-integrated organic–mineral fertilization offers a sustainable approach for enhancing cabbage yield and quality in calcareous soils.

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Novelty Statement

A novel approach is presented in this study, examining the combined impact of phosphate-solubilizing bacteria and organic mineral fertilizers in plant feeding, a strategy that has not been extensively explored in previous research. Their interaction significantly boosts crucial growth traits in cabbage, including head weight, head radius, and stem diameter, opening new insights into optimizing fertilization practices. The study's outcomes point to the promise of using integrated organic-mineral fertilizers to better plant growth and productivity, serving as an inventive and

practical strategy for agricultural improvement.

Author's Contribution

Kahraman H Habeeb: Research ideas and designing research, research administration

Hawraa R Hadi: Data processing, data collection in the field.

Hawraa R Hadi and Kahraman H Habeeb: Wrote the manuscript.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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