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Assessment of biofertilizers, zinc and boron effect on growth and yield of cabbage (*Brassica oleracea* var. *capitata*) in Bundelkhand region

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ABSTRACT

The present experiment was conducted at a rainfed agricultural farm, Narayan Bag, Bundelkhand University, Jhansi, Uttar Pradesh (India), during the Rabi season of 2025-26 to assess the "Assessment of Biofertilizers, Zinc and Boron effect on growth and yield of Cabbage (*Brassica oleracea* var. *capitata*) in Bundelkhand region." The experiment was laid out in a Randomized Block T_0 : RDF (Control), T_1 : RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor, T_2 : RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + Azotobactor, T_3 : RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor, T_4 : RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + Azotobactor, T_5 : RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + PSB, T_6 : RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB, T_7 : RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + PSB, and T_8 : RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB. The seedlings of cabbage cv. Golden Acre was transplanted on 28-Oct-2025 in the evening at 60 cm x 60 cm spacing. Observations were recorded on five randomly selected plants from each plot for growth attributes (Plant height (cm), leaf width at 30, 45 and 60 days after transplanting and at final harvesting), Yield attributes and yield (head length, head diameter, head weight, Yield per hectare (q ha⁻¹)) and available nutrients in soil after harvesting (pH, electrical conductivity, available nitrogen, phosphorus, Potassium, zinc and Boron). The maximum plant height recorded in T_8 (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) with 24.91, 32.87, 35.30 and 37.19 cm at 30, 45, 60 DAT and at harvesting, respectively and the maximum leaf width recorded in T_8 (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) with 10.94, 15.64, 19.16 and 34.57 cm at 30, 45 and 60 DAT and at harvesting, respectively, because this treatment ensures the highest nutrient availability and uptake, as Zn (20 kg ha⁻¹) maximizes cell division and growth, while boron (5 kg ha⁻¹) enhances translocation of photosynthetic products for leaf expansion and tissue development. Furthermore, Phosphate Solubilizing Bacteria (PSB) enhance P availability by converting insoluble P, leading to better root development and overall vegetative growth compared to lower doses, control, or other biofertilizers. The maximum head length (16.42 cm), head diameter (18.08 cm) and head weight (1234.42 g) and head yield (377.57 q ha⁻¹) were also recorded in T_8 (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB). In terms of soil analysis. The 7.16 pH, maximum Electric Conductivity (0.41 ds m⁻¹), available nitrogen (180.57 kg ha⁻¹), available phosphorus (13.90 kg ha⁻¹), available Potassium (206.93 kg ha⁻¹), available Zinc (0.93 kg ha⁻¹) and available Boron (2.06 kg ha⁻¹) re also recorded in T_8 (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB). The application of RDF with 20 kg ha⁻¹ Zinc, 5 kg ha⁻¹ Boron and PSB in treatment T_8 is typically found to be the best because it provides a balanced nutrient supply and improves soil biological activity, leading to synergistic enhancements in crop growth and yield. The combination addresses both major (NPK) and micronutrient (Zn, B) deficiencies simultaneously.

Keywords: Cabbage, RDF, Zinc, Boron, PSB, Azotobactor

Introduction

Cabbage (*Brassica oleracea* L. var. *capitata*) is a nutrient-dense, historical crop requiring high levels of nitrogen and phosphorus for optimal growth, making efficient nutrient management vital for sustainable yield. While conventional chemical fertilizers provide rapid nutrient delivery, their exclusive and excessive application leads to severe soil degradation, microbial destruction, and environmental contamination. To mitigate these adverse impacts, adopting Integrated Nutrient Management (INM)—combining reduced rates of chemical fertilizers (75–100% RDF) with biofertilizers and essential micronutrients like Zinc and Boron—is essential for optimizing plant growth, root architecture, and head compactness (Jeelani Zargar *et al.* 2022; Khan *et al.* 2009) [1]. Specifically, *Azotobacter* acts as a free-living nitrogen fixer while synthesizing growth hormones such as Indole-3-Acetic Acid and Gibberellins to accelerate plant maturity (Sumbul *et al.*, 2020) [2]. Concurrently, Phosphate Solubilizing Bacteria (PSB) secrete organic acids that solubilize bound soil phosphorus, enhancing root development, head density, and ascorbic acid levels (IFFCO). Micronutrients

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further complement this biofertilizer consortium: Zinc promotes chlorophyll formation and enzyme activity (Ramiro *et al.* 2021), whereas Boron facilitates cell wall biosynthesis, carbohydrate translocation, and cell division essential for superior head quality (Songsriin *et al.*, 2023) [3]. Implementing these principles alongside the 4R nutrient stewardship framework optimizes nutrient uptake efficiency, lowers production costs, and protects long-term soil health (Haifa Group, 2026) [4]. Grounded in these agronomic principles, the investigation titled “Assessment of Biofertilizers, Zinc and Boron effect on growth and yield of Cabbage (*Brassica oleracea* L. var. *capitata*) in Bundelkhand region” was formulated to standardize an efficient, sustainable nutrient management strategy tailored for localized production.

Materials and Method

The present experiment was conducted at a rainfed agricultural farm, Narayan Bag, Bundelkhand University, Jhansi, Uttar Pradesh (India), during the *Rabi* season of 2025-26. The soil of the experimental field was red loam soil in texture, which is alkaline in reaction with a pH of 7.3. The experiment was laid out in a Randomized Block T₀: RDF (Control), T₁: RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor, T₂: RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + Azotobactor, T₃: RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor, T₄: RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + Azotobactor, T₅: RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + PSB, T₆: RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB, T₇: RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + PSB, and T₈: RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB. The seedlings of cabbage cv. Golden Acre was transplanted on 28-Oct-2025 in the evening at 60 cm x 60 cm spacing. Observations were recorded on five randomly selected plants from each plot for growth attributes (Plant height (cm), leaves width at 30, 45, 60 days after transplanting and at final harvesting), Yield attributes and yield (head length, head diameter, head weight, Yield per hectare (q ha⁻¹)) and available nutrients in soil after harvesting (pH, Electric Conductivity, available nitrogen, phosphorus, Potassium, Zinc and Boron). Data on all observations were recorded, analyzed statistically using Fisher's analysis of variance technique and treatment means were compared using the least significant difference test at 5 % level of probability. During the course of the experiment, observations were recorded as mean values of the data.

Result and Discussion

Growth attributes

Plant height

The analysis of data (Table 1) indicates that plant height increased progressively as the plants advanced in age at 30 DAT, 45 DAT, 60 DAT and at harvest. The maximum plant height recorded in T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) with 24.91, 32.87, 35.30 and 37.19 cm at 30, 45, 60 DAT and at harvesting, respectively and minimum was recorded in T₁ (RDF + Zinc @ 10 kg ha⁻¹ +

Boron @ 2.5 kg ha⁻¹ + Azotobactor) with 19.93, 28.17, 30.50 and 32.50 cm at 30, 45, 60 DAT and at harvesting respectively, the synergistic combination of high-level micronutrients (Zinc/Boron) and Phosphorus Solubilizing Bacteria (PSB) optimizes nutrient uptake and metabolic activity. Zinc promotes auxin synthesis and cell division, Boron regulates meristematic tissue development and carbohydrate translocation, and PSB solubilizes phosphorus, providing the high energy necessary for vegetative growth. This balanced, nutrient-rich, and microbial enhanced environment maximizes growth rates far better than RDF alone or lower nutrient combinations (Mohammadullah Nikzad *et al.* 2020).

Number of leaves

The analysis of data (Table 1) indicates that the number of leaves increased progressively as the plants advanced in age at 30 DAT, 45 DAT, 60 DAT and at harvest. The maximum number of leaves was recorded in T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) with 9.82, 16.12, 19.41 and 22.04 leaves at 30, 45, 60 DAT and at harvesting, respectively and minimum was recorded in T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor) with 9.48, 14.29, 14.68 and 19.60 leaves at 30, 45, 60 DAT and at harvesting, respectively. The highest number of leaves per plant in cabbage is observed with the application of T₈ - RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB due to the synergistic effect of higher nutrient availability and biofertilizers, which enhances cell division, expansion, and chlorophyll synthesis. Increased boron promotes carbohydrate metabolism and meristematic tissue development, while high zinc and PSB (Phosphate Solubilizing Bacteria) improve phosphorus uptake and hormonal balance, leading to more robust vegetative growth (leaf initiation) than controls or lower-nutrient treatments. This balanced, high-dose combination significantly enhances the photosynthetic area and overall metabolic activity necessary for maximizing leaves in number (Merin Jacob *et al.* 2023).

Leaves width

The analysis of data (Table 1) indicates that leaf width increased progressively as the plants advanced in age at 30 DAT, 45 DAT, 60 DAT and at harvest. The maximum leaf width was recorded in T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) with 10.94, 15.64, 19.16 and 34.57 cm at 30, 45, 60 DAT and at harvesting, respectively and minimum was recorded in T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor) with 8.23, 13.45, 15.84 and 30.53 cm at 30, 45, 60 DAT and at harvesting, respectively. Maximum leaf width in cabbage is highest with RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB because this treatment ensures the highest nutrient availability and uptake, as Zn (20 kg ha⁻¹) maximizes cell division and growth, while boron (5 kg ha⁻¹) enhances translocation of photosynthetic products for leaf expansion and tissue development. Furthermore, Phosphate Solubilizing Bacteria (PSB) enhance P availability by converting insoluble P, leading to better root development and overall vegetative growth compared to lower doses, control or other biofertilizers, as supported by improved chlorophyll content and overall metabolism, consistent with findings by Zhen Wang *et al.* 2017 [5].

Table 1. Effect of Biofertilizers, zinc and boron micronutrients on plant height and leaf width at different growth stages

Treat- ments	Plant height (cm)				Number of leaves				Leaves width (cm)			
	30 DAT	45 DAT	60 DAT	At harvest	30 DAT	45 DAT	60 DAT	At harvest	30 DAT	45 DAT	60 DAT	At harvest
T ₀	19.33	27.70	29.17	31.17	9.47	11.85	13.61	17.77	6.94	11.36	14.23	29.18
T ₁	19.93	28.17	30.50	32.50	9.48	14.29	14.68	19.60	8.23	13.45	15.84	30.53
T ₂	20.83	29.47	32.60	34.60	9.56	14.42	14.51	17.50	8.50	13.71	17.08	30.76
T ₃	20.23	28.83	30.77	32.77	9.53	14.30	13.55	16.17	8.24	13.62	16.05	30.74
T ₄	21.93	30.93	33.40	35.40	9.59	14.55	14.57	19.41	8.64	13.85	17.12	32.58
T ₅	22.53	31.20	34.40	36.40	9.60	15.29	16.48	20.40	8.79	14.27	17.22	33.39

(continued on next page)

Treat- ments	Plant height (cm)				Number of leaves				Leaves width (cm)			
	30	45	60	At	30	45	60	At	30	45	60	At
	DAT	DAT	DAT	harvest	DAT	DAT	DAT	harvest	DAT	DAT	DAT	harvest
T ₆	24.20	32.20	34.60	36.60	9.71	15.91	19.09	21.40	10.64	15.60	19.06	34.56
T ₇	22.60	31.43	34.60	36.60	9.65	15.30	17.28	21.6	10.14	15.45	18.70	34.42
T ₈	24.91	32.87	35.30	37.19	9.82	16.12	19.41	22.04	10.94	15.64	19.16	34.57
S. EM(±)	0.25	0.26	0.25	0.21	0.17	0.09	0.11	0.22	0.14	0.21	0.17	0.23
CD 5%	0.75	0.79	0.74	0.63	0.52	0.27	0.33	0.66	0.40	0.64	0.50	0.68

Yield attributes

Head length, head diameter and head weight

There was a progressive increase in head length, head diameter and head weight with the increase in Zinc and Boron levels (Table 2). The maximum head length (16.42 cm), head diameter (18.08 cm) and head weight (1234.42 g) were recorded with T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and minimum head length (13.56 cm), head diameter (14.25 cm) and head weight (1021.79 g) were recorded with T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor). The combination of RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB (Phosphate Solubilizing Bacteria) produces maximum head length, diameter, and weight in cabbage because high-level zinc (20 kg ha⁻¹) and boron (5 kg ha⁻¹) ensure optimal micronutrient availability to correct deficiencies, while PSB enhances phosphorus availability and microbial activity for superior root development, ultimately increasing photosynthetic activity, nutrient uptake, and cell division for greater translocation of photosynthesis into the head (Rohit Sen *et al.* 2015).

Yield (q ha⁻¹)

There was a progressive increase in yield of cabbage with the increase in Zinc and Boron levels (Table 2). The maximum 377.57 q ha⁻¹ head yield was recorded in treatment T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) which was statistically at par with T₆ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and T₇ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + PSB) with 329.28 and 322.56 q ha⁻¹ and minimum head yield 239.07 q ha⁻¹ was recorded in T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor). The maximum cabbage yield with RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB is due to the synergistic effect of higher nutrient availability and improved phosphorus solubilization, which optimizes vegetative growth, enhances head compactness, and increases metabolic activity, as Zn facilitates carbohydrate metabolism/auxin synthesis, Boron aids in translocating sugars/cell division, and PSB increases phosphorus availability, far exceeding the effects of lower dosages or sole Nitrogen-fixing biofertilizers (*Azotobacter*). Increased Phosphorus availability and micronutrient synergy enhance root development and photosynthetic rates, leading to higher dry matter accumulation and ultimately maximizing yield (Singh & Singh, 2010; Chaudhary *et al.*, 2015; Taheri *et al.*, 2020 and J.S. Lahade *et al.*, 2025) [6].

Table 2. Effect of Biofertilizers, zinc and boron micronutrients on yield parameters in cabbage

Treatment	Head length (cm)	Head diameter (cm)	Weight of head (g)	Yield of head (q ha ⁻¹):
T ₀	13.05	13.42	959.52	218.08
T ₁	13.56	14.25	1021.79	239.07
T ₂	14.62	14.85	1122.21	257.65
T ₃	14.51	14.66	1080.18	250.81
T ₄	14.86	15.35	1143.64	272.74
T ₅	14.88	15.85	1168.69	282.09
T ₆	15.94	17.87	1214.71	329.28
T ₇	15.41	16.22	1190.15	322.56
T ₈	16.42	18.08	1234.42	377.57
SE(m) ±	0.20	0.09	12.44	23.36
CD at 5%	0.59	0.26	37.28	70.04

Soil studies (available nutrient content in soil study after harvesting)

Soil pH

The Soil pH of cabbage stabilized with an increase in Zinc and Boron doses (Table 3). The 7.16 pH was recorded with the soil treated with T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and maximum 7.30 pH was recorded with T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor).

Electric conductivity

The Electric Conductivity of cabbage increased with an increase in Zinc and Boron doses (Table 3). The maximum Electric Conductivity (0.41 dS m⁻¹) was recorded with T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and the minimum 0.32 dS m⁻¹ was recorded with T₀ (Control- RDF only).

Available nitrogen in soil

The available nitrogen of cabbage increased with an increase in Zinc and Boron doses (Table 3). The maximum available nitrogen (180.57 kg ha⁻¹) was recorded with T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and minimum available nitrogen 152.74 kg ha⁻¹ was recorded with T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor).

Available phosphorus in Soil

The available phosphorus of cabbage increased with an increase in Zinc and Boron doses (Table 3). The maximum available phosphorus (13.90 kg ha⁻¹) was recorded with T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and minimum available phosphorus 12.73 kg ha⁻¹ was recorded with T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobactor).

Available Potassium**in Soil**

The available Potassium of cabbage increased with an increase in Zinc and Boron doses (Table 3). The maximum available Potassium (206.93 kg ha⁻¹) was recorded with T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and minimum available Potassium 172.05 kg ha⁻¹ was recorded with T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobacter).

Available Zinc**in Soil**

The available Zinc of cabbage increased with an increase in Zinc and Boron doses (Table 3). The maximum available Zinc (0.93 kg ha⁻¹) was recorded with T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and minimum available Zinc 0.84 kg ha⁻¹ was recorded with T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobacter).

Available Boron**in Soil**

The available Boron of cabbage increased with an increase in Zinc and Boron doses (Table 3). The maximum available Boron (2.06 kg ha⁻¹) was recorded with T₈ (RDF + Zinc @ 20 kg ha⁻¹ + Boron @ 5 kg ha⁻¹ + PSB) and minimum available Boron 1.05 kg ha⁻¹ was recorded with T₁ (RDF + Zinc @ 10 kg ha⁻¹ + Boron @ 2.5 kg ha⁻¹ + Azotobacter).

Conclusion

The application of RDF with 20 kg ha⁻¹ Zinc, 5 kg ha⁻¹ Boron and PSB in treatment T₈ is typically found to be the best because it provides a balanced nutrient supply and improves soil biological activity, leading to synergistic enhancements in crop growth and yield. The combination addresses both major (NPK) and micronutrient (Zn, B) deficiencies simultaneously.

Table 3. Effect of Biofertilizers, Zinc and Boron micronutrients on Soil Study (Available nutrient content in soil study after harvesting) in cabbage

Treatment	Soil pH	Electric Conductivity (dS m ⁻¹)	Available				
			Nitrogen (Kg ha ⁻¹)	P ₂ O ₅ (Kg ha ⁻¹)	K ₂ O (Kg ha ⁻¹)	Zinc (kg ha ⁻¹)	Boron (kg ha ⁻¹)
T ₀	7.86	0.30	132.02	12.36	164.36	0.72	0.36
T ₁	7.30	0.32	152.74	12.73	172.05	0.84	1.05
T ₂	7.25	0.35	157.38	13.12	181.44	0.85	1.76
T ₃	7.12	0.36	161.84	12.85	192.29	0.84	1.05
T ₄	7.05	0.38	165.35	13.31	215.17	0.92	1.84
T ₅	7.45	0.32	169.46	13.40	178.99	0.89	1.28
T ₆	7.32	0.34	174.17	13.80	187.05	0.86	1.86
T ₇	7.22	0.36	176.10	13.72	204.49	0.92	1.12
T ₈	7.16	0.41	180.57	13.90	206.93	0.93	2.06
SE(m) ±	0.03	0.01	1.54	0.042	1.04	0.010	0.023
CD at 5%	0.10	0.02	4.51	0.127	3.13	0.030	0.070

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