



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(6): 563-568
Received: 15-04-2026
Accepted: 20-05-2026

Prateek Raj
M.Sc. (Ag.) Horticulture
(Vegetable Science), Faculty of
Agricultural Sciences and Allied
Industries, Rama University,
Mandhana, Kanpur (Uttar
Pradesh), India

Jitendra Kumar
Assistant Professor, Horticulture
(Vegetable Science), Faculty of
Agricultural Sciences and Allied
Industries, Rama University,
Mandhana, Kanpur (Uttar
Pradesh), India

Hari Shankar Singh
Soil Science and Agricultural
Chemistry (Soil Science), Chandra
Shekhar Azad University of
Agriculture and Technology,
Kanpur, Uttar Pradesh, India

Corresponding Author:
Jitendra Kumar
Assistant Professor, Horticulture
(Vegetable Science), Faculty of
Agricultural Sciences and Allied
Industries, Rama University,
Mandhana, Kanpur (Uttar
Pradesh), India

Effect of integrated nutrient management on growth and yield of Cabbage (*Brassica oleracea* var. *capitata*)

Prateek Raj, Jitendra Kumar and Hari Shankar Singh

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6g.5750>

Abstract

Cabbage (*Brassica oleracea* var. *capitata*) is a premier cruciferous vegetable in the Indian agricultural landscape, highly regarded for its substantial commercial value and its role as a concentrated source of essential vitamins and minerals. Optimizing the productivity of this crop necessitates a strategic approach to fertilization, as a total reliance on synthetic inputs often leads to soil degradation and diminished crop sustainability. In order to overcome the aforementioned problems, an experiment was carried out during the Rabi Season of 2025–2026 at the Primary Experimental Station of Rama University, Kanpur, Uttar Pradesh, India, to study the performance of INM on cabbage. A Randomized Block Design (RBD) was used for this purpose, which consisted of eight treatments repeated three times each and involving combinations of RDF, organic manures (Vermicompost and FYM) and Azotobacter as bio-fertilizer.

The main aim of the experiment was to investigate the impact of INM on the growth characteristics of cabbage. As per the findings of the present study, Treatment T₈ (75% RDF + 25% Vermicompost + Azotobacter) yielded the best results for growth characteristics, including the tallest plant height (39.99 cm) and the largest number of leaves per plant (20.57).

Regarding yield and quality parameters T₈ (75% RDF + 25% Vermicompost + Azotobacter) achieved the maximum head diameter (16.62 cm), greatest head weight (1244.12 g) and the highest total yield per hectare (29.49 t/ha q), while the minimum yield was recorded in the control (T₁). In terms of quality, T₈ (75% RDF + 25% Vermicompost + Azotobacter) produced the highest ascorbic acid content (30.98 mg/100g). These findings suggest that the integration of *Azotobacter* and vermicompost with a 75% inorganic nutrient level serves as a viable, sustainable alternative for high-quality cabbage production while effectively reducing chemical input requirements.

Keywords: *Azotobacter*, Bio-fertilizers, Cabbage, FYM, Integrated Nutrient Management (INM)

Introduction

Vegetables constitute a paramount niche in human nutrition, functioning as the third most essential dietary component globally behind cereals and dairy to mitigate food insecurity and address "hidden hunger" (Darnton-Hill, 2019) ^[7]. With the global population projected to reach 9 billion by 2050, over 80% of demographic expansion is expected in developing nations where 2 billion individuals already suffer from micronutrient malnutrition. India, currently the world's second-largest vegetable producer, faces a sustained population growth rate of 1.8%, escalating projected vegetable demand to 350 million tonnes by 2030 and necessitating a strategic 200–300% surge in productivity (Anonymous, 2024) ^[2]. Among prominent cole crops, Cabbage (*Brassica oleracea* var. *capitata* L.; 2n = 18) represents a globally significant leafy vegetable within the *Brassicaceae* family, valued for its versatile culinary applications and digestive therapeutic properties (Chatterjee *et al.*, 2012; Sher and Mishra, 2023) ^[6, 25]. Descending from the wild progenitor *Brassica oleracea* var. *sylvestris* along the Mediterranean coastline, this biennial crop has demonstrated remarkable phenotypic plasticity, enabling its diversification from temperate European climates into varied tropical agro-climatic zones where advanced hybrid cultivars allow for spring and summer cultivation alongside traditional Rabi production (Maggioniet *al.*, 2010; NHB, 2024) ^[13]. Beyond its distribution, cabbage is prized for a biochemical profile rich in sulfur-containing glucosinolates like sulforaphane, which impart its distinct flavor and documented anti-carcinogenic properties (Melimet *al.*, 2022) ^[14]. Nutritionally, 100 g of the edible portion delivers a robust, low-caloric, nutrient-dense energy source (~103 KJ), yielding

93% water, high-quality protein, essential vitamins (A, B-complex, C, K) and a substantial mineral matrix comprising 114 mg potassium, 44 mg phosphorus, 40 mg calcium, 10 mg magnesium and 30–65 mg ascorbic acid (Rai *et al.*, 2005; Singh *et al.*, 2006) [22]. National production data indicates a cultivated area of 454,000 hectares with a total output of 10.51 million tonnes, while in Uttar Pradesh, the crop occupies approximately 12,990 hectares, contributing significantly to the regional horticultural economy (Anonymous, 2025) [3].

The optimization of yield and quality in cruciferous vegetables is heavily dependent on a balanced supply of primary macronutrients and essential secondary elements within a strict thermal range of 4 °C to 24 °C; however, the prevailing agronomic trend involves the excessive and indiscriminate application of straight synthetic nitrogenous fertilizers during the vegetative growth phase (Ojetayo *et al.*, 2011) [18]. This chemical over-dependence frequently induces physiological disorders, such as loose or "puffy" heads, while concurrently degrading post-harvest shelf life and suppressing the synthesis of essential antioxidants and secondary metabolites. To mitigate these deleterious environmental impacts, including soil acidification, nitrate leaching and greenhouse gas emissions, the implementation of Integrated Nutrient Management (INM) defined by the synchronized application of organic amendments alongside inorganic fertilizers represents a superior agronomic paradigm for maintaining ecological equilibrium and maximizing net productivity (Yadav and Yadav, 2001; Singh *et al.*, 2014) [26, 33]. Organic inputs such as farmyard manure (FYM) and vermicompost optimize the soil-plant continuum; well-decomposed FYM acts as a structural conditioner that fosters a favorable rhizosphere for root proliferation and moisture retention (Prasad & Sinha, 2000; Khan *et al.*, 2010) [12, 21], while vermicompost serves as an eco-friendly substrate with a stable C:N ratio (15.5) rich in primary nutrients (1.6% N, 0.7% P, 0.8% K), micronutrients and growth-promoting phytohormones like auxins and gibberellins (Asif *et al.*, 2019; Rehman *et al.*, 2023) [4, 23]. Because organic manures possess slow-release kinetics and low nutrient concentrations, neither organic nor chemical sources alone can sustain intensive production systems, necessitating a balanced, integrated approach to ensure long-term agricultural sustainability (Jangire *et al.*, 2021) [10].

Complementing these organic substrates, biofertilizers constitute a vital biological intervention to mobilize immobile element pools in the soil matrix through Biological Nitrogen Fixation (BNF) and mineral transformation without environmental degradation (Yadav *et al.*, 2009) [32]. The incorporation of free-living aerobic nitrogen-fixing *Azotobacter* species can substitute 10% to 20% of required inorganic nitrogenous inputs within the root zone while synthesizing critical growth-promoting substances like thiamine, riboflavin, indole acetic acid (IAA) and gibberellins to stimulate robust plant development (Mohandas, 1999; Aasfaret *et al.*, 2021) [1, 15]. In the intensive agro-climatic conditions of Uttar Pradesh, evaluating the precise integration of these diverse organic matrices, microbial bio-inoculants and chemical fertilizers is essential to activate rhizospheric microbial populations and stabilize nutrient mineralization. Keeping these facts in view, the current investigation entitled "Effect of integrated nutrient management on growth and yield of Cabbage (*Brassica oleracea* var. *capitata*)" was undertaken to achieve the following objectives: to study the effect of INM on the vegetative growth dynamics of cabbage; to evaluate its impact on subsequent yield parameters, head compactness and biochemical quality attributes; and to assess the economic viability of different treatment

combinations in terms of net returns and benefit-cost ratios to ensure long-term edaphic sustainability and environmental resilience.

Materials and Methods

The rabi experiment was conducted in 2025-26 in the primary experimental station of Rama University situated at Kanpur (U.P.). The farm portrays typical physiographic and agroclimatic characteristics of Central Plain Zone of Uttar Pradesh. The region can be mapped by the geographic coordinates extending from 25°34' to 26°11'N latitudes and 81°19' to 82°27' E longitudes, lying at an altitude of around 137 m above mean sea level. The texture of the soil at the experimental site showed sandy loam properties with a pH level of 7.2, depicting neutral acidity. The organic carbon content was found to be very low at 0.51% and available nitrogen content was recorded to be 171.48 kg N/ha. There were low levels of available phosphorus at 17.60 kg P/ha but medium available potassium at 216.40 kg K/ha. The total rainfall for the crop was 7.51 mm.

The experiment consisted eight treatments viz. T₁: Control, T₂: 100% RDF (175: 75 :70), T₃: 75% RDF + 25% FYM, T₄: 50% RDF + 50% FYM, T₅: 75% RDF + 25 % Vermicompost, T₆: 75% RDF + 25% FYM + *Azotobacter*, T₇: 50% RDF + 50% FYM + *Azotobacter*, T₈: 75% RDF + 25 % Vermicompost + *Azotobacter* which was analyzed in randomized block design with three replications. The experimental field underwent primary tillage with a moldboard plough followed by harrowing to attain an optimal, finely pulverized tilth. Prior to transplanting, raised nursery beds measuring 3 m × 1 m at an elevation of 20 cm were meticulously prepared and uniform, healthy seedlings of cabbage variety 'Neon' were transplanted during the evening hours of October 5, 2025, at a standardized spacing of 60 cm between rows and 45 cm between plants. Before sowing in the nursery beds, the seeds were treated with the systemic fungicide Carbendazim (Bavistin) and for specified biological treatments, *Azotobacter* biofertilizer was soil-applied at a rate of 2 kg/ha by pre-mixing the inoculant with organic manure. A consistent plant population was maintained through gap-filling operations conducted one week after transplanting and a standardized irrigation schedule was maintained at 15-day intervals alongside five manual weeding operations executed up to 50 days post-transplanting. In the cultivation of cabbage, a total recommended inorganic dose of 175 kg of nitrogen (N), 75 kg of phosphorus (P₂O₅) and 70 kg of potassium (K₂O) was applied using Urea, Single Super Phosphate and Muriate of Potash, with half of the nitrogen and the full quantum of phosphorus and potassium applied basally at transplanting, while the remaining nitrogen was top-dressed 30 days post-transplanting. Additionally, organic amendments consisting of farmyard manure (FYM) and vermicompost were incorporated as a basal dose in accordance with the specified treatment combinations, while foliar sprays of Acephate and Dichlorvos were applied to manage aphid vectors. Crucial observations concerning the vegetative growth, head yield and biochemical quality attributes of cabbage were documented from five tagged representative plants at the appropriate developmental intervals. Statistical analysis was conducted on the data collected during the experiment, in accordance with the guidelines established by Panse and Sukhatme (1985) [20]. The "F" test, along with a significance level of 5%, was employed to evaluate the differences in treatment outcomes.

Result and Discussion

Effect of integrated nutrient management on growth attributes of cabbage

The data on growth traits of cabbage presented in the table 1 indicates the significant effects of integrated nutrient management regimes. Plant vegetative parameters, including plant height and the number of leaves, varied significantly across different treatments. The highest plant height was consistently recorded in treatment 75% RDF + 25% Vermicompost + *Azotobacter*(T₈), observing a maximum height of 39.99 cm, which significantly surpassed all other treatments except 75% RDF + 25% FYM + *Azotobacter*(T₆) and 75% RDF + 25% Vermicompost(T₅), which were found to be statistically at par with heights of 39.23 cm and 36.40 cm, respectively. Conversely, the minimum plant height was recorded under the Control treatment (T₁) at 23.87 cm. Regarding the leaf characteristics, the number of leaves per plant followed an identical trend to plant height, showing highly significant variations among the nutrient regimes. The maximum number of leaves (20.57) was achieved under 75% RDF + 25% Vermicompost + *Azotobacter* (T₈), showing a significant increase over the Control (T₁), which recorded the lowest number of leaves per plant (12.32 leaves). The physiological transition periods, measured by the days taken to head initiation and days taken to head maturity, were strongly influenced by the different treatment combinations. 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) demonstrated the highest crop efficiency and rapid development, taking the minimum number of days to initiate head formation (30.02 days) and the shortest duration to reach head maturity (55.97 days), significantly advancing crop maturity compared to the other groups. In contrast, the Control treatment (T₁) significantly delayed the crop growth cycle, requiring the maximum duration for both head initiation (38.77 days) and maturity (68.38 days), indicating that a complete lack of integrated nutrient inputs slows down metabolic efficiency and vegetative development.

The significant acceleration and enhancement of vegetative growth attributes and phenological transitions in cabbage under treatment 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) is a direct result of the favorable nutritional and physiological environment established by combining structured organic substrates with a microbial consortium. The maximum plant height and leaf production recorded under T₈ stem from the synergistic interaction between inorganic fertilizers, organic amendments and microbial inoculants; the 75% RDF ensured an immediate supply of essential macronutrients, particularly nitrogen, to catalyze early cellular division and elongation (Sharma *et al.*, 2026) ^[24], while the humifiedvermicompost base modified the physical architecture and moisture retention of the rhizosphere to foster root proliferation and provide easily mineralizable nutrients (Rehman *et al.*, 2023) ^[23]. This vegetative organogenesis was further enhanced by *Azotobacter* inoculation, which fixed atmospheric nitrogen and synthesized growth regulators like auxins, gibberellins and cytokinins to stimulate meristematic activity, increase nutrient-uptake efficiency and promote a greater initiation of leaf primordia into a vigorous photosynthetic canopy (Hafez *et al.*, 2016) ^[9]. Consequently, this optimized and balanced nutrient flux enabled the plants to quickly satisfy their vital vegetative biomass thresholds, thereby triggering the earliest head initiation and hastening physiological head maturity via the efficient translocation of solutes from the foliar source to the compact economic sink. This comprehensive interpretation is strongly supported by the parallel empirical advancements documented by Jaswal *et al.* (2025) ^[11], Chanuet *al.* (2024) ^[5] and Bopcheet *al.* (2024).

Effect of integrated nutrient management on yield attributes and yield of cabbage

The data on the yield attributes and yield of cabbage presented in the table 2 reveals a highly significant impact from the integrated nutrient management amendments. The physical dimensions of the cabbage head, measured via head diameter, exhibited notable variations across the different nutrient treatments. The maximum head diameter was recorded 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) at 16.62 cm. On the other hand, the smallest head diameter was observed in Control treatment (T₁), recording a 14.16 cm diameter.

The average weight of the cabbage head followed a corresponding trend, showing a highly significant response to the synchronized nutrient treatments. The highest average head weight was successfully achieved under treatment 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) observing a 1244.12 g weight, which significantly surpassed all other treatments except 75% RDF + 25% FYM + *Azotobacter* (T₆), which was found to be statistically at par with a head weight of 1180.28 g. Conversely, the Control treatment (T₁) recorded the lowest average head weight at 704.14 g, highlighting a substantial decrease in physical growth. Total marketable yield per hectare was strongly influenced by the various nutrient management matrices. Reflecting the patterns observed in head diameter and weight, treatment 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) produced the maximum yield at 29.49 t/ha, performing statistically at par with treatment 75% RDF + 25% FYM + *Azotobacter* (T₆), which yielded 27.98 t/ha. The lowest total yield was documented under the Control treatment (T₁) at 16.69 t/ha\$, showing that a complete lack of integrated nutrient management and balanced fertilization severely restricts overall crop productivity. The highly significant enhancement in the yield attributes and total marketable output of cabbage under 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) is a direct consequence of the synergistic interaction between mineral fertilizers, humified organic amendments and functional microbial inoculants. The maximum head diameter (16.62 cm) and peak average head weight (1244.12 g) achieved under T₈ indicate a highly efficient source-to-sink translocation of photosynthates during the critical head-filling stage, fueled by the immediate availability of macronutrients from the 75% RDF for early-stage establishment and the gradual mineralization of the vermicompost base for sustained nutrient flux (Jaswal *et al.*, 2025) ^[11]. Vermicompost specifically ensured a steady supply of essential micronutrients while improving soil moisture retention, which is critical during head expansion to maintain cell turgor and facilitate continuous lateral growth (Oyege and Bhaskar, 2023) ^[19]. The integration of *Azotobacter* within this module further expanded the head dimensions and volume through its capacity to fix atmospheric nitrogen and synthesize endogenous growth regulators such as gibberellins, auxins and cytokinins which promote cell division, longitudinal cell elongation and lateral bud development to yield a more compact and expansive head surface area (Sumbulet *al.*, 2020) ^[30]. Consequently, this optimized nutritional matrix and improved soil physico-chemical framework maximized individual head weight, allowing T₈ to produce the maximum total yield of 29.49 t/ha. These findings are strongly validated by the independent work of Chanu *et al.* (2024) ^[5], Bopcheet *al.* (2024) and Nayaket *al.* (2023) ^[17].

Effect of integrated nutrient management on quality of cabbage

The data on the quality parameters of cabbage presented in the

table 3 reveals that integrated nutrient management regimes exert a distinct influence on the physical structure and biochemical composition of the crop. Head compactness, a crucial physical parameter determining marketability and shelf life, showed variations among the evaluated treatment matrices; however, the statistical analysis indicated non-significant (NS) differences among the treatments.

The biochemical sweetness and consumer preference index, evaluated through TSS (°Brix), followed a closely corresponding trend with highly significant responses across the treatment combinations. The highest TSS concentration was successfully achieved under 75% RDF + 25% Vermicompost + *Azotobacter* (T₈), reaching a peak value of 5.80 (°Brix). This indicates that a robust biological inoculation combined with balanced organic sources effectively satisfies the physiological demands for secondary metabolite and carbohydrate synthesis. In contrast, the lowest accumulation of soluble solids was documented under the Control treatment (T₁), which yielded only 4.45 (°Brix).

The antioxidant and nutritional profile of the cabbage heads, quantified by the ascorbic acid (Vitamin C) content, was strongly enhanced by the integrated bio-organic frameworks. Consistent with the other quality metrics, 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) produced the maximum ascorbic acid content at 30.98 mg/100g. Conversely, the Control applicationControl treatment (T₁) resulted in a significant reduction in nutritional quality, recording the minimum ascorbic acid concentration of 24.02 mg/100g. This demonstrates that

unbalanced or deficient fertilization strategies lacking integrated macro- and micronutrient mobilization constraints can negatively impact the plant's overall biochemical biosynthesis and nutritional value.

The enhancement of physical and biochemical quality attributes in cabbage under treatment 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) can be attributed to the steady, balanced supply of macro- and micronutrients combined with the continuous mobilization of nutrients by functional bio-inoculants. Although variations in head compactness were statistically non-significant. For the biochemical parameters, the peak Total Soluble Solids (°Brix) and highest ascorbic acid concentration (mg/100g) observed in T₈ are directly linked to the metabolic synergy between the 75% inorganic RDF, vermicompost and microbial inoculants. Because the biosynthesis of ascorbic acid is a carbohydrate-dependent physiological process, the augmented photosynthetic efficiency and expansive leaf canopy established under this integrated module created an abundant pool of hexose sugar precursors necessary for L-ascorbic acid synthesis (Smirnoff and Wheeler, 2024) [29]. Furthermore, inoculation with *Azotobacter* facilitated enhanced rhizospheric nutrient uptake and metabolic vigor, which positively correlated with the accumulation of soluble solids, secondary metabolites and essential vitamins within the cabbage tissues (Davis *et al.*, 2004) [8]. These interpretations closely align with the parallel investigations of Jaswal *et al.* (2025) [11], Walling *et al.* (2022) [31] and Singh *et al.* (2023) [27].

Table 1: Effect of integrated nutrient management on growth of cabbage

S. No.	Treatment	Treatment combination	Plant height (cm)	Number of leaves per plant	Days taken to head initiation	Days taken to head maturity
1	T ₁	Control	23.87	12.32	38.77	68.38
2	T ₂	100% RDF (175: 75 :70)	31.58	16.22	35.02	62.61
3	T ₃	75% RDF + 25% FYM	35.48	18.23	33.77	60.90
4	T ₄	50% RDF + 50% FYM	27.86	14.30	37.52	66.11
5	T ₅	75% RDF + 25 % Vermicompost	36.40	18.70	32.52	59.23
6	T ₆	75% RDF + 25% FYM + <i>Azotobacter</i>	39.23	20.17	31.27	57.59
7	T ₇	50% RDF + 50% FYM + <i>Azotobacter</i>	28.67	14.72	36.27	64.34
8	T ₈	75% RDF + 25 % Vermicompost + <i>Azotobacter</i>	39.99	20.57	30.02	55.97
S.E. (m) (±)			1.29	0.60	1.39	2.57
C.D. @ 5%			3.91	1.82	4.22	7.80

Table 2: Effect of integrated nutrient management on yield and yield attributes of cabbage

S. No.	Treatment	Treatment combination	Head diameter (cm)	Average weight of head (g)	Yield per hectare (t/ha)
1	T ₁	Control	14.66	704.14	16.69
2	T ₂	100% RDF (175: 75 :70)	15.04	947.79	22.47
3	T ₃	75% RDF + 25% FYM	14.79	1065.68	25.26
4	T ₄	50% RDF + 50% FYM	14.16	834.78	19.79
5	T ₅	75% RDF + 25 % Vermicompost	15.35	1094.09	25.93
6	T ₆	75% RDF + 25% FYM + <i>Azotobacter</i>	16.21	1180.28	27.98
7	T ₇	50% RDF + 50% FYM + <i>Azotobacter</i>	14.75	859.89	20.38
8	T ₈	75% RDF + 25 % Vermicompost + <i>Azotobacter</i>	16.62	1244.12	29.49
S.E. (m) (±)			0.44	39.31	0.93
C.D. @ 5%			1.35	119.24	2.83

Table 3: Effect of integrated nutrient management on quality of cabbage

S. No.	Treatment	Treatment combination	Head compactness (g/cm ³)	TSS (°Brix)	Ascorbic acid (mg/100g)
1	T ₁	Control	22.33	4.45	24.02
2	T ₂	100% RDF (175: 75 :70)	28.02	5.18	27.49
3	T ₃	75% RDF + 25% FYM	32.99	5.39	28.65
4	T ₄	50% RDF + 50% FYM	29.52	4.85	26.15
5	T ₅	75% RDF + 25 % Vermicompost	30.30	5.49	29.23
6	T ₆	75% RDF + 25% FYM + Azotobacter	27.96	5.69	30.34
7	T ₇	50% RDF + 50% FYM + Azotobacter	26.81	4.97	26.33
8	T ₈	75% RDF + 25 % Vermicompost + Azotobacter	27.34	5.80	30.98
S.E. (m) (±)			1.67	0.11	0.64
C.D. @ 5%			NS	0.32	1.94

Acknowledgement

The author expresses his gratitude to the Department of Horticulture, Rama University, Kanpur (U.P.). for their invaluable help (both teaching and non-teaching staff).

Conclusion

From the above results of the current experiment, 75% RDF + 25% Vermicompost + *Azotobacter* (T₈) had the best effect in terms of growth attributes, yield parameters and quality traits of cabbage. In terms of integrated nutrient management practices, treatment T₈ was found to be significantly effective over all other treatments on growth and yield attributes like plant height, number of leaves per plant, head diameter, average weight of head and total marketable yield, while also shortening the days to head initiation and maturity and optimizing biochemical quality indices including TSS and ascorbic acid content. Given that this is based on a single season trial, additional evaluation trials are required to validate the findings.

References

- Aasfar A, Bargaz A, Yaakoubi K, Hilali A, Bennis I, Zeroual Y, Kadmiri M. Nitrogen fixing *Azotobacter* species as potential soil biological enhancers for crop nutrition and yield stability. *Front Microbiol.* 2021;12:628379.
- Anonymous. Horticulture crops: vegetables: cauliflower: Uttar Pradesh. CEIC Data. 2024.
- Anonymous. Area and production of horticulture crops, 2025–26 (first advance estimates). Department of Agriculture & Farmers' Empowerment. 2025.
- Asif M, Mughal AH, Mehdi Z, Malik MA, Masood A, Sideeque S, et al. Vermicompost technology and its application in forest nursery raising. *Int J Curr Microbiol Appl Sci.* 2019;8(1):1290–1296.
- Chanu NC, Sanasam J, Maisnam G, Thakur D. Effect of various organic manures on growth and yield of cabbage (*Brassica oleracea* L.). *BIO Web Conf.* 2025;178:01009. <https://doi.org/10.1051/bioconf/202517801009>
- Chatterjee R, Jana J, Paul PK. Enhancement of head yield and quality of cabbage (*Brassica oleracea*) by combining different sources of nutrient. *Indian J Agric Sci.* 2012;82(4):323–327.
- Darnton-Hill I. Public health aspects in the prevention and control of vitamin deficiencies. *Curr Dev Nutr.* 2019;3(9):nzz075.
- Davis DR, Epp MD, Rioden HD. Changes in USDA food composition data for 43 garden crops from 1950–1999. *J Am Coll Nutr.* 2004;23:1–2.
- Hafez SK, El-Beik AK, El-Tantawy AM, ElKasas AI. Effect of organic and bio-fertilizer sources on summer squash under El-Arish conditions. *Sinai J Appl Sci.* 2016;5(2):155–172.
- Jangir R, Thanki JD, Patil KB, Saini LK. Residual and direct effect of integrated nutrient management on growth, yield, monetary efficiency, nutrient uptake of cowpea and soil properties under grain amaranth–cowpea cropping sequence in Inceptisols of western India. *J Plant Nutr.* 2021;1–21.
- Jaswal S, Kumar A, Sepehya S, Kochithara EJ, Jaswal K. Synergistic effect of nitrogen substitution through vermicompost on productivity and quality of cauliflower in low hills of Himachal Pradesh, India. *Int J Plant Soil Sci.* 2025;37(9):435–445.
- Khan NI, Malik AU, Umer F, Bodla MI. Effect of tillage and farm yard manure on physical properties of soil. *Int Res J Plant Sci.* 2010;1(4):75–82.
- Maggioni L, Bothmer R, Poulsen G, Branca F. Origin and domestication of cole crops (*Brassica oleracea* L.): linguistic and literary considerations. *Econ Bot.* 2010;64(2):109–123.
- Melim C, Lauro MR, Pires IM, Oliveira PJ, Cabral C. The role of glucosinolates from cruciferous vegetables (Brassicaceae) in gastrointestinal cancers: from prevention to therapeutics. *Pharmaceutics.* 2022;14(1):190.
- Mohandas S. Bio-fertilizer of horticultural crops. *Indian Hortic.* 1999;43(4):32–37.
- National Horticulture Board. State wise area and production estimates of horticultural crops. Ministry of Agriculture, Government of India. 2024.
- Nayak DA, Jena S, Mohanty S, Jena SS. Effect of micronutrient, *Azotobacter*, *Azospirillum* and chemical fertilizers on growth and yield of cabbage (*Brassica oleracea* var. capitata L.). *Environ Ecol.* 2023;41(2):877–882.
- Ojetayo AE, Olaniyi JO, Akanbi WB, Olabiyi TI. Effect of fertilizer types on nutritional quality of two cabbage varieties before and after storage. *J Appl Biosci.* 2011;48(5):3322–3330.
- Oyege I, Bhaskar MSB. Effects of vermicompost on soil and plant health and promoting sustainable agriculture. *Soil Syst.* 2023;7(4):3390.
- Panse VG, Sukhatme PV. Statistical methods for agricultural workers. New Delhi: Indian Council of Agricultural Research; 1985.
- Prasad B, Sinha SK. Long-term effects of fertilizers and organic manures on crop yields, nutrient balance and soil properties in rice–wheat cropping system in Bihar. In: Long-term soil fertility experiments in rice–wheat cropping systems. Rice-Wheat Consortium Paper Series. 2000;6:105–119.
- Rai N, Yadav GD. Advances on vegetable production. Kolkata: Kalyani Publications; 2005. p. 52.
- Rehman SU, De Castro F, Aprile A, Benedetti M.

- Vermicompost: enhancing plant growth and combating abiotic and biotic stress. *Agronomy*. 2023;13(4):1134.
24. Sharma V, Sharma OP, Joshi D, Shekhawat AS. Influence of fertility levels, biofertilizers and stress extenuating chemicals on growth and yield of mungbean (*Vigna radiata* L.). *Int J Sci Res Arch*. 2026;18(2):542–552.
 25. Sher A, Mishra S. Effect of FYM, biochar and biofertilizers on growth and yield of kharif cabbage (*Brassica oleracea* L. var. capitata) cv. Pride of India. *Pharma Innov J*. 2023;12(4):641–650.
 26. Singh A, Maji S, Kumar S. Effect of biofertilizers on yield and biomolecules of anti-cancerous vegetable broccoli. *Int J Bio-resour Stress Manag*. 2014;5(2):262–268.
 27. Singh H, Kerketta A, Prasad VM, Bahadur V. Effect of organic manure and biofertilizer on growth, yield and quality in cabbage (*Brassica oleracea* var. capitata). *Int J Environ Clim Change*. 2023;13(10):1982–1988. <https://doi.org/10.9734/ijecc/2023/v13i102856>
 28. Singh J, Upadhyay AK, Bahadur A, Singh B, Singh KP, Rai M. Antioxidant phytochemicals in cabbage (*Brassica oleracea* L. var. capitata). *Sci Hortic*. 2006;108(3):233–237.
 29. Smirnov N, Wheeler GL. The ascorbate biosynthesis pathway in plants is known, but there is a way to go with understanding control and functions. *J Exp Bot*. 2024;75(9):2604–2630.
 30. Sumbul A, Ansari RA, Rizvi R, Mahmood I. Azotobacter: a potential bio-fertilizer for soil and plant health management. *Saudi J Biol Sci*. 2020;27(12):3634–3640.
 31. Walling I, Kanaujia SP, Changini M. Response of broccoli (*Brassica oleracea* var. italica) to integrated nutrient management. *Ann Plant Soil Res*. 2022;24(1):106–109.
 32. Yadav RP, Tripathi ML, Trivedi SK. Effect of irrigation and nutrient levels on productivity and profitability of sunflower (*Helianthus annuus*). *Indian J Agron*. 2009;54(3):332–335.
 33. Yadav VS, Yadav BD. Effect of NICAST (organic manure) in comparison to recommended doses of manure and fertilizers in onion. *South Indian Hortic*. 2001;49:160–161.