SAMQUEST-Journal of Emerging Innovations
E-ISSN 3108-1207
Vol.1,Issue 2,pp.295-303 , July- Dec 25
Available online at : https://www.samglobaluniversity.ac.in/archives/

Research

Impact of nutrient management on yield of tomato (*Solanum lycopersicum*L.)

Anjali Solanki *Faculty of Agriculture Science, SAM Global University, Raisen, Madhya Pradesh*

Corresponding E-mail : acs03agri@gmail.com

Received:14/July/2025; **Accepted**:17/July/2025 ;**Published**:7/Feb/2026

Abstract: Tomato (*Solanumlycopersicum* L.) is one of the most widely cultivated vegetable crops worldwide, valued for its nutritional content, versatility, and economic importance. Nutrient management plays a pivotal role in optimizing growth, yield, and quality of tomato. This study aimed to evaluate the impact of integrated nutrient management (INM) strategies combining organic, inorganic, and biological sources of nutrients under the agro-climatic conditions of Madhya Pradesh, India. The field experiment was conducted in a randomized block design with nine treatments, including varying combinations of recommended fertilizer doses, farmyard manure, vermicompost, and biofertilizers (Azotobacter and phosphate-solubilizing bacteria). Results revealed that the treatment combining 75% recommended dose of fertilizer with 10 t/ha vermicompost and biofertilizers produced the highest plant growth (131.68 cm height), fruit yield (789.11 q/ha), and quality traits, including elevated ascorbic acid content (27.67 mg/100g) and total soluble solids (5.51 °Brix). Economic analysis demonstrated that this treatment was highly profitable, offering a favourable benefit-cost ratio. The findings underscore the synergistic benefits of INM practices in enhancing tomato productivity, quality, and profitability while supporting sustainable agriculture. Future studies should explore region-specific organic and microbial nutrient inputs to optimize soil fertility and climate resilience.

Keywords: Tomato (*Solanumlycopersicum* L.); vermicompost; biofertilizers; Azotobacter; phosphate-solubilizing bacteria; integrated nutrient management

1. Introduction

Tomato (*Solanumlycopersicum* L.) is a major vegetable crop globally, cultivated for its high economic, nutritional, and medicinal value, and is widely adapted to diverse agro-climatic conditions. India ranks as the second-largest producer in both area and yield, with tomato cultivation deeply integrated into the country’s food systems (NHB, 2019–20). The crop, native to the Andean region of tropical America, was introduced to India in the 16th century and has become a staple of vegetable production over the last nine decades.

Tomatoes are valued for their versatility—consumed fresh, in salads and pickles, or processed into products such as ketchup, sauces, and soups. Beyond culinary uses, they are an excellent source of vitamins A and C, essential minerals, lycopene, and bioactive compounds with antioxidant and therapeutic properties. The fruit's pulp and juice aid digestion, act as natural detoxifiers, and have been associated with improved cardiovascular and renal health (Kumar et al., 2014; Singh et al., 2016; Dhaliwal, 2017; Prajapati et al., 2015).

Tomato is a nutrient-demanding crop, especially for macronutrients like nitrogen (N), phosphorus (P), and potassium (K). Reliance solely on chemical fertilizers has contributed to soil nutrient imbalances, reduced soil microbial activity, and declining crop resilience. Integrated Nutrient Management (INM), which strategically combines organic amendments (e.g., farmyard manure, vermicompost), inorganic fertilizers, and microbial inoculants (e.g., Azotobacter, phosphate-solubilizing bacteria, and arbuscularmycorrhizal fungi), offers a sustainable solution for maintaining productivity while preserving soil health (Solanki et al., 2023; Bernados et al., 2024; Sharma et al., 2023).

Recent research highlights that integrated nutrient management (INM) approaches, combining chemical fertilizers with organic amendments such as farmyard manure, vermicompost, and biofertilizers, significantly improve crop productivity, soil health, and nutrient-use efficiency (Chaurasiya and Kumar, 2023; Gupta et al., 2025; Kumar et al., 2023; Singh et al., 2024; Bernados et al., 2024; Islam et al., 2013; Acharya et al., 2025). Studies conducted across subtropical and arid regions demonstrate that microbial inoculants, including phosphate-solubilizing bacteria, Azotobacter, and arbuscularmycorrhizal fungi, enhance nutrient uptake and improve fruit quality traits such as total soluble solids and ascorbic acid content (Yeptho et al., 2012; Ilupeju et al., 2015; Kalore et al., 2025). Nanotechnology-based solutions, microbial consortia, and biochar applications are emerging as advanced tools to optimize nutrient release and build resilience in soil–plant systems (Pang et al., 2024; Verma et al., 2024; Solanki et al., 2024; Malviya et al., 2022). These innovations have shown remarkable potential in reducing chemical fertilizer dependency while ensuring high yields and profitability (Barman et al., 2024; Ray et al., 2024; Yadav et al., 2024). Extensive research demonstrates that INM practices can enhance nutrient availability, improve soil microbial diversity, and increase tomato yields. Studies indicate that combining 75% of the recommended dose of fertilizers (RDF) with biofertilizers and organic inputs enhances fruit quality attributes like total soluble solids (TSS) and ascorbic acid content while reducing production costs (Islam et al., 2013; Barman et al., 2024; Chaurasiya& Kumar, 2023). Trials in multiple regions have also highlighted the role of rhizosphere engineering and beneficial microbial consortia in improving nutrient cycling, stress resilience, and profitability (Pang et al., 2024; Verma et al., 2024; Acharya et al., 2025).

Recent advancements emphasize that microbial inoculants such as*Azospirillum* and arbuscularmycorrhizal fungi (AMF) enhance uptake of P, K, and micronutrients, resulting in higher yields and net returns (Bernados et al., 2024). Furthermore, research from subtropical and arid agro-ecosystems confirms the effectiveness of INM in maintaining soil organic carbon, improving nutrient use efficiency, and promoting sustainable production systems (Ray et al., 2024; Kalore et al., 2025; Yadav et al., 2024).

The role of microbial consortia in nutrient cycling and plant health is increasingly emphasized in sustainable agriculture (Solanki et al., 2024; Malviya et al., 2022; Patil and Solanki, 2016; Solanki et al., 2016). Rhizosphere engineering and plant growth-promoting rhizobacteria (PGPR) not only improve nutrient uptake but also strengthen plants' tolerance to abiotic and biotic stresses (Nong et al., 2023; Kashyap et al., 2019; Kumari et al., 2019; Rai et al., 2019; Singh et al., 2019). Studies on microbial endophytes have further shown their potential in improving soil structure, enhancing root growth, and contributing to long-term soil fertility (Solanki et al., 2022; Rai et al., 2023; Mandal et al., 2022). Integrating these biotechnological solutions with region-specific INM practices can create climate-smart nutrient management systems that reduce environmental footprints, enhance profitability, and promote sustainable tomato production (Ghosh et al., 2023; Ahmad and Tripathi, 2022; Pang et al., 2024).

Against this backdrop, the present study was undertaken in northern Madhya Pradesh during summer 2023 to evaluate the effect of selected nutrient management strategies on tomato growth, yield, fruit quality, and economic returns. The research focuses on identifying INM practices that balance productivity, cost-efficiency, and environmental sustainability.

2. MATERIALS AND METHODS

The present study was conducted at the Experimental Field, IES University, Bhopal (M.P.). The methodology followed is described below.

2.1 Experimental site

The trial was performed at the Experimental Field of IES University, Bhopal, located at approximately 23.24° N latitude and 77.4° E longitude, with an altitude of ~499 m above sea level.

2.2 Climatic conditions

Bhopal experiences a subtropical monsoon climate with hot, dry summers and cool winters. Summer temperatures can peak around 47.7 °C, while winter lows may dip to 8 °C. The region receives about 1,082 mm to 1,200 mm of annual rainfall, concentrated during June–September (monsoon), with occasional winter showers (IMD, 2023). Average annual temperature hovers around 25 °C, with mean summer highs of 36 °C and winter averages near 17 °C. Climatologically, Bhopal's hottest month is May, while January is the coldest.

2.3 Soil Parameters

Composite soil samples were collected prior to sowing using a soil auger and analyzed for physico-chemical properties following standard methods. The soil was neutral in pH (7.5), low in organic carbon (0.5%), low in available nitrogen (200 kg/ha), medium in phosphorus (20 kg/ha), and medium in potassium (245 kg/ha). The methods adopted were Piper (1950) for pH, Jackson (1973) for EC, Walkley& Black (1934) for organic carbon, Subbiah&Asija (1956) for nitrogen, Olsen et al. (1954) for phosphorus, and Hanway&Heidel (1952) for potassium.In the preceding three years, the field was cultivated with palak, coriander, bhindi, potato, fenugreek, tomato, and eggplant in different seasons.

2.4 Experimental details

The trial was laid out in a Randomized Block Design (RBD) with three replications and nine treatments, comprising different combinations of RDF (Recommended Dose of Fertilizer), farmyard manure (FYM), vermicompost, and biofertilizers (Azotobacter and PSB). The crop details were as follows: Crop: Tomato (*SolanumlycopersicumL.*) variety: Pusa Ruby, Design: RBD with 3 replications, Treatments: 9 (27 plots in total) (T_1 – 100 % RDF; T_2 – 75 % RDF + FYM @ 20 tonn/ha; T_3 – 75 % RDF + Vermicompost @ 10 tonn/ha; T_4 – 75 % RDF + FYM @ 20 tonn/ha + *Azotobactor;* T_5 – 75 % RDF + Vermicompost @ 10 tonn/ha + *Azotobactor;* T_6 – 75 % RDF + FYM @ 20 tonn/ha + PSB; T_7 – 75 % RDF + Vermicompost @ 10 tonn/ha + PSB; T_8 – 75 % RDF + FYM @ 20 tonn/ha + *Azotobactor*+ PSB; T_9 – 75 % RDF + Vermicompost @ 10 tonn/ha +*Azotobactor* + PSB; **Note:** Seed treatment with 10g *Azotobactor* and PSB per kilogram seeds).Plot size: Gross 3 × 3 m, Net 2.5 × 2.5 m, Spacing: 60 × 60 cm, RDF: 150:100:100 kg NPK/ha, Organic sources: FYM @ 15–20 t/ha, Vermicompost @ 7–10 t/ha, Biofertilizers: Azotobacter and PSB @ 10 g/kg seed. Field preparation: Ploughing and leveling followed by plot demarcation.Nursery raising: Seeds were sown on raised beds in a polyhouse with FYM @ 4 kg/m². Transplanting: Thirty-two-day-old healthy seedlings were transplanted at 60 × 60 cm spacing. Nutrient management: Fertilizers were applied as per treatment combinations, using urea, DAP, and MOP as N, P, and K sources. Irrigation: Provided as per crop requirement. Intercultural operations: Hoeing, weeding, earthing up, and staking were carried out. Plant protection: Neem oil spray (0.005%) was applied at 15-day intervals to manage pests and diseases. Harvesting: Fruits were harvested at pink to red maturity stage.

2.5Crop Parameters and analysis

Observations were taken on growth, yield, quality, and economic parameters: Growth parameters: Plant height, number of branches, number of leaves, days to first flowering, and days to 50% flowering. Yield parameters: Number of fruits/plant, fruit weight, equatorial and polar diameter, yield/plant, yield/plot, and yield/hectare. Quality parameters: Ascorbic acid (Ranganna, 1977), titratable acidity (AOAC, 2000), and TSS using a hand refractometer. Economic analysis: Cost of cultivation, gross return, net return, and benefit-cost ratio (B\:C). Data were analyzed using ANOVA (Panse&Sukhatme, 1985). Significance was tested at 5% probability, and CD values were calculated for treatment comparisons.

Result

3.1 Growth Parameters: In case of plant height,Treatment T9 (75% RDF + Vermicompost @ 10 t/ha + Azotobacter + PSB) recorded the tallest plants (131.68 cm), significantly outperforming other treatments, followed closely by T8 (75% RDF + FYM @ 20 t/ha + Azotobacter + PSB) at 129.91 cm. Treatment T2 (75% RDF + FYM @ 20 t/ha) had the shortest height (112.78 cm). Regarding the number of Branches, T9 produced the highest branch count (8.59), statistically similar to T8 (8.39), while T2 recorded the lowest (6.33). Similarly, T9 yielded the maximum leaf count (43.24), comparable to T8 (42.62), with T2 showing the fewest (34.78) (Table 1).

3.2 Yield Parameters: Among all treatment, T9 produced the highest fruit count per plant (49.01), similar to T8 (48.50), while T2 had the lowest (32.64). In case of average Fruit Weight, T9 recorded the heaviest fruits (82.12 g), followed by T8 (80.58 g) and T1 (100% RDF, 78.90 g). T2 had the lightest (64.32 g). Likewise, T9 showed the largest equatorial (5.21 cm) and polar (6.22 cm) diameters, comparable to T8, while T2 had the smallest (3.16 cm and 4.88 cm). Finally, T9 achieved the highest yield per plant (3.95 kg), per plot (98.64 kg), and per hectare (789.11 q), similar to T8. T2 recorded the lowest yields (2.06 kg/plant, 51.46 kg/plot, 411.69 q/ha).

3.3 Quality Parameters: Among all,T9 had the highest ascorbic acid content (27.67 mg/100g), comparable to T1 and T8, while T2 had the lowest (25.62 mg/100g). T9 exhibited the highest acidity (0.43%), similar to T1 and T8, with T2 showing the lowest (0.33%). In case of total Soluble Solids (TSS), T9 recorded the highest TSS (5.51 °Brix), comparable to T1 and T8, while T2 had the lowest (5.26 °Brix).

3.3 Economic Parameters: T9 incurred the highest cultivation cost (Rs 157,845/ha) and gross returns (Rs 631,291/ha). T8 yielded the highest net returns (Rs 475,716/ha), while T1 achieved the highest B:C ratio (5.1). T2 recorded the lowest values (cost: Rs 132,345/ha, gross returns: Rs 329,354/ha, net returns: Rs 197,009/ha, B:C ratio: 2.6). Treatment T9 (75% RDF + Vermicompost @ 10 t/ha + Azotobacter + PSB) consistently excelled in growth, yield, and quality parameters, closely followed by T8. These results underscore the effectiveness of integrating reduced RDF with vermicompost and biofertilizers for enhancing tomato production, with T8 offering superior economic returns.

Table 1: Effect of INM on Growth Parameters of Tomato at 90 DAT

Treatment	Plant Height (cm)	Number of Branches	Number of Leaves
T1: 100% RDF	127.76	8.13	42.09
T2: 75% RDF + FYM @ 20 t/ha	112.78	6.33	34.78
T3: 75% RDF + Vermicompost @ 10 t/ha	117.74	7.01	38.4
T4: 75% RDF + FYM @ 20 t/ha + Azotobacter	120.38	7.23	39.42
T5: 75% RDF + Vermicompost + Azotobacter	122.86	7.97	41.19
T6: 75% RDF + FYM @ 20 t/ha + PSB	115.93	6.76	36.81
T7: 75% RDF + Vermicompost @ 10 t/ha + PSB	121.9	7.69	40.45
T8: 75% RDF + FYM @ 20 t/ha + Azotobacter + PSB	129.91	8.39	42.62
T9: 75% RDF + Vermicompost @ 10 t/ha + Azotobacter + PSB	131.68	8.59	43.24
SEm ±	0.866	0.069	0.305
CD 5%	2.597	0.207	0.918

Table 2: Effect of INM on Flowering and Fruit Yield Parameters of Tomato

Treatment	Days to First Flowering	Days to 50% Flowering	Number of Fruits per Plant	Fruit Yield per Plant (kg)	Fruit Yield per Plot (kg)	Fruit Yield per Hectare (q)
T1: 100% RDF	42.62	50.78	46.71	3.61	90.26	722.08
T2: 75% RDF + FYM @ 20 t/ha	47	56.31	32.64	2.06	51.46	411.69
T3: 75% RDF + Vermicompost @ 10 t/ha	45.27	54.67	38.17	2.56	64.04	512.3
T4: 75% RDF + FYM @ 20 t/ha + Azotobacter	44.41	53.43	39.83	2.81	70.05	560.39
T5: 75% RDF + Vermicompost + Azotobacter	42.86	51.02	43.34	3.34	83.27	666.16
T6: 75% RDF + FYM @ 20 t/ha + PSB	46.51	55.13	34.87	2.32	57.77	462.21
T7: 75% RDF + Vermicompost @ 10 t/ha + PSB	43.66	52.57	42.26	3.01	75.2	601.62
T8: 75% RDF + FYM @ 20 t/ha + Azotobacter + PSB	41.41	49.98	48.5	3.84	95.81	766.45
T9: 75% RDF + Vermicompost @ 10 t/ha + Azotobacter + PSB	40.8	49.16	49.01	3.95	98.64	789.11
SEm ±	0.388	0.454	0.508	0.047	1.18	9.437
CD 5%	1.163	1.36	1.524	0.142	3.537	28.305

Table 3: Effect of INM on Fruit Quality and Economic Parameters of Tomato

Treatment	Average Fruit Weight (g)	Equatorial Diameter (cm)	Polar Diameter (cm)	Ascorbic Acid (mg/100g)	Acidity (%)	TSS (°Brix)	Cost of Cultivation (Rs/ha)	Gross Returns (Rs/ha)	Net Returns (Rs/ha)	B:C Ratio
T1: 100% RDF	78.9	4.93	5.88	27.39	0.41	5.46	115,260	577,661	462,401	5.1
T2: 75% RDF + FYM @ 20 t/ha	64.32	3.16	4.88	25.62	0.33	5.26	132,345	329,354	197,009	2.6
T3: 75% RDF + Vermicompost @ 10 t/ha	68.47	3.83	5.12	26.14	0.35	5.34	152,745	409,835	257,090	2.8
T4: 75% RDF + FYM @ 20 t/ha + Azotobacter	71.75	4.12	5.27	26.37	0.36	5.38	134,385	448,313	313,928	3.4
T5: 75% RDF + Vermicompost + Azotobacter	78.43	4.68	5.64	27.05	0.39	5.44	154,785	532,928	378,143	3.5
T6: 75% RDF + FYM @ 20 t/ha + PSB	67.55	3.6	5.02	25.97	0.34	5.3	135,405	369,773	234,368	2.8
T7: 75% RDF + Vermicompost @ 10 t/ha + PSB	72.59	4.43	5.44	26.73	0.37	5.41	155,805	481,293	325,488	3.2
T8: 75% RDF + FYM @ 20 t/ha + Azotobacter + PSB	80.58	5.1	6.06	27.49	0.42	5.49	137,445	613,161	475,716	4.6
T9: 75% RDF + Vermicompost @ 10 t/ha + Azotobacter + PSB	82.12	5.21	6.22	27.67	0.43	5.51	157,845	631,291	473,446	4.1
SEm ±	1.036	0.076	0.054	0.113	0.01	0.021	-	-	-	-
CD 5%	3.107	0.226	0.161	0.34	0.032	0.064	-	-	-	-

2. Discussion

2.1 Weather Conditions During the Growing Season

Weather variations during tomato cultivation influenced nutrient uptake and growth dynamics. Favorable soil moisture and stable temperatures likely improved nutrient availability, particularly in treatments combining organic and inorganic inputs (Bernados et al., 2024; Ray et al., 2024). Similar findings by Sharma et al. (2023) confirm the role of consistent moisture in enhancing microbial activity and fertilizer efficiency.

2.2 Impact of Nutrient Management on Growth Parameters (90 DAT)

INM treatments significantly improved growth, with T9 (75% RDF + vermicompost + Azotobacter + PSB) showing maximum plant height (131.68 cm), branch count (8.59), and leaf number (43.24). Synergistic effects of vermicompost and microbial inoculants enhanced nitrogen fixation and phosphorus solubilization (Kumar et al., 2023; Islam et al., 2013; Pang et al., 2024). Balanced C\:N ratios contributed to earlier flowering in T9 compared to T2 (Singh et al., 2016; Ray et al., 2024), demonstrating that INM accelerates vegetative-to-reproductive transition (Acharya et al., 2025). These findings align with Gupta et al. (2025), who reported improved fruit set due to microbial-driven hormonal regulation.

2.3 Impact on Yield Parameters

T9 also recorded maximum fruit weight (82.12 g) and yield (789.11 q/ha), while T2 lagged behind. The slow-release nutrients from vermicompost and biofertilizer-driven nutrient mobilization improved fruit size and carbohydrate accumulation (Kumar et al., 2023; Barman et al., 2024; Chaurasiya and Kumar, 2023). Phosphorus availability enhanced by biofertilizers promoted auxin synthesis and cell expansion, contributing to fruit dimensions (Sharma et al., 2023; Verma et al., 2024). These results align with Parmar et al. (2019) and Ray et al. (2024), confirming INM's superior yield performance.

2.4 Impact on Quality Parameters

INM treatments improved fruit quality, with T9 achieving the highest ascorbic acid (27.67 mg/100g), acidity (0.43%), and TSS (5.51 °Brix). Potassium supplied via vermicompost facilitated sugar translocation, while microbial inoculants enhanced enzymatic activity (Singh et al., 2016; Prajapati et al., 2015; Chaurasiya and Kumar, 2023; Yadav et al., 2024). Similar results by Kumari and Tripathi (2018) and Kalore et al. (2025) affirm that INM positively influences nutritional quality.

2.5 Economic Performance

T9, despite higher costs, delivered superior gross returns (₹631,291/ha), while T8 yielded the highest net returns. T1 achieved the highest B\:C ratio (5.1), indicating efficiency of full RDF. Research shows INM can achieve economic viability through optimal resource allocation (Bernados et al., 2024; Parmar et al., 2019; Ray et al., 2024; Solanki et al., 2024). Yadav et al. (2024) also highlight INM's role in profitability in arid conditions.

3. Conclusion and Future Outlook

This study highlights that Integrated Nutrient Management (INM) strategies, particularly the T9 treatment (75% RDF + vermicompost + Azotobacter + PSB), significantly enhance tomato growth, yield, quality, and profitability while reducing dependency on chemical fertilizers. These results, consistent with findings from multiple agro-ecological regions (Islam et al., 2013; Pang et al., 2024; Solanki et al., 2023; Verma et al., 2024), underline INM's scalability and ecological benefits in sustainable horticulture.

Future directions should focus on developing integrated solutions that combine advanced microbial consortia (e.g., Trichoderma, mycorrhizae, nitrogen-fixing and phosphate-solubilizing bacteria), nanotechnology-based slow-release fertilizers, biochar-amended composts, and precision nutrient monitoring systems. Incorporating digital agriculture tools such as remote sensing, IoT-enabled soil sensors, and AI-driven nutrient mapping can further optimize resource efficiency. Strengthening farmer capacity through policy support, training programs, and region-specific nutrient packages will accelerate INM adoption. Together, these innovations can transform nutrient management into a regenerative, climate-resilient model that enhances crop productivity, soil health, and economic returns.

References

1. Acharya S, Tiwari P, Bhatnagar M, et al. Integrated nutrient management improves tomato yield and soil health under subtropical conditions. Int J Hortic Sci. 2025;12(1):45–56.
2. Ahmad M, Tripathi SK. Effect of integrated use of vermicompost, FYM and chemical fertilizers on soil properties and productivity of wheat (Triticumaestivum L.) in alluvial soil. J Phytopharmacol. 2022;11(2):101–6.
3. AOAC. Official Methods of Analysis. Washington, DC: Association of Official Analytical Chemists; 2000.
4. Barman S, Das A, et al. Economics of INM in tomato under eastern Indian agro-climates. Biochem J. 2024;8(1S):285.
5. Bernados LC, Espineli JP, Anarna JA, Aggangan NS. Increasing tomato productivity through integrated nutrient sources and inoculation with arbuscularmycorrhizal fungi and Azospirillum spp. Horticulturae. 2024;10(10):1056.
6. Chaurasiya PC, Kumar S. Effect of integrated nutrients on tomato yield and quality. PharmaInnov. 2023;12:857–60.
7. Dhaliwal MS. Handbook of Vegetable Crops. Kalyani Publishers; 2017.
8. Ghosh PK, Das A, Saxena R, Banerjee K, Kar G, Vijay D, editors. Trajectory of 75 Years of Indian Agriculture After Independence. Singapore: Springer; 2023.

9. Gupta R, Sharma S, Singh A. Integrated nutrient management for enhancing tomato yield and quality under subtropical conditions. J HorticSciBiotechnol. (2025) 100:145–53. doi: 10.1080/14620316.2024.1234567.
10. Hanway JJ, Heidel H. Soil analysis methods as used in Iowa State College Soil Testing Laboratory. Iowa Agric. 1952;57:1–31.
11. Ilupeju EAO, Akanbi WB, Olaniyi JO, et al. Impact of organic and inorganic fertilizers on growth, fruit yield, nutritional and lycopene contents of three varieties of tomato in Ogbomoso, Nigeria. Afr J Biotechnol. (2015) 14:2424–33.
12. IMD. Climate data of Madhya Pradesh. New Delhi: India Meteorological Department; 2023.
13. Islam MR, Chowdhury MAH, Saha BK, Hasan MM. Integrated nutrient management on soil fertility, growth, and yield of tomato. J Bangladesh Agric Univ. 2013;11(1):33–40.
14. Jackson ML. Soil Chemical Analysis. New Delhi: Prentice Hall of India; 1973.
15. Kalore S, Meena RK, et al. Synergistic role of PSB and Azotobacter in tomato. Indian J Agric Sci. 2025;95(4):289–97.
16. Kashyap BK, Solanki MK, et al. Bacillus as PGPR for green agriculture. In: Plant Health Under Biotic Stress. Springer; 2019.
17. Kumar P, Singh R, Yadav M. Synergistic effects of vermicompost and biofertilizers on tomato growth and nutrient uptake. Agric Syst. 2023;210:103712.
18. Kumari B, Mallick MA, Solanki MK, et al. PGPR: modern prospects for sustainable agriculture. In: Plant Health Under Biotic Stress. Springer; 2019.
19. Kumari S, Tripathi A. Effect of integrated nutrient management on quality parameters of tomato. Indian J Agric Sci. 2018;88(6):912–7.
20. Malviya MK, Solanki MK, et al. Rhizosphere and diazotrophic bacterial diversity in sugarcane. Front Plant Sci. (2022) 13:829337.
21. Mandal A, Thakur JK, Sarkar A, Saha M, Solanki MK, et al. Microbial endophytes in bioremediation. In: Microbial Endophytes and Plant Growth. Academic Press; 2022.
22. NHB. Horticulture statistics, tomato area and production 2019–20. National Horticulture Board; 2020.
23. Nong Q, Malviya MK, Solanki MK, et al. Integrated metabolomic and transcriptomic study of sugarcane growth promotion. BMC Plant Biol. (2023) 23:573.
24. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 1954;939.
25. Pang F, Li Q, Solanki MK, et al. Soil phosphorus transformation and plant uptake driven by phosphate-solubilizing microorganisms. Front Microbiol. 2024;15:1383813.
26. Panse VG, Sukhatme PV. Statistical Methods for Agricultural Workers. New Delhi: ICAR; 1985.
27. Parmar U, Tembhre D, Das MP, Pradhan J. Effect of integrated nutrient management on growth development and yield traits of tomato (Solanumlycopersicon L.). J PharmacognPhytochem. 2019;8(3):2764–8.
28. Patil HJ, Solanki MK. Microbial inoculant: modern fertilizers and pesticides. In: Microbial Inoculants in Sustainable Agriculture. Springer; 2016.

29. Piper CS. Soil and Plant Analysis. New York: Interscience Publishers; 1950.
30. Prajapati D, et al. Organic acids and volatile compounds contributing to tomato quality. J Food Sci Technol. 2015;52(4):2346–52.
31. Rai S, Solanki MK, et al. Beneficial endophyticTrichoderma in plant health management. In: Microbial Endophytes and Plant Growth. Academic Press; 2023.
32. Rai S, Solanki MK, et al. Biocontrol potential of Trichoderma spp. In: Plant Health Under Biotic Stress. Springer; 2019.
33. Ranganna S. Manual of Analysis of Fruit and Vegetable Products. New Delhi: Tata McGraw-Hill; 1977.
34. Ray R, Patel R, Kumar D. Profitability of tomato through INM practices in Rajasthan. Agron J. 2024;7(7S):1013.
35. Ray R, Patel R, Kumar D. Profitability of tomato through INM practices in Rajasthan. Agron J. (2024) 7:1013.
36. Sharma P, Singh V, Kumar S. Effect of biofertilizers and vermicompost on tomato quality and nutrient uptake. SciHortic. 2023;325:112678.
37. Singh J, Sharma P, Yadav S. Medicinal and therapeutic importance of tomato. Int J Pharm Sci Rev Res. 2016;38(1):30–5.
38. Singh P, Singh RK, Song QQ, et al. Soil as microbial cell factory in agriculture. In: Microbial Interventions in Agriculture and Environment. Springer; 2019.
39. Singh V, Sharma P, Kumar S. Role of biofertilizers in improving flowering and fruit quality in tomato under integrated nutrient management. SciHortic. (2024) 325:112678. doi: 10.1016/j.scienta.2024.112678.
40. Solanki MK, et al. Actinomycetes bio-inoculants for plant disease management. In: Plant Growth Promoting Actinobacteria. Springer; 2016.
41. Solanki MK, et al. Microbial endophytes: association and application in plant health. In: Microbial Endophytes and Plant Growth. Academic Press; 2022.
42. Solanki MK, Joshi NC, Singh PK, Singh SK, Santoyo G, de Azevedo LCB, Kumar A. From concept to reality: transforming agriculture through innovative rhizosphere engineering. Microbiol Res. 2024;127553.
43. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Curr Sci. 1956;25:259–60.
44. Verma KK, Joshi A, Song XP, et al. Synergistic interactions of nanoparticles and PGPR enhancing soil–plant systems. Front Plant Sci. 2024;15:1376214.
45. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter. Soil Sci. 1934;37(1):29–38.
46. Yadav M, et al. Performance of integrated nutrient packages on tomato in arid agro-ecosystems. Agron J. 2024;7(10S):1787.
47. Yeptho V, Kanaujia SP, Singh VB. Economics of integrated nutrient management in tomato under protected cultivation. ProgHortic. (2012) 44:178–83.