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Incorporation of Integrated Nutrient Management on Physio-chemical Characteristics on Tomato (*Solanum lycopersicum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The physical and quality attributes of tomato was significantly altered by the application of integrated nutrient management. There are many micro and macro nutrients deficiency was observed in tomato which substantially reduced the physical and quality attributes of tomato fruits. To overcome these problems the present study was planned to enhance the physical and quality attributes of tomato by the application of integrated nutrients management on tomato. The application of 75% RDF + FYM @ 20 ton/ha + vermi-compost @ 10 ton/ha + VAM + PSB significantly produced the maximum plant height (123.67 cm), leaf length (21.78), number of flowers/ plant (57.98), fruit weight (82.67 g), fruit diameter (18.79 cm), total soluble solids (5.91 %), ascorbic acid (31.33 mg/100 g), lycopene content (3.12 mg/100 g), and minimum days to first fruiting (44.87) followed by 75 % RDF + FYM @ 20 ton/ha + VC @ 10 ton/ha + VAM as compared to rest of the treatments. Therefore, it can be concluded that application of 75% RDF + FYM @ 20 ton/ha + vermi-compost @ 10 ton/ha + VAM + PSB significantly improved the physical and qualitative characteristics of tomato as compared to control.

Keywords: Ascorbic acid; lycopene content; physical attributes; tomato; vermi-compost.

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetables crops belong to the family of Solanaceae. In India, tomato is cultivated an area of 8.43 million ha with the annual production of 20.69 metric tons/ha (FAOSTAT, 2022). In India tomato is mainly grown in the states of Uttar Pradesh, Maharashtra, Haryana, Punjab, and Bihar. High productive ability of tomato puts tremendous pressure on soil for removal of nutrients (Singh et al., 2021). It is a rich source of vitamins, particularly ascorbic acid, lycopene, and β-carotene, and plays a vital role in human nutrition and health (Naika et al., 2005). In India, tomato ranks second in area and production after potato, with productivity being influenced by soil fertility, nutrient management practices, and environmental factors (FAO, 2023). Intensive cultivation and continuous use of chemical fertilizers without adequate organic matter replenishment have resulted in soil health deterioration, reduced nutrient-use efficiency, and environmental concerns (Bhatt et al., 2020).

Integrated nutrient management (INM), which combines organic manures, biofertilizers, and chemical fertilizers, has emerged as an effective approach to maintain soil fertility, enhance crop yield, and improve product quality. The combined use of organic sources such as farmyard manure (FYM) and vermi-compost improves soil physical properties, microbial activity, and nutrient availability (Ramesh et al., 2019). Biofertilizers such as vesicular arbuscular mycorrhiza (VAM), phosphate-solubilizing bacteria (PSB), and Azotobacter play a pivotal role in enhancing nutrient mobilization, stimulating root growth, and promoting sustainable crop production (Etesami et al., 2021). Partial substitution of recommended doses of fertilizers (RDF) with organic inputs not only reduces dependency on chemical fertilizers but also increases nutrient-use efficiency and crop resilience against abiotic stress.

Previous studies have reported that the integration of FYM and vermi-compost with biofertilizers significantly improves yield attributes, biochemical quality parameters such as total soluble solids (TSS), ascorbic acid, and lycopene content, as well as soil organic carbon status in tomato (Verma et al., 2024). Furthermore, mycorrhizal inoculation improves phosphorus uptake, while PSB enhances phosphorus solubilization from insoluble forms, and Azotobacter fixes atmospheric nitrogen, thus contributing to a balanced nutrient supply (Singh et al., 2021).

Given this background, the present investigation was undertaken to study the effect of integrated application of RDF, organic manures, and biofertilizers on growth, yield, and quality attributes of tomato. The ten treatment combinations in this study included varying proportions of chemical fertilizers (75% RDF) supplemented with FYM, vermi-compost, VAM, PSB, and Azotobacter either singly or in combinations, with the objective of identifying the most effective and sustainable nutrient management practice for tomato cultivation under field conditions.

2. MATERIALS AND METHODS

2.1 Location

Kota district is located at 25.18° N to 75.83° E Latitude in South Eastern Rajasthan. It covers an area of 221.36 km^2. Agro-climatically, the district falls in Zone V, known as Humid South Eastern Plain. The average rainfall in the region is 660.6. mm. Maximum temperature range in the summer is 40 to 48°C and minimum 1.0-2.6°C during *winter*. Main *Rainy season* crops of the district are maize, soybean and pulses. While in *winter*, wheat, mustard, coriander and garlic are main crops.

2.2 Experimental Details

A field experiment was conducted at the Instructional Farm (Horticulture), Career Point University, Alaniya, Kota during 2023-2024. The experiment was laid out in Randomized Block Design (RBD) comprising of 10 treatments and 3 replications. Treatments were randomly arranged in each replication, divided into 10 plots. The treatment consisted of ten treatments combination viz., Recommended dose of fertilizer 120:60:60 NPK (T_1), 75 % RDF + FYM @ 20 ton.ha^{-1} (T_2), 75 % RDF + Vermi-compost @ 10 ton.ha^{-1} (T_3), 75 % RDF + VAM @ 5 kg /ha^{-1} (T_4), 75 % RDF + PSB @ 5 kg/ha^{-1} (T_5), 75 % RDF + Azotobacter @ 5 kg/ha^{-1} (T_6), 75 % RDF + FYM @ 20 ton.ha^{-1} + VC @ 10 ton.ha^{-1} (T_7), 75 % RDF + FYM @ 20 ton.ha^{-1} + VC @ 10 ton.ha^{-1} + VAM (T_8), 75 % RDF + FYM @ 20 ton.ha^{-1} + VC @ 10 ton.ha^{-1} + VAM + PSB (T_9) and 75 % RDF + FYM + VC +VAM + PSB + Azotobacter (T_{10}) thereby making 10 treatment combinations and replicated thrice.

2.3 Measurement of the Parameters

2.3.1 Vegetative and physical parameters

The height of five randomly selected plants from each plot was measured in cm with of a 100cm meter scale from ground level to tip of the shoot at 90 days after transplanting. The length of the fully expanded third leaf from the apex was measured at 90 days after transplanting (DAT) using a measuring scale. Measurements were taken from the base of the petiole to the tip of the leaf blade. The total number of flowers produced per plant was recorded by counting all the flowers from the randomly selected plants in each plot during the peak flowering stage. Observations were expressed as the average number of flowers per plant (Sharma et al., 2013). Days to first fruiting were recorded as the number of days from the date of transplanting to the date of visible fruit set on 50% of the plants in each plot (Singh et al., 2021). The average fruit weight was calculated by weighing ten randomly selected marketable fruits from each treatment using a digital balance and then computing the mean weight in grams (Alam et al., 2007). Fruit diameter was measured across the equatorial region of ten randomly selected marketable fruits from each treatment using a Vernier caliper, and the mean value was expressed in centimeters.

2.3.2 Biochemical parameters

TSS was measured at 20 °C using a hand refractometer and expressed in °Brix following the method of Ranganna (2010). Ascorbic acid content was determined by the 2,6-dichlorophenol indophenol (DCPIP) dye titration method using 4% oxalic acid as an extracting, and results were expressed as mg/100 g fresh weight (AOAC, 2005). Lycopene was estimated by extracting tomato pulp with an acetone–ethanol–hexane mixture (1:1:1 v/v/v) containing 5% BHT, and absorbance of the hexane layer was recorded at 503 nm using a UV–Vis spectrophotometer, following Fish et al. (2002).

2.4 Data Analysis

The experiment was conducted following a Randomized Block Design, and the data were analyzed using SAS statistical software (version 9.4, SAS Institute Inc., USA). Where interactions were significant, the means were compared through analysis of variance followed by Tukey's HSD test at $p \leq 0.05$.

3. RESULTS AND DISCUSSION

The data presented in Table 1 indicate that plant height of tomato varied significantly among the treatments at 90 days after transplanting (DAT). The tallest plants were obtained in T_9 (123.67 cm), which was statistically comparable to T_8 (119.96 cm) and T_{10} (118.88 cm), followed by T_7 (117.76 cm). The shortest plants were recorded in T_1 (60.87 cm), which was significantly lower than all other treatments. The increase in plant height under combined use of organic and bio-fertilizers with reduced RDF could be attributed to the synergistic effect of enhanced nutrient availability, improved soil structure, and stimulation of beneficial microbial activity in the rhizosphere. Organic manures like FYM and vermi-compost are known to supply macro- and micronutrients in available forms, increase cation exchange capacity, and promote root proliferation, leading to better vegetative growth (Meena et al., 2017). Similarly, bio-fertilizers such as VAM enhance phosphorus solubilization and uptake, while PSB and Azotobacter contribute to phosphate solubilization and biological nitrogen fixation, resulting in higher biomass accumulation (Iftikhar et al., 2023).

Leaf length at 90 days after transplanting (DAT) varied significantly among the different treatments (Table 1). The maximum leaf length was recorded in treatment T_9 (21.78 cm), which was found to be significantly superior over all other treatments. It was followed by T_8 (19.23 cm) and T_7 (18.86 cm), which were statistically at par with each other, whereas the minimum leaf length was recorded in T_1 (13.76 cm). The superiority of integrated nutrient management in promoting leaf length can be attributed to the balanced supply of macro- and micronutrients, enhancement of soil microbial activity, and improvement in soil physical properties. These findings are in line with the reports of Singh et al., (2020), which observed improved vegetative growth in tomato with the combined application of organic manures, bio-fertilizers, and reduced chemical fertilizers.

The data highlighted in Table 1 showed a significant variation in the number of flowers per plant was observed among the treatments. The maximum number (57.98) of flowers per plant was recorded in T_9 which was comparable to T_8 and T_{10}. On the other hands, the minimum flower count was recorded in T_1 (30.43), which remained statistically similar to T_2 (33.67) and T_3 (36.57). The increase in the number of flowers in these treatments may be attributed to the combined effect of balanced nutrient supply through inorganic fertilizers and sustained release of macro- and micronutrients from organic manures and bio-fertilizers. Such combinations improve soil physical, chemical, and biological properties, leading to enhanced root growth, nutrient uptake, and photosynthetic efficiency, which ultimately promotes floral initiation and development. These findings are in line with the reports of Singh et al. (2018), who observed that the integration of FYM, vermi-compost, and bio-fertilizers significantly increased the reproductive parameters in tomato due to improved nutrient synchronization with crop demand.

A significant variation was observed among the treatments for days to first fruiting (Table 1). The maximum number of days to first fruiting was recorded in T_1 (57.98 days), which was statistically superior to all other treatments. The earliest fruiting was observed in T_9 (44.87 days) and T_8 (45.12 days), which were statistically at par and significantly earlier than other treatments. T_7 (47.54 days) and T_{10} (48.66 days) also exhibited early fruiting compared to most treatments but was statistically distinct from the earliest and latest fruiting groups. The significant advancement in flowering under (T_9) could be due to the synergistic effect of integrating chemical fertilizers with organic manures and bio-fertilizers, which not only improve the soil physical properties and water-holding capacity but also enhance nutrient availability through microbial activity (Babalola, 2010). The role of FYM and vermi-compost in promoting early flowering may be attributed to their ability to supply a steady release of macro- and micronutrients, improve cation exchange capacity, and stimulate root growth (Edwards et al., 2011). Similarly, VAM fungi facilitate better phosphorus uptake and enhance plant growth-promoting hormones, while PSB solubilizes insoluble phosphates, thus improving P availability during the early growth stages (Sharma et al., 2013).

Table 1 reveals that both fruit weight and fruit diameter in tomato varied significantly among the different treatments. The highest fruit weight (82.67 g) was recorded in treatment T9, which was statistically at par with T_8 (80.22 g), whereas plants receiving the recommended dose of fertilizers (T_1) produced the lowest fruit weight (44.76 g). Similarly, fruit diameter exhibited significant variation, with the maximum value (18.79 cm) also obtained in T_9, which was statistically superior to all other treatments. This was followed by T_8 (17.76 cm) and T_{10} (16.54 cm), both of which differed significantly from each other. Intermediate fruit diameters were recorded in T_6 (16.08 cm), T_5 (15.43 cm), and T_7 (15.11 cm), while the smallest diameters were noted in T_1 (12.67 cm) and T_3 (12.77 cm), which were at par with each other. The improvement in fruit parameters under integrated nutrient management (INM) could be attributed to the balanced and synchronized nutrient supply, enhanced microbial activity, and better root proliferation, which collectively facilitate efficient nutrient uptake and translocation of assimilates towards fruit development. Similar findings were reported by Kumar et al. (2022), where the application of 50 % RDF in combination with vermi-compost (2 t ha⁻¹) and bio-fertilizers (Azotobacter and phosphate solubilizing bacteria) significantly enhanced fruit weight, size, and yield attributes of tomato compared to sole chemical fertilizer application.

The data presented in (Fig. 1A) reveal that the total soluble solids (TSS) content of tomato fruits varied significantly among the treatments. The maximum TSS (5.91 %) was recorded in treatment T_9, which was statistically at par with T_8 (5.76 %). This was followed by T_{10} (5.66 %), which also exhibited a significantly higher TSS than most of the other treatments. The minimum TSS (4.82 %) was observed in T_1, which was statistically similar to T_2 (4.88 %) and T_3 (4.97 %). The increase in TSS under integrated use of organic manures and bio-fertilizers might be attributed to the improved supply of both macro- and micronutrients, enhanced microbial activity in the rhizosphere, and better translocation of photosynthesis towards the fruits, leading to higher sugar accumulation. Verma et al. (2024) evaluated organic inputs (farmyard manure and vermi-compost), combined with reduced chemical fertilizer application in tomato cultivar Pusa Sheetal.

The ascorbic acid content of tomato fruits varied significantly among the different treatments (Fig. 1B). The maximum ascorbic acid content (31.33 mg/100 g) was recorded in treatment T_9, which was statistically at par with T_8 (29.67 mg/100 g). The lowest ascorbic acid content (20.34 mg/100 g) was observed in T_1. The increase in ascorbic acid content in these treatments could be attributed to a balanced supply of macro- and micro-nutrients through the combined application of organic manures and bio-fertilizers, which may have enhanced the synthesis of antioxidants and vitamins in tomato fruits. These findings are in agreement with the results of Singh et al. (2019), who reported that integrated nutrient management practices enhanced ascorbic acid content in tomato by improving nutrient availability, stimulating enzyme activities, and promoting the accumulation of primary metabolites which serve as precursors for vitamin C synthesis.

The lycopene content of tomato fruits was significantly influenced by different integrated nutrient management (INM) treatments (Fig. 1C). The maximum lycopene content (3.12 mg/100 g) was recorded in treatment T_9, which was statistically at par with T_8 (3.02 mg/100 g), whereas the minimum (2.67 mg/100 g) was observed under T_1 (RDF alone). The variation in lycopene content among treatments may be attributed to the combined effect of organic manures and bio-fertilizers in enhancing carotenoid synthesis through improved nutrient availability and better physiological activity in plants. These findings are in conformity with the results of Singh et al. (2019), who reported higher lycopene content in tomatoes under integrated use of FYM, vermi-compost, and bio-fertilizers compared to sole chemical fertilization. Similar results were also reported by (Quddus et al., 2025), indicating that the synergistic effect of organic and inorganic nutrient sources improves fruit quality traits, including lycopene accumulation.

Table 1. Modulation of physical attributes of tomato plants by incorporation of integrated nutrient management

Treatments	Plant height (cm) 90 DAT	Leaf length (cm) 90DAT	Number of flowers/plant	Days to first fruiting	Fruit weight (g)	Fruit diameter (cm)
T1	60.87^{f}	13.76^{f}	30.43^{g}	57.98^{a}	44.76^{h}	12.77^{h}
T2	88.76^{e}	13.98^{f}	33.67^{f}	54.23^{b}	48.98^{g}	13.56^{g}
T3	98.65^{d}	14.87^{f}	36.57^{f}	53.67^{b}	53.22^{f}	12.67^{h}
T4	112.76^{bc}	16.76^{e}	39.76^{e}	52.87^{b}	65.45^{e}	14.32^{f}
T5	114.90^{bc}	17.66^{de}	43.65^{d}	51.45^{bc}	77.88^{bc}	15.43^{de}
T6	112.54^{c}	18.18^{bcd}	48.77^{c}	52.33^{b}	73.21^{d}	16.08^{cd}
T7	117.76^{abc}	18.86^{bc}	53.45^{b}	47.54^{de}	75.67^{cd}	15.11^{e}
T8	119.96^{ab}	19.23^{b}	55.87^{ab}	45.12^{e}	80.22^{ab}	17.76^{b}
T9	123.67^{a}	21.78^{a}	57.98^{a}	44.87^{e}	82.67^{a}	18.79^{a}
T10	118.88^{abc}	17.76^{cde}	54.23^{b}	48.66^{cd}	76.67^{c}	16.54^{c}
CD at 0.05%	7.36	1.12	3.06	2.91	3.29	0.73
S. Em. (±)	1.45	0.22	0.60	0.57	0.64	0.14

**Means with same alphabets do not vary significantly (0.05)*

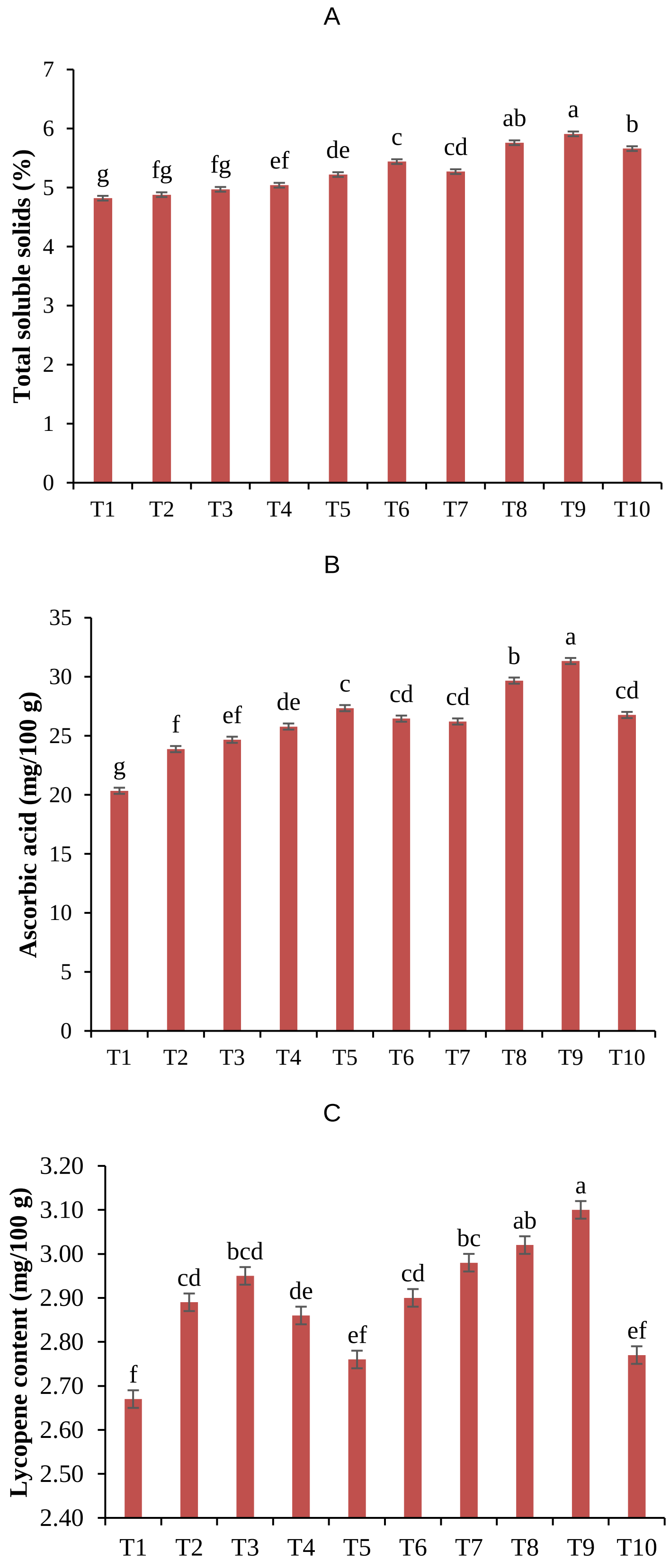

Fig. 1. Influence of INM on bio-chemical properties of tomato (A) Total soluble solids (%); (B) Ascorbic acid (mg/100 g); (C) and Lycopene content (mg/100 g)

4. CONCLUSION

Integrated nutrient management (INM) significantly enhanced growth, yield, and quality parameters of tomato compared to the sole application of chemical fertilizers. The combination of reduced RDF with organic manures (FYM/vermi-compost) and bio-fertilizers (VAM, PSB, Azotobacter) improved plant height, leaf length, flowering, fruit weight, diameter, TSS, ascorbic acid, and lycopene content. Among the treatments, T_9 consistently performed best, followed by T_8 and T_{10}, indicating the synergistic benefits of nutrient integration on crop performance and fruit quality. Conduct long-term trials to assess soil health and profitability, test INM across cultivars and regions, integrate precision nutrient tools, and evaluate post-harvest quality of INM-grown tomatoes.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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