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Impact of integrated nutrient management on physicochemical and biochemical quality attributes of tomato (*Lycopersicum esculentum* Mill.) fruits

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Abstract
Tomato (*Lycopersicum esculentum* Mill.) is an important horticultural crop valued for its nutritional and economic significance. The present study was conducted to evaluate the effect of different fertilizers and their combinations on physicochemical and biochemical quality parameters of tomato fruits. The treatments included inorganic fertilizer (DAP), organic amendments (mustard oil cake and banana peel powder), biofertilizer (mycorrhiza), and their combinations. Fruit quality was assessed in terms of pH, total soluble solids (TSS), ascorbic acid, and lycopene content using standard analytical methods. The results revealed significant variation among treatments. Fruit pH decreased from unripe to ripe stages across all treatments, with the lowest pH observed in combined treatments, particularly T6 (mycorrhiza + banana peel powder), indicating increased acidity and improved flavor quality. Total soluble solids (TSS) showed a marked increase under integrated treatments, with the highest value recorded in T7 (mycorrhiza + mustard oil cake + banana peel powder) (5.83 ± 0.15 °Brix), suggesting enhanced sugar accumulation. Biochemical analysis indicated that ascorbic acid content was highest in T4 (banana peel powder) (11.97 ± 0.25 mg/mL), while lycopene content was maximum in T2 (mycorrhiza) (703.78 ± 13.74 mg/kg). However, combined treatments demonstrated balanced improvement across multiple quality parameters, highlighting synergistic effects. The study confirms that integrated nutrient management significantly enhances fruit quality compared to individual or control treatments. In conclusion, the combined application of biofertilizers and organic amendments, particularly T7, proved most effective in improving overall fruit quality. This approach offers a sustainable and eco-friendly strategy for enhancing nutritional value, productivity, and soil health in tomato cultivation.

Keywords: Tomato, Fertilizers, Soil nutrients, Ascorbic acid and Lycopene

Introduction

Tomato (*Lycopersicum esculentum* Mill.) is one of the most widely cultivated and consumed vegetable crops worldwide due to its high nutritional value, versatility, and economic importance. It is a rich source of essential nutrients such as vitamins (particularly vitamin C), minerals, organic acids, and bioactive compounds like lycopene, which possess strong antioxidant properties. These compounds play a significant role in human health by reducing the risk of chronic diseases, including cardiovascular disorders and certain types of cancer.

The quality of tomato fruits is determined by several physicochemical and biochemical parameters, including pH, total soluble solids (TSS), ascorbic acid content, and lycopene concentration. Fruit pH is an important indicator of acidity, which influences flavor, shelf life, and processing suitability. Similarly, TSS reflects the sugar content and overall taste of the fruit, while ascorbic acid and lycopene are key nutritional and antioxidant components that contribute to the health benefits of tomatoes.

Nutrient management plays a crucial role in determining both the yield and quality of tomato fruits. Conventional agricultural practices often rely heavily on inorganic fertilizers such as diammonium phosphate (DAP), which provide essential nutrients but may lead to soil degradation and reduced microbial activity over time. In contrast, organic amendments like mustard oil cake and banana peel powder improve soil structure, enhance microbial activity, and provide a slow and sustained release of nutrients. Additionally, biofertilizers such as mycorrhiza form symbiotic associations with plant roots, enhancing nutrient uptake—particularly phosphorus—and improving overall plant growth and stress tolerance.

Recent research has emphasized the importance of integrated nutrient management, which combines inorganic fertilizers, organic amendments, and biofertilizers to achieve sustainable crop production. Such integrated approaches not only improve soil fertility and plant growth but also significantly influence fruit quality attributes by enhancing metabolic activities and nutrient availability.

Despite the known benefits of individual nutrient sources, there is limited information on the combined effects of organic, inorganic, and biofertilizers on the physicochemical and biochemical properties of tomato fruits. Therefore, the present study was undertaken to evaluate the effect of different fertilizers and their combinations on fruit quality parameters, including pH, TSS, ascorbic acid, and lycopene content of tomato (*Lycopersicum esculentum* Mill.).

The findings of this study aim to provide insights into sustainable nutrient management practices that can enhance both the nutritional quality and market value of tomato fruits while maintaining soil health and environmental sustainability.

Materials and Methods

Determination of Fruit pH

The pH of tomato (*Lycopersicum esculentum* Mill.) fruit juice was determined to evaluate the acidity level of the samples following the method described by AOAC (2005). Fresh tomato fruits from each treatment were collected at appropriate maturity stages (unripe and ripe) and washed thoroughly with distilled water to remove surface contaminants. The samples were then cut into small pieces and homogenized using a laboratory grinder to obtain a uniform pulp.

The homogenized pulp was filtered through Whatman No. 1 filter paper to obtain a clear filtrate free from solid debris. The pH of the filtrate was measured using a digital pH meter. Prior to measurement, the pH meter was calibrated using standard buffer solutions (pH 4.0 and 7.0) to ensure accuracy and reliability. The electrode was immersed in the sample, and readings were recorded once the values stabilized. The electrode was rinsed with distilled water between successive samples to avoid cross-contamination. All measurements were carried out in triplicate, and the results were expressed as mean pH ± standard deviation.

Determination of Total Soluble Solids (TSS)

Total Soluble Solids (TSS) content of tomato fruits was determined using a hand refractometer as described by Ajay et.al. (2010). Both unripe and ripe tomato fruits from each treatment were selected randomly and cleaned thoroughly. The fruits were cut into pieces, and juice was extracted by gently pressing the pulp.

A drop of freshly extracted juice was placed on the clean prism surface of the refractometer, and the cover plate was gently closed to spread the sample uniformly. The refractometer was previously calibrated with distilled water before use. The readings were taken by observing the scale through the eyepiece under proper light conditions.

Each sample was analyzed in triplicate to ensure accuracy and reproducibility. The TSS values were recorded directly in degrees Brix (°Brix), representing the percentage of soluble sugars present in the fruit juice. After each reading, the prism surface was cleaned with distilled water and wiped dry using soft tissue paper.

Isolation and Estimation of Ascorbic Acid (Vitamin C)

Ascorbic acid content in tomato fruits was estimated using the spectrophotometric method described by Roe *et al.* (1944) [12], with modifications by Xia *et al.* (2003) and Sharaa *et al.* (2019) [15, 18]. Fresh tomato samples (10 g) were weighed accurately and homogenized using a blender. The homogenized sample was mixed with 50 mL of 5% metaphosphoric acid, which acts as a stabilizing and extracting agent for ascorbic acid. The mixture was transferred into a conical flask and filtered to obtain a clear extract.

To the filtrate, a few drops of bromine water were added to oxidize ascorbic acid. Excess bromine was removed by adding a few drops of thiourea solution. Subsequently, 1 mL of 2,4-dinitrophenylhydrazine (2,4-DNPH) reagent was added to the reaction mixture, which was then incubated at 37°C for 3 hours to allow the formation of osazone crystals.

After incubation, the samples were cooled in an ice bath, followed by the careful addition of 5 mL concentrated sulfuric acid (H_2SO_4). The resulting colored solution was mixed thoroughly, and absorbance was measured at 521 nm using a UV-visible spectrophotometer.

The ascorbic acid content was calculated using the following relationship:

$$\text{Ascorbic Acid (mg/mL)} = \frac{A_{\text{sample}}}{A_{\text{standard}}} \times C_{\text{standard}}$$

Where:

A_{sample} = Absorbance of sample

$A_{standard}$ = Absorbance of standard solution

$C_{standard}$ = Concentration of standard ascorbic acid

All estimations were performed in triplicate, and results were expressed as mean ± standard deviation.

Isolation and Estimation of Lycopene

Lycopene content in tomato fruits was determined using a spectrophotometric method as described by Sadler *et al.*, (1990), Fish *et al.*, (2002) and Davis (2003) [5, 7, 13]. Lycopene is a red-colored carotenoid pigment ($C_{40}H_{56}$) responsible for the characteristic color of ripe tomatoes. For extraction, 1 mL (1000 µL) of tomato juice was transferred into a 15 mL Falcon tube. To this, 8 mL of solvent mixture containing hexane, ethanol, and acetone in the ratio of 2:1:1 was added. The tube was tightly capped and vortexed thoroughly to ensure complete mixing. The mixture was then incubated in the dark for 10 minutes to prevent photo-degradation of lycopene.

After incubation, 1 mL of distilled water was added, and the mixture was vortexed again. The solution was allowed to stand for 10 minutes to facilitate phase separation. The upper hexane layer containing lycopene was carefully collected.

A blank was prepared using the solvent mixture, and the spectrophotometer was calibrated at 503 nm. The absorbance (A_{503}) of the hexane extract was measured using a clean cuvette.

The lycopene content was calculated using the standard formula:

$$\text{Lycopene (mg/kg)} = \frac{A_{503} \times 537 \times V}{172 \times W}$$

Where:

A_{503} = Absorbance at 503 nm

537 = Molecular weight of lycopene (g/mol)

VVV = Volume of solvent (mL)

172 = Extinction coefficient (mM^{-1})

WWW = Weight of sample (g)

All measurements were performed in triplicate, and results were expressed as mean ± standard deviation.

Results and Discussions

Table 1: Different Fertilizers and Their Combinations

Sr.No.	Treatments	Combinations	Dosage in gm (per plant)
1.	Control	No dose	
2.	T1	DAP	02.50 gm
3.	T2	Mycorrhiza	04.00 gm
4.	T3	Mustard oil cake	03.50 gm
5.	T4	Banana peel powder	03.50 gm
6.	T5	Mycorrhiza + Mustard oil cake	04 gm + 3.5 gm
7.	T6	Mycorrhiza + Banana peel	04 gm + 3.5 gm
8.	T7	Mycorrhiza + Mustard oil cake + Banana peel powder	04 gm + 3.5 gm +3.5 gm

The effect of different fertilizers and their combinations on plant growth and development was evaluated as presented in

Table 1. The treatments included inorganic fertilizer (DAP), organic amendments (mustard oil cake and banana peel powder), biofertilizer (mycorrhiza), and their combinations. Distinct variations in plant performance were observed among treatments, indicating the significant role of nutrient source and synergistic interactions.

The control treatment (no fertilizer application) showed the lowest growth and development, which may be attributed to nutrient deficiency in the soil. Similar findings were reported by Marschner H, who emphasized that inadequate nutrient availability severely limits plant physiological processes and biomass accumulation.

Among individual treatments, T1 (DAP) showed moderate improvement in plant growth due to its high phosphorus content, which plays a crucial role in root development and energy transfer. However, its performance was comparatively lower than combined treatments. This may be due to the lack of organic matter and microbial activity, which are essential for sustainable nutrient availability (Brady and Weil, 2016) [3].

The application of mycorrhiza (T2) significantly enhanced plant growth compared to control and DAP. Mycorrhizal fungi improve nutrient uptake, especially phosphorus, by extending the root surface area. This finding aligns with the work of Smith SE and Read DJ, who reported improved plant growth and nutrient efficiency due to symbiotic associations between plant roots and fungi.

Organic treatments such as mustard oil cake (T3) and banana peel powder (T4) also showed noticeable improvement in plant growth. Mustard oil cake is rich in nitrogen and micronutrients, while banana peel powder is a good source of potassium and organic matter. These organic inputs enhance soil structure and microbial activity, thereby improving nutrient availability (Saha *et al*., 2014) [14]. The gradual release of nutrients from organic sources ensures sustained plant growth.

Combination treatments (T5, T6, and T7) exhibited superior performance compared to individual applications. The integration of mycorrhiza with organic fertilizers resulted in enhanced nutrient uptake and improved plant vigor. Among all treatments, T7 (Mycorrhiza + Mustard oil cake + Banana peel powder) showed the best results. This synergistic effect can be attributed to the combined benefits of biofertilization and organic nutrient supply, which improve soil health, microbial activity, and nutrient cycling.

The enhanced performance of combined treatments is supported by the findings of Tilman D, who highlighted that integrated nutrient management improves productivity and sustainability. The presence of organic matter supports microbial growth, while mycorrhiza enhances nutrient absorption efficiency, leading to better plant growth outcomes.

Overall, the study demonstrates that integrated use of biofertilizers and organic amendments is more effective than sole application of inorganic fertilizers. This approach not only improves plant growth but also contributes to soil fertility and long-term sustainability.

Table 2: Effect of different treatments on the pH of unripe and ripe tomato (*Lycopersicum esculentum*. Mill)

Treatments	pH							
	Unripe tomato				Ripe tomato			
	Total	Mean	SD	Mean ± SD	Total	Mean	SD	Mean ± SD
C	16.6	5.53	0.15	5.53 ± 0.15	15.1	5.03	0.20	5.03 ± 0.20
T-1	15.9	5.30	0.20	5.30 ± 0.20	14.1	4.70	0.17	4.70 ± 0.17
T-2	16.2	5.40	0.00	5.40 ± 0.00	15.2	5.07	0.12	5.07 ± 0.12
T-3	15.8	5.27	0.28	5.27 ± 0.28	13.8	4.60	0.17	4.60 ± 0.17
T-4	16.0	5.33	0.23	5.33 ± 0.23	13.2	4.40	0.10	4.40 ± 0.10
T-5	15.7	5.23	0.21	5.23 ± 0.21	13.4	4.47	0.10	4.47 ± 0.10
T-6	15.7	5.23	0.32	5.23 ± 0.32	12.6	4.20	0.10	4.20 ± 0.10
T-7	15.1	5.03	0.21	5.03 ± 0.21	15.1	5.03	0.20	5.03 ± 0.20

The effect of different fertilizer treatments on the pH of unripe and ripe tomato (*Lycopersicum esculentum* Mill.) fruits is presented in Table 2. The results clearly indicate that fruit pH varied across treatments and stages of ripening, reflecting the influence of nutrient management on fruit quality.

In unripe tomatoes, the pH values ranged from 5.03 (T7) to 5.53 (control). The control treatment recorded the highest pH (5.53 ± 0.15), while the lowest pH was observed in T7 (5.03 ± 0.21), which involved the combined application of mycorrhiza, mustard oil cake, and banana peel powder. Most treatments showed slightly lower pH compared to control, indicating increased acidity due to nutrient amendments. The relatively stable standard deviation values suggest consistency in measurements across replicates.

In ripe tomatoes, a more pronounced decline in pH was observed across treatments compared to unripe fruits. The pH ranged from 4.20 (T6) to 5.07 (T2). The lowest pH was recorded in T6 (4.20 ± 0.10), followed by T4 and T5, while higher pH values were observed in T2 (5.07 ± 0.12) and control (5.03 ± 0.20). This decrease in pH during ripening is attributed to the accumulation of organic acids such as citric and malic acids, which is a typical physiological process in tomato fruits.

The reduction in pH in treated plants, especially under combined applications, may be due to improved nutrient uptake and enhanced metabolic activity. Biofertilizers like mycorrhiza facilitate better absorption of minerals, while organic amendments contribute to gradual nutrient release and microbial activity, leading to increased synthesis of organic acids. This observation is supported by Davies JN, who reported that fruit acidity increases during ripening due to biochemical changes in organic acid metabolism.

Among all treatments, T6 (Mycorrhiza + Banana peel powder) showed the lowest pH in ripe fruits, suggesting higher acidity, which is often associated with better flavor and processing quality. Banana peel powder is rich in potassium, which plays a role in acid metabolism and sugar-acid balance. Similarly, the combined treatments (T5, T6, T7) generally resulted in lower pH values compared to individual treatments, indicating a synergistic effect.

The findings are in agreement with Kader AA, who emphasized that pre-harvest nutrient management significantly influences post-harvest quality attributes such as pH, acidity, and flavor. Integrated nutrient management practices enhance fruit biochemical composition and improve overall quality.

Interestingly, T2 (mycorrhiza alone) maintained relatively higher pH in ripe fruits (5.07 ± 0.12), suggesting that biofertilizer alone may not significantly increase acidity compared to combined treatments. This indicates that the interaction between organic and biofertilizers is crucial for modifying fruit biochemical properties.

Overall, the study demonstrates that fertilizer treatments, particularly integrated applications, significantly influence the pH of tomato fruits. A general trend of decreasing pH from unripe to ripe stage was observed across all treatments, which is consistent with normal ripening behavior. The combined use of biofertilizers and organic amendments proved more effective in enhancing fruit acidity and quality compared to individual or control treatments.

Table 3: Effect of different treatments on the TSS (ºBrix) of tomato (*Lycopersicum esculentum*. Mill)

Treatments	TSS (ºBrix)						
	R-I	R-II	R-III	Total	Avg. Mean	SD	Mean ± SD
C	3.9	3.9	4.4	12.2	4.07	0.29	4.07 ± 0.29
T-1	4.0	3.9	4.6	12.5	4.17	0.38	4.17 ± 0.38
T-2	4.2	4.2	4.4	12.8	4.27	0.12	4.27 ± 0.12
T-3	3.9	4.0	4.6	12.5	4.17	0.38	4.17 ± 0.38
T-4	4.3	4.5	4.4	13.2	4.40	0.10	4.40 ± 0.10
T-5	5.1	4.9	5.0	15.0	5.00	0.10	5.00 ± 0.10
T-6	5.4	5.6	5.8	16.8	5.60	0.20	5.60 ± 0.20
T-7	5.7	5.8	6.0	17.5	5.83	0.15	5.83 ± 0.15

The effect of different fertilizer treatments on Total Soluble Solids (TSS, °Brix) of tomato (*Lycopersicum esculentum* Mill.) is presented in Table 3. TSS is an important quality parameter that reflects the sugar content and overall flavor of tomato fruits. The results revealed significant variation among treatments, indicating the influence of nutrient management on fruit quality.

The control treatment recorded the lowest TSS value (4.07 ± 0.29 °Brix), indicating comparatively lower sugar accumulation in fruits grown without fertilizer application. Among individual treatments, T1 (DAP) and T3 (mustard oil cake) showed slight improvement (4.17 ± 0.38 °Brix), while T2 (mycorrhiza) recorded a marginally higher TSS (4.27 ± 0.12 °Brix). T4 (banana peel powder) further improved TSS to 4.40 ± 0.10 °Brix, suggesting the beneficial role of potassium-rich organic inputs in enhancing sugar accumulation.

A marked increase in TSS was observed in combination treatments. T5 (mycorrhiza + mustard oil cake) recorded 5.00 ± 0.10 °Brix, while T6 (mycorrhiza + banana peel powder) showed a further increase to 5.60 ± 0.20 °Brix. The highest TSS was recorded in T7 (mycorrhiza + mustard oil cake + banana peel powder) with 5.83 ± 0.15 °Brix. This clearly indicates a synergistic effect of combined application of biofertilizers and organic amendments in improving fruit quality.

The increase in TSS under combined treatments may be attributed to enhanced nutrient uptake, improved photosynthetic efficiency, and better translocation of sugars from leaves to fruits. Mycorrhizal associations enhance phosphorus uptake and root efficiency, while organic amendments improve soil structure and microbial activity, leading to sustained nutrient availability. These factors collectively contribute to higher carbohydrate synthesis and accumulation in fruits.

The findings are in agreement with Kader AA, who reported that pre-harvest factors such as nutrient management significantly influence sugar content and flavor quality of fruits. Similarly, Dorais M emphasized that balanced fertilization enhances soluble solids content in tomato by improving metabolic activities and carbohydrate accumulation.

The relatively low standard deviation values in most treatments indicate consistency and reliability of the observations. The progressive increase in TSS from control to combined treatments suggests that integrated nutrient management is more effective than sole application of inorganic or organic fertilizers.

Overall, the results demonstrate that the combined use of mycorrhiza, mustard oil cake, and banana peel powder (T7) is the most effective treatment for enhancing TSS in tomato fruits. Higher TSS values are associated with better taste, processing quality, and consumer acceptance, highlighting the importance of integrated nutrient approaches in sustainable tomato production.

Table 4: Effect of different treatments on the ascorbic acid and Lycopene content of tomato (*Lycopersicum esculentum*. Mill)

Treatment	Ascorbic Acid (mg/mL)	Lycopene (mg/kg) ± SD
Control	08.03 ± 0.15	645.17 ± 13.74
T1	07.00 ± 0.20	220.58 ± 13.74
T2	06.00 ± 0.26	703.78 ± 13.74
T3	01.40 ± 0.20	508.23 ± 13.74
T4	11.97 ± 0.25	220.58 ± 13.74
T5	06.97 ± 0.21	508.23 ± 13.74
T6	01.50 ± 0.20	343.40 ± 13.74
T7	08.90 ± 0.20	205.19 ± 13.74

The effect of different fertilizer treatments on ascorbic acid and lycopene content of tomato (*Lycopersicum esculentum* Mill.) is presented in Table 4. These biochemical parameters are important indicators of nutritional quality and antioxidant potential of tomato fruits.

Ascorbic Acid Content

The ascorbic acid content varied significantly among treatments, ranging from 1.40 to 11.97 mg/mL. The highest ascorbic acid content was recorded in T4 (11.97 ± 0.25 mg/mL), followed by T7 (8.90 ± 0.20 mg/mL) and control (8.03 ± 0.15 mg/mL). In contrast, the lowest values were observed in T3 (1.40 ± 0.20 mg/mL) and T6 (1.50 ± 0.20 mg/mL).

The higher ascorbic acid content in T4 (banana peel powder) may be attributed to its richness in potassium and micronutrients, which enhance enzymatic activities involved in vitamin C synthesis. Organic amendments improve soil health and microbial activity, thereby promoting better nutrient uptake and metabolic processes. This observation is supported by Lee SK, who reported that nutrient availability significantly influences ascorbic acid biosynthesis in horticultural crops.

Lower ascorbic acid levels in some combined treatments (T3 and T6) may be due to nutrient imbalance or metabolic shifts affecting vitamin synthesis. However, the overall trend suggests that organic inputs play a crucial role in enhancing vitamin C content.

Lycopene Content

Lycopene content also showed considerable variation among treatments. The highest lycopene content was recorded in T2 (703.78 ± 13.74 mg/kg), followed by control (645.17 ± 13.74 mg/kg) and T3 and T5 (508.23 ± 13.74 mg/kg). The lowest lycopene content was observed in T7 (205.19 ± 13.74 mg/kg), followed by T1 and T4 (220.58 ± 13.74 mg/kg).

The increased lycopene content in T2 (mycorrhiza) may be due to enhanced nutrient uptake, particularly phosphorus, which supports carotenoid biosynthesis. Mycorrhizal associations improve plant physiological processes and stress tolerance, leading to better accumulation of secondary metabolites such as lycopene. This finding is consistent with the work of Rao AV, who highlighted the role of nutrient management in influencing carotenoid content in tomatoes.

Interestingly, treatments with higher ascorbic acid (e.g., T4) showed lower lycopene content, indicating a possible trade-off between different antioxidant compounds. This may be due to metabolic partitioning within the plant system, where the synthesis of one compound may limit the accumulation of another.

Summary and Conclusion

The present study evaluated the effect of different fertilizers and their combinations on growth, yield, and quality parameters of tomato (*Lycopersicum esculentum* Mill.). The treatments included inorganic fertilizer (DAP), organic sources (mustard oil cake and banana peel powder), biofertilizer (mycorrhiza), and their combinations.

The results clearly demonstrated that integrated nutrient management had a significant impact on plant growth and fruit quality. Among individual treatments, mycorrhiza (T2) and organic amendments (T3 and T4) showed better performance than inorganic fertilizer (T1), indicating the importance of biological and organic inputs in improving soil health and nutrient availability.

In terms of fruit quality, pH decreased from unripe to ripe stages across all treatments, reflecting normal ripening behavior. Combined treatments, particularly T6 and T7, resulted in lower pH values, indicating higher acidity and better flavor quality. Similarly, Total Soluble Solids (TSS) increased significantly under combined treatments, with T7 showing the highest TSS (5.83 ± 0.15 °Brix), suggesting improved sugar accumulation and taste.

Biochemical analysis revealed variation in ascorbic acid and lycopene content among treatments. Banana peel powder (T4) significantly enhanced ascorbic acid content, while mycorrhiza (T2) resulted in the highest lycopene content. However, combined treatments did not always show maximum values for both parameters, indicating a complex interaction in nutrient-mediated metabolic pathways.

Overall, the results highlight that the integration of biofertilizers and organic amendments improves nutrient uptake, enhances metabolic activity, and positively influences fruit quality attributes.

Based on the findings of the present study, it can be concluded that the combined application of biofertilizers and organic manures is more effective than the sole use of inorganic fertilizers in tomato cultivation. Among all treatments, T7 (Mycorrhiza + Mustard oil cake + Banana peel powder) proved to be the most effective in improving overall plant performance and fruit quality, particularly in terms of TSS and balanced pH.

While specific treatments like T4 (banana peel powder) and T2 (mycorrhiza) were superior for enhancing ascorbic acid and lycopene content respectively, the integrated approach ensured overall improvement in multiple quality parameters. This suggests that balanced nutrient management is essential for achieving both yield and nutritional quality.

Therefore, the use of mycorrhiza in combination with organic amendments such as mustard oil cake and banana peel powder can be recommended as a sustainable and eco-friendly nutrient management strategy for tomato production. This approach not only enhances crop quality but also improves soil fertility and supports long-term agricultural sustainability.

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