**Quality Improvement in Tomato through Integrated Application of Nano and Conventional Fertilizers in Mid-Hill Conditions of Himachal Pradesh, India**

**ABSTRACT**

**Background:** The overuse of conventional fertilizers in tomato cultivation has led to reduced nutrient use efficiency and environmental concerns. Integrating nano-fertilizers with conventional sources offers a sustainable approach to enhance fruit quality and nutrient efficiency under field conditions.

**Methodology:** The present study was conducted to evaluate the impact of integrated application of conventional and nano-fertilizers on the quality parameters of tomato (under field conditions in the mid-hill zone of Himachal Pradesh. The experiment was laid out during the summer season of 2023 in a Randomized Block Design (RBD) with 11 treatment combinations involving different levels of recommended dose of fertilizers (RDF) along with foliar-applied nano-NPK at 0.25%, 0.5%, and 1.0% concentrations. The standard RDF was applied through conventional sources, while nano-NPK was applied at 30 and 60 days after transplanting.

**Results:** The results revealed significant improvements in fruit quality attributes under integrated nutrient treatments compared to the absolute control and sole RDF. Among all treatments, T7 (80% RDF + 1.0% nano-NPK) recorded the highest total soluble solids (4.56 °B), reducing sugar (2.69%), total sugar (3.55%), antioxidant activity (41.58%), and total chlorophyll content (1.80 mg g⁻¹). The highest ascorbic acid content (83.50 mg 100⁻¹ g) was observed under T4 (80% RDF + 0.5% nano-NPK), indicating improved physiological and biochemical traits. The absolute control (T11) consistently recorded the lowest values across all parameters.

**Conclusion:** The enhanced performance of integrated treatments may be attributed to improved nutrient use efficiency, greater metabolic activity, and enhanced biosynthesis of primary and secondary metabolites promoted by nano-fertilizer application. The study demonstrates that the conjoint use of nano and conventional fertilizers, particularly at 80% RDF + 1.0% nano-NPK, is an effective and sustainable strategy for improving tomato fruit quality while reducing chemical fertilizer input.

**Keywords:** Tomato, Nano-fertilizer, Conventional fertilizer, Fruit quality

**INTRODUCTION**

Tomato (Solanum lycopersicum L.) is among the most widely cultivated and economically important vegetable crops worldwide, owing to its rich nutritional profile, culinary versatility, and diverse industrial applications (Sattar et al. 2024). It is a rich source of essential vitamins particularly vitamins C and A, minerals, dietary fibers, and powerful antioxidants such as lycopene, all of which contribute to its growing demand in both fresh and processed forms (Marti et al., 2018). Despite its nutritional and economic importance, ensuring high yield and superior quality of tomatoes under sustainable agricultural practices remains a significant challenge, particularly in the context of declining soil fertility, inefficient nutrient use, and the adverse environmental consequences of chemical fertilizer overuse (Pathak et al., 2018; Kumar et al., 2020).

Conventional fertilizers have played a vital role in boosting tomato production by providing essential nutrients in plant-available forms. However, their long-term and excessive use has led to imbalances in soil nutrient composition, reduced nutrient use efficiency (NUE), environmental pollution through leaching and volatilization, and compromised produce quality (Panhwar et al., 2019; Kumar et al., 2019). As a response to these concerns, nanotechnology has emerged as a promising tool for modern agriculture, particularly in the form of nano-fertilizers. Due to their extremely small size, large surface area, and controlled-release behavior, nano-fertilizers enhance nutrient absorption, reduce losses, and positively influence plant growth, yield, and produce quality (Solanki et al., 2015; Babu et al., 2022).

Several studies have demonstrated that the integration of nano-fertilizers with reduced doses of conventional fertilizers can sustain or even enhance crop productivity while improving physiological efficiency and quality attributes of horticultural crops (Adhikari and Ramana, 2019; Nongbet et al., 2022). These improvements include increased ascorbic acid content, higher total soluble solids (TSS), improved sugar profiles, and enhanced antioxidant activity, contributing to better nutritional and sensory quality. However, systematic studies evaluating the synergistic effects of nano and conventional fertilizers on tomato fruit quality remain limited, especially under field conditions.

Therefore, the present study was undertaken to assess the impact of different combinations of conventional and nano-fertilizers on the quality parameters of tomato. The primary objective was to identify an optimized nutrient management strategy that enhances fruit quality measured in terms of total soluble solids (TSS), titratable acidity, sugar content, ascorbic acid concentration, and antioxidant activity, while simultaneously promoting nutrient use efficiency and environmental sustainability.

**MATERIALS AND METHODS**

**Experimental Site and Climate**

The field experiment was conducted during the summer season of April to August 2023 at the Research Farm of the Department of Soil Science and Water Management, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. The site is situated at 30°52′ N latitude, 77°11′ E longitude, with an altitude of 1175 m above mean sea level. The location falls under Zone II (sub-temperate, sub-humid) agro-climatic conditions. During the cropping period, the site experienced moderate temperatures and adequate rainfall, with most precipitation occurring during the onset of the monsoon (June–August).

The soil of the experimental site belongs to the Typic Eutrochrept subgroup (USDA classification) and has a sandy clay loam texture, neutral pH (6.68), and moderate fertility. The initial physico-chemical properties of the soil were assessed prior to transplanting.

**Experimental Design and Treatments**

The experiment was laid out in a Randomized Block Design (RBD) with 11 treatments, each replicated three times. Treatments included different combinations of conventional NPK fertilizers and foliar-applied nano-fertilizers. The treatment details are as follows: T1: 80% RDF + 0.25% Nano NPK, T2 : 60% RDF + 0.25% Nano NPK; T3 : 40% RDF + 0.25% Nano NPK: T4 : 80% RDF + 0.5% Nano NPK:; T5 : 60% RDF + 0.5% Nano NPK: T6 : 40% RDF + 0.5% Nano NPK; T7 : 80% RDF + 1.0% Nano NPK: T8 : 60% RDF + 1.0% Nano NPK; T9 : 40% RDF + 1.0% Nano NPK; T10 : 100% RDF; T11 : Absolute Control (No fertilizers). The recommended dose of fertilizers (RDF) for tomato was 100 kg N, 76 kg P₂O₅, and 54 kg K₂O ha-1 along with 250 q FYM ha-1, as per the Package of Practices of the university. Conventional fertilizers used were urea (46% N), single super phosphate (16% P₂O₅), and muriate of potash (60% K₂O). Nitrogen was applied in three splits: at transplanting, 30 days after transplanting (DAT), and 60 DAT. Nano-fertilizers (Nano Urea, Divanophos, and Nano K Geolife) were applied as foliar sprays at 30 and 60 DAT in the prescribed concentrations.

**Crop Establishment and Management**

The tomato cultivar ‘Solan Lalima’ was used for the study. Nursery sowing was done in the last week of February 2023, and one-month-old healthy seedlings were transplanted on mid-April, 2023 at a spacing of 90 cm × 30 cm, accommodating 20 plants per 2.1 m × 2.1 m plot. The field was thoroughly prepared and levelled before transplanting. Standard agronomic practices including irrigation, weed control, and pest management were uniformly adopted throughout the experimental period.

**Observations Recorded:** Fruit quality was assessed at harvest using the following standard methods:

Total Soluble Solids (TSS, °Brix): Hand refractometer method (Ranganna, 1986)

Ascorbic Acid (mg 100 g-1): AOAC titrimetric method (AOAC, 1980).

Titratable Acidity (g l-1): Titration with 0.1 N NaOH using phenolphthalein indicator (AOAC, 1980)

Total, Reducing, and Non-Reducing Sugars (%): Lane and Eynon method (AOAC, 1980)

Antioxidant Activity (%): DPPH radical scavenging assay (Williams et al., 1995)

Leaf Chlorophyll Content (mg g-1): DMSO extraction method (Barnes et al., 1992)

**Statistical Analysis**

All recorded data were subjected to analysis of variance (ANOVA) at a 5% significance level using OPSTAT and Microsoft Excel. The treatment means were compared using Duncan’s Multiple Range Test (DMRT), as per the methodology outlined by Panse and Sukhatme (2000).

**RESULTS**

**Total Soluble Solids (TSS)**

The data presented in Figure 1 revealed that TSS content in tomato fruits varied significantly across treatments. The highest TSS was recorded in treatment T7 (4.56 °B), which was statistically at par with T4 (4.55 °B) and T8 (4.53 °B), indicating that these treatments effectively enhanced the accumulation of soluble solids. This improvement may be attributed to better nutrient assimilation and enhanced physiological activity. On the other hand, the lowest TSS was observed in T11 (3.46 °B), suggesting limited sugar accumulation due to suboptimal treatment practices.

**Figure 1: Effect of various fertilizer treatments on tomato TSS**

Titratable acidity also showed significant differences among treatments (Figure 2). The highest acidity was observed in T4 (0.49 mg 100-1 g), followed closely by T7 (0.48 mg 100-1 g) and T8 (0.47 mg 100-1 g). These treatments likely promoted enhanced organic acid biosynthesis, contributing to improved flavour and storage potential. In contrast, T11 exhibited the lowest acidity (0.38 mg 100-1 g), reflecting diminished metabolic activity.

**Figure 2. Effect of various fertilizer treatments on titratable acidity**

**Sugar Content**

Figure 3 presents the data on sugar content under various treatments. Significant variations were observed among treatments. The maximum reducing sugar was recorded in T7 (2.69%), followed by T4 (2.66%) and T1 (2.60%), indicating efficient carbohydrate metabolism and translocation. The lowest value was recorded in T11 (2.42%). Similarly, treatment T7 also registered the highest non-reducing sugar content (0.86%), closely followed by T4 and T1 (0.85%). T11 (0.71%) showed the lowest value. The highest total sugar content was again noted in T7 (3.55%), followed by T4 (3.50%) and T1 (3.43%), whereas the lowest was recorded in T11 (3.13%). These findings indicate that treatments T7 and T4 were effective in enhancing the sugar accumulation and fruit quality.

**Figure 3. Effect of different treatments on tomato sugar content**

**Ascorbic Acid**

As shown in Figure 4, different treatments significantly influenced the ascorbic acid content of tomato fruits. The maximum ascorbic acid was recorded in T4 (83.50 mg 100-1 g), followed by T1 (81.25 mg 100-1 g) and T8 (79.42 mg 100-1 g). These results reflect the positive influence of these treatments on the synthesis and retention of this vital antioxidant. The lowest content was found in T11 (64.36 mg 100-1 g).

**Antioxidant Activity**

Total antioxidant activity varied significantly among treatments. The highest antioxidant activity was observed in T7 (41.58%), followed by T4 (41.31%) and T8 (40.69%), indicating enhanced biosynthesis of antioxidant compounds under these treatments. Conversely, T11 exhibited the lowest antioxidant activity (35.86%), highlighting the need for improved nutrient strategies.

**Figure 4. Effect of various fertilizer treatments on antioxidant activity of tomato**

**Chlorophyll Content**

The data presented in Figure 5 revealed that total chlorophyll content was significantly affected by the treatments. The highest total chlorophyll content was observed in T7 (1.80 mg g-1), followed closely by T4 (1.78 mg g-1) and T8 (1.77 mg g-1). These treatments likely enhanced chlorophyll biosynthesis, improving photosynthetic capacity and plant health. The lowest chlorophyll content was recorded in T11 (1.21 mg g-1), reflecting the adverse impact of suboptimal treatment on chlorophyll retention.

**Figure 5. Effect of various fertilizer treatments on chlorophyll content of tomato**

**DISCUSSION**

This study aimed to assess the effects of integrated nano and conventional fertilizer application on tomato quality parameters. The results demonstrated significant improvements in qualitative traits of tomato which are critical for fruit marketability and nutritional value. The application of nano-NPK significantly enhanced the total soluble solids (TSS) content in tomatoes, a key indicator of fruit quality and ripeness. This improvement can be attributed to enhanced carbohydrate metabolism, facilitated by the efficient delivery of nutrients, particularly potassium, which plays a crucial role in photosynthesis and sugar accumulation (Benzon et al., 2015; Borrill et al., 2014). The nano-scale formulation likely improved nutrient uptake and translocation, leading to more effective nutrient utilization in biochemical pathways. As a result, fruits exhibited superior sweetness and flavour, characteristics closely linked with higher market value. Similar findings have been reported by Salman and Razzaq (2022), Merghany et al. (2019), and Keerthana et al. (2024), further validating the positive impact of nano-fertilizer application on fruit quality.

In addition to TSS, the titratable acidity of tomatoes was also positively influenced by nano-NPK application. This may be due to enhanced synthesis of organic acids, likely regulated by potassium-mediated enzymatic activity involved in acid metabolism (Algym and Alasady, 2020). A balanced acid profile not only improves the taste but also prolongs the shelf life of tomatoes, making them more attractive to both consumers and retailers. These results align with the work of Mishra et al. (2020) and Panda et al. (2020), who also observed increased acidity levels following nano-fertilizer application. Nano-NPK treatments also led to a notable increase in total sugar content. The mechanism behind this enhancement involves improved photosynthetic activity due to higher chlorophyll content facilitated by nitrogen, and efficient conversion of photosynthates into sugars through potassium action (Benzon et al., 2015; Elshayb et al., 2021). Since TSS governs sugar concentration in fruit, higher TSS directly translated to sweeter fruits with superior consumer appeal. Similar trends were reported by Alimohammadi et al. (2020) and Helaly et al. (2021).

Ascorbic acid levels in tomato fruits were also significantly elevated in response to nano-NPK application. This improvement can be linked to the enhanced activity of enzymatic pathways responsible for vitamin C biosynthesis, supported by controlled nutrient delivery, especially of nitrogen, phosphorus, and potassium (Kumari et al., 2022; Khanday et al., 2017). Additionally, improved photosynthesis and increased carbohydrate accumulation provided the necessary substrates for ascorbic acid synthesis. These findings are consistent with those of Al-Juthery et al. (2020), Helaly et al. (2021), and Biswas et al. (2023), who observed similar enhancements in ascorbic acid levels following nano-nutrient interventions.

Antioxidant activity, another important functional quality trait, was also significantly boosted under nano-NPK treatments. This can be attributed to increased synthesis of secondary metabolites such as phenols, flavonoids, and carotenoids, which are critical in enhancing the plant’s defense system and nutritional value (Abdelkader et al., 2024; Benzon et al., 2015; Elemike et al., 2019). Similar improvements in antioxidant potential have been reported by Rahman et al. (2021a) and Abdel-Hakim et al. (2023), confirming the efficacy of nano-fertilizers in improving the functional quality of horticultural crops.

Moreover, nano-NPK application significantly improved total chlorophyll content in tomato plants. This is primarily due to the steady and efficient supply of nitrogen, a key element in chlorophyll biosynthesis (Ahmed et al., 2019; Dhoke et al., 2013). Elevated chlorophyll levels enhance photosynthetic efficiency, promote vegetative growth, and ultimately contribute to better fruit yield and quality. These findings are in agreement with those of Ekinci et al. (2014), Ha et al. (2019), Al-Juthery (2018), Abdel-Hakim et al. (2023), and Mustafa et al. (2023), who also reported improved chlorophyll content and plant vigour following nano-nutrient application.

Overall, the integration of nano-NPK with conventional fertilizers not only enhanced nutrient use efficiency but also significantly improved key quality attributes of tomato fruits. These results support the growing body of literature advocating nano-fertilizer use as a sustainable and effective strategy in modern horticultural production systems.

**Conclusion**

The results of the present study clearly demonstrate that the integrated application of nano-fertilizers with reduced doses of conventional fertilizers significantly improves the quality attributes of tomato fruits. Among the various treatment combinations, the application of 80% RDF supplemented with 1.0% foliar-applied nano-NPK (T7) emerged as the most effective strategy, leading to significant enhancement in total soluble solids, sugar content, antioxidant activity, and chlorophyll levels. Additionally, the highest ascorbic acid content was observed in the treatment receiving 80% RDF + 0.5% nano-NPK (T4), further highlighting the role of nano-fertilizers in improving fruit nutritional quality. These improvements can be attributed to enhanced nutrient use efficiency, better physiological and metabolic functions, and improved assimilation and translocation of photoassimilates resulting from nano-scale nutrient delivery. Importantly, this approach also allows for a reduction in chemical fertilizer use without compromising crop quality, thereby supporting the goals of sustainable and resource-efficient agriculture. Therefore, the integration of nano-fertilizers with reduced levels of conventional fertilizers holds significant promise for enhancing the nutritional and functional quality of tomatoes while minimizing environmental impact. This nutrient management strategy can serve as an effective tool in developing climate-smart, eco-friendly, and economically viable vegetable production systems.

**Disclaimer (Artificial intelligence)**

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