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Nano calcium preharvest spray efficacy in improving tomato (*Solanum lycopersicum* L.) yield, physicochemical qualities and shelf-life

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Abstract
This investigation evaluated the impact of preharvest nano calcium (nano Ca) sprays on tomato yield, physicochemical attributes and shelf-life performance under field conditions at the College of Horticulture, Anantharajupeta, Annamaya district. A total of twelve treatments comprising nano Ca, including varying concentrations ranging from nano Ca 50 to 500 ppm, were sprayed at 30 and 45 days after transplanting. The application of results indicated that nano Ca at 350 ppm significantly increased the total number of fruits (45.90) and yield (1.83 kg) per plant, while 500 ppm notably improved fruit firmness (4.28 kg cm^{-2}) and extended shelf life (14.33 days). Nano Ca treatments also modulated biochemical parameters, with higher concentrations resulting in elevated titratable acidity and diminished lycopene content, attributed to reduced activity at higher concentrations due to suppressed ethylene biosynthesis and enzymatic activity. In conclusion, optimized nano-calcium application significantly enhanced yield and postharvest quality, offering a promising strategy to reduce spoilage and enhance the shelf life of tomato.

Keywords: Tomato, Nano calcium, preharvest spray, yield, shelf life, physicochemical attributes

1. Introduction

Horticulture plays a pivotal role in meeting global nutritional demands by fostering the cultivation of high-quality, nutrient-rich crops, enhancing their storability and dietary value (Ghaly and Alkoaik, 2010) [6]. These nutritional and economic benefits of horticultural produce are often undermined by substantial postharvest losses, which can exceed 30% in developing regions due to inadequate handling and preservation strategies (Bisht and Singh, 2024) [4]. These losses pose a significant global challenge, particularly for fruits and vegetables, owing to their fragile and highly perishable nature (Wakene and Sharew, 2024) [18]. Minimizing these postharvest losses and promoting sustainable practices contributes to food security and agricultural resilience. These losses are especially severe in tomatoes, which are climacteric with high water content, making them highly prone to physical damage and rapid spoilage after harvest (Mohan *et al*., 2023) [9].

Tomato (*Solanum lycopersicum* L.), a widely cultivated Solanaceae crop, thrives in tropical and subtropical climates with optimal growth between 15°C and 30°C and moderate rainfall of around 1000 mm Motamedzadegan and Tabarestani (2018) [21]. Renowned for its nutritional richness and versatility, the tomato is considered an essential protective food. However, as a climacteric and highly perishable fruit, it experiences substantial global postharvest losses ranging from 25% to 42%, leading to reduced nutritional quality and market value (Arah *et al*., 2015) [2]. Postharvest deterioration poses a major challenge in horticultural crops due to its impact on nutritional quality and marketability. To mitigate this, different strategies are present that enhance crop resilience and prolong shelf life. Among them, calcium plays a vital role (Abdelkader *et al*., 2022) [1].

Calcium (Ca) is an essential macronutrient that contributes to structural integrity in plants through its divalent cation form (Ca^{2+}), which binds with pectin in the middle lamella to form calcium pectate (Wdowiak *et al*., 2024) [22], thereby reinforcing cell-to-cell adhesion and mechanical stability. It also suppresses cell wall-degrading enzymes such as pectinases and cellulases to help in the preservation of fruit firmness and to extend the shelf life (Thor, 2019) [26].

Nanotechnology offers a promising approach to sustainability, particularly in developing countries, by addressing key challenges in horticultural crop production, protection and postharvest storage (Satheeshkumar *et al*., 2025) [27]. Nanoparticles improve nutrient uptake and utilization in plants through advanced formulations and delivery systems, while their large surface area minimizes softening and chemical degradation, promoting sustainability and enhancing the shelf life (Yang *et al*., 2025) [25].

Nano calcium (1 to 100 nm) offers superior benefits due to its large surface area to volume ratio and high activation potential (Ling and Ling, 2007) [8]. The small size of nano Ca enhances its penetration into the cell wall and membrane, improving absorption and translocation in plants compared to conventional calcium (Elemike *et al*., 2019) [5]. It enhances cell wall strength, reducing softening and bruising during transport and storage. This prolongs shelf life by minimizing weight loss, delaying ripening and preventing rot in vegetables (Zakaria *et al*., 2018) [20].

Existing research on preharvest nano calcium sprays remains limited, with their full effects on fruit yield, biochemical properties and postharvest storage not yet fully understood. This study aims to evaluate the impact of preharvest nano calcium sprays on tomato yield, biochemical parameters, and shelf life of tomato.

2. Materials and Methods

The impact of preharvest nano Ca sprays on yield, biochemical and shelf-life parameters was evaluated at the College of Horticulture, Anantharajupeta, Annamayya district, Andhra Pradesh, during the 2024-2025 *Rabi* season. The experiment employed a Randomized Block Design (RBD) with twelve treatments and three replications with the spacing of 60 cm x 60 cm.

Treatment	Treatment details
T_1	Control
T_2	Preharvest spray with $CaNO_3$ 2g L^{-1}
T_3	Preharvest spray with Nano Ca 50 ppm
T_4	Preharvest spray with Nano Ca 100 ppm
T_5	Preharvest spray with Nano Ca 150 ppm
T_6	Preharvest spray with Nano Ca 200 ppm
T_7	Preharvest spray with Nano Ca 250 ppm
T_8	Preharvest spray with Nano Ca 300 ppm
T_9	Preharvest spray with Nano Ca 350 ppm
T_{10}	Preharvest spray with Nano Ca 400 ppm
T_{11}	Preharvest spray with Nano Ca 450 ppm
T_{12}	Preharvest spray with Nano Ca 500 ppm

In this experiment, treatments were imposed with different concentrations of nano Ca in two preharvest sprays after 30 and 45 days after transplanting, along with the recommended dose of fertilizers, *viz.*, nitrogen in two equal splits, whereas phosphorus and potassium were applied as a single dose of application.

Yield parameters were assessed by counting the total number of fruits at picking, and yield per plant (kg) was determined by weighing the total number of fruits.

Physicochemical attributes such as total soluble solids (TSS) of the fruits were determined with the help of an Erma hand refractometer and expressed as °Brix. Total sugars were estimated by the method explained by Ranganna (1986). Estimation of titrable acidity was carried out by using the method given by Ranganna (1986). Lycopene content was measured in milligrams and it was measured by using the formula given by R. P. Srivastava and Kumar (2002).

O. D. of 1.0 = 3.1206 µg of lycopene/ml

Lycopene (mg/100g) =

$$\frac{3.1206 \times OD\ of\ sample \times vol.of\ made\ up \times Dilution}{Weight\ of\ sample \times 1000} \times 100$$

Fruit firmness was measured by using a penetrometer, and direct readings were obtained in terms of kg cm $^{-2}$. The days to 50% spoilage of the fruits were determined by recording the number of days at which half of the stored fruits became unfit for consumption remaining fruits remained in good condition.

3. Results and Discussion

Total number of fruits and yield per plant

Preharvest spray of nano Ca at 350 ppm (T_9) resulted in the maximum number of fruits per plant (45.90) and the highest fruit yield per plant (1.83 kg). This may be due to nano Ca increased phosphorus uptake, which stimulates additional flower clusters and enhances fruit number Dey (2000) [3]. Calcium also regulates hormonal balance, particularly auxin and gibberellin activity, essential for floral retention and fruit development and inhibits flower abscission, thereby improving fruit retention and set (Smit and Combrinke, 2005) [17].

TSS and Total sugars

The higher levels of total sugars (3.2%) and TSS (4.97°Brix) were observed in fruits treated with a preharvest spray of nano Ca at 500 ppm (T_{12}). This significant effect of nano Ca in maintaining low TSS and total sugars in tomatoes may be due to calcium reducing ethylene production, which in turn slows the ripening process and leads to lower TSS accumulation (Ranjbar *et al*., 2018; Rajani *et al*., 2022) [11, 23].

Titrable acidity

Preharvest spray of nano calcium at 500 ppm resulted in elevated titratable acidity (0.68%). This may be attributed to its effect in delaying fruit ripening and reducing respiration. This inhibition of metabolic activity reduced the hydrolysis of organic acids into carbon dioxide and water, thereby preserving acidity levels (Mosa *et al*., 2015) [10]. Elevated acidity levels slow enzymatic degradation, which collectively delay ripening and reduce postharvest decay (Shehata *et al*., 2021) [16]. Calcium treatments enhanced the shelf life of tomato fruits by stabilizing titratable acidity, preserving overall fruit quality (Hao *et al*., 2020) [7].

Lycopene content

Preharvest spray of nano calcium at 500 ppm resulted in lower levels of lycopene content (5.85 mg/100 g). This may be due to lycopene being linked to the ripening process, which is regulated by ethylene. Calcium delays ripening by stabilizing cell membranes and reducing ethylene biosynthesis. This delay can suppress the expression of genes involved in carotenoid biosynthesis, including phytoene synthase and lycopene β-cyclase, leading to reduced lycopene accumulation (Rao & Rao, 2007; Elemike *et al.*, 2019; Rajani *et al.*, 2022) [24, 5, 23].

Fruit firmness and Shelf life

Tomato fruits with a preharvest spray of nano calcium at 500 ppm had shown the highest fruit firmness (4.28 kg cm^{-2}) and long shelf life (14.33). Calcium ions bind with cell wall pectin, forming calcium pectate through salt bridges between Ca^{2+} and the COO^- groups (Agar *et al.*, 1999). Forming calcium pectate complexes that reinforce cell wall rigidity, which enhances fruit firmness and mechanical strength and improves the shelf life of tomato fruits (Ramana Rao *et al.*, 2011; Rajani *et al.*, 2022) [12, 23]. It contributes to membrane integrity by maintaining selective permeability and reducing the loss of phospholipids and proteins (Saure, 2005) [14]. Nano calcium treatments further improve postharvest quality by lowering electrolyte leakage and sustaining higher turgor pressure, which are vital for reducing spoilage, preserving visual and textural attributes, and reducing softening, which improves the firmness and shelf life of fruits during ambient storage conditions (Shan *et al.*, 2023; Sahin *et al.*, 2024) [15, 13].

Table 1: Influence of preharvest sprays of nano calcium on total number of fruits, yield per plant, fruit firmness and shelf life.

Treatments	Total number of fruits	Yield/plant (kg)	Fruit firmness (kg cm^{-2})	Shelf life
T_1	38.20	1.29	3.38	8.33
T_2	40.03	1.42	3.62	10.33
T_3	41.18	1.40	3.77	8.77
T_4	41.87	1.45	3.85	9.00
T_5	42.09	1.54	3.90	9.77
T_6	42.52	1.58	3.96	10.77
T_7	43.63	1.65	4.04	11.33
T_8	44.27	1.70	4.09	12.00
T_9	45.90	1.83	4.15	12.77
T_{10}	44.03	1.73	4.18	13.33
T_{11}	43.13	1.76	4.23	13.77
T_{12}	42.87	1.80	4.28	14.33
Mean	42.48	1.60	3.96	11.16
SEm ±	0.49	0.03	0.05	0.18
CD (5%)	1.44	0.08	0.15	0.54

Table 2: Influence of preharvest sprays of nano calcium on TSS, total sugars, titrable acidity and lycopene content of tomato fruits

Treatments	TSS (ºBrix)	Total sugars (%)	Titrable acidity (%)	Lycopene content (mg/100g)
T_1	4.97	3.20	0.40	6.42
T_2	4.44	2.96	0.61	6.13
T_3	4.75	3.12	0.51	6.37
T_4	4.69	3.08	0.53	6.31
T_5	4.57	3.04	0.55	6.24
T_6	4.49	2.98	0.57	6.17
T_7	4.35	2.95	0.58	6.11
T_8	4.28	2.92	0.60	6.05
T_9	4.19	2.89	0.62	5.99
T_{10}	4.05	2.86	0.64	5.94
T_{11}	3.98	2.82	0.65	5.91
T_{12}	3.85	2.78	0.68	5.85
Mean	4.38	2.97	0.57	6.12
SEm ±	0.07	0.05	0.01	0.07
CD (5%)	0.20	0.16	0.02	0.20

Conclusion

Preharvest spray of nano Ca at 350 ppm improved the total number of fruits and yield per plant, while preharvest spray at 500 ppm enhanced firmness and shelf life by strengthening cell walls and membranes. Higher concentrations of nano Ca reduced lycopene, TSS and sugars due to delayed ripening. Optimizing nano Ca levels is essential to balance structural integrity with nutritional value for sustainable tomato production.

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