



Role of Pre-Harvest Elicitors in Modifying Yield and Quality Parameters of Acid Lime cv. Balaji under Hasta Bahar Conditions

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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

Aims: This study examined the impact of preharvest elicitors, specifically glycine betaine, potassium silicate and salicylic acid, on the enhanced growth of acid lime trees (*Citrus aurantifolia*)

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Swingle) Cv. Balaji, as measured by fruit yield, physical and biochemical parameters and fruit storability.

Study Design: Eleven treatments and three replications were used in the Randomized Block Design (RBD) experiment.

Place and Duration of Study: The study was carried out at a private orchard in the Chengalpattu District of Tamil Nadu, close to the State Horticultural Farm in Aathur during 2024-25.

Methodology: Treatments included T₁ (25 mM) glycine betaine, T₂ (50 mM) and T₃ (75 mM) glycine betaine. T₄ has 0.2 per cent potassium silicate, T₅ contains 0.4 per cent potassium silicate and T₆ contains 0.6 per cent potassium silicate. T₇ - 50 ppm of salicylic acid, T₈ - 100 ppm of salicylic acid and 150 ppm of salicylic acid T₉, Water (T₁₀) and Control (No Spray) (T₁₁). Sprays were scheduled as follows: pre-bloom in early September (one month before flowering), post-peak bloom in early October and final application in early January by using a power sprayer.

Results: According to the findings, trees treated with potassium silicate 0.4 per cent K₂SiO₃ had the highest fruit length (7.23 cm), fruit diameter (4.29 cm), fruit weight (82.35 g), yield per tree (9.73 kg), fruit juice (52.47 per cent), TSS (8.26 ° Brix), ascorbic acid (53.47 (mg 100 g⁻¹), acidity (6.21 per cent), total sugar (1.74 per cent), reducing sugar (0.83 per cent), non-reducing sugar (0.91 per cent), PLW (10.30 per cent) and shelf life (21.74 days).

Conclusion: According to the research's evidence-based recommendations, potassium silicate 0.4 per cent K₂SiO₃ registered application is recommended for acid lime fruit production, fruit storability and fruit physical and biochemical characteristics.

Keywords: Preharvest elicitors; yield; fruit quality; acid lime; Balaji.

1. INTRODUCTION

Citrus fruits are widely grown in tropical and subtropical climates and are of great worldwide significance. Citrus, is the third most popular subtropical fruit crop worldwide. In the citrus family, acid lime (*Citrus aurantifolia Swingle*) is the third most significant fruit crop, behind sweet orange and mandarin (Baruah & Talukdar, 2024). India now produces the most acid lime in the world, with 3.09 lakh hectares producing 37.71 lakh metric tons (Anonymous, 2023-24). More than 10 per cent of the whole land used for citrus production. Every year, acid lime goes through three separate flowering cycles, which correspond to January - February, June - July and September - October. These phenological stages are categorised as Hasta bahar, Mrig bahar and Ambia bahar, respectively. Acid lime is a continuous bloomer distinguished by its distinct cyclic discharge pattern. Its primary flowering time is between February and March; however, it typically has a lean phase from July to August. During the peak season, an oversupply of lime fruits leads to the market glut, resulting in unfavourable prices for producers (Shirsath et al., 2024). However, the decreased blooming and fruit set seen in unmanaged circumstances is a significant limitation during the Hasta bahar season in South India. The main cause of this restriction is the southwest monsoon rains, which have a negative impact on reproductive development and occur before floral initiation (Rai et al., 2018). Different cultural

methods have been used to stress acid lime plants in order to encourage the commencement of flowers, but their effectiveness varies depending on the agroclimatic circumstances. Therefore, as a more focused strategy, the use of treatments and exogenous plant growth regulators has been suggested. It is projected that these treatments will improve acid lime blooming intensity and fruit output by boosting vigor, regulating the timing of reproductive development and inducing bud burst. Thus, the goal of the current study was to preharvest elicitors affected acid lime output and quality after harvest.

2. MATERIALS AND METHODS

In 2024 - 2025, a field experiment was carried out on acid lime trees that were six years old in a farmer's field in Aathur, Chengalpattu district. The location of the experimental site is 12° 40' 54.8' North latitude, 79° 59' 19.7' East longitude and 118 feet above mean sea level (MSL). Eleven treatments and three replications were used in the Randomized Block Design (RBD) experiment. Each treatment consists of fifteen trees. With a 5 x 5 m spacing, the orchard was designed using a square system. Each tree was chosen and given the appropriate amount of fertilizer, manures, watering and plant protection measures. Treatments included T₁ (25 mM) glycine betaine, T₂ (50 mM) and T₃ (75 mM) glycine betaine. T₄ has 0.2 per cent potassium

silicate, T₅ contains 0.4 per cent potassium silicate and T₆ contains 0.6 per cent potassium silicate. T₇ - 50 ppm of salicylic acid, T₈ - 100 ppm of salicylic acid and 150 ppm of salicylic acid T₉, Water (T₁₀) and Control (No Spray) (T₁₁). Sprays were scheduled as follows: pre-bloom in early September (one month before flowering), post-peak bloom in early October, and final application in early January by using a power sprayer. The orchard's basic upkeep involved applying fertilizer in the prescribed dosages and scheduling watering for every seven to ten days.

2.1 Fruit Quality

Sixty fruits from each treatment (three replicates) were randomly picked during harvest (the first week of May) and taken to the lab to ascertain the physical and chemical properties of the fruit.

2.2 Fruit Length (cm)

Five fruits from each treatment were selected at random, and using digital vernier callipers, the average distance between the fruit's stem and floral ends was measured. The result was given in cm.

2.3 Fruit Diameter (cm)

Five fruits were selected at random from each treatment, and using digital vernier callipers, the diameter was measured at the widest centre point where the largest diameter was seen. Centimetres were used to represent the average value.

2.4 Fruit Weight (g)

Following harvest, five individual fruits from each treatment were selected at random. A computerized analytical balance was used to measure the weight, and the average weight was reported in grams.

2.5 Yield Per Tree

A weighing scale was used to record each treatment's fruit production. Kilograms were used to express the yield.

2.6 Fruit Chemical Characteristics

2.6.1 Juice (per cent)

A juice extractor was used to extract the fruit's juice. For each treatment, the weight of the fruit was compared to the percentage of juice content.

2.6.2 Total soluble solids (TSS)

TSS was measured using a hand refractometer using the juice extract. The hinged portion was replaced after a few drops of extracted juice were applied to the prism's surface. After that, the refractometer was held up to the sun, and the eyepiece was rotated at room temperature to record the measurements. (A.O.A.C., 1977).

2.6.3 Titratable acidity (per cent)

The titratable acidity of the juice was determined according to the method given in A.O.A.C. Association of the Official Analytical Chemists (Baur & Ensminger, 1977). For titratable acidity estimation, 5g of crushed fruit sample or segments or 5 ml of syrup was taken and diluted with distilled water and filtered through muslin cloth and the filtrate was made up to 50 ml. To 5 ml of an aliquot taken in a conical flask, a few drops of phenolphthalein indicator were added. The solution was titrated against 0.1 N NaOH until a definite pink colour, which persisted for at least 30 seconds, was obtained and the titre value was recorded.

Total acid (%) =

$$\frac{\text{Titre} \times \text{normality of NaOH} \times \text{Vol. Made up} \times \text{Eq. Wt of acid}}{\text{Wt. of sample} \times \text{Volume taken for titration} \times 1000} \times 100$$

2.6.4 Ascorbic acid content (mg 100⁻⁹)

According to Ranganna's (1991) approach, the ascorbic acid was calculated by titrating 2, 6-dichlorophenol indophenol dye. Eight millilitres of metaphosphoric acid (20 per cent) were added to two grams of fruit sample or segment or two millilitres of syrup, and the mixture was filtered through muslin fabric. After that, 5 ml of metaphosphoric acid and 2 ml of the filtrate were added, and the mixture was titrated against the dye solution.

The amount of ascorbic acid was calculated by using the following formula:

Dye Factor = (Weight of Ascorbic Acid in Standard Solution (mg) / Volume of Dye Used (mL))

$$\text{Ascorbic acid} \left(\frac{\text{mg}}{100\text{g}} \right) = \frac{\text{Ascorbic acid (mg) taken} \times \text{Vol. of dye}}{\text{Dye used for standard} \times \text{Wt. of sample} \times \text{Vol. of sample taken}} \times 100$$

2.7 Total Sugar (Per Cent)

After pipetting 50 ml of the cleared solution into a 250 ml flask, 50 ml of water and 5 g of citric acid were added. To finish the inversion of sucrose, it was gently heated for ten minutes before being chilled. After transferring it to a 250 ml flask, it was titrated with Fehling solution and neutralized with 1N NaOH using phenolphthalein and make-up volume.

$$\text{Total sugar \%} = \frac{\text{Factor} \times \text{Dilution} \times 100}{\text{Titre value} \times \text{Weight of sample}}$$

2.8 Reducing Sugar (Per Cent)

The pipette Fill 250 ml conical flasks (5A and 5B) with 10 ml of the combined Fehling solution. The prepared sample solution was put into the burette. Next, practically the whole volume (15–50 ml) of solution needed to lower the Fehling solution should be run into the flask, leaving 0.5–1.0 ml needed for the subsequent titration. After mixing, the mixture was brought to a boil and simmered for two minutes. Then, without touching the sides, three drops of methylene blue were added. Adding two to three drops of sugar solution at 5- to 10-second intervals allowed the indicator to completely decolourise from blue to brick red of cuprous oxide, completing the titration in one minute. Noted the amount of solution needed.

Note: Since the indicator quickly suffers reverse oxidation when air has free entry into the flask, the end point was established within one drop of sugar and without stopping the boiling for longer than a few seconds.

$$\text{Total sugar \%} = \frac{\text{Factor} \times \text{Dilution} \times 100}{\text{Titre value} \times \text{Weight of sample}}$$

2.9 Non-Reducing Sugar (Per Cent)

The proportion of non-reducing sugar content was determined by computing the difference between the projected total and reducing sugars.

2.10 Shelf Life (Days)

The onset of discolouration, such as darkened skin, off-flavor, fungal assault, and skin shrivelling, determined the fruit's shelf life. The end of shelf life was defined as the point at which over 50 per cent of the fruits in storage were no longer fit for human consumption.

2.11 Physiological Loss in Weight (PLW)

At weekly intervals, an electronic balance was used to weigh ten fruits from each treatment's duplicates. White's (1946) method was used to determine the physiological weight loss, which was then reported as a percentage.

$$\text{Physiological loss in weight (per cent)} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100$$

2.12 Statistical Analysis

The AGRES program was used to do statistical analysis on the data (Panse & Sukhatme 1985). To evaluate how treatments affected the acid lime, a Randomized Block Design was used. After calculating the analysis of variance (ANOVA), standard deviation (SE(d)), and least significant difference (LSD) values, mean comparisons were performed. The crucial difference was set at a five per cent significance level.

3. RESULTS AND DISCUSSION

The use of preharvest elicitors had a substantial impact on the fruit diameter and length in acid lime. Following the imposition of the treatments, the potassium silicate treatment at 0.4 per cent (7.23 cm) and (4.29) showed the largest fruit length and diameter (Table 1). Among the treatments, potassium silicon's effect on the acid lime fruit length was noteworthy. This is because the application of potassium silicate boosted photosynthetic activity, which in turn caused more metabolites to translocate and, therefore, cell division, increasing the fruit's size and length (Mangali Mounika et al., 2021). Lalithya et al. (2013), Thippeshappa et al. (2014), Ibrahim et al. (2014), Valencia orange, Khawaga et al. (2014), Washington navel orange, Mukunda et al. (2014), acid lime, Vijay et al. (2016) and sweet orange all obtained results that are consistent with these findings. Likewise, the maximum fruit weight (82.35 g per fruit) was obtained with a potassium silicate treatment of 0.4 per cent (Table 1). Growth and fruiting activities may benefit from silicon's favorable function in improving plant tolerance to a variety of environmental challenges, such as drought and salt, as well as its capacity to mitigate biotic and abiotic stress (Olivia et al., 2016).

Table 1. Effect of pre-harvest spray of elicitors on fruit physical parameters and yield of acid lime

Treatments	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Yield per tree (kg)
T ₁ - Glycine betaine at 25 mm	5.87	3.42	71.33	6.52
T ₂ - Glycine betaine at 50 mm	6.27	3.73	74.65	7.29
T ₃ - Glycine betaine at 75 mm	6.53	3.78	71.20	6.68
T ₄ - Potassium silicate at 0.2 per cent	6.85	3.85	75.99	7.80
T ₅ - Potassium silicate at 0.4 per cent	7.23	4.29	82.35	9.73
T ₆ - Potassium silicate at 0.6 per cent	6.94	4.02	77.13	8.60
T ₇ - Salicylic acid at 50 ppm	5.53	3.29	70.46	6.15
T ₈ - Salicylic acid 100 ppm	5.17	3.21	69.74	5.77
T ₉ - Salicylic acid 150 ppm	5.41	3.24	69.32	5.59
T ₁₀ – Water	4.81	3.12	68.22	5.14
T ₁₁ - Control (No spray)	4.27	3.04	67.01	4.89
SE(d)	0.18	0.11	2.27	0.51
CD (0.05)	0.36	0.21	4.63	1.03

Table 2. Effect of pre-harvest spray of elicitors on Juice per cent, TSS, Ascorbic acid (mg 100 g⁻¹) and Acidity (%)

Treatments	Juice percent (%)	TSS (°Brix)	Ascorbic acid (mg 100 g ⁻¹)	Titrateable acidity (%)
T ₁ - Glycine betaine at 25 mm	49.45	7.17	48.01	6.74
T ₂ - Glycine betaine at 50 mm	49.72	7.32	48.32	6.70
T ₃ - Glycine betaine at 75 mm	50.07	7.64	49.48	6.53
T ₄ - Potassium silicate at 0.2 per cent	50.23	7.85	51.15	6.47
T ₅ - Potassium silicate at 0.4 per cent	52.47	8.26	53.47	6.21
T ₆ - Potassium silicate at 0.6 per cent	51.94	8.03	52.24	6.38
T ₇ - Salicylic acid at 50 ppm	49.11	6.94	47.52	6.89
T ₈ - Salicylic acid 100 ppm	47.86	6.47	44.15	7.01
T ₉ - Salicylic acid 150 ppm	48.52	6.73	45.43	7.17
T ₁₀ – Water	45.47	6.33	43.97	7.28
T ₁₁ - Control (No spray)	44.81	6.21	43.24	7.33
SE(d)	1.06	0.16	0.99	0.24
CD (0.05)	2.17	0.33	2.02	0.49

The application of silicon through potassium silicate at a rate of 0.4 per cent (10.33 kg per tree) had a substantial impact on fruit output compared to the control. The favorable impact of silicon in the plant, which improves architecture to exhibit more erect leaves that intercept higher solar brightness and increase photosynthetic efficiency, may be the reason for the increase in production. Silicon improved the plant's photosynthetic efficiency, which led to a higher solids accumulation in the leaf tissues. Fruits, which are powerful metabolic drains, can absorb these photoassimilates. It might have contributed to the rise in production (Vijayan et al., 2021). When potassium silicate was sprayed on the leaves, Lalithya et al. (2014) reported the maximum fruit yield of sapota.

According to the fruit juice (per cent) data in Table 2, applying potassium silicate at a rate of 0.4 per cent considerably raised the fruit juice percentage (52.47 per cent) compared to the other treatments. The increase in juice content could be the result of potassium's regulatory role in a number of physiological and biochemical processes in plants, such as protein synthesis, enzyme activation, stomatal function, internal pH stabilization, photosynthesis, turgor-related processes, metabolite transport, and extensibility (Alva et al. 2006). As an osmosis agent, potassium helps stomata open and close, which is a crucial process for water intake and use. The amount of juice increased as a result of increased nutritional water absorption. Citrus juice recovery was enhanced by potassium

treatment (Alva et al., 2006). Findings from Fatma et al. (2017) in Valencia orange, Vijay et al. (2016) in sweet orange, and Shraky et al. (2016) in olinda Valencia orange corroborate the findings.

The application of 0.2 per cent potassium silicate shows that TSS levels in fruits often rise. As they ripen and develop, they contain 0.4 per cent potassium silicate K_2SiO_3 (8.26°B) in Table 2. One helpful indicator of fruit maturity or ripeness stage is the amount of soluble solids in the fruit. High TSS in bananas is caused by the climacteric period, when the accumulated polysaccharide is quickly broken down and mostly transformed into soluble sugars (Seymour et al., 1993). In order to enhance the total soluble solids in fruits, silicon and potassium aid in photosynthesis, increased solute translocation, and greater absorption of synthates from source to sink. The findings of

this study are consistent with those of Bhavya (2010) in Bangalore Blue grapes and Stamatakis et al. (2003) in "Hass" avocado. The highest total soluble solids were found in potassium silicate K_2SiO_3 . Potassium silicate increased the maximum amount of soluble solids in fruits by aiding in the production of additional sugar (Stamatakis et al. 2003). TSS increased as a result of silicon and potassium helping the fruit synthesize more sugars (Bhavya et al. 2010). Potassium's function in the translocation of sugars from leaves to fruits is linked to an increase in the total soluble solids content when potassium is applied (Havlin et al. 2007). Potassium has a significant role in the translocation of photoassimilates, sugars, and other soluble solids, which may be the source of the rise in total soluble solids content (TSS) (Kumar et al. 2015). The findings are consistent with those of Vijay et al. (2016) in sweet orange and Kumar et al. (2015) in guava.

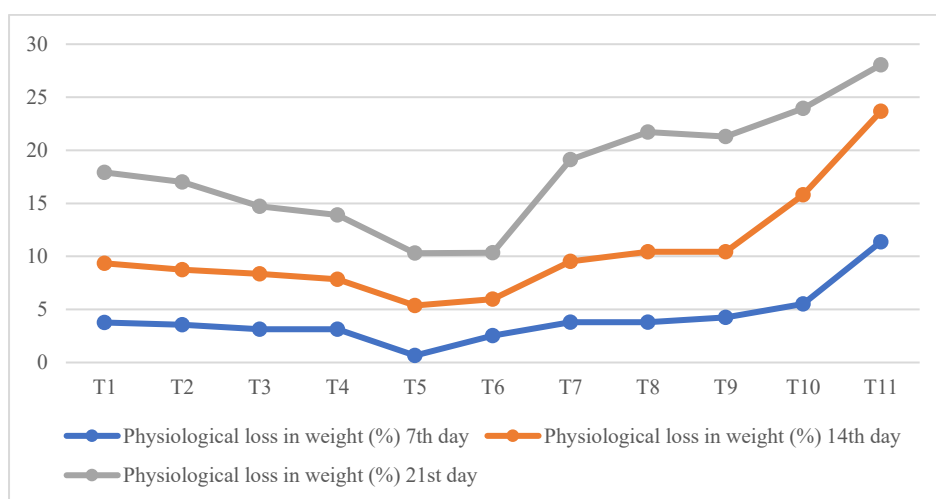


Fig. 1. Effect of pre-harvest spray of elicitors on PLW of acid lime cv. Balaji

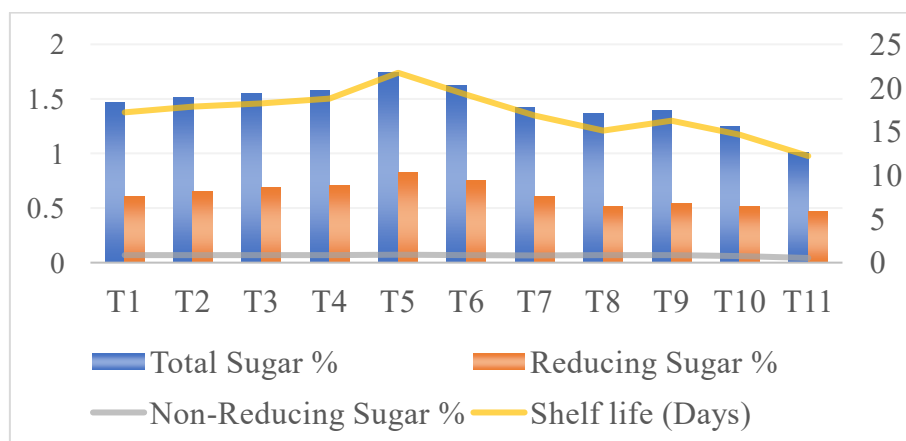


Fig. 2. Effect of pre-harvest spray of elicitors on biochemical parameters and shelf life of acid lime cv. Balaji

The proportion of overall fruit acidity dramatically dropped as potassium silicate levels in the current study increased. The rapid conversion of metabolites into sugar and their derivatives and the rise in total soluble solids, may be the causes of the decrease in acidity with potassium silicate. Potassium helps regulate the fruit juice's pH and acidity by neutralizing organic acids. Higher sugar buildup, improved sugar translocation into fruit tissues, and the conversion of organic acids into sugars all contribute to lower fruit acidity (Beniwal et al 1992). The rapid conversion of acids into sugars and their derivatives, their use in respiration, or both may be the cause of the decline in organic acids (Gupta & Brahmachari 2004). The findings are consistent with those published in Peach and Nectarine by Abidi et al. (2023).

There was significant variation in the vitamin C concentration across treatments. The vitamin C content was increased by the treatments. Lemon showed comparable outcomes (Mditshwa, 2013). Prior research has documented silicon's power to preserve or boost antioxidant capacity, which in turn lowers the risk of abiotic stress (Tsfay et al., 2011). The previously reported findings by El-Gioushy (2016), who found that potassium silicate spray considerably raised all fruiting measurements of Washington navel orange, support our findings.

In the current study, foliar spraying with potassium silicate significantly increased the percentage of total fruit sugars, as well as the reducing and non-reducing sugar content (Fig. 2). Potassium's application raises decreasing sugar and total sugar since it is known to aid in sugar translocation in plants. According to Vijay et al. (2016), sweet oranges with higher sugar content have less acidity; conversely, a higher TSS content in the fruit may be the cause of this decrease. Similar outcomes were noted by Sharad et al. (2014) in guava, Prasad et al. (2015) in peach, and Vikramjeet et al. (2018) in peach.

The foliar application of silicon and potassium to the plant in the proper amounts and at the appropriate times may be the cause of the improved fruit quality. It was discovered that potassium silicate, a combination of silicon and potassium, was a successful treatment for sweet orange quality enhancement. The production of additional sugars in fruit was aided by silicon and potassium, which raised total soluble solids (TSS), which in turn reduced acidity. A key

process of water intake and utilization, potassium aids in the translocation of sugar and also acts as an osmotic agent to open and close stomata; higher nutritional water uptake led to higher juice content (Mangali Mounika et al., 2021). Potassium is known to aid in the translocation of sugar in plants, therefore its application raises total sugar and reducing sugar and according to Chaudhary et al. (2016) in Kinnow Mandarin. Si has a major role in strengthening plant structure and improving tolerance, especially when exposed to abiotic stresses (Wang et al., 2021). Its function involves regulating important physiological and biochemical processes that support crop yield and quality (Costa et al., 2025; Souza Júnior et al., 2022), flowering (Souza Junior et al., 2024; Souza Junior et al., 2023), oxidative damage reduction (Mostofa et al., 2021), and photosynthetic efficiency (Rastogi et al., 2022).

Under all investigated treatments, including the control treatment, the weight loss of acid lime fruits rose dramatically as the storage period increased. However, when compared to the control, the evaluated pre-harvest treatments had a reducing effect on fruit weight loss (%), particularly at high potassium silicate levels. This could be because fruits' stomata are closed, suppressing their transpiration and respiration rates. These findings are consistent with the Anna apple observations made by Tarabih et al. (2014). The primary cause of potassium silicate's low respiration rate was the chemical's anti-senescence properties, which inhibited the production of ethylene (Babak & Majid, 2011). The outcomes of these trials are consistent with the findings of Ramesh and Kumar (2010) regarding banana cv. Ney Poovan, Sateesh and Bangarusamy (2006) with banana cv. Rasthali. In a similar vein, the potassium silicate treatments increased the shelf life of acid lime fruits in the current study by decreasing the amount of rotten fruit (Fig. 2). Hanumanthaiah et al. (2015) discovered that the application of silicon had a positive impact on the fruits' shelf life when kept at room temperature. Bhavya (2010) noted a similar finding in blue grapes from Bengaluru. According to Babak and Majid Rahmei (2011), using silicon extended the vase life of carnations by reducing the generation of ethylene and by forming complexes with organic compounds in the cell wall of epidermal cells, which strengthened the cells' resistance to enzyme degradation. Because potassium silicate may have reduced the physiological weight loss and so extended the shelf life, it also extends the

shelf life of fruits. Gonchikari Lokesh et al. (2020) showed a comparable improvement in shelf life and decrease in physiological loss in fruit weight with silicon treatment.

4. CONCLUSION

Among the various pre-harvest spray treatments, foliar application of potassium silicate at 0.4 per cent concentration resulted in significantly superior performance, registering the highest values for fruit weight, length, diameter and overall yield. This treatment also enhanced key biochemical parameters including total soluble solids (TSS), reducing and non-reducing sugars and ascorbic acid content while effectively extending shelf life under ambient storage conditions, compared to other evaluated treatments.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declares 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.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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