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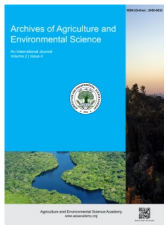

ORIGINAL RESEARCH ARTICLE

Effect of calcium chloride and gibberellic acid as post-harvest treatments on quality and shelf life of tomato (*Solanum lycopersicum* L. Var. Srijana) in Chitwan, Nepal

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ABSTRACT

The research entitled, effect of calcium chloride and gibberellic acid as post-harvest treatments on quality and shelf life of tomato (*Solanum lycopersicum* L.) var. Srijana in Chitwan, Nepal, was conducted to find out the best concentration of calcium chloride ($CaCl_2$) and Gibberellic acid (GA_3) for better quality and shelf life of tomato under ambient room conditions (28±5°C, 64% RH). The experiment was laid out in a completely randomized design, which comprised six treatments: control (water), $CaCl_2$ @2%, $CaCl_2$ @4%, $CaCl_2$ @6%, $CaCl_2$ @8%, GA_3 @1.5% GA_3 @3% each replicated three times. Different postharvest parameters were assessed over a 12-day storage period. Results demonstrated that $CaCl_2$ @4%, $CaCl_2$ @6%, GA_3 @1.5%, and GA_3 @3% were found to be more effective in maintaining the quality and longer shelf life of tomatoes. On the 12th day of storage, the lowest decay loss was observed with $CaCl_2$ @6% (0), GA_3 @3% (0), followed by $CaCl_2$ @4% (6.67%) and GA_3 @1.5% (6.67%). The minimum TSS was observed in $CaCl_2$ @4% (3.33˚Brix). Treatments GA_3 @1.5% (1.12 kg/cm²), GA_3 @3% (1.11 kg/cm²), $CaCl_2$ @4% (1.08 kg/cm²) $CaCl_2$ @6% (0.94 kg/cm²) effectively maintained the firmness of tomatoes fruits. Physiological loss in weight was minimum in $CaCl_2$ @6% (4.50%) which was at par with $CaCl_2$ @4%, GA_3 @1.5%, GA_3 @3%. Thus, it can be concluded that $CaCl_2$ @4%, $CaCl_2$ @6%, GA_3 @1.5%, and GA_3 @3% are effective in maintaining post-harvest quality and prolonging the shelf life of tomato. In addition to this, enhance marketability without reliance on cold storage.

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INTRODUCTION

The tomato (*Solanum lycopersicum*, L., 2n=24), belonging to the family Solanaceae (Ebert, 2020), is grown as an annual plant and is the most widely consumed vegetable in the world after potatoes. From a botanical standpoint, the tomato is classified as a fruit, specifically a berry, due to its development from the ovary of a flower and the presence of seeds. Nonetheless, in culinary and commercial contexts, it is conventionally categorized and utilized as a vegetable. The tomato is regarded as the most extensively cultivated and processed vegetable in the world, with a production of 192 million tons (FAOSTAT, 2023). Tomatoes are grown on about 22,911 hectares in Nepal, yielding 18.45 mt/ha and a total production of 422,703 mt (MOALD, 2020, 2022). Tomatoes are a nutrient-rich food that contains vitamins, minerals, and dietary fibers (Ghimire *et al.*, 2018; Vats *et al.*, 2022). Consumption of about 100 g of tomato can supply the human body with 40% of the recommended daily dosage of vitamin C, which can enhance the immune system, lower blood pressure, and cholesterol (Zeng *et al.*, 2020; Dhami *et al.*, 2023). The fruits can be eaten raw in salads, stews, sandwiches, or salsa, while the processed tomato crops can be consumed in juices, pastes, stews, and drinks. The demand for tomatoes for processing and fresh consumption throughout the year is gradually rising due to factors like urbanization, hotels, tourism, and increased public awareness of nutrition (Al-Dairi *et al.*, 2021). These factors are opening up opportunities for off-season production (KC *et al.*, 2023). Tomatoes are typically cultivated during the spring in Nepal's mid-hill regions, while in the plains, they are grown as winter crops (Pokharel, 2021). Tomatoes are harvested at various maturity stages, including green mature, breaker, turning, light red, and full red. Among these, the light red and full red stages are the most favored by consumers due to their appealing color and taste. However, tomatoes at these stages are highly perishable and tend to spoil quickly after harvest. The quality of fruit and vegetables is mainly affected by postharvest conditions such as transportation and storage conditions (Pathare *et al.*, 2021). Postharvest management practices are advanced and efficient in developed countries, which prevent loss after harvest (KC *et al.*, 2023). Due to improper harvesting causing mechanical injuries, a sizable portion of the veggies is damaged at the farm gate (Devkota *et al.*, 2014); When it reaches retailers, these losses rise to 30%, and when it reaches consumers, it exceeds 50%, often due to a lack of cold chain infrastructure and poor handling throughout the supply chain (Debebe *et al.*, 2023). Detailed studies in the Kathmandu Valley show that 10% of the total loss occurs from harvest to market, 2% during packaging, 4% during transportation, and 2% during storage. This problem is exacerbated by the inherent susceptibility of ripening fruits to physiological injury, shrinkage, and the mature fruits are more prone to physical damage, biochemical activity toward senescence, disease, and insect infestation during storage (Arah *et al.*, 2016). Even though research efforts have been made to increase production, the parallel mission of minimizing postharvest losses is critical for achieving maximum profitability and enhancing food security (Jamir & Khawlhring, 2017).

In Nepal, due to inadequate equipment at the collection center, inadequate technology, improper handling, packaging, lack of basic amenities at the wholesale market, retailers, and lack of trained manpower in post-harvest handling are major problems causing heavy loss in quantity as well as the quality of tomato (Tiwari *et al.*, 2020). In numerous developed nations, chemical agents like gibberellic acid (GA_3), calcium chloride ($CaCl_2$), sodium benzoate, salicylic acid, and benzyl adenine are commonly used to extend the shelf life of tomatoes (Zewdie *et al.*, 2022). However, such preservation techniques have not yet been adopted in Nepal. Concurrently, studies on high-quality production and advancements are increasingly focused on scalable and affordable technologies for developing nations, such as edible coatings to extend shelf life and the adoption of circular bioeconomy principles to utilize waste (El-Ramady *et al.*, 2022). The large amounts of loss begin right from harvesting, and the loss increases significantly during the post-harvest steps (Tiwari *et al.*, 2020). This study addresses the systematic evaluation and efficacy of GA_3 and $CaCl_2$ as chemical preservatives specifically for the Nepalese agricultural context, where tomatoes are typically stored and transported at ambient room temperature. The significance of this work lies in its potential to provide a practical, low-cost, and scalable solution to pressing economic and food security issues. By reducing postharvest losses, the research aims to directly increase farmer incomes, improve market supply, and enhance the availability of nutritious food. Consequently, the ultimate goal is to identify the optimal concentration of chemical preservatives for extending the shelf life and maintaining the quality of tomato under realistic, room temperature storage conditions, thereby offering a viable strategy to mitigate postharvest losses in Nepal.

MATERIALS AND METHODS

The study was conducted at the Horticultural Laboratory of Agriculture and Forestry University, Rampur, Chitwan, Nepal. The experiment utilized a completely randomized design with seven treatments and three replications. Various physical and chemical parameters were analyzed, including pH, physiological loss in weight (PLW), titratable acidity (TA), total soluble solids (TSS), shelf life (decay loss), and firmness.

Experimental details

Fruits of the Srijana variety were selected, which were uniform in size, and they were sorted out to eliminate bruised, damaged, and punctured ones. After removing the dust from the surface of the fruits. The experiment was laid out in a Completely Randomized Design (CRD) with 7 treatments and 3 replications at the Horticulture lab of Agriculture and Forestry University, Rampur, Chitwan, Nepal. Two chemical preservatives of different concentrations used as treatment were calcium chloride ($CaCl_2$) and gibberellic acid (GA_3), obtained from the lab. The seven treatments used are given in Table 1.

Table 1. Treatments used in the experiment.

Symbol	Treatment details
T1	$CaCl_2$@2%
T2	$CaCl_2$@4%
T3	$CaCl_2$@6%
T4	$CaCl_2$@8%
T5	GA_3@1.5%
T6	GA_3@3%
T7	Control (water dipped)

pH: To determine the pH of the fruit juice, a digital pH meter was employed.

Physiological loss in weight percent: To determine the physiological weight loss percentage, the initial weight of the tomato was first recorded. Then, the final weight was recorded on the observation day, i.e., after 2 days of recording the initial weight, and finally, the weight loss percent was calculated according to the following formula, as explained by Devkota *et al.* (2019).

$$\text{Weight Loss Percentage (\%)} = \frac{(\text{Initial Weight} - \text{Final Weight}) \times 100}{\text{Initial Weight}}$$

Titratable acidity: According to Teka (2013), the titration method was used to determine the titratable acidity of fruit juice. The titratable acidity was determined in terms of the percentage of citric acid. Using 2 to 3 drops of phenolphthalein as an indicator, 5 milliliters of tomato juice were titrated against 0.1N NAOH to determine the juice's TA. It was determined by using the following equation:

$$\text{Titratable Acidity (\%)} = \frac{\text{Volume of NaOH used x milliequivalent weight of citric acid x 10}}{\text{Volume of sample in ml}}$$

Shelf life (days): The shelf life of the fruit is defined as the time from the harvest until the onset of decay of the fruit (Devkota *et al.*, 2019). The decay percentage was computed as the number of decayed fruits divided by the total number of fruits and multiplied by 100.

Data analysis

Data were collected at two-day intervals in Microsoft Excel 2016 (Microsoft Corporation, Redmond, Washington, USA). Analysis of variance (ANOVA) for the parameters was performed using R-Studio version 4.1.1(Posit, PBC, Boston, Massachusetts, USA). All analyzed data were subjected to LSD (least significant difference) for comparison of means. A 5% significance level was considered for ANOVA analysis.

RESULTS AND DISCUSSION

pH of tomato juice

The pH values for $CaCl_2$ treatments (2%, 4%, 6%, and 8%) are relatively close to each other, with no significant differences observed (Table 2). The pH values for $CaCl_2$ treatments tend to fluctuate slightly over time, with the 6% concentration showing a notable drop at 6 DAS (4.09) but recovering by 12 DAS (4.41). The GA_3 treatments (1.5% and 3%) show pH values that are also similar to each other, with the 1.5% concentration showing a slightly higher pH (4.28) at 3 DAS compared to the 3% concentration (4.26). However, both treatments maintain relatively stable pH levels throughout the storage period. These fluctuations could indicate a temporary effect of these treatments on the acidity of the tomatoes (Shrestha *et al.*, 2018). The pH values for GA_3 treatments are lower than those of the control group but do not significantly differ from the $CaCl_2$ treatments, indicating that GA_3 also has a stabilizing effect on the pH of tomato during storage (Sharma *et al.*, 2018). The observed decline in pH levels across treatments, excluding the control, may be attributed to the enzymatic breakdown of starch, polysaccharides, and pectin into soluble sugars, which are subsequently utilized in metabolic activities during the storage period (Rathore *et al.*, 2007). This interpretation is further supported by the findings of Devkota *et al.* (2019), who reported a comparable trend, with the control treatment exhibiting the highest pH value at 21 days after treatment (DAT). These results are consistent with and reinforce the outcomes of the present study.

Table 2. Effect of different concentrations of $CaCl_2$ and GA_3 as post-harvest treatment on pH of tomato.

	pH on days after storage			
Treatment	**3 DAS**	**6 DAS**	**9 DAS**	**12 DAS**
$CaCl_2$@2%	4.21^b	4.39	4.48	4.36
$CaCl_2$@4%	4.25^b	4.19	4.27	4.33
$CaCl_2$@6%	4.23^b	4.09	4.32	4.41
$CaCl_2$@8%	4.21^b	4.23	4.35	4.39
GA_3@1.5%	4.28^{ab}	4.28	4.34	4.37
GA_3@3%	4.26^b	4.25	4.39	4.37
Control (water dipped)	4.35^a	4.31	4.45	4.46
LSD (0.05)	0.087	ns	ns	ns
SE_m (±)	0.11	0.03	0.02	0.02
CV (%)	1.20	1.20	2.36	2.41
Grand mean	4.26	4.249	4.37	4.38

Note: CV = Coefficient of Variation, SEm = Standard error of the mean, LSD = Least Significant Difference; ns= non-significant.

Table 3. Effect of $CaCl_2$ and GA_3 as a post-harvest treatment on physiological loss in weight (PLW) of tomato.

	Physiological loss in weight (%)			
Treatment	**3 DAS**	**6 DAS**	**9 DAS**	**12 DAS**
$CaCl_2$@2%	0.49^{b}	0.49^{b}	4.94^{ab}	5.96^{bc}
$CaCl_2$@4%	1.36^{b}	1.36^{b}	4.81^{ab}	5.68^{bc}
$CaCl_2$@6%	0.59^{b}	0.59^{b}	3.22^{b}	4.50^{c}
$CaCl_2$@8%	1.49^{ab}	1.49^{ab}	5.17^{ab}	7.03^{abc}
GA_3@1.5%	1.33^{b}	1.33^{b}	4.72^{ab}	6.25^{bc}
GA_3@3%	0.86^{b}	0.86^{b}	5.41^{ab}	8.08^{ab}
Control (water dipped)	2.57^{a}	2.57^{a}	7.62^{a}	10.01^{a}
LSD (0.05)	1.14	1.14	3.12	3.532
SE_m (±)	0.15	0.15	0.40	0.45
F-probability	**	**	.	**
Grand mean	1.24	1.24	5.1	6.78

Note: CV = Coefficient of Variation, SEm = Standard error of the mean, LSD = Least Significant Difference; ns= non-significant.

Table 4. Effect of $CaCl_2$ and GA_3 as post-harvest treatment on titratable acidity of tomato.

	Titratable acidity (%)			
Treatment	**3 DAS**	**6 DAS**	**9 DAS**	**12 DAS**
$CaCl_2$@2%	1.92	1.41^{a}	1.54	1.28
$CaCl_2$@4%	1.92	1.37^{ab}	1.49	0.75
$CaCl_2$@6%	2.56	1.23^{abc}	1.49	0.93
$CaCl_2$@8%	2.13	1.19^{c}	1.45	1.23
GA_3@1.5%	2.56	1.15^{bc}	1.28	0.73
GA_3@3%	2.64	1.24^{abc}	1.66	1.02
Control (water dipped)	2.04	1.19^{abc}	1.02	0.89
LSD (0.05)	ns	0.26	ns	ns
$SE_{m\,(\pm)}$	0.12	0.03	0.07	0.08
CV (%)	24.94	12.039	21.96	-
Grand mean	2.255	1.24	1.42	0.98

Note: CV = Coefficient of Variation, SEm = Standard error of the mean, LSD = Least Significant Difference; ns= non-significant.

Physiological loss in weight

The result of ANOVA showed statistically significant differences in PLW among the postharvest treatments ($CaCl_2$, GA_3, and control) on the 3rd, 6th, 9th, and 12th day of storage of tomato. As indicated in Table 3, PLW of tomato fruits increased progressively as the storage duration increased. PLW on the 3rd day of storage was the highest (2.57%) in control and the lowest in tomatoes treated with $CaCl_2$@2% (0.49%), $CaCl_2$@6% (0.59%), GA_3@3% (0.86%), and GA_3@1.5% (1.33%). Weight loss on the 12th day of storage was the highest (10.01%) in control and the lowest in tomatoes treated with $CaCl_2$@4% (5.68), $CaCl_2$@6 % (4.50%), and GA_3@3% (8.08%). This indicated the significant role of $CaCl_2$ as an ethylene absorbent. This could be attributed to the membrane functionality and integrity maintenance quality of calcium, which helps to bind polygalactonic acids to each other (Devkota *et al*., 2019). Pila *et al*. (2010) reported that the physiological weight loss percentage was significantly lower for GA_3 and $CaCl_2$ than for the control. This could be due to the anti-senescent effect of GA_3 on fruits and vegetables (Sudha *et al*., 2007). Moreover, the reduction in weight loss by $CaCl_2$ treatment could be due to the role of calcium in the creation of calcium pectate hydrogel, which holds more water and slows the dehydration process (Turmanidze *et al*, 2017).

Effect on the titratable acidity of tomato

The TA values for $CaCl_2$ treatments (2%, 4%, 6%, and 8%) show a general trend of higher acidity levels compared to the control group. The 6% concentration has the highest TA value at 3 DAS (2.56%) and 9 DAS (1.49%), indicating that this concentration is effective in maintaining acidity during storage (Table 4). The GA_3 treatments (1.5% and 3%) also show higher TA values compared to the control, with the 3% concentration achieving a TA value of 2.64% at 3 DAS and 1.02% at 12 DAS. The change in total titrable acids during storage was primarily due to the metabolic activities of living tissues, which cause organic acid depletion (Hossain *et al*., 2020). Devkota *et al*. (2019) observed that fruits treated with $CaCl_2$ and GA_3 had significantly higher TA than the control. The experiment conducted by Arthur *et al*. (2015) reported that TA for $CaCl_2$ @6% treated fruits had a significantly higher value than the control during the storage period. This could be due to the slow degradation of ascorbic acid in treated fruits (Moradinezhad *et al*., 2020).

Table 5. Effect of $CaCl_2$ and GA_3 as post-harvest treatment on total soluble solids (TSS) content of tomato.

	TSS of tomato juice (˚Brix)			
Treatment	**3 DAS**	**6 DAS**	**9 DAS**	**12 DAS**
$CaCl_2$@2%	3.03^{ab}	2.87	3.5	3.27
$CaCl_2$@4%	2.63^{b}	3.00	3.67	3.33
$CaCl_2$@6%	2.67^{b}	4.00	3.67	4.33
$CaCl_2$@8%	2.56^{b}	3.00	3.67	3.57
GA_3@1.5%	2.53^{b}	3.00	3.67	3.70
GA_3@3%	3.47^{ab}	3.33	3.33	3.34
Control (water dipped)	3.80^{a}	3.57	3.16	4.67
LSD (0.05)	0.83	ns	ns	ns
SE_m (±)	0.11	0.10	0.08	0.14
Grand mean	2.96	3.25	3.52	3.74

Note: CV = Coefficient of Variation, SEm = Standard error of the mean, LSD = Least Significant Difference; ns= non-significant

Table 6. Effect of $CaCl_2$ and GA_3 as post-harvest treatment on decay loss of tomato.

	Decay loss (%)	
Treatment	**9 DAS**	**12 DAS**
$CaCl_2$@2%	0	6.7
$CaCl_2$@4%	0	6.7
$CaCl_2$@6%	0	0
$CaCl_2$@8%	0	0
GA_3@1.5%	0	6.7
GA_3@3%	0	0
Control (water dipped)	26.67	33.33

Total soluble solids

The TSS levels were closely associated with the physiological maturity of the fruit, exhibiting a progressive decline as the storage duration increased. This trend suggests that both postharvest handling and the stage of ripeness play critical roles in determining the biochemical composition of the fruit during storage. The GA_3 treatments (1.5% and 3%) also show lower TSS values compared to the control, with the 3% concentration achieving a TSS value of 3.47 °Brix at 3 DAS and 3.34 °Brix at 12 DAS (Table 5). The findings of this study are consistent with those reported by Moradinezhad *et al.* (2020), who observed that control samples of 'Chinese' jujube fruit exhibited the highest levels of total soluble solids (TSS). In contrast, the lowest values were recorded in fruits treated with 1% calcium chloride. Similarly, Pila *et al.* (2010) demonstrated that immersion of 'Duke' tomato fruits in calcium-based solutions resulted in a reduction in TSS content. This decline in TSS among calcium chloride-treated fruits may be attributed to a deceleration in biochemical processes such as sugar synthesis, respiration, and metabolite translocation within the fruit tissue.

Decay loss

This study recorded no decayed fruits for 9 days at room temperature. Decayed fruits appeared in untreated fruits (control) at day 9th at room temperature (26.67%). After the 12th day of storage, decaying was observed in $CaCl_2$@4% (6.67%) which was at par with GA_3@1.5% $CaCl_2$ @2%. No decaying was observed in $CaCl_2$@6%, GA_3@3% (Table 6). $CaCl_2$ treatments resulted in the reduction of decay percentage. Pila *et al.* (2010) reported that $CaCl_2$ application helps in the maintenance of membrane integrity, tissue firmness, and cell turgor, as well as in the delay of membrane lipid catabolism and extension of storage life. Gol *et al.* (2011) reported that postharvest coatings of fruits with GA_3 delayed the conversion of starch into sugars and reduced peroxidase activity and ethylene production, which helps increase the shelf life of tomato (Lee & Kader, 2000; Kader, 2008).

Effect on firmness

After 12 days of storage, the highest firmness was observed in tomato treated with GA_3@1.5% (1.12 kg/cm^2), followed by GA_3 @3% (1.11kg/cm^2), $CaCl_2$ @4% (1.08 kg/cm^2), and $CaCl_2$@6% (0.94 kg/cm^2). In contrast, on the same day, control samples showed 0.89 kg/cm^2 of firmness, which is lower than that of any other treatment (Figure 1). The progressive decline in fruit firmness across all treatments is consistent with standard ripening-related physiological changes. These include the enzymatic disassembly of pectin networks by pectin methylesterase and polygalacturonase, which disrupts cell wall integrity and middle lamella cohesion (Safitri *et al.*, 2024). Furthermore, the osmotic-driven translocation of water from the peel to pulp exacerbates tissue softening by contributing to cell wall swelling and dilution of pectic substances (Tagheabady *et al.*, 2024).

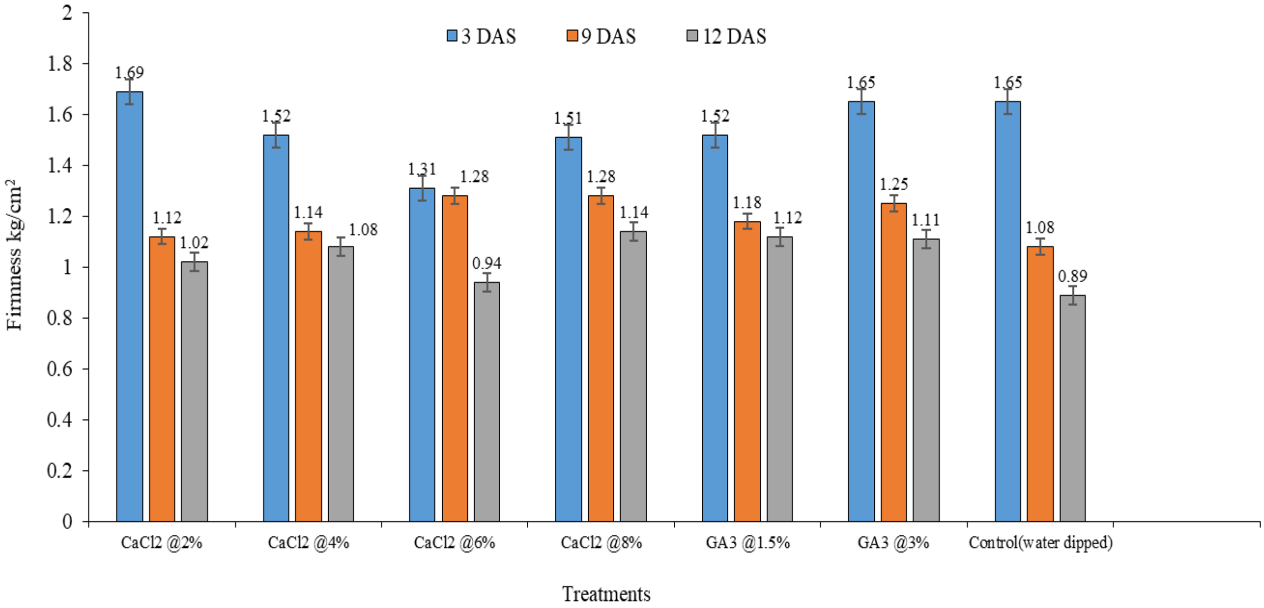

Figure 1. *Effect of different concentrations of $CaCl_2$ and GA_3 as post-harvest treatment on firmness of tomato.*

Conclusion

The present study demonstrated that postharvest treatments, such as the application of gibberellic acid (GA) and Calcium chloride ($CaCl_2$), effectively delayed the ripening process in tomato fruits. Compared to untreated controls, these treatments significantly reduced physiological weight loss, microbial spoilage, and alterations in key quality parameters, including pH, titratable acidity (TA), and total soluble solids (TS). The PLW was minimum with GA_3 @3% followed by $CaCl_2$@4% and GA_3 @1.5%. TSS was maximum for control and minimum for $CaCl_2$@4%, and GA_3 @3%. TA was observed as maximum for GA_3 and CaCl2-treated fruit and minimum for the control. The pH was maximum for the control and minimum for GA_3@3% and GA_3@1.5%. Shelf life was reported as maximum for GA_3@3%, $CaCl_2$@6%, and minimum for the control. The findings suggest that such postharvest interventions are capable of maintaining the physicochemical quality of tomato fruits while prolonging their shelf life. However, further research is warranted to identify the most efficacious postharvest treatment alternatives.

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DECLARATIONS

Author contribution statement: Conceptualization: B.K.; Methodology: B.K.; Software and validation: B.K. and B.S.; Formal analysis and investigation: B.K.; Resources: B.K.; Data curation: B.K.; Writing—original draft preparation: B.K.; Writing—review and editing: B.K. and B.S.; Visualization: B.K.; Supervision: B.K.; Project administration: B.K. All authors have read and agreed to the published version of the manuscript.

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