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RESEARCH

Effects of Postharvest Chemical Preservatives on Shelf Life of Tomato (*Lycopersicon esculentum* cv. Srijana)

Mahesh K. C. [1], Bronika Thapa [2,*], Archana Bhatt [3], Sabina Aryal [3] and Biraj Poudel [4]

[1] Institute of Agriculture and Animal Science, Department of Agriculture, Tribhuvan University, Lamjung 22600, Nepal
[2] Gauradaha Agriculture Campus, Department of Agriculture, Tribhuvan University, Jhapa 57200, Nepal
[3] Institute of Agriculture and Animal Science, Department of Agriculture, Tribhuvan University, Kirtipur 4460, Nepal
[4] Gokuleshwor Agriculture and Animal Science College, Department of Agriculture, Tribhuvan University, Baitadi 10200, Nepal
[*] Author responsible for correspondence; Email: bronikathapa@gmail.com.

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Abstract

In recent years, the practice of increasing the shelf life of post-harvest crops is gaining attention worldwide due to the failure of proper techniques to increase post-harvest shelf life. Tomatoes are fragile and have a low shelf life. It fetches low market prices during on-season production and fetches high market prices during off-season production. To address this scenario, research was conducted to study the effect of different preservatives on various physiochemical attributes of tomato (Lycopersicum esculentum). The effects of preservatives were studied on shelf life, disease infestation days, total soluble solids (TSS), titratable acidity (TA), pH, and weight loss percentage (WLP) at 2-day intervals during the storage period. The 7 treatments used were 2% $CaCl_2$, 4%, $CaCl_2$, 1% GA_3, 3% GA_3, 1000 ppm sodium benzoate, 2000 ppm sodium benzoate, and control in distilled water with 3 replications each. Each replication was immersed in a chemical preservative for 20 minutes and kept in a polyethylene bag. Among the treatments, fruits treated with 3% GA3 recorded the longest shelf life of 31.33 days, followed by 1% GA_3 (27 days) and 4% $CaCl_2$ (22 days) over the control (15.667 days). Disease incidence days were highest for 3% GA_3 (32.33 days) followed by 1% GA_3 (28.33 days) and 4% $CaCl_2$ (23 days) over control (16.667 days). The percentage of physical weight loss on the day of data recording was minimum for 3% GA_3 treated fruits and maximum for control. Similarly, TA, TSS, and pH of treated fruits show significant results over control.

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Statement of Sustainability: This research study on the effect of postharvest preservatives on the shelf life of tomatoes contributes to the Sustainable Development Goal SDG 2 (Zero Hunger), by providing a comprehensive understanding of the postharvest loss incurred and solutions to reduce such losses. It also contributes to SDG 12 (Responsible Consumption and Production) by demonstrating that reducing postharvest loss makes more available for consumption, reduces overall production, and reduces food loss.

1. Introduction

Nepal has great potential in tomato production due to its climatic characteristics. In Nepal, we can find different agroecological climates in different periods, so we can produce tomatoes throughout the year (MoALD, 2018), but still, we are lagging in producing enough. About 7.4% of the total cultivated area and 9.3% of the total vegetable production is covered by tomatoes. Tomato is cultivated in an area of about 22,566 ha with a total productivity of 18 tons per ha per year (MoALD, 2020). Every year, 25-40 % post-harvest loss of tomatoes is observed during storage in countries like Nepal (Paul and Pandey, 2013). Lack of proper information about post-harvest treatment, packaging materials, storage, and transportation of tomatoes causes significant loss in post-harvest life as well as quality. Many physiological changes such as an increase in respiration, transpiration, reducing sugar content, conversion of organic acids to sugars, decrease in pectin content, etc., are observed in tomatoes after harvesting, resulting in short shelf life (Le et al., 2018). Similarly, the production of ethylene in tomatoes continues even after harvesting, which induces further ripening and the tomato starts to deteriorate (Sammi and Masud, 2009). Research has shown that ethylene makes vegetables more susceptible to pathogens that ultimately reduce shelf life (Wills et al., 2000). Ethylene production can't be stopped, but it can be controlled or slowed, resulting in a delay in ripening (Martínez-Romero et al., 2009).

Various available technologies such as the use of fungicides, cold storage, controlled atmosphere storage, anti-transpirants, wax coating, plant growth hormones, irradiation, treatment with different preservatives, and different types of packaging materials, etc. have been used to extend the shelf life of fruits in the past decades (Arah et al., 2016; Zewdie, 2017). Among these methods, the treatment of tomato fruits with some chemical preservatives has shown remarkable results in prolonging the shelf life. In many developed countries, various chemical preservatives such as GA_3, $CaCl_2$, sodium benzoate, salicylic acid, benzyl adenine, etc. are in practice to increase the shelf life of tomatoes (Zewdie, 2017), but not yet in Nepal. In the context of Nepal, many efforts are in practice to increase the shelf life of vegetables (Sudha et al., 2007). Research in the Kathmandu Valley shows that 10% of the total loss occurs from harvest to market, 2% during packaging, 4% during transportation, and 2% during storage (Tiwari et al., 2020). The large amounts of loss start right from harvesting and the loss increases many times during the post-harvest steps (Tiwari et al., 2020). Globally, postharvest losses of tomatoes are about 5-25% in developed countries and 20-50% in developing countries (Lee and Kader, 2000). In Nepal, postharvest losses have been observed up to 50% (Rawal et al., 2017).

It is very difficult to increase yield by 10% but easy to reduce loss by 10% without bringing additional land under production (Bhattarai and Gautam, 2006). Tomato consumption has been increasing rapidly in recent years. Despite a good market and production, the price of tomatoes often fluctuates. This is because there is a huge loss in the post-harvest stage during storage and the demand can't be met. Thus, the main problem to be addressed by this research project is to explore the efficient chemical preservatives that will improve the post-harvest life and maintain the quality of vegetables during storage at ambient conditions required for increasing market demand. The objective of this research is to find out the appropriate concentration of chemical preservatives to minimize the high postharvest losses and maintain the qualitative and quantitative parameters during storage.

2. Materials and Methods

Srijana was the cultivar that was chosen. The experiment was conducted from September 11 to October 8, 2021, at the horticultural laboratory of IAAS, Lamjung, Nepal. Randomly selected fresh ripe fruits were harvested at the breaker stage along with calyx in the afternoon. These fruits were used in the experiment.

2.1 Experiment Design and Treatment Details

The experiment was designed in Completely Randomized Design (CRD) with 7 treatments and 3 replications. Three chemical preservatives used as treatment were calcium chloride ($CaCl_2$), gibberellic acid (GA_3), and sodium benzoate obtained from the local agro vet of Sundarbazar Lamung, Nepal. Seven treatments used were 2% $CaCl_2$, 4% $CaCl_2$, 1% GA_3, 3% GA_3, 1000 ppm of sodium benzoate, 2000 ppm of sodium benzoate, and distilled water as T1, T2, T3, T4, T5, T6, and T7, respectively. All preservative solutions were prepared in distilled water at the required concentration. All treatments were kept in a ventilated polyethylene bag with 6 holes in each. Each replication had 3 fruits and a separate destructive sample for total soluble solid (TSS), titratable acidity (TA), and pH. After the treatment, the physical and chemical parameters of the fruits were observed and recorded.

2.2. Analytical Methods

- **Physiological weight loss 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 Kumar et al. (2018).

$$\text{Weight Loss Percentage}(\%) = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 10$$

All treated fruits were weighed with an electronic digital balance at 2-day intervals.

- **Shelf life (days):** The shelf life is a period that starts from harvesting and extends to the beginning of the rotting of the fruit. The tomatoes treated with different chemicals were observed and the maximum number of days they retained their consumable quality was recorded.
- **Disease infestation days (DID):** Disease incidence days were the day of disease onset. The fruit was observed and recorded on the day of the first sign of disease.
- **Total soluble solid (TSS):** TSS was determined using a handheld refractometer (0-32° Brix) by exposing the fruit juice to the refractometer (Brix meter). The tomato fruit was taken from the destructive sample and crushed in a mortar and pestle to form juice. Then the crushed tomato was filtered in a muslin cloth and the filtered juice was kept in a handheld refractometer for TSS calculation. Finally, the data obtained was recorded.
- **Titratable acidity (TA):** TA was determined by titrating the juice against 0.1 NaOH using a pH meter as an indicator. The tomato juice was crushed in a mortar with a pestle and centrifuged for 30 min. The pure juice was then filtered through a muslin cloth. About 5 mL of juice was taken and mixed with 50 mL of distilled water. Then the pH meter was dipped into a beaker and the pH reading was recorded in a beaker containing tomato juice. A solution of 0.1 N NaOH was poured into a beaker through a burette until the pH reached 8.1/8.2. The volume of NaOH was recorded and TA was calculated using the following formula as explained by Chilson et al. (2011):

$$\text{Titratable Acidity (g citric acid per kg of tomato)} = \frac{\text{V} \times \text{NB} \times 1000 \times 0.064}{\text{m or mL}}$$

Where V is the volume of NaOH required (mL), NB is the normality of the base (NaOH), which is 0.1, 0.064 is the conversion factor for citric acid, and m is the mass of the tomato juice sample used or mL taken (g).

- **pH:** The pH value was recorded with a pH meter at 2-day intervals according to the methods of AOAC (2005). The tomato juice was crushed in a mortar using a pestle. The pure juice was then filtered through a muslin cloth. Approximately 5 mL of juice was collected and mixed with 50 ml of distilled water. Then the previously calibrated pH meter was dipped into a beaker and the pH reading was recorded.
- **Temperature and relative humidity:** Temperature and relative humidity were recorded daily by a digital thermo-hygrometer (Clock/Humidity HTC-1, VackerGlobal, Ittihad, Dubai).

2.3. Statistical Methods

Data were collected at 2-day intervals in Microsoft Excel 2016 (Microsoft Corporation, Redmond, Washington, USA). Analysis of variance 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 of variance).

3. Result and Discussion

3.1. Effect on Shelf Life of Tomato

The effects of different preservatives show a significant role in the shelf life of tomatoes. The highest shelf life of tomato was recorded for 3% GA_3 at 31.33 days and the lowest shelf life was recorded for the control at 15.667 days as shown in Table 1 and Figure 1a. The experiment is consistent with (Srividya et al., 2014). The study found the highest shelf life of 43 days in 0.3% GA_3 followed by $CaCl_2$ 40 days. GA_3 has general anti-senescence properties that have been shown to delay fruit ripening (Tsomu et al., 2015). Rao and Chundawat (1988) found that postharvest immersion of fruits in GA_3 delayed the conversion of starch to sugars and reduced peroxidase activity and ethylene production. This may be the reason for the long shelf life. Khader et al. (Khader et al., 1988) found that postharvest dipping with GA_3 helps to delay fruit senescence. $CaCl_2$ reduces ethylene production by decreasing PG activity, which helps in delaying ripening and prolonging shelf life. This experiment also supports this view (Srividya et al., 2014).

3.2. Effect on Disease Infestation Days of Tomato

The experiment is statistically significant for disease days. Figure 1b below shows that the longest disease incidence days were observed on 3% GA_3 and the shortest on control. Table 1 shows the best results of 3% GA_3 (32.33 days) followed by 1% GA_3 (28.33 days) and 4% $CaCl_2$ (23.00 days). GA_3 and $CaCl_2$ are ethylene-inhibiting hormones that reduce ripening days and ultimately delay disease incidence days. Chloride in calcium helps to maintain the rigidity and turgidity of the cell wall and ultimately delay ripening (Chaplin and Scott, 1980), which could be the reason for the longest disease infestation days. $CaCl_2$ acts as an inhibitor for the growth of various fungi, which could be the reason for the longest disease infestation days for calcium-treated fruits (Le et al., 2018). An experiment conducted by Mazumder et al. (2021) showed that $CaCl_2$ helps in reducing ripening days as well as controlling different fungal diseases. (Molnár et al., 2020) found that apples treated with sodium benzoate help to keep apples healthy over control which supports this experiment. The disease was bacterial rot, which is quite common during storage. The disease infestation days for the control was 16.667 days which is statistically different with 2% $CaCl_2$ (20.33), SB 2000 ppm (21.667), and SB 1000 ppm (20.66).

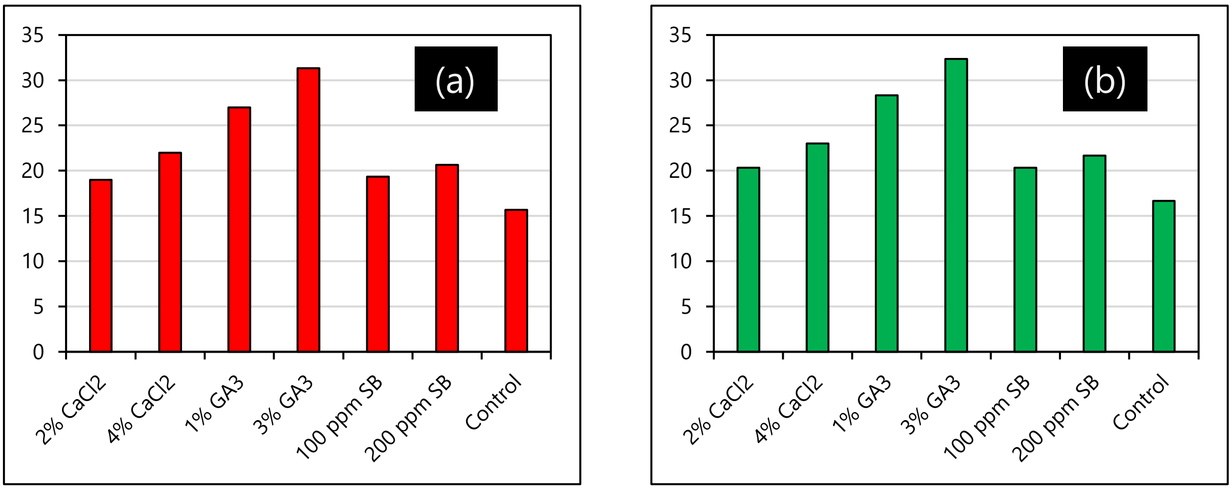

Figure 1. Effect of different preservatives on a) shelf life and b) disease infestation of tomato (Note: $CaCl_2$: calcium chloride; GA_3: gibberlic acid; ppm: part per million; SB: sodium benzoate).

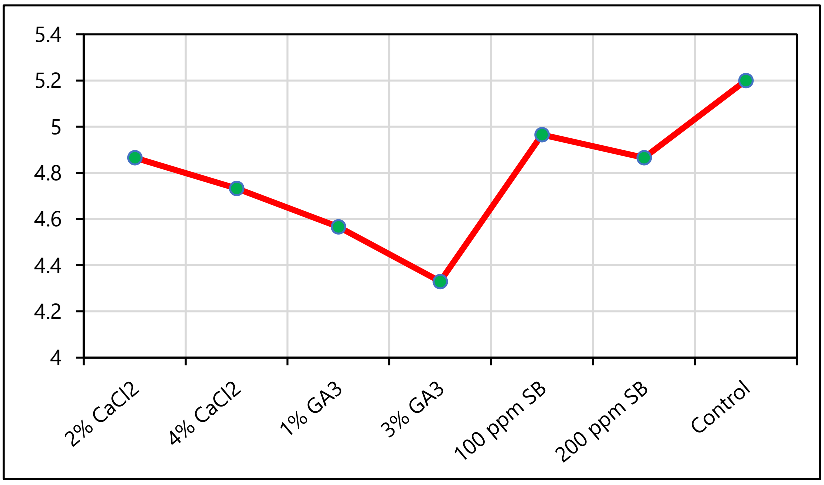

Figure 2. Effect of different preservatives on the pH of tomato (Note: $CaCl_2$: calcium chloride; GA_3: gibberlic acid; ppm: part per million; SB: sodium benzoate).

3.3. Effect on pH of Tomato

It was evident that the pH of tomatoes increased with storage days for all treatments. A gradual decrease in ascorbic acid content over the storage period is an inevitable event for many fruits and vegetables (Lee and Kader, 2000). A study by Sinha et al. (2019) also supports found a similar trend of results for pH change in tomatoes. From Figure 2, the pH observed during storage for each chemically treated fruit was significantly different from the control. This could be due to the degradation of ascorbic acid which reduces the acidity of tomatoes. Khader et al. (1988) in their study conclude that GA_3 helps in the slow degradation of ascorbic acid which helps to preserve the quality of tomatoes for a long time. pH observed on the 1st day for all treatments was 4.1, which was statistically significant at par. The pH of the treated fruits on the 16th day of storage was highest for the control (5.200) and lowest for 3% GA_3 (4.567). Table 1 shows that the for-treated fruits increased during the storage period, but not as much as the control. This result was also supported by (Demes et al., 2021) where an increase in pH was less for $CaCl_2$ and GA_3 and more for the control. Variation in acidity during storage could be the reason for changes in pH (Pila et al., 2010) also supports that tomato treated with different concentration of $CaCl_2$ helps to lower pH.

Table 1. Effect of various preservatives on shelf life (days), disease infestation (days), and pH of tomato.

Treatment / Parameter	Shelf Life	Disease infestation (Days)	pH16
2% $CaCl_2$	19cd	20.33^{c}	4.866^{bc}
4% $CaCl_2$	22.00^{c}	23.00^{c}	4.733^{cd}
1% GA_3	27^{b}	28.33^{b}	4.566^{d}
3% GA_3	31.33^{a}	32.33^{a}	4.33^{e}
Sodium benzoate (1000 ppm)	19.33^{c}	20.33^{c}	4.966^{b}
Sodium benzoate (2000 ppm)	20.66^{c}	21.66^{c}	4.866^{bc}
Control	15.667^{d}	16.667^{d}	5.20^{a}
LSD (0.05)	3.308	3.37	0.1751
CV (%)	8.532	8.288	2.087

$CaCl_2$: calcium chloride; GA_3: gibberellic acid; ppm: part per million; LSD: least significant difference; CV: coefficient of variation.

3.4. Effect on Weight Loss Percent of Tomato

The effects of the different treatments on the control showed significant differences in the percentage of weight loss during the storage period. The highest weight loss percentage was recorded for the control and the lowest for 3% GA_3. The percentage of weight loss recorded on different observation days is shown in Table 2. The strong and rigid membrane may be due to 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 the control. This could be due to the anti-senescent effect of GA_3 on fruits and vegetables (Sudha et al., 2007). (Lester and Grusak, 1999) also considered that weight loss percentage is more in control over treated fruits. Srividya et al. (2014) experimented that fruits treated with GA_3 and $CaCl_2$ had less weight loss percentage than the control. Singh (2014) also found that the action of GA_3 helps to reduce the weight loss percentage. Demes et al. (2021) and Choudhary and Dhruve (2014) also supported the findings of this experiment on specific weight loss in tomato crops. Kaur et al. (2019) in their experiment found that the effect of sodium benzoate on postharvest conditions helps to reduce the weight loss percentage. Similarly, Venkatram et al. (2015) reported that the application of sodium benzoate on apples during storage also helped to reduce the weight loss percentage.

Table 2. Effects of various preservatives on weight loss percent (WLP) of tomato.

Treatment / WLP	WLP 4	WLP 7	WLP 10	WLP 13	WLP 16
2% $CaCl_2$	0.878c	1.912c	2.455bc	3.312c	4.779d
4% $CaCl_2$	0.907c	1.909c	2.238c	3.301c	3.858e
1% GA_3	0.884c	1.854c	2.449bc	3.184c	3.884e
3% GA_3	0.563d	1.287d	1.599d	2.337d	3.504f
Sodium benzoate (1000 ppm)	1.443b	2.280b	3.032b	3.690b	6.102b
Sodium benzoate (2000 ppm)	1.031c	1.770c	2.539bc	3.487bc	5.320c
Control	1.771a	2.816a	3.653a	4.845a	7.874a
LSD (0.05)	0.249	0.3660	0.6020	0.324	0.3458
CV (%)	13.330	10.580	13.394	5.374	3.913

$CaCl_2$: calcium chloride; GA_3: gibberellic acid; ppm: part per million; LSD: least significant difference; CV: coefficient of variation.

3.5. Effect on Titratable Acidity of Tomato

The TA recorded was maximum for GA_3 and lowest for control as shown in Table 3. From the table below it was evident that TA in control was statistically significant from other treatments. Devkota et al. (2019) observed that fruits treated with $CaCl_2$ and GA_3 had significant results of TA over control. The experiment conducted by Arthur et al. (2015a) reported that TA for $CaCl_2$ (6%) treated fruits had a significantly higher value over control during the storage period. This could be due to the slow degradation of ascorbic acid in treated fruits (Mansourbahmani et al., 2017). Pila et al. (2010) also supported this experiment with the findings of maximum TA in 0.1% GA followed by 0.3% GA and least in control. Fruits treated with sodium benzoate also showed significant results over the control. Anti-senescence effects of GA_3 could be the causal factors for the reduction of TA over control. Khader et al. (1988) obtained the same type of result that GA_3 slowed down the degradation of ascorbic acid.

Table 3. Effects of various preservatives on titratable acidity (TA) of tomato.

Treatment / TA	TA4	TA7	TA10	TA13	TA16
2% $CaCl_2$	7.022^c	5.635^c	4.608^d	4.082^c	3.939^d
4% $CaCl_2$	7.178^b	5.854^b	4.868^c	4.483^b	4.161^c
1% GA_3	7.481^a	5.887^b	5.189^b	4.483^b	4.423^b
3% GA_3	7.033^c	6.142^a	5.416^a	4.999^a	4.660^a
Sodium Benzoate (1000 ppm)	6.602^e	5.253^e	4.351^f	3.982^d	3.421^e
Sodium Benzoate (2000 ppm)	6.789^d	5.574^d	4.468^e	3.829^e	5.372^e
Control	6.490^f	5.124^f	3.854^g	3.584^f	3.158^f
LSD (0.05)	0.0700	0.0580	0.1134	0.0428	0.2086
CV (%)	0.576	0.5881	1.384	0.5823	3.051

$CaCl_2$: calcium chloride; GA_3: gibberellic acid; ppm: part per million; LSD: least significant difference; CV: coefficient of variation.

Table 4. Effects of various preservatives on total soluble solids (TSS) of tomato.

Treatment / TSS	TSS4	TSS7	TSS10	TSS13	TSS16
2% $CaCl_2$	2.33^d	2.4667^{de}	2.80^c	3.033^b	3.233^b
4% $CaCl_2$	2.166^e	2.433^e	2.60^e	2.80^d	3.00^c
1% GA_3	2.166^e	2.533^{cd}	2.6667^{de}	2.833^d	2.966^c
3% GA_3	2.066^f	2.333^f	2.5667^e	2.633^e	2.80^d
Sodium Benzoate (1000 ppm)	2.566^b	2.80^b	2.933^b	2.966^{bc}	3.20^b
Sodium Benzoate (2000 ppm)	2.433^c	2.60c	2.733^{cd}	2.900^{cd}	3.30^b
Control	2.70^a	3.00a	3.2333^a	3.466^a	4.00
LSD (0.05)	0.0936	0.0763	0.1267	0.108	0.143
CV (%)	2.278	1.679	2.594	2.0954	2.346

$CaCl_2$: calcium chloride; GA_3: gibberellic acid; ppm: part per million; LSD: least significant difference; CV: coefficient of variation.

3.6. Effect on Total Soluble Solid of Tomato

The chemical treatments affected the TSS content of tomato fruits. The TSS observed for the treated fruits was found to be statistically significant from the control. On each recording day, the control recorded the highest TSS while 3% GA_3 recorded the lowest as shown in Table 4. This experiment is consistent with (Srividya et al., 2014) who found that TSS gradually increased in all treated fruits during the day of storage but was significantly lower than the control. In the current study, an increase in TSS content was observed from day 4 to day 16 of storage. This increase in TSS during storage could be due to the conversion of pectic substances, starch, hemicellulose, or other polysaccharides into soluble sugars and the dehydration of the fruit (Singh et al., 2005). Also, Choudhary and Dhruv (2014) concluded that the action of GA_3 helps to maintain the TSS of tomato fruits during the storage period over the control. Devkota et al. (2019) also supported the research with the findings of the highest TSS in control and lowest in 1% $CaCl_2$ followed by 0.1% GA_3. Demes et al. (2021) observed the highest TSS in control and the lowest in $CaCl_2$ treatment. Similarly, Youssef et al. (2012) argue that starch degradation to sugars and hydrolysis of cell wall polysaccharides during ripening causes an increase in TSS at maturity. $CaCl_2$ treatment delays the increase in free sugar concentration during storage, resulting in reduced TSS (Cheour et al., 1991). Also, GA_3 treatments cause slow respiration and metabolic activity resulting in delayed ripening and reduced TSS (Pila et al., 2010).

4. Conclusion

The experiment was carried out to find out the effects of post-harvest preservatives on the shelf life and physico-chemical properties of tomato (Lycopersicon esculentum) under ambient conditions. The percentage weight loss was minimum for 3% GA_3 followed by 4% $CaCl_2$ and 1% GA_3. Similarly, maximum weight loss was recorded for control.

Similarly, TSS recorded was maximum for control and minimum for 3% GA_3. All the treated fruits showed significant differences from the control. TA observed was maximum for GA_3 and minimum for control which was supported by many researchers. The pH observed during the experiment was maximum for control and minimum for 3% GA_3 followed by other preservatives. Shelf life was reported to be maximum for 3% GA_3 and minimum for control. Disease attack day was maximum for 3% GA_3 treated fruits and minimum for control. The treated fruits were significantly better than the control in all parameters of the experiment. But 3% GA_3 showed better than other treatments. Therefore, if we were to choose preservatives over control, any preservative could be the better option, but if we were to choose among preservatives, 3% GA_3 could be the better option.

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References

AOAC (2005). Official methods of analysis of the Association of Analytical Chemists International. Official Methods: Volume 1, 15th Edition, Gaithersburg, MD, USA. Available online: https://law.resource.org/pub/us/cfr/ibr/002/aoac.methods.1.1990.pdf (accessed on 20 June 2023).

Arah, I. K., Ahorbo, G. K., Anku, E. K., Kumah, E. K., & Amaglo, H. (2016). Postharvest handling practices and treatment methods for tomato handlers in developing countries: a mini review. *Advances in Agriculture*, 2016, 1–8. https://doi.org/10.1155/2016/6436945

Arthur, E., Oduro, I., & Kumah, P. (2015a). Postharvest quality response of tomato (*Lycopersicon esculentum*, Mill) fruits to different concentrations of calcium chloride at different dip-times. *American Journal of Food and Nutrition*, 5(1), 1–8. https://doi.org/10.5251/ajfn.2015.5.1.1.8

Bhattarai, D. R., & Gautam, D. M. (2006). Effect of harvesting method and calcium on post harvest physiology of tomato. *Nepal Agriculture Research Journal*, 7, 37–41.

Chaplin, G. R., & Scott, K. J. (1980). Association of calcium in chilling injury susceptibility of stored avocados. *HortScience*, 15(4), 514-515. https://doi.org/10.21273/HORTSCI.15.4.514

Cheour, F., Willemot, C., Arul, J., Makhlouf, J., & Desjardins, Y. (1991). Postharvest response of two strawberry cultivars to foliar application of $CaCl_2$. *HortScience*, 26(9), 1186-1188. http://doi.org/10.21273/HORTSCI.26.9.1186

Chilson, D., Delgado, A., & do Nascimento Nunes, M. C. (2011). Shelf Life of cluster tomatoes (*Lycopersicum esculentum*) stored at a non-chilling temperature and different relative humidity levels. In Proceedings of the Florida State Horticultural Society, Volume 124, pp. 246-255.

Choudhary, P., & Dhruve, J. (2014). Influence of post-harvest treatments of gibberellic acid, potassium nitrate, and silicic acid in tomato (*Lycopersicon esculentum* Mill.). *Green Farming*, 5(5), 844–846.

Demes, R., Satheesh, N., & Fanta, S. W. (2021). Effect of different concentrations of the gibberellic acid and calcium chloride dipping on quality and shelf-life of ko choro variety tomato. *Philippine Journal of Science*, 150(1), 335–349. https://doi.org/10.56899/150.01.30

Devkota, P., Devkota, P., Khadka, R., Gaire, K. R., & Dhital, P. R. (2019). Effects of chemical additives on shelf life of tomato (solanum lycopersicum) during storage. *Journal of Agriculture and Forestry University*, 3, 69–76.

Kaur, A., Gill, P. P. S., & Jawandha, S. K. (2019). Effect of sodium benzoate application on quality and enzymatic changes of pear fruits during low temperature. *Journal of Food Science and Technology*, 56(7), 3391–3398. https://doi.org/10.1007/s13197-019-03823-5

Khader, S. E. S. A., Singh, B. P., & Khan, S. A. (1988). Effect of GA_3 as a post-harvest treatment of mango fruit on ripening, amylase, and peroxidase activity and quality during storage. *Scientia Horticulturae*, 36(3–4), 261–266. https://doi.org/10.1016/0304-4238(88)90060-X

Kumar, N., Tokas, J., Kumar, P., Singal, H. R., & Jayanti Tokas, C. (2018). Effect of salicylic acid on post-harvest quality of tomato (*Solanum lycopersicum* L.) fruit. *International Journal of Chemical Studies*, 6(1), 1744-1747.

Le, T. T., Vo, T. K., Nguyen, T. M. L., Trieu, P. L., Ngo, V. T., & Nguyen, H. H. (2018). Efficacy of $CaCl_2$ against some important postharvest fungi on orange, chili, and Cavendish banana fruits. *Journal of Vietnamese Environment*, 10(2), 120–128. https://doi.org/10.13141/jve.vol10.no2.pp120-128

Lee, S. K., & Kader, A. A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology*, 20(3), 207–220. https://doi.org/10.1016/S0925-5214(00)00133-2

Lester, G. E., & Grusak, M. A. (1999). Postharvest application of calcium and magnesium to honeydew and netted muskmelons: Effects on tissue ion concentrations, quality, and senescence. *Journal of the American Society for Horticultural Science*, 124(5), 545–552. https://doi.org/10.21273/jashs.124.5.545

Mansourbahmani, S., Ghareyazie, B., Kalatejari, S., Mohammadi, R. S., & Zarinnia, V. (2017). Effect of post-harvest UV-C irradiation and calcium chloride on enzymatic activity and decay of tomato (*Lycopersicon esculentum* L.) fruit during storage. *Journal of Integrative Agriculture*, 16(9), 2093–2100. https://doi.org/10.1016/S2095- 3119(16)61569-1

Martínez-Romero, D., Guillén, F., Castillo, S., Zapata, P. J., Serrano, M., & Valero, D. (2009). Development of a carbon-heat hybrid ethylene scrubber for fresh horticultural produce storage purposes. *Postharvest Biology and Technology*, 51(2), 200–205. https://doi.org/10.1016/j.postharvbio.2008.07.013

Mazumder, M. N. N., Misran, A., Ding, P., Wahab, P. E. M., & Mohamad, A. (2021). Effect of harvesting stages and calcium chloride application on postharvest quality of tomato fruits. *Coatings*, 11(12), 1445. https://doi.org/10.3390/coatings11121445

MoALD (2018). Statistical Information on Nepalese Agriculture 2074/75(2018). Singhadurbar, Kathmandu: Agri-Business Promotion and Statistics Division. Agri Statistics Section, Government of Nepal.

MoALD (2020). Krishi Diary. Agriculture Information and Training Centre. Singha durbar, Kathmandu: Agri-Business Promotion and Statistics Division, Agri Statics Section, Government of Nepal.

Molnár, B., Szabó, S., Veres, Á., & Holb, I. J. (2020). Effect of postharvest sodium benzoate treatment on some fruit parameters of two organic apple cultivars. *International Journal of Horticultural Science*, 26, 35–37. https://doi.org/10.31421/ijhs/26/2020/8004

Nasrin, T. A. A., Molla, M. M., Hossaen, A. (2008). Effect of postharvest treatments on shelf life and quality of tomato. *Bangladesh Journal of Agricultural Research*, 33, 579–585.

Paul, V., & Pandey, R. (2013). Delaying tomato fruit ripening by using 1- Methylcyclopropene (1-MCP) for better postharvest management: Current status and prospects in India. *Indian Journal of Plant Physiology*, 18(3), 195–207. https://doi.org/10.1007/s40502-013-0039-6

Pila, N., Gol, N. B., & Rao, T. V. R. (2010). Effect of post-harvest treatments on physicochemical characteristics and shelf life of tomato (*Lycopersicon esculentum* Mill.) fruits during storage. *Journal of Agriculture and Environmental Sciences*, 9(5), 470–479.

Rao, D. V. R., & Chundawat, B. S. (1988). Ripening changes in Sapota cv. Kalipati at ambient temperature. *Indian Journal of Plant Physiology*, 31, 205-208.

Rawal, R., Gautam, D. M., Gautam, I. P., Khadka, R. B., Tripathi, K. M., Hanson, P., Acedo, A. L., Easdown, W., Hughes, J. A., & Keatinge, J. D. H. (2017). Evaluation of AVRDC advanced lines of long-shelf-life tomatoes in the Terai region of Nepal. *Acta Horticulturae*, 1179, 317–322. https://doi.org/10.17660/ActaHortic.2017.1179.49

Sammi, S., & Masud, T. (2009). Effect of different packaging systems on the quality of tomato (*Lycopersicon esculentum* var. Rio Grande) fruits during storage. *International Journal of Food Science & Technology*, 44(5), 918-926.

Singh, S., Singh, A. K., & Joshi, H. K. (2005). Prolonging storability of Indian gooseberry (*Embtica officinalis*) under semi-arid ecosystem of Glajarat. *Indian Journal of Agricultural Science*, 75(10), 647-650.

Singh, T. A., & Patel, A. D. (2014). Regulation of fruit ripening through post-harvest treatments of gibberellic acid (GA) and other chemicals on quality and shelf-life of tomato. *Research Journal of Agricultural Sciences*, 5(5), 845-851.

Sinha, S. R., Singha, A., Faruquee, M., Jiku, M. A. S., Rahaman, M. A., Alam, M. A., & Kader, M. A. (2019). Post-harvest assessment of fruit quality and shelf life of two elite tomato varieties cultivated in Bangladesh. *Bulletin of the National Research Centre*, *43*(1). https://doi.org/10.1186/s42269-019-0232-5

Srividya, S., Ramanjaneya Reddy, A., & Sudhavani, V. (2014). Effect of post-harvest chemicals on fruit physiology and shelf life of tomato under ambient conditions. *International Journal of Agriculture and Food Science Technology*, 5(2), 99–104.

Sudha, R., Amutha, R., Muthulaksmi, S., Baby Rani, W., Indira, K., & Mareeswari, P. (2007). Influence of pre- and post-harvest chemical treatments on physical characteristics of Sapota (*Achras sapota* L.) var. PKM 1. *Research Journal of Agriculture and Biological Sciences*, 3(5),450–452.

Tiwari, I., Shah, K. K., Tripathi, S., Modi, B., Shrestha, J., Pandey, H. P., Bhattarai, B. P., & Rajbhandari, B. P. (2020). Post-harvest practices and loss assessment in tomato (*Solanum lycopersicum* L.) in Kathmandu, Nepal. *Journal of Agriculture and Natural Resources*, 3(2), 335–352. https://doi.org/10.3126/janr.v3i2.32545

Tsomu, T., Patel, H. C., Thakkar, R. M., Ajang, M., & Vasara, R. P. (2015). Response of post-harvest treatments of chemical and plant growth regulators on biochemical characteristics of sapota fruit cv. Kalipatti. *The Bioscan*, 10(1), 33-36.

Venkatram, A., Bhagwan, A., Thirupathi, J., & Kumar, S. (2015). Effect of antioxidants and modified atmospheric packaging on physic-chemical characteristics of Balanagar custard apple (*Annona squamosa* L.) fruits. *Environmental & Ecology*, 33(4), 1513-1518.

Wills, R. B. H., & Warton, M. A. (2000). A new rating scale for ethylene action on postharvest fruit and vegetables. In: Improving Postharvest Technologies of Fruits, Vegetables and Ornamentals. Institute International of Refrigeration, Murcia, Spain, pp. 43-47.
Youssef, K., Ligorio, A., Sanzani, S. M., Nigro, F., & Ippolito, A. (2012). Control of storage diseases of citrus by pre-and postharvest application of salts. *Postharvest Biology and Technology*, 72, 57-63. https://doi.org/10.1016/J.POSTHARVBIO.2012.05.004
Zewdie, T. M. (2017). Tomato quality is influenced by different packaging materials and practices. *Journal of Scientific Agriculture*, 1, 91. https://doi.org/10.25081/jsa 2017.v1i0.33