International Journal of Plant & Soil Science

Volume 35, Issue 18, Page 199-207, 2023; Article no.IJPSS.102994
ISSN: 2320-7035

Effect of Calcium Chloride ($CaCl_2$) and Carbon Dioxide (CO_2) on Post Harvest Quality of Apple Fruit (*Malus domestica*) cv. Gala

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i183283

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/102994

Original Research Article

Received: 02/06/2023
Accepted: 10/07/2023
Published: 15/07/2023

ABSTRACT

The study investigated the effects of calcium chloride ($CaCl_2$) and carbon dioxide (CO_2) on the post-harvest quality of Gala apple fruit (*Malus domestica*). The apples were stored under controlled refrigerated conditions for 90 days, and eight different treatment combinations were tested: 0.5% $CaCl_2$, 1.0% $CaCl_2$, 900ppm CO_2, 1000ppm CO_2, 0.5% $CaCl_2$ + 900ppm CO_2, 0.5% $CaCl_2$ + 1000ppm CO_2, 1.0% $CaCl_2$ + 900ppm CO_2, and 1.0% $CaCl_2$ + 1000ppm CO_2. Various quantitative

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and quality parameters were evaluated throughout the experiment, including fruit weight loss, firmness, total soluble solids (TSS), pH, titratable acidity (TA), ascorbic acid, and sensory evaluation at 30, 60, and 90 days of post-harvest storage. The results demonstrated that fruit weight loss was significantly in the treatments with calcium and carbon dioxide compared to the control group. Furthermore, the calcium and carbon dioxide treatments led to an increase in pH and total soluble solids, and causing a decrease in firmness, titratable acidity, and ascorbic acid during the 90-day cold storage at 0 to 2°C. The findings also indicated that the calcium and carbon dioxide treatments influenced the production of ethylene to the control group. Overall, the experiment revealed that post-harvest calcium treatments prevented fruit softening and minimized weight losses. The application of 1.0% $CaCl_2$ + 1000ppm CO_2 showed superior results compared to other treatments, effectively controlling weight loss, maintaining firmness, and minimizing fruit decay. In conclusion, storing Gala apples under controlled atmosphere conditions with the application of calcium chloride and carbon dioxide successfully inhibited fungal growth, maintained firmness, minimized weight loss, and extended the shelf life compared to the control group. These findings have significant implications for the apple industry, as they provide a means to improve fruit quality and increase the shelf life of apples. Future research may build upon these results to refine treatment conditions, gain a deeper understanding of the underlying mechanisms, and explore the application of these techniques to other apple varieties and different fruits. Ultimately, these experimental findings have the potential to contribute to the development of practical strategies for enhancing the shelf life of apple fruits, ensuring better quality and reduced post-harvest losses.

Keywords: Gala apples; shelf life; calcium chloride treatment; carbon dioxide treatment; post-harvest life, physio- chemical parameters.

1. INTRODUCTION

The Gala apple (*Malus domestica*) is a highly sought-after apple variety, renowned for its vibrant appearance, delightful flavor, and crisp texture. Originating in New Zealand in the 1930s, Gala apples were later introduced to the United States in the 1980s, quickly becoming a favorite worldwide. Today, they are one of the most commercially grown apple varieties, cherished for their consistent quality and versatility.

One of the standout features of the Gala apple is its visually appealing appearance. With a distinct yellow to orange-red skin, often adorned with streaks of bright red, Gala apples are instantly recognizable. Their medium size and round shape make them convenient for both eating fresh and for use in various culinary creations. But their taste that truly sets them apart. Gala apples offer a delightful balance of sweetness and tanginess, with a crisp and juicy flesh that provides a satisfying crunch with every bite [1].

The flavor profile of Gala apples can vary slightly depending on the growing region, but they generally exhibit a refreshing sweetness with subtle notes of pear and citrus, which creates a harmonious and enjoyable taste experience. Their firm texture and juiciness also make them excellent choice for snacking. Additionally, Gala apples are popular for use in salads, pies, sauces, and other culinary delights, thanks to their exceptional flavor and texture.

In India, fruit and vegetable production plays a significant role in the agricultural sector. According to the Food and Agriculture Organization (FAO) of the United Nations, India ranks second in fruit and vegetable production globally, after China. However, post-harvest losses remain a challenge, with 30-40% of the produce being lost during harvesting, handling, and storage. Apples, being highly perishable and prone to damage due to their high water content, are no exception [2,3 and 4].

Calcium chloride ($CaCl_2$) has been widely studied for its potential role in maintaining the post-harvest quality of fruits, including apples. Calcium plays a vital role in stabilizing cellular membranes and delaying senescence in horticultural and agronomic crops. Post-harvest calcium dips can effectively increase the calcium content in fruits without causing damage. Calcium application helps maintain cell turgor, membrane integrity, tissue firmness, and delays membrane lipid breakdown, thereby extending the storage life of fresh fruits [5,6,7,8 and 9].

In the case of Gala apples, the application of calcium chloride has shown promising results in improving firmness, reducing decay and maintaining color, and enhancing nutritional value. Additionally, it can influence ethylene production and enzyme activities in the fruit. Further studies are needed to optimize the treatment conditions and assess consumer acceptance [10,11,12 and 13].

Carbon dioxide (CO_2) also plays a crucial role in agriculture. In post-harvest processes, CO_2 is used during controlled atmosphere storage or short-term high-CO_2 treatments to maintain fruit freshness and increase shelf life. High-CO_2 treatments effectively reduce the respiration rate, fruit decay, and increase firmness. However, excessive CO_2 concentrations can cause physiological injuries such as fruit discoloration and off-flavors [14,15,16,17,18 and 19].

The combined use of calcium chloride and carbon dioxide has been explored to enhance the shelf life and improve the quality of apples. By leveraging the benefits of both treatments, researchers aim to maximize the preservation of fruit freshness, reduce post-harvest losses, and improve overall consumer satisfaction [20,21,22 and 23].

The Gala apple stands out as a popular apple variety cherished for its exceptional flavor, crisp texture, and versatility. In India, where fruit and vegetable production is significant, post-harvest losses remain a challenge. The application of calcium chloride and carbon dioxide shows promise in improving the shelf life and quality of apples, including the Gala variety. By understanding and optimizing these treatments, farmers and researchers can contribute to reducing post-harvest losses and ensuring a steady supply of fresh, high-quality apples for consumers [24 and 25].

Therefore, with a view of increasing the shelf life of apple and its keeping quality, an attempt to use different sources of calcium chloride and carbon dioxide on the shelf life of apple has been carried out.

2. MATERIALS AND METHODS

The experiment on prolonging the shelf life of apple was conducted at Post Harvest Laboratory, Department of Horticulture, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology & Sciences, PRAYAGRAJ (UP) during 2022-2023. Statistical analysis was done using the method of analysis of variance (ANOVA) for completely randomized block design (CRBD) by Panse and Sukhtme (1984). The overall significance of difference among the treatment was tested, using critical difference (C. D. at 5%) level of significance. The results were statistically analyzed with the help of a window based computed package OPSTAT (Sheoran, 2004).

3. RESULTS AND DISCUSSSION

3.1 Physiological Loss in Weight (%)

As revealed from the Table 1, there was a considerable loss in weight of the fruits under all the treatments but the difference among the treatments was non-significant after 30 days of storage. Whereas, the significant loss in weight was observed after 60 days of storage with maximum loss (4.30%) in T_3 (fruits treated with 900 ppm CO_2) while minimum loss in weight (1.53%) was associated in T_8 (fruits treated with 1.0% $CaCl_2$ + 1000 ppm CO_2). Similarly, significant effect of weight loss was found after 60 and 90 days of storage. After 90 days of storage, the minimum weight loss (2.10%) was recorded in T_8 (fruits treated with 1.0% $CaCl_2$ + 1000 ppm CO_2) followed by (2.28%) T_2 (fruits treated with 1.0% $CaCl_2$).

3.2 Firmness (kg/cm²)

Flesh firmness is a characteristic used to indicated fruit quality. Firmness of apple as related to stages of maturity or degree of ripeness on the basis of visual red color intensification [26].

Fruit quality assessments usually involve measuring flesh firmness using a penetrometer. Generally, a probe, with either a flat or convex tip is driven into the flesh, and the maximum force is recorded.

The firmness in apple fruit as influenced by application of calcium chloride and carbon dioxide during storage (refrigerated condition) are presented in Table 2.

Storage period significantly influenced the firmness of the fruits. As the storage period extended, the firmness reduces in controlled temperature (refrigerated condition). The low storage temperature increased firmness, and in this connection Hawkins and Sando (2008) found that low temperatures increased the resistance of the apple epidermis to puncturing.

Table 1. Effect of different levels of calcium chloride and carbon dioxide on physiological loss in weight (%) of apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	30	60	90
T0	CONTROL	154.73	4.46	-	-
T1	0.5% $CaCl_2$	141.1	2.88	2.46	3.93
T2	1.0% $CaCl_2$	172.95	1.22	2.43	2.28
T3	900 ppm CO_2	169.78	2.95	4.3	3.68
T4	1000 ppm CO_2	171.88	1.65	3.08	2.92
T5	0.5% $CaCl_2$ + 900 ppm CO_2	149.65	1.76	3.03	3.07
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	136.15	1.37	2.43	3.13
T7	1.0% $CaCl_2$ + 900 ppm CO_2	156.32	1.25	2.24	2.66
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	156.73	1.17	1.53	2.1
	C.D. at 0.5%	21.19	1.6	1.49	1.08

Table 2. Effect of different levels of calcium chloride and carbon dioxide on firmness (kg/cm^2) of apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	30	60	90
T0	CONTROL	6.1	5.63	-	-
T1	0.5% $CaCl_2$	6	5.97	4.93	3.97
T2	1.0% $CaCl_2$	6.63	6.5	5.23	4.8
T3	900 ppm CO_2	5.8	5.67	4.83	3.9
T4	1000 ppm CO_2	5.77	5.77	5	4.07
T5	0.5% $CaCl_2$ + 900 ppm CO_2	6.07	6.07	5.03	4.07
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	6.53	6.57	5.43	4.83
T7	1.0% $CaCl_2$ + 900 ppm CO_2	6.73	6.63	5.7	4.87
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	6.83	6.7	6.2	5.53
	C.D. at 0.5%	0.38	0.55	0.54	0.69

The minimum firmness in apple (3.90 kg/cm^2) was recorded in T_3 (fruits treated with 900 ppm CO_2) followed by (3.97 kg/cm^2) T_1 (fruits treated with 0.5% $CaCl_2$) respectively.

3.3 Total Soluble Solid (°Brix)

Storage period has significantly influenced the percentage of TSS in apple fruit. As the storage period extended, irrespective of the treatments, the TSS percentage increases respectively.

A significant difference in the effectiveness of the treatments was found regarding the total soluble solids. The steady rise in TSS was noted up to the end of the study with all treatments. The lowest rising TSS was observed in T_8, fruits treated with 1.0% $CaCl_2$ + 1000 ppm CO_2 (14.02) followed by T_6, T_7, fruits treated with 0.5% $CaCl_2$ + 1000 ppm CO_2, 1.0% $CaCl_2$ + 900 ppm CO_2 (14.03), and in T_2 fruits treated with 1.0% $CaCl_2$ (14.04) respectively. The maximum increase in TSS was observed in T_1 fruits treated with 0.5% $CaCl_2$ after 90 days of storage.

The increase in TSS during the initial stages may be attributed due to the conversion of starch and other polysaccharides into sugars and decrease in TSS at advance stage, is owing to the increased rate of respiration in later stages of storage (Mukherjee and Dutta, 1967).

Total soluble solids comprise mostly fruit sugars, which are derived from starch during ripening process. The starch after hydrolysis into sucrose, fructose and glucose have contributed to increase in TSS values during storage. This is in confirmation to Bhalereo et al. (1994), Sam and Conway (1984) in apple, Parmar, P. B et al. (1989) in mango observed higher TSS in control compared to packaged and fruits treated with $CaCl_2$. They attributed this to the higher moisture loss in control sample than treated fruits.

Table 3. Effect of different levels of calcium chloride and carbon dioxide on Total soluble solids (ºBrix) of apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	30	60	90
T0	CONTROL	12.7	13.02	-	-
T1	0.5% $CaCl_2$	12.72	12.74	13.4	14.08
T2	1.0% $CaCl_2$	12.37	12.39	13.09	14.04
T3	900 ppm CO_2	12.77	12.8	14.03	14.07
T4	1000 ppm CO_2	12.71	12.73	13.38	14.05
T5	0.5% $CaCl_2$ + 900 ppm CO_2	12.7	12.73	13.38	14.05
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	12.4	12.71	13.07	14.03
T7	1.0% $CaCl_2$ + 900 ppm CO_2	12.37	12.39	13.06	14.03
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	12.37	12.39	13.03	14.02
	C.D. at 0.5%	0.06	0.31	0.57	0.03

3.4 Ascorbic Acid (mg/100ml)

A significant difference in the effectiveness of the treatments was found regarding the ascorbic acid. A steady decrease in ascorbic acid was noted up to the end of the study with all the treatments.

The lowest reduction in ascorbic acid (5.55) was found in T_3 (fruits treated with 900 ppm CO_2). Whereas the highest reduction in ascorbic acid (10.18) was reported in T_8 (fruits treated with 1.0% $CaCl_2$ + 1000 ppm CO_2) after 90 days of storage under refrigerated condition.

A progressive decrease in ascorbic acid content of apple fruits in all the treatments with the progress in storage period is evident from the data Table 4. A gradual but continuous reduction in ascorbic acid may be attributed to its degradation in various metabolic processes of stored fruit.

Lamikanra and Watson (2001) reported that the decrease in ascorbic acid content of apple fruit may be due to higher rate of respiration and oxidation. Similar decrease in ascorbic acid content with various treatments along with storage. Similar decreasing trend in ascorbic acid content was obtained by James P. Mattheis et al. (2005) and Hussain et al. (2008).

3.5 pH of apple

The minimum pH (4.70) was found in T_8 (fruits treated with 1.0% $CaCl_2$ + 1000 ppm CO_2) followed by (4.71) in T_7 (fruits treated with 1.0% $CaCl_2$ + 900 ppm CO_2). The maximum pH (4.85) was found in T_3 (fruits treated with 900 ppm CO_2) followed by (4.82) in T_1 (fruits treated with 0.5% $CaCl_2$) respectively after 90 days of storage under refrigerated condition.

Table 4. Effect of different levels of calcium chloride and carbon dioxide on ascorbic acid (mg/100 g) of apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	30	60	90
T0	CONTROL	12.03	9.26	-	-
T1	0.5% $CaCl_2$	12.96	12.03	6.48	6.48
T2	1.0% $CaCl_2$	14.81	13.88	10.18	7.4
T3	900 ppm CO_2	12.96	12.03	9.26	5.55
T4	1000 ppm CO_2	13.88	12.96	9.26	7.4
T5	0.5% $CaCl_2$ + 900 ppm CO_2	12.96	12.03	7.4	6.48
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	13.7	12.77	8.33	7.37
T7	1.0% $CaCl_2$ + 900 ppm CO_2	13.88	12.03	9.26	8.33
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	15.73	14.81	11.11	10.18
	C.D. at 0.5%	1.43	2.58	2.427	2.42

Table 5. Effect of different levels of calcium chloride and carbon dioxide on ph of apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	**30**	**60**	**90**
T0	CONTROL	3.53	3.81	-	-
T1	0.5% $CaCl_2$	3.4	3.72	4.48	4.82
T2	1.0% $CaCl_2$	3.58	3.62	4.27	4.73
T3	900 ppm CO_2	3.63	3.8	4.59	4.85
T4	1000 ppm CO_2	3.63	3.7	4.39	4.79
T5	0.5% $CaCl_2$ + 900 ppm CO_2	3.58	3.64	4.32	4.74
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	3.57	3.64	4.14	4.75
T7	1.0% $CaCl_2$ + 900 ppm CO_2	3.57	3.61	4.05	4.71
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	3.57	3.6	4.04	4.7
	C.D. at 0.5%	0.082	0.084	0.16	0.05

The increased pH was due to the decrease in acidity of the fruit juice. Fruit juices have low pH because they are comparatively rich in organic acids (Tasnim et al. 2010). The increase in pH might be due to the decrease in total titratable acid of the beverage samples as acidity and pH are inversely proportional to each other Rehman et al. (2014).

3.6 Titratable Acidity (%)

Storage period has significantly influenced the percentage of acidity in apple fruit. As the storage period extended, irrespective of the treatments, the acidity also decreases respectively.

The total titratable acidity gradually decreases under all the treatments by prolonging the period of apple fruits during storage. The highest titratable acidity (0.21%) in T_8 was recorded by treated fruits with 1.0% $CaCl_2$ + 1000 ppm CO_2, whereas the minimum acidity (0.12%) were recorded in T_1, T_2, and T_3 (fruits treated with 0.5% $CaCl_2$, 1.0% $CaCl_2$ and 900 ppm CO_2). Decrease in acidity in fruits during storage has been attributed to conversion of acid to sugar (Pool et al. 1972) or its utilization in respiration.

Similar decreasing trend in the acidity of apple fruit over a storage period was observed by Fagundes et al. (2013) and Wani et al. (2008).

3.7 Color of Apple

The effect of post-harvest treatments on color scores of apple fruits during 90 days of storage under refrigerated conditions is shown in Table 7.

The results revealed that treated apples retained their color during storage period. The maximum color score (8.67) was obtained in T_8 with 1.0% $CaCl_2$ + 1000 ppm CO_2 treated fruits compared to minimum score (6.33) in T_1 with 0.5% $CaCl_2$ treated fruits after 90 days of storage.

With the advancement of storage period, color appreciation by panellists declined gradually [29,28]. It is in confirmatory with the observation made by Yommi, A. et al. (2001) and Bhartiya, S. P. (1998).

Table 6. Effect of different levels of calcium chloride and carbon dioxide on titratable acidity (%) of apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	**30**	**60**	**90**
T0	CONTROL	0.36	0.3	-	-
T1	0.5% $CaCl_2$	0.28	0.25	0.14	0.12
T2	1.0% $CaCl_2$	0.32	0.27	0.23	0.14
T3	900 ppm CO_2	0.27	0.23	0.17	0.12
T4	1000 ppm CO_2	0.32	0.25	0.23	0.14
T5	0.5% $CaCl_2$ + 900 ppm CO_2	0.3	0.25	0.21	0.12
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	0.3	0.27	0.21	0.14
T7	1.0% $CaCl_2$ + 900 ppm CO_2	0.3	0.27	0.23	0.17
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	0.34	0.32	0.25	0.21
	C.D. at 0.5%	0.03	0.05	0.059	0.054

Table 7. Effect of different levels of calcium chloride and carbon dioxide on color (pt) of Apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	30	60	90
T0	CONTROL	8.67	8.33	-	-
T1	0.5% $CaCl_2$	8.33	7.67	6.67	6.33
T2	1.0% $CaCl_2$	8.67	8.67	7.67	8
T3	900 ppm CO_2	8.33	7.33	6.33	6.67
T4	1000 ppm CO_2	8.33	8	7.33	7.33
T5	0.5% $CaCl_2$ + 900 ppm CO_2	8.33	8	7	7
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	8	8	7.33	7
T7	1.0% $CaCl_2$ + 900 ppm CO_2	8.33	8	7.67	8
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	8.67	8.67	8.33	8.67
	C.D. at 0.5%	0.57	0.73	0.94	1.42

3.8 Taste/ Flavour of Apple

The effect of post-harvest treatments on taste and flavour scores of apple fruits during 90 days of storage under refrigerated conditions is shown in Table 8.

The treated fruits scored significantly higher taste and flavour scored compared to control and score increased significantly with storage period and were influenced by the type of treatments [29 and 30].

After 90 days of storage T_8 (fruits treated with 1.0% $CaCl_2$ + 1000 ppm CO_2) maintained the superiority compared to other treatments and were awarded maximum score (9.0). The minimum score (6.33) was recorded in T_3 (fruits treated with 900 ppm CO_2) during storage.

3.9 Overall Acceptability of Apple

The effect of post-harvest treatments on overall acceptability scores of apple fruits during 90 days of storage under refrigerated conditions is shown in Table 9.

The overall acceptability scores decline gradually with the advancement of storage period. The panellists awarded maximum score (8.67) to apples treated with 1.0% $CaCl_2$ + 1000 ppm CO_2. However, the minimum similarity score (6.33) were found in T_3 (900 ppm CO_2), T_5 (0.5% $CaCl_2$ + 900 ppm CO_2) and in T_6 (0.5% $CaCl_2$ + 1000 ppm CO_2).

Table 8. Effect of different levels of calcium chloride and carbon dioxide on taste/flavour (pt) of apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	30	60	90
T0	CONTROL	8.33	6	-	-
T1	0.5% $CaCl_2$	8	6.33	6.67	7
T2	1.0% $CaCl_2$	8.33	6.33	7.33	8.33
T3	900 ppm CO_2	8	6.33	6	6.33
T4	1000 ppm CO_2	7.67	6.67	6.33	7.67
T5	0.5% $CaCl_2$ + 900 ppm CO_2	8	7	6.67	8
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	8	6.67	6.33	7.67
T7	1.0% $CaCl_2$ + 900 ppm CO_2	8.33	6.33	7	8.33
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	8.67	7.33	7.67	9
	C.D. at 0.5%	0.73	0.73	0.87	1.46

Table 9. Effect of different levels of calcium chloride and carbon dioxide on overall acceptability (pt) of Apple fruits during storage

Treatments	Concentrations	No. of days in refrigerated conditions			
		0	**30**	**60**	**90**
T0	CONTROL	8.67	9	-	-
T1	0.5% $CaCl_2$	7.67	8	6.33	6.67
T2	1.0% $CaCl_2$	8	8.67	8.33	7
T3	900 ppm CO_2	7.67	8	7	6.33
T4	1000 ppm CO_2	8.33	8.33	8	6.67
T5	0.5% $CaCl_2$ + 900 ppm CO_2	8.67	8	7.67	6.33
T6	0.5% $CaCl_2$ + 1000 ppm CO_2	8	8.33	7.33	6.33
T7	1.0% $CaCl_2$ + 900 ppm CO_2	8.67	8.67	8	7
T8	1.0% $CaCl_2$ + 1000 ppm CO_2	8.67	9	9	8.67
	C.D. at 0.5%	0.57	0.57	1.12	1.23

4. CONCLUSION

From the present investigation, it is concluded that post-harvest treatment of apple fruit with 1.0% $CaCl_2$ + 1000 ppm CO_2 performed best in shelf life during storage in terms of Physiological loss in weight, firmness, TSS, ascorbic acid, pH, titratable acidity, organoleptic quality and overall acceptability.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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