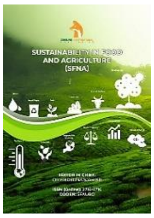
ZIBELINE INTERNATIONAL™ PUBLISHING
ISSN: 2716-6716 (Online)
CODEN: SFAUBO

Sustainability in Food and Agriculture (SFNA)

DOI: http://doi.org/10.26480/sfna.01.2024.35.43



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RESEARCH ARTICLE

EFFICACY OF POSTHARVEST TREATMENTS ON PROLONGING SHELF LIFE OF SWEET ORANGE (*Citrus sinensis* L. Osbeck.) IN RAMECHHAP, NEPAL

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ARTICLE DETAILS

Article History:

Received 20 January 2024
Revised 18 February 2024
Accepted 07 March 2024
Available online 11 March 2024

ABSTRACT

An experiment was conducted to evaluate the effect of different postharvest treatments on maintaining the quality and prolonging the shelf life of sweet orange (*Citrus Sinensis* L. Osbeck.) from February to April 2021 at ambient room condition (15.49 ± 0.45^{0}C and 69.68 ± 5.11%RH). The experiment was conducted under two-factor CRD with 9 treatments replicated thrice: bavistin, calcium chloride, control as the first factor and packaging materials, i.e. corrugated box, LDPE polythene, and open as the second factor. The data were taken at 8 days interval. The parameters recorded were Physiological weight loss, Juice Recovery Percentage, Total Soluble Solid (TSS), Titratable Acidity (TA), TSS/TA, pH, pathological disorder rating, and shelf life. Fruits stored in perforated plastic had minimum physiological weight loss (3.09%) whereas fruits kept open showed the highest weight loss (24.86%) at 56 days of storage. Minimum loss in weight was observed in fruits treated with bavistin (12.83%) and the maximum was observed in control (16.29%). The highest juice recovery percentage was observed in fruits treated with bavistin (30.34%) and fruits kept in perforated plastic (32.03%) and the minimum was observed in open fruits (25.82%). The highest TSS was recorded in fruits left untreated (14.26^0 Brix) and fruit kept in open condition (15.17^0 Brix) whereas the lowest was observed in fruits treated with bavistin (13.87^0 Brix) and fruits stored in polythene (13.22^0 Brix). The least decrease in TA was observed in bavistin-treated fruits (0.57) and fruits stored in perforated polythene (0.61) thereby, resulting highest TSS: TA ratio in untreated fruits (27.17) and fruit kept open (29.91). However, a non-significant effect was observed on pH by postharvest treatments. The pathological disorder was found minimum in the fruits treated with bavistin (2.00) which was at par with calcium chloride-treated fruits (2.33). The earlier pathological disorder was observed in fruits kept open and late with the minimum disorder was observed in fruits stored in perforated polythene. Postharvest life was found the maximum in fruits treated with bavistin and stored in perforated polythene (95 days) and the minimum was observed in fruits under control and left open (56 days).

KEYWORDS

Physiological weight loss, Bavistin, Perforated polythene, Shelf life

1. INTRODUCTION

Citrus is the largest genus belonging to the family Rutaceae which includes sweet oranges (*Citrus sinensis*), tangerines/mandarin (*Citrus reticulata*), lemon (*Citrus limon*), limes (several species), and grapefruits (*Citrus paradisi*). Citrus is the most important horticultural crop grown worldwide in terms of medicinal and nutritive value. Citrus fruits contribute about 22.95% of the total fruit production in Nepal (MoALD, 2020/21). Sweet orange contributes 71 % of total citrus fruit production and is in second position in terms of area and productivity (Syed et al., 2012). *C. sinensis* is an evergreen flowering tree with a height of about 9-10 m. Leaves are alternate, with elliptical, oblong to oval leaf blades which emit strong citric odor due to the presence of copious oil. Flowers are axillary borne single or in whorl of 6 with five white petals. The fruit may be globose to oval that ripens to orange or yellow (González-Santiago et al., 2016).

The chemical constituents of sweet orange include water (86-92%), sugar (5-8%), pectin (1-2%), glycosides (0.1-1.5%), pentosans (0.8-1.2%), citric acid (0.4 to 1.5%), fibre (0.6-0.9%), proteins (0.6-0.8%), fat (0.2-0.5%), minerals (0.5-0.9%) and essential oils (0.2-0.5%) (Veeravenkatesh and Vishnuvardhan, 2014). In Nepal, Sweet orange is grown in huge amounts in Ramechhap and Sindhuli. Therefore, Sindhuli is called as Super zone and Ramechhap is called as zone of sweet orange. Ramechhap covers total of 1,323 hectares of land with a production of 10,744 metric tons and a productivity of 13.65 metric tons per hectare whereas Sindhuli covers a total of 1,335 hectares of land with a production of 10,075 metric tons and a productivity of 13.69 metric tons per hectare (MoALD, 2020/21). As sweet orange is perishable in its nature and is produced in remote and isolated hilly areas, there is the problem of storage and transportation facilities which results in heavy post-harvest losses.

Since, sweet orange is a non-climacteric fruit, its freshness and quality cannot be retained for a longer time. Post-harvest loss is influenced by several factors like physical, physiological, mechanical, and hygienic conditions which cause a substantial percentage of loss between harvesting to consumption point (Mardiyya and Yahaya, 2019). Lack of improved techniques during the pre and postharvest stages, both qualitative and quantitative attributes are lost causing low productivity (Rokaya, 2017). Due to the lack of appropriate postharvest techniques, there occurs glut in the market during the seasonal month of sweet orange leading to earning of unreasonable prices by growers whereas during the

Quick Response Code	Access this article online	
	Website: www.sfna.org.my	**DOI:** 10.26480/sfna.01.2024.35.43

Cite The Article: Shruti Shrestha, Bhawana Regmi, Sagar Bhusal, Shreesha Khatri, Sudip Subedi, Arvind Srivastava (2024). Efficacy of Postharvest Treatments on Prolonging Shelf Life of Sweet Orange (*Citrus Sinensis* L. Osbeck.) in Ramechhap, Nepal. *Sustainability in Food and Agriculture, 5(1): 35-43.*

off-season the growers cannot supply fruits to the market due to its unavailability. As a consequence, fruits are imported in a huge scale for which the consumers have to pay higher prices. In spite of the huge potentiality of sweet orange production and export of the mid-hill region of Nepal, we are dependent on the import of fruits from different countries (Bhattarai, 2018).

The application of various chemicals either alone or in combination with different packaging materials may be used for extending the postharvest life of citrus during storage (Paudel et al., 2019). Creation of a modified environment with the use of various packaging materials results in blockage of the pores within the fruits that will ultimately lower the respiration rate resulting in enhancement of postharvest fruit quality. The role of these packaging alone or in combination with pre-storage treatment needed much focus on correlating the positive mode of applicability to sweet orange. Different pathological species such as *Penicillium digitatum, P. italicum* contributed to the highest percentage of fruit rot causing green and blue mold of sweet orange. Excessive moisture loss due to transpiration also causes wilting, shrinkage, and softening of fruits that results in weight loss, degradation of fruit quality, and increase in disease susceptibility (Li et al., 2018). Therefore, to overcome above mentioned problem and to increase postharvest life, possible packaging practices and treatments at low cost should be an alternative method of storage in which the fruit can be kept in good condition that leads to the producers getting their expected price. Taking into account the aforementioned things, this study was conducted with the main goal of analyzing the impact of various postharvest treatments to increase the shelf-life and preserve sweet orange quality.

2. METHODS AND METHODOLOGY

The study was conducted in the Ramechhap district, one of Nepal's leading districts for sweet orange production. The experiment was carried out from February to April 2021 and the average mean temperature was noted to be (15.49±0.45) °C and RH (69.68±5.11) %.

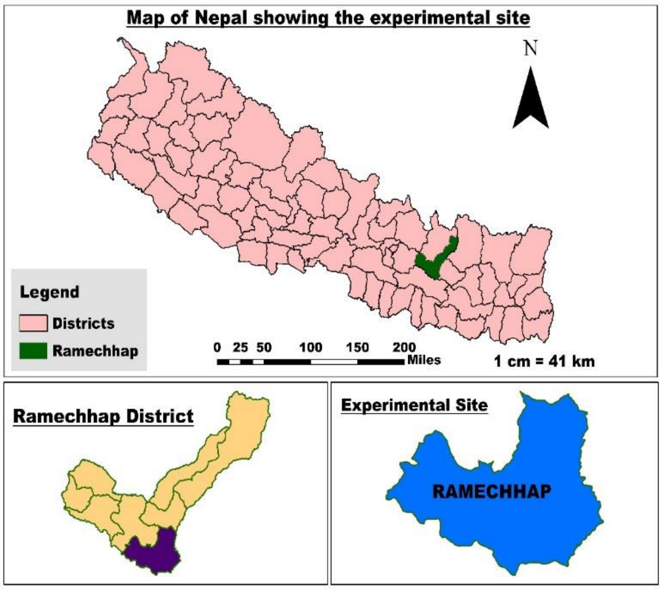

Figure 1: Map of Nepal showing the experimental site

Fruit clippers were used to harvest the uniformly mature fruit from the orchard of the progressive farmer of Okhreni, Ramechhap leaving the half-cm pedicel intact. The fruits were graded, sorted, and transported to the experiment site in plastic crates. The abnormal, pathologically disordered sweet orange, mechanically injured fruits were discarded at the experimental site. The fruits were kept at room temperature in Ramechhap.

2.1 Experimental details

The experiment was carried out in 2 factor Completely Randomized Design (CRD) with nine treatments and three replications. A total of 11 fruits were taken for each treatment. Out of 11 fruits, 4 were taken as a non-destructive sample whereas 7 were taken as a destructive sample. Data recording of one fruit per replication was taken every 8 days interval up to 56 days for measuring different parameters like physiological weight loss, juice recovery percentage, total soluble solid, titratable acidity, TSS, TA, TSS/TA, and pH whereas data for pathological disorder rating was recorded up to 72 days. The treatment details are as follows:

Factor A: - Chemicals

- Bavistin (0.1%)
- Calcium chloride (1%)
- Control

Factor B: - Packaging materials

- Corrugated box
- Perforated polythene
- Open

Table 1: Treatment combination

S.N.	Treatments	Abbreviations
1	Bavistin (0.1%) + LDPE	T1
2	Bavistin (0.1%) + Corrugated box	T2
3	Bavistin (0.1%) + Open	T3
4	Calcium chloride (1%) + LDPE	T4
5	Calcium chloride (1%) + Corrugated box	T5
6	Calcium chloride (1%) + Open	T6
7	Control + LDPE	T7
8	Control + Corrugated box	T8
9	Control + Open	T9

2.2 Preparation and treatment of fruits

The fruits were cleaned with tap water to get rid of any external blemishes and left to dry overnight. 0.1% concentration of Bavistin was prepared by diluting 1 gm of bavistin in 1000 ml of distilled water and 1% concentration of Calcium Chloride was prepared by diluting 10 gm of Calcium chloride in 1000 ml of distilled water. Then, fruits were dipped in the prepared solutions of chemicals for 5 minutes and were left for shade drying. For packaging materials, LDPE plastic of 20-micron thickness was brought from plastic suppliers in which 4 equal-sized perforation of 5 mm diameter was made. For storage of fruits in corrugated boxes, corrugated boxes were procured from the market each 7 cm in length, 7 cm in breadth, and 7 cm in height. Each fruit was kept individually in the box.

2.3 Observation

The different parameters recorded were:

2.3.1 Physiological Weight Loss in percentage

The weight was taken from non-destructive sample using digital sensitive balance. The initial weight of each treatment from each replication was taken during the experimental setup time and successive weight was taken at every 8 days interval. The weight loss percentage was calculated by using the formula:

$$\text{PWL (\%)} = \frac{(\text{Initial weight} - \text{Weight after storage})}{\text{Initial weight}} * 100$$

Source: (Aborisade & Ajibade, 2010)

2.3.2 Juice Recovery Percentage

The juice content was taken from one destructive sample of each replication by squeezing through manual methods at every 8 days interval of experimental setup successively for 7 times. The sample was taken; its initial weight was measured using a weighing machine before squeezing. Then, the sample was cut and squeezed, and the squeezed juice was placed in the small measuring beaker and finally volume of juice was measured in ml. The average juice recovery percentage per fruit was obtained from the following formula:

$$\text{Juice Recovery (\%)} = \frac{(\text{Juice weight per fruit})}{(\text{Individual fruit weight})} * 100$$

Source: (Joshi, Ojha, & Kafle, 2020)

2.3.3 Total Soluble Solid (TSS)

The total soluble solid was determined using a hand-held refractometer. Juice extracted after squeezing was used to measure TSS in degree brix using a refractometer at 8 days intervals.

2.3.4 Titratable acidity (TA)

The acidity of the fruits from each treatment was estimated.10ml of the clear homogenized juice of fruit from each treatment was taken and titrated against standard 0.1N of sodium hydroxide (NaOH) solution using 2-3 drops of phenolphthalein as an indicator. Then the titratable acidity of the fruit was expressed in percentage using the following formula:

$$TA\ (\%) = \frac{(\text{ml of NaoH used} * 0.1\text{N NaoH} * \text{milliequivalent factor})}{\text{Volume of sample}} * 100$$

Source: (Bhandari, et al., 2020)

S.N.	Commodity	Predominant acid	Milliequivalent factor
1	Citrus	Citric acid	0.064

2.3.5 TSS/TA

TSS/TA ratio was calculated by dividing the TSS content by the titratable acidity of each treatment. The following formula was used to calculate TSS/TA ratio:

$$TSS\ /TA = \frac{\text{Total soluble solids}}{\text{Titrable acidity}}$$

2.3.6 pH

pH of the juice was measured with the help of a digital pH meter.

2.3.7 Pathological disorder rating

The pathological disorder rating was analyzed from the non-destructive sample at every 8 days interval of the experimental setup. Arbitrary numbers were set and numbers were given through visual inspection as:

"1" – No disorder

"2" –Slightly disorder

"3" – Moderately disorder

"4" – Highly disorder

2.3.8 Temperature and Relative Humidity

Temperature and Relative Humidity were recorded each day during the experimental period using a thermo-hygrometer.

2.3.9 Statistical Analysis

MS-Excel was used to compile the gathered data. R-studio was used for the analysis of variance (ANOVA) and mean comparison of the data. Duncan's Multiple Range Test was used to compare the treatment's mean values at a 5% level of significance. As a result, the data was analyzed and the findings were discussed and interpreted.

3. Results and Discussion

3.1 Physiological Weight Loss

Significant differences existed among different postharvest treatments for physiological loss in weight with the advancement of the storage period. The maximum weight loss was observed in untreated fruits and kept open at 56 days of storage. At 56th day, 16.294% of the weight loss was recorded under control whereas the weight loss in the fruits treated with Bavistin and calcium chloride was statistically at par with each other. In the case of packaging, minimum physiological weight loss was observed in the fruits kept in the perforated polythene (3.096%) and maximum weight loss was observed in fruits kept in open condition (24.861%).

Lower loss in weight was noted in fruits packed in plastic wrapping due to the creation of a modified atmosphere that slow down evapotranspiration and respiration of the fruits within the package. Minimum physiological loss in weight (2.38%) was reported when stored in perforated polythene in comparison to its storage in a corrugated box because of more loss of moisture from fruits due to higher transpiration in the box (Paudel et al., 2019). Some researchers reported that the least amount of weight loss was related to bavistin treatment mainly due to its fungicidal property inhibiting mycelium growth ultimately resulting in lower decaying loss due to mold ((Jafarpour and Fatemi, 2012). Some researchers reflected the benefits of treating sweet orange with bavistin followed by wrapping in LDPE bags resulting in lower physiological weight loss with the development of desirable sensorial quality and better shelf life (Sakhale and Kapse, 2012).

Table 2: Effect of chemicals and packaging materials on physiological weight loss (%) of sweet orange fruit during storage at ambient condition (15.49 ± 0.45) ^{0}C mean temperature and (69.68 ± 5.11) % RH in Ramechhap, Nepal

Treatments	**The physiological loss in weight (%) on days indicated**						
	Day 8	Day 16	Day 24	Day 32	Day 40	Day 48	Day 56
Chemical							
Bavistin	1.181	2.181^c	3.581^b	5.606^b	7.927^c	10.124^c	12.833^b
Calcium chloride	1.138	2.529^b	3.859^{ab}	6.074^b	8.665^b	10.902^b	13.151^b
Control	1.060	2.826^a	4.023^a	7.129^a	9.992^a	13.169^a	16.294^a
SEm (±)	0.0415	0.081	0.115	0.167	0.149	0.149	0.211
LSD(=0.05)	0.123	0.239	0.340	0.495	0.443	0.443	0.626
CV	11.05	9.627	8.989	7.975	5.047	3.924	4.488
F-test	NS	<0.001	<0.05	<0.001	<0.001	<0.001	<0.001
Package							
Corrugated box	1.322^b	2.762^b	4.665^b	6.642^b	7.908^b	11.72^b	14.321^b
Perforated Polythene	0.383^c	0.81^c	0.973^c	1.685^c	1.941^c	2.261^c	3.096^c
Open	1.675^a	3.965^a	5.826^a	10.482^a	16.735^a	20.215^a	24.861^a
SEm (±)	0.0415	0.081	0.115	0.167	0.149	0.149	0.211
LSD(=0.05)	0.123	0.239	0.340	0.495	0.443	0.443	0.626
CV	11.05	9.627	8.989	7.975	5.047	3.924	4.488
F-test	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Grand Mean	1.126	2.512	3.821	6.269	8.861	11.398	14.093

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean, CV= Coefficient of Variance)

The significant interaction between chemicals and packaging materials was observed at 32nd, 40th and 48th days of storage. The two-way table shows the lowest physiological weight loss in fruits treated with bavistin and stored in perforated polythene and the highest loss was observed in untreated fruits and kept in open condition. Similar results were observed in 40th and 48th days of storage.

Table 3: Interaction effect of chemicals and packaging materials on 32nd day on physiological weight loss (%) of sweet orange fruit during storage at ambient condition in Ramechhap, Nepal

Packaging materials	Chemicals		
	Bavistin	Calcium chloride	Control
Corrugated box	5.049d	6.256c	8.621b
Perforated polythene	1.571e	1.739e	1.744e
Open	10.196a	10.227a	11.021a
SEm (±)	0.289		
LSD(=0.05)	0.857		
F-test	<0.001		

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean, CV= Coefficient of Variance)

Table 4: Interaction effect of chemicals and packaging materials on 40th day on physiological weight loss (%) of sweet orange fruit during storage at ambient condition in Ramechhap, Nepal

Packaging materials	Chemicals		
	Bavistin	Calcium chloride	Control
Corrugated box	6.094d	7.170c	10.46b
Perforated polythene	1.416f	1.950ef	2.458e
Open	16.273a	16.874a	17.057a
SEm (±)	0.258		
LSD(=0.05)	0.767		
F-test	<0.001		

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean)

Table 5: Interaction effect of chemicals and packaging materials on 48th day on physiological weight loss (%) of sweet orange fruit during storage at ambient condition in Ramechhap, Nepal

Packaging materials	Chemicals		
	Bavistin	Calcium chloride	Control
Corrugated box	8.766e	10.570d	15.821c
Perforated polythene	2.00f	2.011f	2.771f
Open	19.605b	20.125b	20.915a
SEm (±)	0.258		
LSD(=0.05)	0.767		
F-test	<0.001		

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean)

Table 6: Interaction effect of chemicals and packaging materials on 56th day on physiological weight loss (%) of sweet orange fruit during storage at ambient condition in Ramechhap, Nepal

Packaging materials	Chemicals		
	Bavistin	Calcium chloride	Control
Corrugated box	11.540d	12.086d	19.337c
Perforated polythene	2.917e	2.733e	3.638e
Open	24.043b	24.634b	25.906a
SEm (±)	0.365		
LSD(=0.05)	1.085		
F-test	<0.001		

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean**)**

3.2 Juice Recovery Percentage

Table 7: Effect of chemicals and packaging materials on juice recovery (%) of sweet orange fruit during storage at ambient condition (15.49 ± 0.45)^{0}C mean temperature and (69.68 ± 5.11) % RH in Ramechhap, Nepal

Treatments	**Juice recovery % of fruit on days indicated**						
	Day 8	Day 16	Day 24	Day 32	Day 40	Day 48	Day 56
Chemical							
Bavistin	37.33	35.562	34.502	33.152	32.17a	31.60a	30.34a
Calcium chloride	36.37	34.711	33.579	32.233	31.53a	31.23a	29.77a
Control	36.73	35.118	33.712	31.957	29.55b	28.56b	27.671b
SEm (±)	0.923	0.855	0.872	0.924	0.649	0.525	0.443
LSD(=0.05)	2.742	2.54	2.591	2.746	1.930	1.559	1.316
CV, %	7.520	7.299	7.709	8.544	6.270	5.17	4.542
F-test	NS	NS	NS	NS	<0.05	<0.01	<0.01
Package							
Corrugated box	36.65	35.12	34.07	32.484	31.79a	30.81b	29.926b
Perforated Polythene	36.59	34.709	33.686	32.636	32.26a	32.55a	32.032a
Open	37.20	35.554	34.037	32.222	29.20b	28.04c	25.821c
SEm (±)	0.923	0.855	0.872	0.924	0.649	0.525	0.443
LSD(=0.05)	2.742	2.54	2.591	2.746	1.930	1.559	1.316
CV,%	7.520	7.299	7.709	8.544	6.270	5.17	4.542
F-test	NS	NS	NS	NS	<0.01	<0.001	<0.001
Grand Mean	36.815	35.130	33.931	32.447	31.082	30.465	29.26

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean, CV= Coefficient of Variance)

The juice recovery percentage was found to decrease with time during storage in all the treatments. There was a significant effect of treatment on juice recovery percentage at 40th, 48th and 56th days of storage. At 56th days of storage, the maximum juice recovery percentage was recorded in fruits treated with bavistin (30.34%). This is due to the anti-fungicidal property of bavistin that causes minimum decay loss resulting in a higher juice recovery percentage.

In the case of packaging materials, fruits packaged in perforated polythene (32.032%) were found to have the highest juice recovery percentage. Similarly, the lowest juice recovery percentage was observed in fruits kept in open condition (25.821%). The decrease in juice percentage during the storage is due to the loss of moisture from the surface of the fruits due to transpiration. The perforated plastic created the modified atmospheric environment acting as a barrier which reduced the moisture loss from the fruit attributed to low respiration and transpiration rate resulting in a higher juice recovery percentage (Bhattarai and Shah, 2017).

3.3 Total soluble solids (TSS)

Total soluble solids content increased with the increasing period of storage in all the treatments. The increasing trend is higher in the fruits under control and kept open than that of the treated fruits and kept in packaged condition. There was no significant effect of chemicals on the TSS of fruits throughout the experimental periods. However, the highest TSS was obtained in fruits under control than that of treated fruits. At 56th days of storage, TSS content was found to be lowest in bavistin-treated fruits (13.878°brix) and the highest TSS was obtained in the fruits left untreated (14.265°brix). In the case of packaging materials, Fruits that are kept open showed the maximum TSS content during the storage period and ranged from 12.358°brix during 8th day to 15.17°brix during 56th day. Fruits kept in perforated polythene reflected the slow increase in TSS ranging from 11.941°brix during 8th day to 13.227 °brix during 56th day.

The trend showed that polythene packaged fruits were significantly superior because of the gradual increment in the TSS change whereas TSS was found to increase at a faster pace in fruits kept open. The increase in TSS with the advancement of storage may be accounted for the moisture loss, hydrolysis of polysaccharides, and concentration of juice as a result of dehydration. TSS of the fruits stored in plastic packaging rises slowly which may be due to a lower rate of metabolic processes. Polythene provides a protective covering which slowed down the rate of respiration and delayed ripening as stated by (Rokaya et al., 2016; Sohail et al., 2015).

Table 8: Effect of chemicals and packaging materials on Total Soluble Solids (TSS) of sweet orange fruit during storage at ambient condition (15.49 ± 0.45)^{0}C mean temperature and (69.68 ± 5.11) % RH in Ramechhap, Nepal

Treatments	TSS of fruits on days indicated						
	Day 8	Day 16	Day 24	Day 32	Day 40	Day 48	Day 56
Chemical							
Bavistin	11.924	12.533	12.800	13.262	13.394	13.637	13.878
Calcium chloride	12.128	12.750	13.063	13.342	13.419	13.704	14.023
Control	12.308	12.858	13.320	13.491	13.52	13.727	14.265
SEm (±)	0.517	0.509	0.505	0.369	0.212	0.181	0.205
LSD(=0.05)	1.535	1.515	1.501	1.099	0.631	0.539	0.608
CV,%	12.79	12.033	11.607	8.305	4.738	3.975	4.365
F-test	NS	NS	NS	NS	NS	NS	NS
Package							
Corrugated box	12.061	12.659	13.121	13.287	13.345^b	13.528^b	13.77^b
Perforated Polythene	11.941	12.603	13.029	12.830	12.744^b	12.914^c	13.227^b
Open	12.358	12.880	13.033	13.979	14.243^a	14.626^a	15.170^a
SEm (±)	0.517	0.509	0.505	0.369	0.212	0.181	0.205
LSD(=0.05)	1.535	1.515	1.501	1.099	0.631	0.539	0.608
CV,%	12.79	12.033	11.607	8.305	4.738	3.975	4.365
F-test	NS	NS	NS	NS	<0.001	<0.001	<0.001
Grand Mean	12.12	12.714	13.061	13.365	13.44	13.689	14.056

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean, CV= Coefficient of Variance)

3.4 Titratable acidity (TA)

Table 9: Effect of chemicals and packaging materials on titratable acidity (TA) of sweet orange fruit during storage at ambient condition (15.49 ± 0.45) ^{0}C mean temperature and (69.68 ± 5.11) % RH in Ramechhap, Nepal

Treatments	Titratable acidity (%) on days indicated						
	Day 8	Day 16	Day 24	Day 32	Day 40	Day 48	Day 56
Chemical							
Bavistin	1.1322	1.025	0.925	0.830	0.741	0.666^a	0.578^a
Calcium chloride	1.139	1.016	0.916	0.831	0.743	0.655^a	0.569^a
Control	1.133	0.981	0.881	0.798	0.701	0.619^b	0.533^b
SEm (±)	0.019	0.018	0.018	0.02	0.019	0.008	0.007
LSD(=0.05)	0.0567	0.053	0.053	0.059	0.056	0.024	0.022
CV,%	5.054	5.344	5.9	7.209	7.804	3.725	3.910
F-test	NS	NS	NS	NS	NS	<0.01	<0.001
Package							
Corrugated box	1.12	1.016	0.916	0.825	0.739	0.644^b	0.558^b
Perforated Polythene	1.164	1.023	0.923	0.839	0.743	0.693^a	0.614^a
Open	1.12	0.983	0.884	0.795	0.703	0.603^c	0.508^c
SEm (±)	0.019	0.018	0.018	0.02	0.019	0.008	0.007
LSD(=0.05)	0.0567	0.0533	0.053	0.059	0.056	0.024	0.022
CV,%	5.054	5.344	5.9	7.209	7.804	3.725	3.910
F-test	NS	NS	NS	NS	NS	<0.001	<0.001
Grand Mean	1.135	1.007	0.907	0.819	0.728	0.647	0.560

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean, CV= Coefficient of Variance)

As data presented in Table 9, titratable acidity was found to decrease significantly with the advancement of the storage period. The least decrease in the TA was observed in the fruits treated with the bavistin (0.578) which was statistically at par with the fruits treated with the calcium chloride (0.569) and the highest decrease in the TA was observed in the untreated fruits. In the case of packaging materials, the lowest decrease in TA was observed in the fruits stored in the perforated polythene (0.614) which was statistically different than that of the fruits stored in the corrugated box (0.558). The highest decrease in the TA was observed in the fruits kept in the open condition (0.508).

The higher acidity in chemically treated fruits and stored in perforated polythene might be due to less utilization of the acids in the respiration process during the storage whereas untreated and open fruits had minimum acids and might be due to faster utilization of the acids in the respiration process during storage. The decreasing trend of titratable acidity during the storage period was probably due to the utilization of acid in the tricarboxylic acid cycle in the respiration process. The present findings are supported by (Rokaya et al., 2016).

3.5 TSS/TA ratio

The TSS/TA ratio of fruit as influenced by a different combination of treatments is depicted in Table 10. On the 56th day of storage, a significant maximum ratio was observed with untreated fruits (27.177) while the minimum ratio was observed with bavistin (24.276) which was found to be at par with the calcium chloride treated fruits (24.858). On the other hand, no significant differences were found due to packaging materials till 24th day of storage. At 56th days of storage, fruits packaged in perforated polythene was found to have the least ratio (21.609) which was statistically different from the fruits kept in a corrugated box (24.784). The highest ratio was found to be in the fruits kept open (29.918).

Table 10: Effect of chemicals and packaging materials on the ratio between Total Soluble Solid and Titratable acidity (TSS/TA) of sweet orange fruit during storage at ambient condition (15.49 ± 0.45) ^{0}C mean temperature and (69.68 ± 5.11) % RH in Ramechhap, Nepal

Treatments	TSS/TA on days indicated						
	Day 8	Day 16	Day 24	Day 32	Day 40	Day 48	Day 56
Chemical							
Bavistin	10.562	12.270	13.888	16.049	18.193	20.709^b	24.276^b
Calcium chloride	10.706	12.562	14.282	16.123	18.116	21.060^{ab}	24.858^b
Control	10.573	13.130	15.170	16.978	19.581	22.295^a	27.177^a
SEm (±)	0.538	0.510	0.581	0.513	0.597	0.484	0.562
LSD(=0.05)	1.599	1.516	1.727	1.525	1.772	1.439	1.669
CV,%	15.215	12.094	12.071	9.397	9.607	6.804	6.625
F-test	NS	NS	NS	NS	NS	<0.1	<0.01
Package							
Corrugated box	10.500	12.455	14.335	16.152^b	18.227^b	21.080^b	24.784^b
Perforated Polythene	10.259	12.339	14.144	15.309^b	17.215^b	18.684^c	21.609^c
Open	11.083	13.168	14.862	17.689^a	20.448^a	24.3^a	29.918^a
SEm (±)	0.538	0.510	0.581	0.513	0.597	0.484	0.562
LSD(=0.05)	1.599	1.516	1.727	1.525	1.772	1.439	1.669
CV,%	15.215	12.094	12.071	9.397	9.607	6.804	6.625
F-test	NS	NS	NS	<0.05	<0.01	<0.001	<0.001
Grand Mean	10.614	12.654	14.447	16.383	18.630	21.355	25.437

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean, CV= Coefficient of Variance)

3.6 pH of the fruit

Table 11: Effect of chemicals and packaging materials on pH of sweet orange fruit during storage at ambient condition (15.49 ± 0.45)^{0}C mean temperature and (69.68 ± 5.11) % RH in Ramechhap, Nepal

Treatments	p^H on days indicated						
	Day 8	Day 16	Day 24	Day 32	Day 40	Day 48	Day 56
Chemical							
Bavistin	3.910	4.084	4.169	4.181	4.531	4.563	4.789
Calcium chloride	3.996	4.149	4.234	4.234	4.584	4.689	4.830
Control	3.918	4.120	4.205	4.225	4.531	4.621	4.882
SEm (±)	0.0408	0.042	0.042	0.045	0.044	0.054	0.042
LSD(=0.05)	0.121	0.126	0.125	0.133	0.131	0.161	0.123
CV (%)	3.106	3.079	3.016	3.19	2.913	3.524	2.589
F-test	NS	NS	NS	NS	NS	NS	NS
Package							
Corrugated box	3.968	4.105	4.190	4.215	4.565	4.630	4.836
Perforated Polythene	3.900	4.100	4.185	4.143	4.492	4.575	4.789
Open	3.956	4.148	4.233	4.284	4.589	4.669	4.876
SEm (±)	0.0408	0.042	0.042	0.045	0.044	0.054	0.042
LSD(=0.05)	0.121	0.126	0.125	0.133	0.131	0.161	0.123
CV(%)	3.106	3.079	3.016	3.19	2.913	3.524	2.589
F-test	NS	NS	NS	NS	NS	NS	NS
Grand Mean	3.941	4.118	4.203	4.214	4.549	4.625	4.834

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean, CV= Coefficient of Variance)

When the storage period was increased, the pH value of fruits was also increased gradually under all the treatments. It may be due to the conversion and utilization of different acids in the respiration process. In comparison, the pH of the treated fruits was found to be lower than the pH of the fruits of the control set, which might be due to the creation of different modified atmospheres. The result of the statistical analysis shows the highest pH in the fruit left untreated (4.882) and the lowest pH in the fruits treated with the bavistin (4.789). The mean table also shows the highest pH in the fruits stored in open condition (4.876) and the lowest pH was found in the fruits stored in the perforated polythene (4.789).

The decline in acidity is attributed to increased activities of citric acid glyoxalase during ripening. Reduction in acid content might be due to their conversion into sugars during the metabolic process during storage as stated by (Rathore et al., 2007). The results are also in line with the findings of in Kinnow (Singh, 2017).

3.7 Pathological disorder rating

The pathological disorder was found to increase throughout the experimental periods. The significant pathological disorder was first observed in untreated fruits at 32nd day, in calcium chloride treated fruits at 40th day and in bavistin treated fruits at 56th day of storage. The mean table also shows the highest pathological disorder in the fruits left untreated (3.00^{a}) and the lowest pathological disorder was found to be in the fruits treated with the bavistin (2.00^{b}) which was at par with the calcium chloride treated fruits (2.33^{b}) at 72nd days of storage.

In the case of packaging materials, significant pathological disorder was first observed in fruits stored in open condition at 32nd day, in corrugated box at 40th day and in perforated polythene stored fruits at 56th days of storage. At 56th days of storage, the maximum pathological disorder was observed in the fruits kept in open condition (2.67^{a}) and lowest in fruits stored in perforated polythene (1.66^{b}). The lowest rating for perforated plastic might be due to the inhibition of pathogenic spores in the modified environment. A similar result was obtained in which fruits treated with bavistin resulted in minimal pathological disorder due to its fungicidal property ultimately resulting in a lower decaying loss (Jafarpour and Fatemi, 2012). The results are also in accordance with the results of which reported lower pathological disorder in fruits stored in plastic with an improvement in shelf life (Bhattarai and Shah, 2017).

Table 12: Effect of chemicals and packaging materials on pathological disorder rating of sweet orange fruit during storage at ambient condition (15.49 ± 0.45)^{0}C mean temperature and (69.68 ± 5.11) % RH in Ramechhap, Nepal

Treatments	Pathological disorder rating								
	Day 8	Day 16	Day 24	Day 32	Day 40	Day 48	Day 56	Day 64	Day 72
Chemical									
Bavistin	1.00	1.00	1.00	1.00^{b}	1.11^{c}	1.44^{c}	1.77^{b}	2.00^{b}	2.00^{b}
Calcium chloride	1.00	1.00	1.00	1.00^{b}	1.44^{b}	1.88^{b}	2.11^{b}	2.16^{ab}	2.33^{b}
Control	1.00	1.00	1.00	1.44^{a}	1.89^{a}	2.67^{a}	2.67^{a}	2.70^{a}	3.00^{a}
SEm (±)	-	-	-	0.064	0.110	0.090	0.161	0.163	0.211
LSD(=0.05)	-	-	-	0.190	0.330	0.269	0.782	0.626	0.626
CV,%	-	-	-	16.762	22.49	13.610	21.470	16.597	14.937
F-test	NS	NS	NS	<0.001	<0.001	<0.001	<0.01	<0.1	<0.1
Package									
Corrugated box	1.00	1.00	1.00	1.11^{b}	1.44^{b}	2.11^{b}	2.22^{a}	2.2^{a}	-
Perforated Polythene	1.00	1.00	1.00	1.00^{b}	1.00^{c}	1.33^{c}	1.66^{b}	2.22^{a}	2.44
Open	1.00	1.00	1.00	1.33^{a}	2.00^{a}	2.56^{a}	2.67^{a}	-	-
SEm (±)	-	-	-	0.064	0.110	0.090	0.161	0.163	-
LSD(=0.05)	-	-	-	0.190	0.330	0.269	0.782	0.626	-
CV,%	-	-	-	16.762	22.49	13.610	21.470	16.597	-
F-test	NS	NS	NS	<0.01	<0.001	<0.001	<0.001	<0.01	-
Grand Mean	-	-	-	1.148	1.48	2	2.1	2.2	2.44

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean, CV= Coefficient of Variance)

A significant interaction was also observed in the fruits at 32nd, 40th and 48th days of storage. At 32nd days of storage, maximum pathological disorder rating was observed in the untreated fruits kept open (2.00^{a}) and no disorder was obtained in the fruits kept in a corrugated box, perforated polythene and kept open after treatment with the bavistin and calcium chloride which is found at par with the fruits left untreated and kept in the perforated polythene (1.00^{c}).

Table 13: Interaction effect of chemicals and packaging materials on 32nd day on pathological disorder rating of sweet orange fruit during storage at ambient condition at Ramechhap, Nepal in 2021

Packaging materials	Chemicals		
	Bavistin	Calcium chloride	Control
Corrugated box	1.00^{c}	1.00^{c}	1.33^{b}
Perforated polythene	1.00^{c}	1.00^{c}	1.00^{c}
Open	1.00^{c}	1.00^{c}	2.00^{a}
SEm (±)	0.111		
LSD(=0.05)	0.330		
F-test	<0.01		

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean)

Table 14: Interaction effect of chemicals and packaging materials on 40th day on pathological disorder rating of sweet orange fruit during storage at ambient condition at Ramechhap, Nepal in 2021

Packaging materials	Chemicals		
	Bavistin	Calcium chloride	Control
Corrugated box	1.00^{c}	1.33^{c}	2.00^{b}
Perforated polythene	1.00^{c}	1.00^{c}	1.00^{c}
Open	1.33^{c}	2.00^{b}	2.667^{a}
SEm (±)	0.192		
LSD(=0.05)	0.571		
F-test	<0.05		

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean)

At 40th days of storage, the highest pathological disorder was found in the fruits left untreated and kept open (2.667[a]) which was statistically different from the fruits kept in a corrugated box (2.00[b]) which was similar to the fruits treated with the calcium chloride and kept open. No pathological disorder was found in fruits kept in perforated polythene (1.00[c]) after dipping in bavistin, calcium chloride and distilled water which is similar to the fruits treated with the bavistin and stored in the corrugated box.

Around 70% of the world's total citrus production is grown in the Northern Hemisphere, in particular, Mediterranean region and the United States, although Brazil and South Africa in Southern Hemisphere. Global citrus production reaches to 124.25 million ton in 2016 China ranking as the biggest producer of citrus followed by Brazil, India, USA, Spain, Mexico, Egypt, Iran, and South Africa. Around 70% of the world's total citrus production is grown in the Northern Hemisphere, in particular, Mediterranean region and the United States, although Brazil and South Africa in Southern Hemisphere. Global citrus production reaches to 124.25 million ton

in 2016 China ranking as the biggest producer of citrus followed by Brazil, India, USA, Spain, Mexico, Egypt, Iran, and South Africa [3]. Around 70% of the world's total citrus production is grown in the Northern Hemisphere, in particular, Mediterranean region and the United States, although Brazil and South Africa in Southern Hemisphere. Global citrus production reaches to 124.25 million ton in 2016 China ranking as the biggest producer of citrus followed by Brazil, India, USA, Spain, Mexico, Egypt, Iran, and South Africa Around 70% of the world's total citrus production is grown in the Northern Hemisphere, in particular, Mediterranean region and the United States, although Brazil and South Africa in Southern Hemisphere. Global citrus production reaches to 124.25 million ton in 2016 China ranking as the biggest producer of citrus followed by Brazil, India, USA, Spain, Mexico, Egypt, Iran, and South Africa The pathological rating was found to increase with the increase in storage days. At 48th days of storage, the maximum pathological disorder was found in the fruits left untreated and kept open which is similar to the fruits under control and stored in the corrugated box (3.00[a]) and no disorder was found in the fruits treated with the bavistin and calcium chloride and stored in the perforated polythene (1.00[c]).

Table 15: Interaction effect of chemicals and packaging materials on 48th day on pathological disorder rating of sweet orange fruit during storage at ambient condition at Ramechhap, Nepal in 2021

Packaging materials	Chemicals		
	Bavistin	Calcium chloride	Control
Corrugated box	1.33[c]	2.00[b]	3.00[a]
Perforated polythene	1.00[c]	1.00[c]	2.00[b]
Open	2.00[b]	2.667[a]	3.00[a]
SEm (±)	1.73		
LSD(=0.05)	0.466		
F-test	<0.05		

(Means with the same letter within a column do not differ significantly at p= 0.05 by DMRT. LSD= Least Significant Difference, SEm= Standard error of mean)

3.8 Postharvest Life

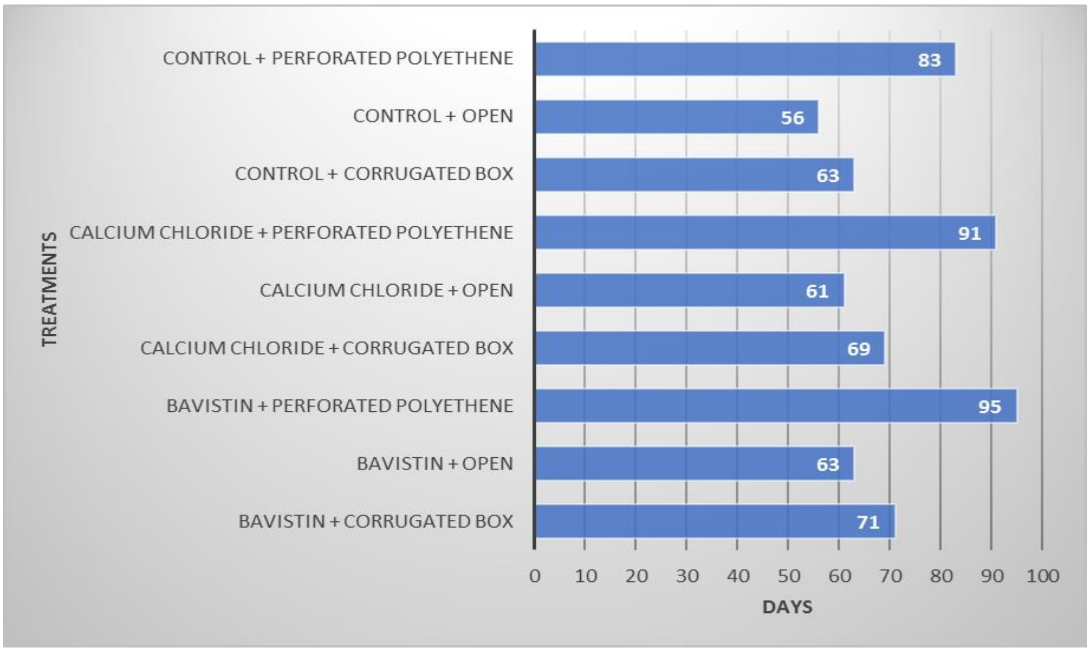

Figure 2: The postharvest life of fruits under different treatments at ambient room condition

Fruits treated with Bavistin and kept in perforated polyethene showed maximum postharvest life of 95 days followed by calcium chloride and kept in perforated polyethene. Similarly, the minimum shelf life was recorded in untreated fruits kept open (56 days).

4. Conclusion

With the application of various treatments, the postharvest life and quality of sweet orange could be prolonged rather than without using them. The shelf life of the fruits was prolonged to 95 days when the fruits were treated with bavistin and packaged in perforated polythene. From this experiment, it can be concluded that the postharvest life prolongation along with the maintenance of quality traits of sweet orange fruits can be best achieved with the bavistin treatment and packaging in the perforated polythene. When the fruits can be preserved for a longer duration without adversely affecting physio-chemical properties, they can be made available in the market during the offseason which benefits both the consumers and producers as well as increases our export potential which fetches higher returns.

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