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Effect of Storage Conditions and Plastic Packaging on Postharvest Quality of Mandarin (*Citrus reticulata* Blanco.) in Dhankuta, Nepal

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***Abstract*— *Postharvest deterioration significantly affects the shelf life and marketability of mandarin fruit in Nepal. The primary causes are inadequate storage and packaging practices. This study aimed to evaluate the effects of storage conditions and plastic packaging with varying ventilation levels on the postharvest quality of mandarin fruit during storage. A laboratory experiment was conducted during January to March of 2021 to study the effect of storage conditions- room storage (15.98± 0.89 °C, 71.15± 5.80% RH), cellar storage (14.72 ± 1.20 °C, 94.28 ± 5.71% RH) and cool chamber with CoolBot (8.12 ± 0.44 °C, 79.43 ± 4.54% RH) and different plastic packaging of 25 micron: two, four, six and eight holes plastic and control (open tray). The experiment was laid out in factorial randomized complete block design with three replications. Result revealed that the lowest physiological loss in weight (9%) was recorded under CoolBot with 8 holes packaging, while the highest (23.66%) was in control under room storage. The highest total soluble solids (14.19 °brix) and the lowest titratable acid (0.88%) were observed in the control. Greater vitamin-C content was observed in CoolBot storage and 8 holes plastic packaging (27.29 mg/100g and 29.11 mg/100g respectively). The longest shelf life (91 days) was found under CoolBot storage with 8 holes plastic packaging as compared to control in room storage (32 days). Further validation across multiple seasons and commercial production settings is recommended.*

***Keywords*— Mandarin, CoolBot, polyethene packaging, shelf life, postharvest quality, storage conditions, preliminary study.**

I. INTRODUCTION

Citrus fruits (genus Citrus; family Rutaceae) are specialized form of berry, named hesperidium, characterized by a juicy pulp made of vesicles within segments (Strano et al., 2017). Citrus, particularly the mandarin orange is the most important and highly commercialized fruit crop in the hills of Nepal. Mandarin is a group name for a class of citrus fruit with thin and loose peel. Mandarin (*Citrus reticulata* Blanco) is a most potent fruit crop that stands in first position of the total fruit industry in Nepal. The mid-hill region (1000 to 1500 m altitude) has a comparative advantage in the cultivation of citrus fruits, especially mandarin and sweet orange (Bhattarai et al., 2013). It shares 0.97 % in AGDP and 0.33 % in GDP (PMD, 2002). The country exports mandarin to India, China, Bangladesh, Bhutan, Pakistan and other countries, is about 600 mt annually (TEPC, 2013).

The postharvest losses of citrus in South Asian region are estimated as 20% (Ladaniya, 2015). Diseases and pests, delay harvest, poor roads, cold storage conditions and glut cause these losses. But the attack of the blue mould (*Penicillium italicum*) and green mould (*P. digitatum*) causes postharvest decays of citrus fruits in cold storage as well as in open citrus fruits and pollutes the environment as well. Different packaging practices and storage helps to reduce post-harvest diseases and prolongs the shelf life of mandarin.

Storage of citrus is essential in order to prolong their usability which aims to slow down the respiration, transpiration, and development of pathological or physiological disorders so that the commodity could be preserved for longer in the most usable form. By proper storage, undesirable processes like rotting, sprouting, toughening, ripening and greening process are minimized. According to Shrestha et al. (1993) most important factors for storage are the commodity itself, the physiochemical environment, and the microbial environment. The commodity should be properly matured, healthy, and should be able to tolerate adverse environmental conditions.

Despite the importance of citrus to Nepalese horticulture, high postharvest losses remain a critical barrier to profitability for smallholder growers. Improving shelf life through better storage and packaging can reduce waste and increase value, but research in this area remains limited. Given the lack of low-cost storage trials for mandarin in Nepal, this study aims to provide insights into how packaging ventilation and storage conditions affect postharvest quality, with the goal of identifying promising solutions for reducing losses.

II. MATERIALS AND METHODS

2.1. Research Location

This study was conducted at the laboratory of the National Citrus Research Program (NCRP), located in Paripatle, Dhankuta, Nepal. The fruits used in the experiment were harvested from the orchard of NCRP. Dhankuta is a mid-hill district situated in Koshi province of Nepal, situated between 26°53' to 27°19' N latitude and 87°08' to 88°33' E longitude. The experimental site lies at an elevation ranging from 1100 to 1400 meters above sea level.

2.2 Experimental design and treatments

The research was laid out in Factorial Randomized Complete Block Design (RCBD) with 15 treatments combination and replicated three times. The mandarins were kept in five different types of packaging materials (P1- Tray (control), P2- Plastic bag with 2 holes, P3- Plastic bag with 4 holes, P4- Plastic bag with 6 holes and P5- Plastic bag with 8 holes) and kept in three different storage conditions (S1- Room storage, S2- Cellar storage and S3- CoolBot storage). The detailed treatment combinations are given in Table 1.

Table 1. Treatment combinations of storage condition and plastic packaging of mandarin

S.N.	Treatment	Symbol	Treatment combination
1	T1	S1P1	Room storage + Control
2	T2	S1P2	Room storage + 2 holes plastic packaging
3	T3	S1P3	Room storage + 4 holes plastic packaging
4	T4	S1P4	Room storage + 6 holes plastic packaging
5	T5	S1P5	Room storage + 8 holes plastic packaging
6	T6	S2P1	Cellar storage + Control
7	T7	S2P2	Cellar storage + 2 holes plastic packaging
8	T8	S2P3	Cellar storage + 4 holes plastic packaging
9	T9	S2P4	Cellar storage + 6 holes plastic packaging
10	T10	S2P5	Cellar storage + 8 holes plastic packaging
11	T11	S3P1	CoolBot storage + Control
12	T12	S3P2	CoolBot storage + 2 holes plastic packaging

13	T13	S3P3	CoolBot storage + 4 holes plastic packaging
14	T14	S3P4	CoolBot storage + 6 holes plastic packaging
15	T15	S3P5	CoolBot storage + 8 holes plastic packaging

Each treatment comprised 4 polyethylene bags (25 microns) containing 10 fruits per bag. One bag per treatment was designated for non-destructive observations, while the remaining bags were used for destructive sampling at scheduled intervals.

2.3 Pre-storage fruit handling

Mature, yellowish mandarin fruits- cultivar *Khoku Local* were carefully harvested from the orchard of the National Citrus Research Program (NCRP) using secateurs to minimize mechanical damage. The fruits were then brought to the laboratory, where they were sorted and graded based on size, uniformity, and absence of visible defects. Following sorting, the fruits were washed in tap water for two minutes to remove any adhering dirt or debris and subsequently air-dried in the shade for 2–3 hours. To strengthen the peel and reduce postharvest decay, the fruits were dipped in a 4 g/L solution of Chlorocal (calcium chloride) for four minutes and then allowed to dry again under shade conditions. A thin, uniform layer of wax was gently applied to the peel surface by hand to reduce moisture loss and improve external appearance. Finally, the waxed fruits were left to dry for an additional two hours before packaging and storage.

2.4. Packaging and Storage

Plastic bags (25 microns) were punched with holes (2, 4, 6, and 8) of 5 mm diameter using a punching machine. Ten fruits were packed per bag, and the bag openings were sealed using rubber bands. Bags were then placed in their designated storage structures (Room, Cellar, or CoolBot).

2.5. Data Collection

Both non-destructive and destructive observations were made throughout the storage period. Non-destructive data included Physiological loss in weight (PLW) and Decay loss whereas, destructive data included Total Soluble Solids (TSS), Titratable Acidity (TA) and Vitamin C content.

2.5.1 Physiological loss in weight (PLW)

Weight loss was recorded at weekly interval over the storage period. A digital sensitive balance was used to record the fruit weight. Weight loss was calculated according the methods described by Joshi et al. (2020).

$$PLW\ (\%) = \{(\mathrm{W0} - \mathrm{Wt.}) \div \mathrm{W0}\} * 100$$

Where, PLW is the physiological loss in weight, W_0 is the initial fruit weight and $W_{t.}$ is the weight of fruits at the designated time.

2.5.2 Decay loss

The fruits of mandarin were visually evaluated for the symptoms of decay. Decay loss was recorded at weekly interval basis.

$$Decay\ loss\ (\%) = (Mass\ of\ decayed\ fruit \div Total\ mass\ of\ fruit) * 100$$

2.5.3 Juice percentage

The juice content was taken from three destructive sample by squeezing through manual methods at every 15 days interval. Juice percentage per fruit was obtained from the following formula adopted by Joshi et al. (2020).

$$Juice\ content\ (\%) = (Juice\ weight\ per\ fruit \div Individual\ fruit\ weight) * 100$$

2.5.4 Total soluble solids (TSS)

TSS was determined by using Pal Brix-Acidity meter. Two to three drops of clear fruit juice were placed on the prism of the instrument for TSS determination. It was measured in ºBrix.

2.5.5 Titratable acidity (TA)

The extracted fruit juice was diluted to the ratio of 1:50 and TA was recorded using Pal Brix-Acidity meter by placing 1-2 drops of diluted juice on the prism surface. TA was measured in terms of percentage.

2.5.6 TSS/TA ratio

$$\frac{TSS}{TA} = Total\ soluble\ \div Titratable\ acidity$$

2.5.7 pH of fruit juice

pH of the sample fruit was measured with the help of digital pH meter.

2.5.8 Vitamin C (Ascorbic acid)

The ascorbic acid of the fruit was measured by volumetric method as per the reference from Sadasivsm and Manickam (1991). Following formula was used to calculate the ascorbic acid content.

$$Amount\ of\ ascorbic\ acid\left(\frac{mg}{100g}\right) = \frac{(0.5\ mg * V2 * 100 * 100)}{(V1 * 5\ ml * weight\ of\ juice)}$$

Where, V_1 = amount of dye consumed during titration, V_2 = Amount of dye consumed when supernatant was titrated with 4% oxalic acid It was determined at the fortnightly interval. The titration was done using the 2,6-dichlorophenolindophenol method (Antoniali et al., 2007)

2.5.9 Index of absorbance difference (IAD)

Index of absorbance difference (IAD) was measured using Delta absorbance (DA) meter. The DA meter emits LED light to fruit skin and measures the amount of light reflected back (Cai & Farcuh, 2021).

2.5.10 Citrus color index (CCI)

Color index of the fruit skin was determined by using Chroma meter (CR-400). Three values i.e. L, a, and b were recorded. The value "L" represents lightness, its value ranges from 0 to 100, more black colors close to zero and more white colors close to 100. The value "a" represents the redness, and the value "b" represents the yellowness. On the basis of the values L, a, and b, citrus color index (CCI) was calculated according to the formula given by Pandey et al. (2021).

$$CCI = \{\frac{(1000 * a)}{L * b}\}$$

2.5.11 Shelf life

Shelf life was determined by visual observation of non-destructive sample. The fruit lots will be considered to have reached the end of shelf life when 50% of fruits showed visual observation of shrinkage or spoilage due to pathogens.

2.6 Statistical Analysis

The collected data was compiled in MS–excel program and analysis of variance for all parameters was done by using Genstat 15 Edition statistical computer package for Factorial Randomized Complete Block Design. Duncan`s Multiple Range Test (DMRT) for the mean separations was done from the reference of Gomez and Gomez (1984). Table and Graph was constructed by using the MS- word and excel computer software program.

III. RESULTS AND DISCUSSION

The following results present the combined effects of storage conditions and plastic packaging with varying ventilation level on key quality parameters including physiological weight loss, vitamin C content, total soluble solids, titratable acidity, and visual deterioration over time.

3.1 Physiological loss in weight

Physiological loss in weight (PLW) differed significantly ($p < 0.05$) among the different storage conditions at 7 days of storage (DOS), 28 DOS, 35 DOS, 42 DOS, and 49 DOS but it did not differ significantly at 14 DOS and 21 DOS (Table 2). Physiological loss in weight (PLW) differed significantly ($p < 0.05$) among the different plastic packaging in all days interval (Table 2).

Higher PLW was observed in case of room storage, intermediate was observed in case of cellar storage and lower percentage of PLW was observed in case of cool chamber with CoolBot, which might be due to the reason that the higher temperature in the room storage leads to greater transpiration resulting in higher physiological loss in weight.

In Mandarin, it was observed that lower temperatures were found to reduce weight loss in all treatments (Lambrinou & Papadopoulou, 1995). Significantly the lower physiological loss in weight was observed in case of perforated polyethene (2.38%) compared to control (19.08%) at 24 days of storage (Paudel et al., 2020; Acharya et al., 2020). The highest PLW at 45 days of storage of Kagzi Lime was observed in case of control (33.46%) while fruits stored in MAP showed a minimum PLW (1.04%) (Hayat et al., 2017).

Table 2. Effect of storage conditions and plastic packaging on physiological loss in weight of mandarin during storage.

Treatments	Physiological loss in weight (%)						
	7 DOS	14 DOS	21 DOS	28 DOS	35 DOS	42 DOS	49 DOS
Storage conditions (Factor A)							
Room storage	2.59^{a}	4.66	7.09	8.60^{a}	10.72^{a}	12.53^{a}	16.93^{a}
Cellar storage	2.41^{a}	4.99	7.10	8.81^{a}	10.27^{a}	10.99^{b}	15.27^{b}
Cool chamber with CoolBot	0.92^{b}	4.14	6.86	7.48^{b}	8.38^{b}	10.13^{b}	12.87^{c}

SEm (±)	0.15	0.26	0.48	0.33	0.46	0.49	0.25
F-value	***	Ns	Ns	*	**	***	***
$LSD_{0.05}$	0.44	-	-	0.94	1.33	1.09	0.72
Plastic packaging (Factor B)							
Control	2.64^{a}	5.75^{a}	8.97^{a}	12.26^{a}	14.18^{a}	16.54^{a}	21.89^{a}
LDPE plastic with two holes	2.19^{ab}	4.54^{bc}	6.99^{b}	8.08^{b}	11.10^{b}	12.44^{b}	15.67^{b}
LDPE plastic with four holes	1.79^{bc}	4.15^{bc}	6.87^{b}	7.02^{b}	7.80^{c}	9.90^{c}	14.00^{c}
LDPE plastic with six holes	1.84^{bc}	4.86^{ab}	6.74^{b}	7.07^{b}	8.12^{c}	9.00^{cd}	12.67^{d}
LDPE plastic with eight holes	1.41^{c}	3.68^{c}	5.49^{b}	7.07^{b}	7.33^{c}	8.21^{d}	10.89^{e}
SEm (±)	0.20	0.34	0.63	0.42	0.59	0.49	0.32
F-value	**	**	*	***	***	***	***
$LSD_{0.05}$	0.57	0.98	1.8	1.22	1.72	1.41	0.93
CV, %	12.7	19.3	13.5	15.3	14.7	13.1	8.4
Grand mean	1.97	4.60	7.01	8.30	9.79	11.22	15.02

Means with same letter in column are not significantly different at p = 0.05 by DMRT. Ns = Not Significant, ** significant at p < 0.01, ***significant at p < 0.001 and ns: not significantly different at p > 0.05. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.2 Decay loss

Decay loss differed significantly ($p < 0.05$) among the different storage conditions at 7 days of storage (DOS), 28 DOS, 35 DOS, and 42 DOS but it did not differ significantly at 14 DOS, 21 DOS, and 49 DOS (Table 3). At 7 DOS, significantly the highest decay loss of 2.12% was observed in room condition while no decay loss was observed at all in the cool chamber with CoolBot. At 49 DOS, the highest decay loss of 12.51% was observed in the room condition while the lowest decay loss of 9.22% was observed in the cool chamber with CoolBot. At 7 DOS, the highest decay loss of 1.55% was observed in the LDPE plastic packaging with two holes while the lowest decay loss of 0.69% was found in the LDPE plastic packaging with eight holes. At 49 DOS, the highest decay loss of 12.00% was found in the control condition while the lowest decay loss of 9.02% was found in the LDPE plastic packaging with eight holes.

Higher decay loss in room storage compared to cellar and cool chamber with CoolBot might be due to higher temperature in room storage, as higher temperature accounted for invasive disease development. The result is in line with Talukder et al. (2015) who reported the highest fruit decay in mandarin without polybag and the lowest observed in 0.5% perforated polybag and kept at 5°C during 90 days of storage period, which indicates that temperature has greater role in decay.

Table 3. Effect of storage conditions and plastic packaging on decay loss of mandarin in storage.

Treatments	Decay loss (%)						
	7 DOS	14 DOS	21 DOS	28 DOS	35 DOS	42 DOS	49 DOS
Storage conditions (Factor A)							
Room storage	2.12^{a}	2.53	4.49	5.46^{a}	8.33^{a}	9.51^{a}	12.51
Cellar storage	1.27^{b}	2.4	4.27	5.41^{a}	7.01^{ab}	7.82^{b}	10.68
Cool chamber with CoolBot	0.00^{c}	1.8	3.47	3.87^{b}	5.02^{b}	6.23^{b}	9.22
SEm (±)	0.24	0.31	0.38	0.39	0.89	0.55	0.96
F-value	***	Ns	Ns	*	*	**	Ns

$LSD_{0.05}$	0.71	-	-	1.13	2.56	1.58	-
Plastic packaging (Factor B)							
Control	1.22	3.00	4.71	5.62	8.56	9.56	12.00
LDPE plastic with two holes	1.55	2.44	4.44	5.24	7.88	9.10	11.30
LDPE plastic with four holes	1.29	2.11	4.44	5.34	6.40	8.03	10.36
LDPE plastic with six holes	0.88	2.00	4.026	4.69	5.61	7.76	10.15
LDPE plastic with eight holes	0.69	1.67	3.82	4.17	5.49	7.52	9.02
SEm (±)	0.31	0.40	0.50	0.50	1.14	0.71	1.24
F-value	Ns	Ns	Ns	Ns	Ns	Ns	Ns
$LSD_{0.05}$	-	-	-	-	-	-	-
CV, %	18.2	15.4	14.3	19.6	25	17.8	21.4
Grand mean	1.13	2.24	4.21	5.02	6.79	8.56	11.13

Means with same letter in column are not significantly different at p = 0.05 by DMRT. Ns = Not Significant, ** significant at p < 0.01, ***significant at p < 0.001 and ns: not significantly different at p > 0.05. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.3 Juice percentage

Juice percentage did not differed significantly ($p < 0.05$) among the different storage conditions at all days of data recording (Table 4). Juice percentage was found to decrease with the increase in storage duration in all storage conditions. At 60 DOS, the juice percentage of 31.68% was found to be the highest in cool chamber with CoolBot. Juice percentage differed significantly ($p < 0.05$) among the different plastic packaging at all days of storage (Table 4). At 45 DOS, the highest juice percentage of 36.23% was found in LDPE plastic packaging with eight holes.

The perforated plastic created the modified atmospheric environment acting as a barrier which reduced the moisture loss from the fruit attributed by low respiration and transpiration rate resulting in the higher juice percentage (Bhattarai & Shah, 2017). Ahamad and Siddiqui (2013) reported higher juice percentage in case of PE-packed fruits followed by the fruits with 100% Sta-Fresh 960 which might be due to less water loss in PE-packaging and waxing treatments as the combination acts as a barrier to moisture loss. Maximum juice percentage was observed in case of GA_3+ perforated polyethene (40.30%) compared to control (32.63%) during 24 DOS of mandarin (Paudel et al., 2020).

Table 4. Effect of storage conditions and plastic packaging on juice percentage of mandarin in storage.

Treatments	Juice Percentage			
	15 DOS	30 DOS	45 DOS	60 DOS
Storage conditions (Factor A)				
Room storage	39.47	35.81	33.52	31.17
Cellar storage	40.00	35.96	33.73	31.52
Cool chamber with CoolBot	41.08	36.62	34.20	31.68
SEm (±)	0.51	0.52	0.51	0.49
F-value	Ns	Ns	Ns	Ns
$LSD_{0.05}$	-	-	-	-
Plastic packaging (Factor B)				
Control	36.46^{c}	32.79^{c}	30.72^{d}	28.40^{c}

LDPE plastic with two holes	39.67^{b}	35.49^{b}	32.72^{c}	29.95^{bc}
LDPE plastic with four holes	39.88^{b}	36.33^{b}	33.88^{bc}	31.17^{b}
LDPE plastic with six holes	41.45^{b}	37.53^{ab}	35.54^{ab}	33.28^{a}
LDPE plastic with eight holes	43.45^{a}	38.52^{a}	36.23^{a}	34.48^{a}
SEm (±)	0.66	0.68	0.66	0.63
F-value	***	***	***	***
$LSD_{0.05}$	1.92	1.96	1.92	1.83
CV, %	5.0	5.6	5.9	6.0
Grand mean	40.18	36.13	33.82	31.45

Means with same letter in column are not significantly different at p = 0.05 by DMRT. Ns = Not Significant, ** significant at $p < 0.01$, ***significant at $p < 0.001$ and ns: not significantly different at $p > 0.05$. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.4 Total Soluble Solids(TSS)

TSS of fruits differed significantly ($p < 0.05$) among the different storage conditions at only 60 DOS but it did not differ significantly at 15 DOS, 30 DOS, and 45 DOS (Table 5). At 60 DOS, significantly the highest TSS was observed in the fruits at room condition with 13.67 ºBrix whereas significantly the lowest TSS was found in the fruits at cellar storage with 13.00 ºBrix.

At 60 DOS, the highest TSS of 14.19 ºBrix was found in control whereas the lowest TSS of 12.77 ºBrix was observed in LDPE plastic packaging with four holes. The increase in TSS with advancement of storage may be accounted to the moisture loss, hydrolysis of polysaccharides and concentration of juice as a result of dehydration. Hussain et al. (2016) also reported that the increase in TSS is attributed to the enzymatic conversion of higher polysaccharides such as starches and pectins into simple sugars during ripening.

Table 5. Effect of storage conditions and plastic packaging on TSS content of mandarin in storage.

Treatments	TSS (ºBrix)			
	15 DOS	30 DOS	45 DOS	60 DOS
Storage conditions (Factor A)				
Room storage	12.19	13.00	13.06	13.67^{a}
Cellar storage	12.45	12.80	12.92	13.00^{b}
Cool chamber with CoolBot	12.08	12.87	12.83	13.14^{b}
SEm (±)	0.21	0.11	0.12	0.11
F-value	Ns	Ns	Ns	***
$LSD_{0.05}$	-	-	-	0.33
Plastic packaging (Factor B)				
Control	12.63	13.07^{a}	13.73^{a}	14.19^{a}
LDPE plastic with two holes	12.31	12.73^{ab}	13.04^{b}	13.31^{b}
LDPE plastic with four holes	12.19	13.07^{a}	12.80^{bc}	12.77^{c}
LDPE plastic with six holes	12.01	12.47^{b}	12.70^{bc}	13.11^{bc}
LDPE plastic with eight holes	12.06	13.11^{a}	12.41^{c}	12.95^{bc}
SEm (±)	0.27	0.14	0.15	0.15

F-value	Ns	*	***	***
$LSD_{0.05}$	-	0.42	0.44	0.43
CV, %	6.5	3.3	3.5	3.3
Grand mean	12.24	12.89	12.94	13.27

Means with same letter in column are not significantly different at p = 0.05 by DMRT. NS = Not Significant, ** significant at p < 0.01, ***significant at p < 0.001 and ns: not significantly different at p > 0.05. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.5 Titratable acidity (TA)

Titratable acidity differed significantly ($p < 0.05$) among the different storage conditions at 15 DOS and 60 DOS but it did not differ significantly at 30 DOS and 45 DOS (Table 6). Minimum TA was observed in case of control and maximum TA was observed in case of LDPE plastic packaging with eight holes.

This might be due to the reason of combined effect of transpiration and TSS. TA was recorded maximum in case of LDPE plastic packaging with eight holes as compared to control which might be due to less oxidation of organic acids within the plastic package. The present findings are supported by Santos et al. (2020) and Rokaya et al. (2016).

Table 6. Effect of storage conditions and plastic packaging on TA of mandarin in storage.

Treatments	TA value (%)			
	15 DOS	30 DOS	45 DOS	60 DOS
Storage conditions (Factor A)				
Room storage	1.52^{b}	1.32	1.16	0.9^{b}
Cellar storage	1.46^{b}	1.31	1.20	1.09^{a}
Cool chamber with CoolBot	1.82^{a}	1.36	1.20	1.11^{a}
SEm (±)	0.05	0.04	0.01	0.04
F-value	***	Ns	Ns	***
$LSD_{0.05}$	0.14	-	-	0.11
Plastic packaging (Factor B)				
Control	1.47	1.27	1.14^{b}	0.88^{c}
LDPE plastic with two holes	1.62	1.44	1.20^{a}	1.02^{bc}
LDPE plastic with four holes	1.63	1.33	1.22^{a}	0.99^{bc}
LDPE plastic with six holes	1.62	1.32	1.17^{ab}	1.04^{b}
LDPE plastic with eight holes	1.65	1.30	1.21^{a}	1.22^{a}
SEm (±)	0.06	0.05	0.02	0.05
F-value	Ns	Ns	*	**
$LSD_{0.05}$	-	-	0.05	0.14
CV, %	11.8	12.2	4.5	14.2
Grand mean	1.6	1.33	1.19	1.03

Means with same letter in column are not significantly different at p = 0.05 by DMRT. Ns = Not Significant, ** significant at p < 0.01, ***significant at p < 0.001 and ns: not significantly different at p > 0.05. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.6 TSS/TA ratio

The ratio between TSS and TA differed significantly ($p < 0.05$) among the different storage conditions at 15 DOS and 60 DOS but did not differ significantly at 30 DOS and 45 DOS (Table 7). At 60 DOS, significantly the highest TSS/TA of 15.24 was found in the fruits kept at room while significantly the lowest TSS/TA of 11.43 was observed in the cool chamber with CoolBot. At 60 DOS, significantly the highest ratio of 15.95 was found in the control whereas the lowest ratio of 11.08 was observed in the fruits kept in LDPE plastic packaging with eight holes.

Table 7. Effect of storage conditions and plastic packaging on TSS/TA ratio of mandarin in storage.

Treatments	TSS/TA ratio			
	15 DOS	30 DOS	45 DOS	60 DOS
Storage conditions (Factor A)				
Room storage	8.12^{a}	9.97	11.40	15.24^{a}
Cellar storage	8.68^{a}	9.89	10.92	12.76^{b}
Cool chamber with CoolBot	6.79^{b}	9.56	10.88	11.43^{c}
SEm (±)	0.22	0.32	0.16	0.38
F-value	***	Ns	Ns	***
$LSD_{0.05}$	0.65	-	-	1.1
Plastic packaging (Factor B)				
Control	8.76^{a}	10.35	12.08^{a}	15.95^{a}
LDPE plastic with two holes	7.74^{b}	8.92	11.05^{b}	13.26^{b}
LDPE plastic with four holes	7.59^{b}	10.05	10.58^{b}	12.16^{bc}
LDPE plastic with six holes	7.61^{b}	9.52	11.10^{b}	13.27^{b}
LDPE plastic with eight holes	7.63^{b}	10.19	10.52^{b}	11.08^{c}
SEm (±)	0.29	0.42	0.21	0.49
F-value	*	Ns	***	***
$LSD_{0.05}$	0.87	-	0.61	1.42
CV, %	11.0	12.8	5.7	11.2
Grand mean	7.87	9.81	11.07	13.15

Means with same letter in column are not significantly different at p = 0.05 by DMRT. Ns = Not Significant, ** significant at $p < 0.01$, ***significant at $p < 0.001$ and ns: not significantly different at $p > 0.05$. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.7 pH of fruit juice

The pH of juice differed significantly ($p < 0.05$) among the different storage conditions at 15 DOS and 30 DOS but it did not differ significantly at 45 DOS and 60 DOS (Table 8). At 45 DOS, the lowest pH was found in cool chamber with CoolBot. At 60 DOS, the highest pH was observed in room condition whereas the lowest was observed in cellar storage. The pH of juice differed significantly ($p < 0.05$) among the different plastic packaging at 15 DOS and 45 DOS but did not differ significantly at 30 DOS and 60 DOS (Table 8). At 60 DOS, the highest pH of 4.47 was obtained in control.

Higher pH was observed in case of room storage which was due to higher TSS and lower acidity level. When the storage period proceeds ahead, the pH of juice was increased gradually under all the treatments. It may be due to the utilization of organic acids present in the fruit during respiration process. The phenomenon of increasing pH during storage might be due to oxidation of acids in respiration process resulting in higher pH which is supported by Islam et al. (2013).

Table 8. Effect of storage conditions and plastic packaging on pH of mandarin in storage.

Treatments	pH of fruit juice			
	15 DOS	30 DOS	45 DOS	60 DOS
Storage conditions (Factor A)				
Room storage	3.81[a]	4.29[a]	4.31	4.47
Cellar storage	3.68[b]	4.25[a]	4.28	4.30
Cool chamber with CoolBot	3.79[a]	4.08[b]	4.18	4.32
SEm (±)	0.027	0.03	0.05	0.06
F-value	**	***	Ns	Ns
$LSD_{0.05}$	0.08	0.09	-	-
Plastic packaging (Factor B)				
Control	3.83[a]	4.28	4.39[a]	4.47
LDPE plastic with two holes	3.76[abc]	4.15	4.14[bc]	4.45
LDPE plastic with four holes	3.80[ab]	4.22	4.12[c]	4.43
LDPE plastic with six holes	3.69[c]	4.13	4.24[abc]	4.14
LDPE plastic with eight holes	3.71[bc]	4.24	4.34[ab]	4.34
SEm (±)	0.03	0.04	0.07	0.08
F-value	*	Ns	*	Ns
$LSD_{0.05}$	0.10	-	0.19	-
CV, %	2.8	3.1	4.8	5.8
Grand mean	3.76	4.21	4.24	4.37

Means with same letter in column are not significantly different at p = 0.05 by DMRT. Ns = Not Significant, ** significant at $p < 0.01$, ***significant at $p < 0.001$ and ns: not significantly different at $p > 0.05$. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.8 Vitamin C (Ascorbic acid)

The vitamin C content of juice differed significantly ($p < 0.05$) among the different storage conditions at 30 DOS and 60 DOS but it did not differ significantly at 15 DOS and 45 DOS (Table 9). The reduction in vitamin C during storage is due to the reason that vitamin C is highly sensitive to oxidation (Ajibola et al., 2009). Greater amount of vitamin C at cool chamber with CoolBot might be due to low temperature at Cool chamber with CoolBot, retarding the oxidation of vitamin C. Modified atmospheric packaging (MAP) is able to maintain a low O_2 concentration around the atmosphere of the fruit during storage, thereby retarding the oxidation of ascorbic acid (Lee et al., 2015). Reddy et al.(2008) also observed that the highest level of vitamin C content of acid lime was maintained at LDPE packaging. LDPE packaging was found to reduce the rate of decrease in vitamin C content (Poudel et al., 2021).

Table 9. Effect of storage conditions and plastic packaging on vitamin C content of mandarin in storage.

Treatments	Vitamin C content(mg/100 g)			
	15 DOS	30 DOS	45 DOS	60 DOS
Storage conditions (Factor A)				
Room storage	31.80	29.64^{b}	27.84	25.30^{b}
Cellar storage	31.93	30.56^{ab}	28.38	25.87^{b}
Cool chamber with CoolBot	32.44	30.87^{a}	29.48	27.29^{a}
SEm (±)	0.24	0.33	0.55	0.40
F-value	Ns	*	Ns	**
$LSD_{0.05}$	-	0.98	-	1.17
Plastic packaging (Factor B)				
Control	30.63^{c}	27.67^{d}	25.00^{c}	22.22^{d}
LDPE plastic with two holes	31.70^{b}	29.70^{c}	27.52^{b}	24.44^{c}
LDPE plastic with four holes	31.89^{b}	30.56^{bc}	28.85^{ab}	26.22^{b}
LDPE plastic with six holes	32.34^{b}	31.52^{ab}	30.50^{a}	28.76^{a}
LDPE plastic with eight holes	33.74^{a}	32.33^{a}	30.96^{a}	29.11^{a}
SEm (±)	0.31	0.43	0.71	0.52
F-value	***	***	**	***
$LSD_{0.05}$	0.91	1.26	2.05	1.51
CV, %	2.9	4.3	7.5	6.0
Grand mean	32.06	30.36	28.57	26.15

Means with same letter in column are not significantly different at p = 0.05 by DMRT. Ns = Not Significant, ** significant at $p < 0.01$, ***significant at $p < 0.001$ and ns: not significantly different at $p > 0.05$. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.9 Index of absorbance difference (IAD)

Index of absorbance difference (IAD) did not differ significantly among the different storage conditions at all days of storage (Table 10). IAD differed significantly ($p < 0.05$) among the different plastic packaging at 15 DOS, 45 DOS, and 60 DOS (Table 10). At 45 DOS and 60 DOS, significantly the highest IAD value of 0.117 and 0.0074 was observed in the LDPE plastic packaging with six holes. IAD values of peaches on-tree ripening were correlated with the amount of ethylene emitted (Spadoni et al., 2016). In our study, IAD value was observed low in case of room storage compared to cellar and cool chamber with CoolBot, which might be due to the reason that room storage allowed rapid degradation of chlorophyll due to higher temperature as Chlorophyll a is heat sensitive in nature.

Table 10. Effect of storage conditions and plastic packaging on index of absorbance difference of mandarin in storage.

Treatments	Index of absorbance difference (IAD)			
	15 DOS	30 DOS	45 DOS	60 DOS
Storage conditions (Factor A)				
Room storage	0.29	0.12	0.063	0.0024
Cellar storage	0.32	0.13	0.064	0.0033

Cool chamber with CoolBot	0.35	0.19	0.062	0.0039
SEm (±)	0.02	0.02	0.014	0.0011
F-value	Ns	Ns	Ns	Ns
$LSD_{0.05}$	-	-	-	-
Plastic packaging (Factor B)				
Control	0.19^{c}	0.11	0.039^{b}	0.0009^{b}
LDPE plastic with two holes	0.36^{ab}	0.15	0.077^{ab}	0.0041^{ab}
LDPE plastic with four holes	0.41^{a}	0.15	0.040^{b}	0.0012^{b}
LDPE plastic with six holes	0.30^{b}	0.16	0.117^{a}	0.0074^{a}
LDPE plastic with eight holes	0.31^{b}	0.14	0.042^{b}	0.0024^{b}
SEm (±)	0.03	0.026	0.018	0.0014
F-value	**	Ns	*	*
$LSD_{0.05}$	0.09	-	0.054	0.004
CV, %	11.2	12.2	14.9	13.5
Grand mean	0.32	0.14	0.063	0.0032

Means with same letter in column are not significantly different at $p = 0.05$ by DMRT. Ns = Not Significant, ** significant at $p < 0.01$, ***significant at $p < 0.001$ and ns: not significantly different at $p > 0.05$. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.10 Citrus color index (CCI)

Citrus color index (CCI) of mandarin differed significantly ($p < 0.05$) among the different storage conditions at 15 DOS and 45 DOS but it did not differ significantly at 30 DOS and 60 DOS (Table 11). The color values L, a, b showed a good correlation with the maturity stage of the tomato (Bui et al., 2010). In our study, greater value of citrus color index in LDPE plastic packaging with eight holes showed proper and uniform color development. It might be due to proper air circulation from the holes creates freshness of fruit with glossy appearance.

Table 11. Effect of storage conditions and plastic packaging on citrus color index of mandarin in storage.

Treatments	Citrus color index (CCI)			
	15 DOS	30 DOS	45 DOS	60 DOS
Storage conditions (Factor A)				
Room storage	10.35^{b}	11.93	12.69^{ab}	11.28
Cellar storage	11.44^{a}	12.00	12.14^{b}	11.10
Cool chamber with CoolBot	11.46^{a}	12.32	13.23^{a}	11.56
SEm (±)	0.08	0.17	0.19	0.17
F-value	***	Ns	**	Ns
$LSD_{0.05}$	0.24	-	0.55	-
Plastic packaging (Factor B)				
Control	9.78^{e}	11.49^{b}	11.94^{c}	10.99
LDPE plastic with two holes	10.74^{d}	11.51^{b}	12.55^{bc}	11.23

LDPE plastic with four holes	11.34[c]	12.52[a]	12.68[bc]	11.43
LDPE plastic with six holes	11.69[b]	12.35[a]	12.77[b]	11.37
LDPE plastic with eight holes	12.04[a]	12.54[a]	13.51[a]	11.56
SEm (±)	0.10	0.22	0.24	0.22
F-value	***	**	**	Ns
$LSD_{0.05}$	0.31	0.63	0.71	-
CV, %	2.9	5.4	5.8	5.9
Grand mean	11.11	12.08	12.69	11.31

Means with same letter in column are not significantly different at p = 0.05 by DMRT. Ns = Not Significant, ** significant at p < 0.01, ***significant at p < 0.001 and ns: not significantly different at p > 0.05. SEm± = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variation and DOS = Days of storage

3.11 Shelf Life

The maximum shelf life was observed in case of LDPE plastic packaging with eight holes in cool chamber with CoolBot (91 days) and the minimum shelf life was observed in case of control in room storage (32 days). In a study on mandarin, maximum shelf life of 48 days was observed in case of GA3(100ppm) + perforated polyethene compared to control under room condition (Paudel et al., 2020).

IV. CONCLUSION

This study showed that the use of eight-hole polyethylene bags combined with CoolBot storage was effective in preserving the postharvest quality of mandarin fruits by minimizing physiological loss and maintaining nutritional content. The combination extended shelf life significantly compared to ambient conditions and non-ventilated packaging. Further research across multiple seasons and commercial storage settings is recommended to validate these findings.

ETHICAL STATEMENT

Not applicable as the study does not require any ethical approval.

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The authors have no relevant financial and non-financial interests to disclose. The authors declare that they have no competing interests.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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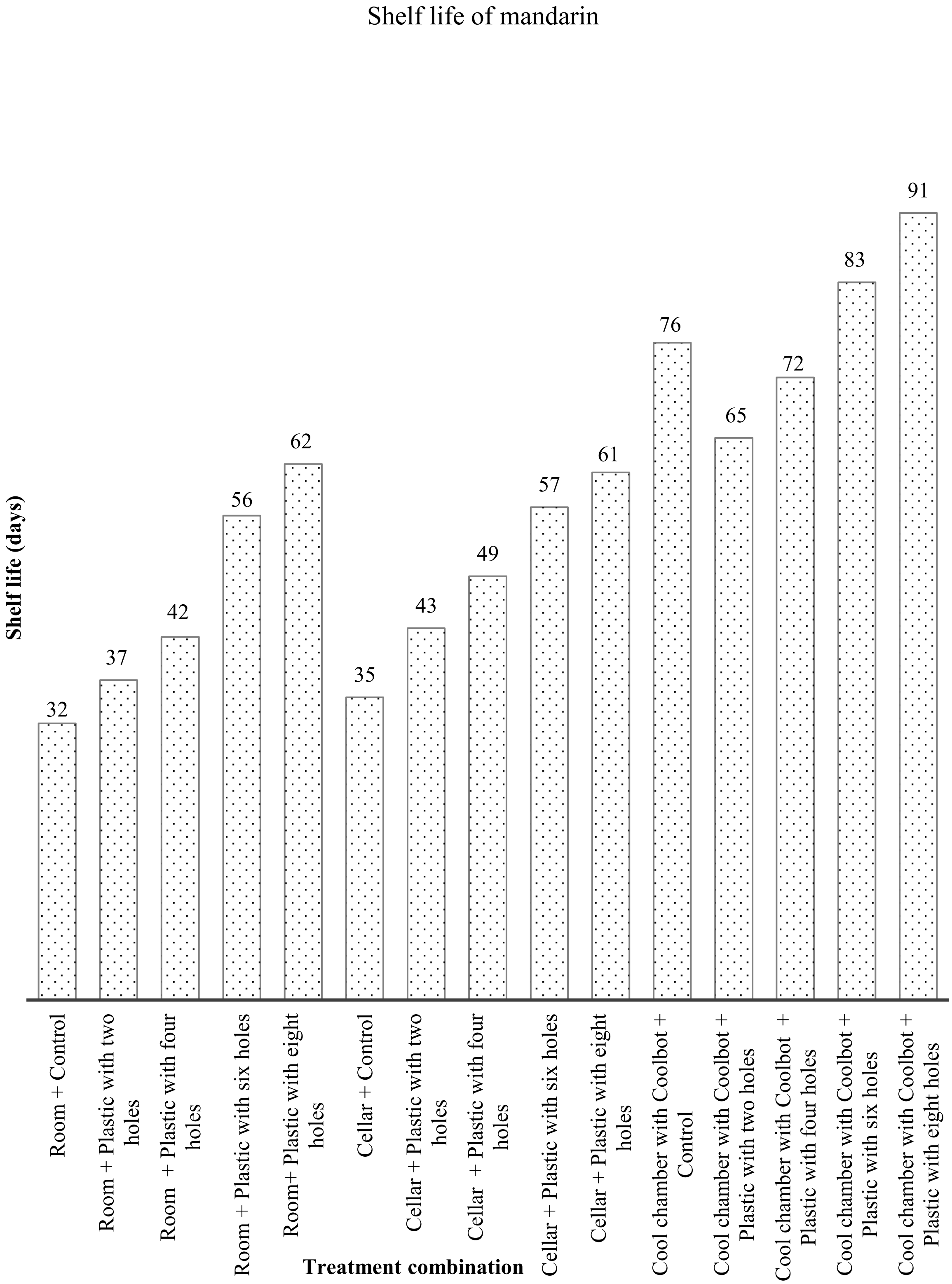

Fig.1. Shelf life of mandarin under different storage conditions and plastic packaging

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Glossary

NCRP : National Citrus Research Program
RCBD : Randomized Complete Block Design
RH : Relative Humidity
% : Percentage
^{0}C : Degree celsius
TSS : Total Soluble Solid
TA : Titratable Acidity
pH : Potential of hydrogen
DA meter : Delta absorbance meter
DOS : Days of Storage
GDP : Gross Domestic Product
AGDP : Agriculture Gross Domestic Product
PMD : Project Management Directorate
TEPC : Trade and Export Promotion Centre
APP : Agriculture Perspective Plan
MAP : Modified atmosphere packaging
U.S. : United States
MoALD : Ministry of Agriculture and Livestock Development
g : gram
mg : milligram
m : metre
cm : centimetre
mm : millimetre
ml : millilitre
mt : metric ton
LDPE : Low density polyethylene