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PROLONGING THE STORAGE PERIOD AND SHELF LIFE OF EARLIGRANDE PEACH FRUIT USING SOME POSTHARVEST TREATMENTS

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ABSTRACT

This study was conducted to extend the storage and shelf life of the EarliGrande peach fruits by applying some postharvest treatments under cold storage during two successive seasons 2021 and 2022. Peach fruits were dipped in 10% citric acid, 6% $CaCl_2$, hot water (45°C), and 2%chitosan, either alone or in combinations as well as distilled water' control' for 10 min. Results showed that the fruit weight loss, TSS content, total sugar, total phenol, and enzyme activity increased in all treatments with a longer cold storage period(28 days) and increased shelf- life to the ninth day, except the phenol content, which decreased at the end of the shelf -life period. The fruit firmness, titratable acidity, flavonoid, DPPH (%), and ascorbic acid decreased gradually with increased cold storage and shelf-life period. There was no microorganism decay (%) observed on treated and untreated fruits during 28 days of cold storage, but it appeared during the shelf-life period. During the cold storage period, the lowest weight loss, besides the highest values of fruit firmness, ascorbic acid, flavonoid, and DPPH (%) were gained by treated fruits with chitosan 2%+$CaCl_2$ 6% treatment. Moreover, the chitosan 2%+ hot water(45°C) was superior in inhibiting fruit decay to a minimum percentage during the shelf-life period. No significant difference was found between chitosan 2%+ hot water (45°C) and chitosan 2%+$CaCl_2$ 6% in slowing down weight loss. The treatment with chitosan 2%+$CaCl_2$ 6% efficiently inhibited the enzyme activity of MDA and PPO, while also maintaining the highest values of DPPH activity (%), phenol content, and ascorbic acid content.

INTRODUCTION

Peaches (*Prunus persica*) belong to the Rosaceae family **(Kaur and Kaur, 2019)**. Global production was around 26 million ton **(FAOSTAT, 2023)** however, Egypt produced approximately 277 thousand ton **(MALR, 2023)**. The fruits are juicy and have high nutritional value because they contain organic acids, antioxidants, and fiber, which has increased the fruit demand locally and regionally **(Khan, 2015)**. Peach fruits ripen quickly in the field due to the unusually high temperatures during fruit growth on the trees. Additionally, peaches belong to climacteric fruits, which means their maturity continues to increase after harvest, leading to a short storage life and quick spoilage **(Nunes, 2008)**.

Under traditional conditions, the life of peach fruit does not exceed 5-7 days. Fruits are exposed to some physiological damage such as mechanical damage, fungal and bacterial infections, wilting, softening, weight loss, and degradation of organic components, resulting in a loss of quality **(Hodges *et al.*, 2011)**. Thus, cold storage is used to prolong fruit shelf -life to ensure a regular supply to markets and for exports. It

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is an effective method for preserving the quality of fruits and preventing weight loss **(Kader, 1992)**, but sometimes it may lead to damage to fruit cells **(Crisosto *et al.*, 1999)**. To extend the fruit shelf -life some researchers have developed post-harvest treatments to minimize the basic damage of storage besides chilling injury. One of these treatments is the edible coating using organic materials (chitosan, *etc*.) and safe chemical materials (citric acid, calcium chloride, *etc*.) or dip the fruits into hot water. These treatments reduce fruit respiration, prevent fruit decay, and delay fruit senescence.

Chitosan, derived from chitin, forms an edible coating on fruits **(Rinaudo, 2006)**. This coating creates a modified atmosphere by regulating gas exchange and reducing transpiration. These actions help maintain fruit quality, control weight loss, reduce post-harvest decay, and prolong shelf- life **(Mohamed *et al.*, 2019)**. Besides, chitosan has antimicrobial properties, which protect against pathogens during cold storage **(El-Ghaouth *et al.*, 1991)**. Some studies have used chitosan during the post-harvest of fruits such as peaches (**El-Badawy, 2012)**, and plums **(Bal, 2013)**. They found that chitosan has enhanced organic components, antioxidant activity, reduced decay, maintained firmness, and decreased fruit weight loss. Moreover, hot water treatment is a safe and cost-effective method for reducing post-harvest damage in fruits. It helps to prevent the growth of pathogens, reduce decay, and lower the accumulation of reactive oxygen species (ROS) **(Lu *et al.*, 2010)**. When followed by cold storage, heat treatment can also decrease chilling injuries and improve overall quality **(McDonald *et al.*, 1999)**. Previous studies indicated that applying hot water treatment before storage is a beneficial strategy for maintaining fruit quality with less damage, enhancing antioxidant activity, decreasing symptoms of internal browning, and extending shelf-life **(Sadiqullah *et al.*, 2023)**.

Calcium plays a crucial role in preserving fruit quality and post-harvest life. Its application can delay senescence, prevent diseases, reduce fruit softening, and increase storage life. Calcium also helps maintain tissue firmness and reduces weight loss during storage **(Gupta *et al.*, 2011; Mosie, 2019)**. Treated peaches with $CaCl_2$ at different concentrations kept a maximum value of firmness, improved TSS (%), acidity, vitamin C, and reduced decay percentage and weight loss compared with the control treatment **(Dorostkar *et al.*, 2022)**. Additionally, citric acid is a natural antioxidant and has been shown to improve fruit quality and shelf-life **(El-Kobisy *et al.*, 2005)**. It increases the activity of antioxidant enzymes while reducing polyphenol oxidase (PPO) activity and free radical content. Citric acid also prevents browning, maintains fruit firmness, and reduces the growth of bacteria and fungi **(Pilizota and Sapers, 2004)**. Recent research has shown that citric acid improves the quality and self- life of peach fruit **(Yang *et al.*, 2019; Alali *et al.*, 2023)**.

Therefore, this study aimed to evaluate the impact of some environmentally safe postharvest treatments on the quality and the prolonging the shelf- life of EarliGrande peaches during cold storage.

MATERIAL AND METHODS

The present study was conducted on sex-year-old EarliGrande peach trees grown at Sheikh Zuweid, North Sinai, Egypt during 2021 and 2022 seasons, budded on bitter almond rootstock planted at 6 × 6 m apart on sandy soil. The trees received the same annual horticultural practices and depended on a rainwater irrigation system. Fruits were harvested at the proper maturity, with similar circumference (55 - 60 mm) and color, while immature and damaged or infected fruits were excluded. Initially, the fruits were immersed in cold distilled water (10°C) for 15 min as a pre-cooling, and to remove dust and any surface contamination.

The fruits were air-dried and randomly divided into eight groups (eight treatments) by immersing the peaches for 10 min into distilled water (control), citric acid solution (10%), $CaCl_2$ solution (6%), hot water (45°C), chitosan solution (2%; Chitosan® Egypt Co., Egypt), a mixture of chitosan (2%) + citric acid (10%), a mixture of chitosan (2%) + $CaCl_2$ (6%), and chitosan solution (2%) at 45°C. Fourteen fruits were used for each treatment which was replicated three times by completely randomized design (CRD).

Peaches were left to air-dried and were placed in plastic boxes with perforated tops inside carton boxes. All boxes were stored at 0±1°C and 90-95 % R.H for 28 days of cold storage period. The physical and chemical properties of fruits from each treatment were measured at 0 days then every 7 days until the 28th day of the cold storage period. The rest of remaining treated fruits were placed on a laboratory shelf at 25±4 °C for 9 days to simulate shelf life. The shelf -life of the fruits was determined by counting number of days without spoilage until 50% damage occurred. The physicochemical properties were measured in unspoiled fruits after 3, 6, and 9 days of the shelf- life period.

Physical Fruit Properties

The fruit weight loss (%) was determined based on the initial fruit weight and expressed as a percentage according to the following equation:

$$FWL\% = \frac{Wi - Ws}{Wi} \times 100$$

Where, Wi= fruit weight at the initial period and Ws= fruit weight at the sampling period.

The fruit decay (%) was calculated by counting the number of spoiled fruits in each treatment and expressed as a percentage according to the following equation:

$$Decay\ fruit\ (\%) = \frac{No.\ of\ spoiled\ fruits}{total\ No.\ of\ fruits} \times 100$$

The firmness of fruits was measured using a penetrometer at two opposite sides of the fruit, and the results were expressed as Newton.

Chemical Fruit Properties

The peach fruit juice was used to determine total soluble solids (%) by a manual refractometer, ascorbic acid (mg/ 100 g) by 2, 6-dichlorophenol method, and total titratable acidity using sodium hydroxide (0.1N) which expressed as malic acid (%) according to **AOAC (2005)**. Total anthocyanin content (mg/100g fresh weight) was extracted from fruit skin and measured at 535 nm wavelength **(Mazumadar and Majumder, 2003)**. The total sugar (%) was assessed by anthrone-H_2SO_4 reaction **(Fales, 1951)**, and reducing sugar (%) by the 2,4-dinitrophenol methods of **(Ross, 1959)**. The total phenolic content in peach fruit was analyzed with a Folin-Ciocalteu assay **(Singleton *et al.*, 1999).** Flavonoid content was determined by the colorimetric method of **Zou *et al.* (2004)**. DPPH radical scavenging assay (%) was determined calorimetrically on the method described by **Brand-Williams *et al.*, (1995)**. Using spectrophotometrically methods, Malondialdehyde activity **(Yang *et al.*, 2010)** and Polyphenol oxidase activity **(Zhang and Xingfeng, 2015)** were estimated in the alcohol extract of peach fruit.

Statistical Analysis

The obtained data were subjected to statistically analyzed using Co-STAT® software. The means were separated using Duncan's test at a 0.05 level **(Steel *et al.*, 1997)**.

RESULTS AND DISCUSSION

Physical Fruit Properties

Fruit weight loss (%)

Significant differences (P≤0.05) in peach fruit weight loss were detected among the different post-harvest treatments and control. As increasing time of cold storage increased from 0 to 28 days the weight loss percentage in peach fruits increased. This finding was true during the two experimental seasons of 2021 and 2022 during the cold storage period (Table 1). The control recorded the highest average weight loss (11.69 and 13.16%) in 1st and 2nd seasons, in comparison with the treated fruits. Untreated fruits achieved an increase in fruit mass loss of about 7.09%, 10.16%, 12.52%, and 17.02% in the first season, and 9.23%, 13.75%, 12.07%, and 17.59% in the second season, at 7, 14, 21, and 28 days of the cold storage period. The results showed that the chitosan 2%+ $CaCl_2$ 6% treatment was more effective in maintaining the fruit weight during the cold storage period. The coated fruits with chitosan 2%+ $CaCl_2$ 6% recorded the lowest mass loss percentage (0.74, 1.67, 5.39%, and 10.38%) in the first season, and (3.62, 3.60, 5.28 and 7.13%) in the second season, at 7, 14, 21, and 28 days of the cold storage period.

The same trend was observed during the shelf -life. A decrease in fruit weight was increased significantly with the control treatment but treated fruits with chitosan 2% + $CaCl_2$ 6% followed by chitosan 2% + hot water (45°C) slowed down the weight loss rate. In addition, in both experimental seasons, fruit weight loss increased significantly as shelf life increased from 3 days to 9 days. On the ninth day, the highest weight loss was recorded in untreated fruits (52.46 and 42.57%) in both seasons, respectively.

During the ripening of peach fruits, an internal breakdown occurs in which organic and inorganic components are consumed through respiration, and moisture is lost through evaporation, resulting in the fruits losing weight as the storage period increases. In the present study, the combination of chitosan and calcium chloride formed an optimal coating that effectively reduced the weight loss rate. This suggests that chitosan and calcium had the potential to minimize moisture loss during storage and delay dehydration. The chitosan layer decreased water loss from the fruit peel, while calcium chloride enhanced the firmness of the cell walls and shielded them from pathogen infiltration **(Ribeiro *et al.*, 2007)**. A similar trend was observed in peach, where the combination of chitosan (1%) with calcium chloride (4%) was superior in reducing weight loss to 9% compared to 13% in the control group **(El-Badawy, 2012)**. Also, a study conducted by **Hernandez-Munoz *et al.* (2008)** on strawberries revealed that untreated fruits experienced a weight loss of 29% in comparison with chitosan-coated fruits (1.5%) loss of 14% from weight at the end of cold storage.

Fruit decay (%)

Results presented in Table 2 reveal that no microorganism decay was visually observed on fruits during the 28 days of cold storage among all fruit coating treatments and the control treatment in both seasons. On the other hand, the control treatment recorded the highest fruit decay percentage within the shelf-life period, whilst the chitosan 2%+ hot water (45°C) treatment recorded the lowest percentage in the 1st and 2nd seasons. No significant difference was found among chitosan 2%+ hot water (45°C) and chitosan 2%+ $CaCl_2$ 6% treatment in the first season in fruit decay (%). It was noticed that no significant differences were found between cold storage periods. Furthermore, it was noticed that the percentage of fruit decay was increased with increasing prolonged periods of shelf-life treatments from (4.16% and 4.86%) at 0 days to (22.22% and 26.38%) at 9 days in 1st and 2nd seasons, respectively.

The results indicated that the fruits remained without damage during cold storage, unlike during their time on the shelf-life period. Cooling and post-harvest treatments played a crucial role in preventing spoilage. Treated fruits with 2% chitosan at 45°C had the lowest fruit decay rate. This decrease in spoilage may be due

Table 1. Effect of some environmentally safe post-harvest treatments on fruit weight loss during cold storage and shelf-life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	0.00 a	7.09 a	10.16a	12.52 a	17.02 a	**11.69 a**	22.01 a	37.22 a	52.46 a	**37.23 a**
Citric acid 10%	0.00 a	5.91 b	5.50 b	12.40 a	12.59 b	**9.10 b**	19.31ab	28.01 b	40.40 b	**29.24 b**
$CaCl_2$ 6%	0.00 a	6.38 ab	5.74 b	11.34ab	10.28 d	**8.43 b**	16.07 b	27.20 b	42.01 b	**28.43bc**
Hot water (45°C)	0.00 a	1.11 c	1.61 d	11.30ab	10.39 d	**6.10 cd**	15.83 b	21.99 cd	40.29 b	**26.03bc**
Chitosan 2%	0.00 a	1.53 c	2.14 c	8.95 bc	12.85 b	**6.37 c**	17.36ab	24.78 bc	38.30 b	**26.81bc**
Chitosan 2%+ Citric acid 10%	0.00 a	1.52 c	1.95 c	9.70abc	11.01 c	**6.05 cd**	15.43 b	22.27 cd	38.09 b	**25.26 c**
Chitosan 2%+ $CaCl_2$ 6%	0.00 a	0.74 d	1.67 d	5.39 d	10.38 d	**4.55 d**	16.30ab	23.75bcd	25.52 c	**21.86 d**
Chitosan 2%+ Hot water (45°C)	0.00 a	1.41 c	1.18 d	7.79 cd	10.06 d	**5.11 cd**	13.43 c	19.58 d	28.06 c	**20.36 d**
Mean	**0.00 d**	**3.21 c**	**3.74 c**	**9.92 b**	**11.82 a**		**16.97 c**	**25.mk60 b**	**38.14 a**	
Season 2022										
Control (Distilled water)	0.00 a	9.23 a	13.75a	12.07 a	17.59 a	**13.16 a**	24.23 a	29.46 a	42.57 a	**32.08 a**
Citric acid 10%	0.00 a	8.04 ab	7.63bc	11.40 a	13.99 ab	**10.26ab**	17.67 b	23.49 b	32.98 b	**24.71 b**
$CaCl_2$ 6%	0.00 a	4.49abc	9.65ab	11.21 a	8.68 cd	**8.50 bc**	12.12cd	20.59 bc	27.69cd	**20.13 c**
Hot water (45°C)	0.00 a	8.54 ab	7.27bc	11.27 a	11.06 bc	**9.53 b**	16.10bc	19.12 c	25.85 d	**20.35 c**
Chitosan 2%	0.00 a	4.47abc	6.57bc	11.15 a	10.15bcd	**8.09bcd**	10.90 d	19.14 c	31.01bc	**20.35 c**
Chitosan 2%+ Citric acid 10%	0.00 a	4.09 bc	2.80 c	6.36 bc	9.54 cd	**5.70 cd**	10.30 d	18.97 c	25.78 d	**18.35cd**
Chitosan 2%+ $CaCl_2$ 6%	0.00 a	3.62 c	3.60 c	5.28 c	7.13 cd	**4.91 d**	9.46 d	16.48 c	24.91 d	**16.95 d**
Chitosan 2%+ Hot water (45°C)	0.00 a	2.67 c	4.53bc	7.89 b	6.67 d	**5.44 cd**	10.67 d	17.59 c	24.63 d	**17.63cd**
Mean	**0.00 d**	**5.65 b**	**6.97 b**	**9.58 a**	**10.60 a**		**13.93 c**	**20.60 b**	**29.43 a**	

- The means were significantly different at the 0.05 probability level.

Table 2. Effect of some environmentally safe post-harvest treatments on fruit decay during cold storage and shelf-life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	22.22 a	55.55 a	77.77 a	**51.85 a**
Citric acid 10%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	11.11 b	22.22 b	44.44 b	**25.92 b**
$CaCl_2$ 6%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	11.11 bc	22.22 c	**11.11 c**
Hot water (45°C)	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	0.00 c	5.55 de	**1.85 d**
Chitosan 2%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	11.11 bc	16.67 cd	**9.26 c**
Chitosan 2%+ Citric acid 10%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	22.22 b	11.11 cde	**11.11 c**
Chitosan 2%+ $CaCl_2$ 6%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	0.00 c	0.00 e	**0.00 d**
Chitosan 2%+ Hot water (45°C)	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	0.00 c	0.00 e	**0.00 d**
Mean	**0.00 a**	**0.00 a**	**0.00 a**	**0.00 a**	**0.00 a**		**4.16 c**	**15.27 b**	**22.22 a**	
Season 2022										
Control (Distilled water)	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	27.77 a	44.44 a	83.33 a	**51.84 a**
Citric acid 10%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	5.55 b	16.66 b	44.44 b	**22.22 b**
$CaCl_2$ 6%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	11.11 b	16.67 c	**9.26 c**
Hot water (45°C)	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	5.55 c	16.66 c	**7.41 c**
Chitosan 2%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	5.55 b	11.11 b	22.22 c	**12.96 bc**
Chitosan 2%+ Citric acid 10%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	5.55 c	22.22 c	**9.26 c**
Chitosan 2%+ $CaCl_2$ 6%	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	0.00 d	5.55 d	**1.85 d**
Chitosan 2%+ Hot water (45°C)	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	**0.00**	0.00 c	0.00 d	0.00 d	**0.00 e**
Mean	**0.00 a**	**0.00 a**	**0.00 a**	**0.00 a**	**0.00 a**		**4.86 c**	**11.80 b**	**26.38 a**	

- The means were significantly different at the 0.05 probability level.

to reduce enzyme activity, fruit softening, and fruit respiration rate **(Kviklienė and Valiuškaitė, 2009)**, likely attributable to the hot water treatment and chitosan coating. Hot water treatment and chitosan coating reduced pathogen levels, disease development, and limited enzymatic browning **(Tsouvaltzis *et al.*, 2011)**. The results align with **Zhang *et al*., (2010)** and **Al-Bamarny and Ahmed (2017)**, who showed that hot water treatment at 45°C or 55°C decreased disease incidence. Likewise, **Bal (2013)** found that immersing plum fruits in chitosan had a decay rate of 5.7%, compared to 33% for untreated fruits.

Fruit firmness (N)

Results in Table 3 indicate that treated fruits with a post-harvest coated treatment maintained higher fruit hardness compared to the control. Minimum mean fruit firmness (44.42 and 42.53 Newton) was recorded with non-treated fruits (control) after 28 days of cold storage in 1st and 2nd seasons, respectively which decreased gradually to 55.84, 52.17, 54.04, and 24.64 Newton in the first season, and 58.80, 47.42, 35.35, and 28.55 Newton in the second season after 7, 14, 21, and 28 days of cold storage. However, peach fruits were treated with chitosan 2% mixed with citric acid 10%, $CaCl_2$ 6%, or with hot water (45°C) recorded high mean firmness values (56.89, 57.22, and 58.73 N) in the first season compared with the initial value (67.40 N). In the second season, chitosan 2%+ $CaCl_2$ 6% treatment gave the highest fruit firmness (59.05 N) compared with the initial value (73.18 N).

A similar trend of fruit firmness was shown during the shelf-life period. Minimum mean fruit firmness (7.25 and 4.76 N) was recorded with control treatment, while the maximum mean fruit firmness (21.52 and 19.03 N) was recorded with chitosan 2%+ $CaCl_2$ 6% treatment in the 1st and the 2nd seasons, respectively. Meanwhile, the maximum loss in fruit firmness (40.10 and 38.14 N) was observed on the twenty-eighth day of cold storage in both seasons, respectively. Under shelf -life conditions, the ninth day recorded the lowest values of fruit firmness (4.67 and 4.33 N) in 1st and 2nd seasons, respectively.

The peach is a climacteric fruit that undergoes a sudden increase in respiration and ethylene production, leading to accelerate fruit ripening and the activation of degrading enzymes that soften the fruit cell walls. However, post-harvest treatments such as a 2% chitosan and 6% $CaCl_2$ mixture solution can decrease respiration and ethylene production to minimal levels, as confirmed by the results of a recent study. This effect may be attributed to the role of calcium in enhancing cell wall rigidity and cohesion through binding to pectin compounds **(White and Broadley, 2003)**. Moreover, chitosan helps maintain the firmness of peach fruits during storage by forming an insulating layer on the fruit surface, reducing gas exchange and inhibiting respiration, thus preserving fruit hardness **(Reddy *et al.*, 2000; Peian *et al.*, 2021)**. These findings are supported by previous studies on cv. Flordaprince peaches **(Kaur and Kaur, 2019)**, demonstrated that treating fruits with $CaCl_2$ solution resulted in the highest firmness retention. Furthermore, applying a combination of 1% chitosan and 2% $CaCl_2$ led to significantly higher fruit firmness **(Gayed *et al.*, 2017)**.

Chemical Fruit Properties

Total soluble solids content (TSS%)

TSS content of peaches increased significantly during the cold storage days irrespective of post-harvest treatments and were decreased thereafter during the shelf-life period. Untreated peach fruits exhibited a statistically higher average in TSS content (12.36 and 13.55%) in 1st and 2nd seasons respectively under cold storage compared to the other treatments. The TSS content were different after 7, 14, 21, and 28 days about

Table 3. Effect of some environmentally safe post-harvest treatments on fruit firmness (Newton) during cold storage and shelf life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	67.40 a	55.84 c	52.17 c	45.04 c	24.64 c	**44.42 c**	15.64 d	5.44 f	0.68 d	**7.25 f**
Citric acid 10%	67.40 a	65.12 ab	61.18abc	49.45abc	38.41b	**53.54b**	24.47 c	9.52 de	1.36 d	**11.78 d**
$CaCl_2$ 6%	67.40 a	59.99abc	54.72 bc	53.74 ab	43.17b	**52.90b**	24.81 c	11.56cd	4.76bc	**13.71 c**
Hot water (45°C)	67.40 a	58.97abc	57.64abc	48.78 bc	39.77b	**51.29b**	19.71 d	6.80 ef	2.72cd	**9.74 e**
Chitosan 2%	67.40 a	58.63 bc	56.42abc	52.45abc	41.98b	**52.37b**	25.66bc	8.16 ef	3.40cd	**12.41cd**
Chitosan 2%+ Citric acid 10%	67.40 a	66.57 a	64.58 a	53.60 ab	42.83b	**56.89 a**	29.57ab	12.92bc	5.44bc	**15.98 b**
Chitosan 2%+ $CaCl_2$ 6%	67.40 a	66.62 a	65.26 a	56.89 a	40.11 b	**57.22 a**	32.63 a	19.71 a	12.24a	**21.52 a**
Chitosan 2%+ Hot water (45°C)	67.40 a	64.24 ab	64.24 ab	56.55 a	49.90 a	**58.73 a**	29.91ab	14.96 b	6.80 b	**17.22 b**
Mean	**67.40 a**	**62.00 b**	**59.53 b**	**52.06 c**	**40.10d**		**25.30 a**	**11.13 b**	**4.67 c**	
Season 2022										
Control (Distilled water)	73.18 a	58.80 d	47.42 d	35.35 c	28.55d	**42.53 e**	10.20 e	4.08 d	0.00 e	**4.76 g**
Citric acid 10%	73.18 a	61.86 c	60.50 c	45.72 b	36.03 c	**51.03d**	19.37 d	8.84 c	2.72 d	**10.31 f**
$CaCl_2$ 6%	73.18 a	65.94 b	63.22 bc	45.55 b	38.41 c	**53.28 c**	25.15 c	9.52 c	4.76bc	**13.14 d**
Hot water (45°C)	73.18 a	65.26 b	61.86 bc	45.89 b	37.39 c	**52.60 c**	21.07 d	9.52 c	2.72 d	**11.10 ef**
Chitosan 2%	73.18 a	64.58 bc	61.18 bc	48.61 b	36.30 c	**52.67 c**	23.79 c	7.48 c	4.08cd	**11.78 e**
Chitosan 2%+ Citric acid 10%	73.18 a	67.30 ab	63.90 b	55.74 a	41.64b	**57.14b**	29.23 b	12.92 b	6.12ab	**16.09 c**
Chitosan 2%+ $CaCl_2$ 6%	73.18 a	69.34 a	67.30 a	54.38 a	45.21 a	**59.05 a**	33.99 a	15.64 a	7.48 a	**19.03 a**
Chitosan 2%+ Hot water (45°C)	73.18 a	67.30 ab	63.90 b	55.06 a	41.64b	**56.97b**	32.63 a	13.60 b	6.80 a	**17.67 b**
Mean	**73.18 a**	**65.04 b**	**61.16 c**	**48.28 d**	**38.14e**		**24.43 a**	**10.19 b**	**4.33 c**	

▸ The means were significantly different at the 0.05 probability level.

10.66, 12.13, 11.73 and 14.93% in the 1st season, and 13.33, 13.00, 14.00, and 13.86% in the 2nd season, respectively. While treated peach fruit with chitosan 2%+ citric acid 10% maintained a relatively low TSS content in comparison with the control treatment. In the first season, it was achieved 8.66, 8.60, 9.46, and 11.33, and 9.00, 11.80, 10.73, and 10.86 in the second season after 7, 14, 21, and 28 days of cold storage period.

During the shelf life, the percentage of soluble solids was high after 3 days (14.63%) in untreated fruit then decreased to 12.36% on the ninth day in the first season. In the second season, it was recorded that 13.53% on the third day then increased to 14.06% after 9 shelf-life days. There was insignificant difference between hot water treatment and control in the second season. Meanwhile, the treated fruits with chitosan 2%+ citric acid 10% recorded the lowest percentage of soluble solids content (9.34 and 10.78%) in the 1st and 2nd seasons.

During cold storage and shelf-life periods, the percentage of total soluble solids may increase due to enzyme activity breaking down starch into sugars, and there may be decreased carbohydrates, pectin, and partial protein hydrolysis during respiration **(Abbasi *et al.*, 2009)**. Citric acid is an important natural antioxidant that acts as a signaling molecule in metabolic physiological pathways. It helped control moisture loss, resulting in slower fruit dehydration and a decrease in the total soluble solids (TSS) of fruits **(El Kobisy *et al.*, 2005)**. Furthermore, chitosan can reduce respiration and regulate gas exchange, which prevented fruits from increasing dry matter versus moisture content **(Jiang and Li, 2001)**. Recent studies have showed that combining 20 mM citric acid and 1.0% chitosan coating significantly slowed an increase in TSS compared to the control **(Liu *et al.*, 2016)**. The application of 2- and 3-mM citric acid can limit an increase in total soluble solids, especially between 10 and 20 days of storage **(Alali *et al.*, 2023)**.

Table 4. Effect of some environmentally safe post-harvest treatments on TSS content during cold storage and shelf -life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	8.67 a	10.66 a	12.13 a	11.73 a	14.93 a	**12.36 a**	14.63 a	13.50 a	12.36 a	**13.50 a**
Citric acid 10%	8.67 a	9.00 bc	11.00 b	10.60abc	12.46bc	**10.76 c**	13.06 b	13.10 a	11.80ab	**12.65 b**
$CaCl_2$ 6%	8.67 a	10.33 a	10.46 b	11.66 a	13.20 b	**11.41 b**	12.66 b	12.60ab	9.83 c	**11.69cd**
Hot water ($45^{\circ}C$)	8.67 a	10.00 a	11.13ab	11.33 a	11.33 c	**10.95bc**	11.06 c	13.60 a	11.93ab	**12.20bc**
Chitosan 2%	8.67 a	10.33 a	10.86 b	11.20 ab	12.93 b	**11.33 b**	13.60ab	11.80bc	11.06 b	**12.15bc**
Chitosan 2%+ Citric acid 10%	8.67 a	8.66 cd	8.60 c	9.46 c	11.33 c	**9.52 e**	10.63 c	10.26 d	7.13 d	**9.34 e**
Chitosan 2%+ $CaCl_2$ 6%	8.67 a	8.00 d	10.46 b	10.00 bc	12.06bc	**10.13 d**	13.00 b	10.80cd	9.00 c	**10.93 d**
Chitosan 2%+ Hot water ($45^{\circ}C$)	8.67 a	9.83 ab	10.36 b	10.80 ab	12.80 b	**10.95bc**	13.40ab	11.53 c	9.66 c	**11.53cd**
Mean	**8.67 d**	**9.60 c**	**10.63 b**	**10.85 b**	**12.63 a**		**12.76 a**	**12.15 b**	**10.35 c**	
Season 2022										
Control (Distilled water)	10.0 a	13.33 a	13.00 a	14.00 a	13.86 a	**13.55 a**	13.53 a	14.26ab	14.40 a	**14.06 a**
Citric acid 10%	10.0 a	11.60abc	12.13 b	11.53 bc	10.93cd	**11.55 e**	11.80ab	12.33bc	11.60bc	**11.91 b**
$CaCl_2$ 6%	10.0 a	12.33 ab	13.13 a	12.40 b	12.53ab	**12.60 b**	11.80ab	12.50 b	11.93bc	**12.07 b**
Hot water ($45^{\circ}C$)	10.0 a	11.73 ab	12.80 a	11.46 bc	12.53ab	**12.13bc**	11.90ab	15.00 a	14.10 a	**13.66 a**
Chitosan 2%	10.0 a	11.26 bc	12.73 a	11.66 bc	12.00bc	**11.91cd**	10.60bc	13.10ab	12.26bc	**11.98 b**
Chitosan 2%+ Citric acid 10%	10.0 a	9.00 d	11.80 b	10.73 c	10.86cd	**10.60 g**	10.50bc	10.46 c	11.40 c	**10.78 c**
Chitosan 2%+ $CaCl_2$ 6%	10.0 a	11.80 ab	12.00 b	10.66 c	10.20 d	**11.16ef**	9.26 c	14.20ab	11.73bc	**11.73 b**
Chitosan 2%+ Hot water ($45^{\circ}C$)	10.0 a	9.80 cd	11.80 b	10.86 c	10.46 d	**10.73fg**	10.20bc	10.60 c	13.10ab	**11.30bc**
Mean	**10.0 d**	**11.36 b**	**12.42 a**	**11.67 b**	**11.67 b**		**11.20 b**	**12.81 a**	**12.56 a**	

- The means were significantly different at the 0.05 probability level.

Total titratable acidity (TA%)

Results in Table 5 indicate that treated fruits with chitosan 2%+ citric acid 10% had statistically higher average total acidity percentages (0.428 and 0.555%) than the other post-harvest treatments during cold storage in 1st and 2nd seasons, respectively. Chitosan 2%+ $CaCl_2$ 6% treatment had non-significant differences ($P \leq 0.05$) with chitosan 2%+ citric acid 10% treatment. It was recorded (0.420 and 0.536%) in 1st and 2nd seasons, respectively. On the other hand, the control treatment decreased the average total titratable acidity percentage (0.272 and 0.402%) in the two seasons, respectively. Also, obtained results in the same table reveal that the longer cold storage period (28 days) induced the highest value of total titratable acidity (0.314 and 0.389%) in 1st and 2nd seasons. On the contrary, the lowest fruit titratable acidity (0.448 and 0.575%) was recorded on the seventh day of cold storage.

On the same line, the chitosan 2%+ citric acid 10% treatment increased the titratable acidity percentage (0.244 and 0.211%), followed by chitosan 2%+$CaCl_2$ 6% treatment which recorded (0.204 and 0.201%) in the ninth day of shelf-life period in 1st and 2nd seasons, respectively. While the control treatment decreased the titratable acidity percentage (0.071 and 0.116%) in experimental seasons.

The observed results are likely due to an increase in the rate of respiration during storage, which gave a higher decomposition of organic matter. The combination of chitosan, calcium, and citric acid has shown beneficial effects in reducing fruit respiration rate and increasing cell wall hardness. Treated fruits with 2% chitosan in combination with 10% citric acid or 6% calcium showed the lowest rate of decrease in total acidity throughout their cold storage and shelf life. This finding aligns with **Gayed *et al.* (2017)** on peaches, where treated fruit with 1% chitosan and 2% $CaCl_2$ exhibited high titratable acid levels compared to the control. Likewise, the application of 2 and 3 mM citric acid maintained the highest level of acidity **(Alali *et al.*, 2023)**.

Table 5. Effect of some environmentally safe post-harvest treatments on titratable acidity (%) during cold storage and shelf -life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	0.511a	0.379 c	0.306 c	0.229 c	0.172 d	**0.272 d**	0.098 c	0.077 c	0.039 d	**0.071 e**
Citric acid 10%	0.511a	0.451 b	0.405ab	0.374 a	0.328abc	**0.389 b**	0.273ab	0.194ab	0.128 b	**0.198abc**
$CaCl_2$ 6%	0.511a	0.440 b	0.362 b	0.293 b	0.277 c	**0.342 c**	0.238 b	0.172 b	0.087 c	**0.166 d**
Hot water (45°C)	0.511a	0.430 b	0.402ab	0.364 a	0.321 bc	**0.379 b**	0.261ab	0.179ab	0.124 b	**0.187bcd**
Chitosan 2%	0.511a	0.442 b	0.399ab	0.355 a	0.312 bc	**0.377 b**	0.254ab	0.178ab	0.098 c	**0.177 cd**
Chitosan 2%+ Citric acid 10%	0.511a	0.505 a	0.437 a	0.386 a	0.384 a	**0.428 a**	0.310 a	0.208 a	0.155 a	**0.224 a**
Chitosan 2%+ $CaCl_2$ 6%	0.511a	0.498 a	0.435 a	0.383 a	0.365 ab	**0.420 a**	0.279ab	0.203ab	0.131 b	**0.204 ab**
Chitosan 2%+ Hot water (45°C)	0.511a	0.440 b	0.417 a	0.368 a	0.351 ab	**0.394 b**	0.284ab	0.190ab	0.125 b	**0.199abc**
Mean	**0.511a**	**0.448 b**	**0.395 c**	**0.344 d**	**0.314 e**		**0.250 a**	**0.175 b**	**0.111 c**	
Season 2022										
Control (Distilled water)	0.589a	0.543 cd	0.457 c	0.362 c	0.244 e	**0.402 d**	0.154 c	0.127 d	0.066 d	**0.116 d**
Citric acid 10%	0.589a	0.555bcd	0.484 c	0.461ab	0.408 bc	**0.477 c**	0.241 b	0.161 c	0.094 b	**0.165 c**
$CaCl_2$ 6%	0.589a	0.585abc	0.531 b	0.436b	0.345 d	**0.474 c**	0.255 b	0.155 c	0.088bc	**0.166 c**
Hot water (45°C)	0.589a	0.521 d	0.469 c	0.441 b	0.409 bc	**0.460 c**	0.246 b	0.164bc	0.093 b	**0.168 c**
Chitosan 2%	0.589a	0.563a-d	0.519 b	0.418bc	0.382 cd	**0.470 c**	0.253 b	0.155 c	0.082 c	**0.164 c**
Chitosan 2%+ Citric acid 10%	0.589a	0.618 a	0.607 a	0.520 a	0.475 a	**0.555 a**	0.320 a	0.196 a	0.117 a	**0.211 a**
Chitosan 2%+ $CaCl_2$ 6%	0.589a	0.605 ab	0.585 a	0.522 a	0.432 ab	**0.536ab**	0.310 a	0.181ab	0.114 a	**0.201 ab**
Chitosan 2%+ Hot water (45°C)	0.589a	0.608 ab	0.551 b	0.504 a	0.419 bc	**0.521 b**	0.267 b	0.180ab	0.117 a	**0.188 b**
Mean	**0.589a**	**0.575 b**	**0.525 c**	**0.458 d**	**0.389 e**		**0.256 a**	**0.165 b**	**0.097 c**	

• The means were significantly different at the 0.05 probability level.

Ascorbic acid (mg/100 g)

The changes in the ascorbic acid content in peach fruits are presented in Table 6. Ascorbic acid content of all treated fruits was significantly lower than that of the untreated fruits during the cold storage period. The highest Vit. C content was observed with chitosan 2%+ $CaCl_2$ 6% (34.32 and 24.46 mg/100g), while the lowest content was found in the control (23.72 and 17.52 mg/100g) after 28 days of cold storage in the1st and the 2nd seasons, respectively. There was no significant difference was found between chitosan 2%+ $CaCl_2$ 6% and chitosan 2%+ hot water (45°C) treatments in the 2nd season.

Vitamin C content of the fruits was decreased sharply during the shelf-life period. While control treatment recorded the lowest content (15.18 and 11.20 mg/ 100g) after 3 days, then (13.12 and 5.60 mg/100g) after 6 days, and finally (4.80 and 3.75 mg/100g) after 9 days by average (11.03 and 6.85 mg/100g) in the two experimental seasons, respectively. On the other hand, the chitosan 2%+ $CaCl_2$ 6% treatment induced the highest average content (21.03 and 12.33 mg/100g) in 1st and 2nd seasons, respectively. It recorded (26.45 and 17.77 mg/100g) after 3 days, (20.52 and 11.72 mg/100g) after 6 days, and (16.13 and 7.49 mg/100g) after 9 days of shelf-life period.

As the fruit ripens, the level of vitamin C was decreased due to the action of the ascorbic acid oxidase enzyme (Ascorbinase) and oxidation, leading to the formation of 2,3-dicetogulonic acid **(Chitarra, 2005)**. Coating peach fruits with chitosan reduced gas permeability, especially oxygen, decreasing oxidation of organic substances, including ascorbic acid **(Dang *et al.*, 2010)**. Moreover, calcium enhanced the firmness of the fruit cell walls and shielded them from softening **(Hernandez-Munoz *et al.*, 2006)**. These findings align with those of **Ghasemnezhad *et al.* (2010)**, who showed that coating apricots with chitosan slowed a

Table 6. Effect of some environmentally safe post-harvest treatments on ascorbic acid (mg/100 g) during cold storage and shelf -life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	39.52a	30.62 c	23.04 e	21.95 e	19.28 e	**23.72 e**	15.18 d	13.12 d	4.80 e	**11.03 e**
Citric acid 10%	39.52a	31.85 c	28.01 c	26.75bc	24.48bc	**27.77 c**	21.85 bc	17.61bc	12.36cd	**17.28bc**
$CaCl_2$ 6%	39.52a	31.00 c	26.20cd	24.52cd	23.36cd	**26.27 d**	21.05 c	16.32bc	12.01cd	**16.46 c**
Hot water (45°C)	39.52a	30.73 c	25.93 d	23.53de	22.46 d	**25.67 d**	16.40 d	15.42 c	10.81 d	**14.21 d**
Chitosan 2%	39.52a	30.99 c	26.19cd	25.28cd	22.13 d	**26.14 d**	21.48 bc	15.61 c	12.04cd	**16.38 c**
Chitosan 2%+ Citric acid 10%	39.52a	34.88 b	32.00 b	28.35 b	26.35 b	**30.39 b**	23.74 b	18.41ab	14.48ab	**18.88 b**
Chitosan 2%+ $CaCl_2$ 6%	39.52a	37.20 a	36.24 a	34.24 a	29.60 a	**34.32 a**	26.45 a	20.52 a	16.13 a	**21.03 a**
Chitosan 2%+ Hot water (45°C)	39.52a	35.29ab	31.77 b	27.85 b	25.92 b	**30.21 b**	23.82 b	18.17 b	13.60bc	**18.53 b**
Mean	**39.52a**	**32.82 b**	**28.67 c**	**26.56 d**	**24.20 e**		**21.24 a**	**16.90 b**	**12.03 c**	
Season 2022										
Control (Distilled water)	31.36a	21.36 e	19.40 d	17.28 c	12.05 b	**17.52 d**	11.20 d	5.60 e	3.75 d	**6.85 f**
Citric acid 10%	31.36a	22.56de	21.60cd	20.27ab	16.32 a	**20.18 c**	13.02 cd	7.36 cd	5.25 c	**8.54 de**
$CaCl_2$ 6%	31.36a	24.48cd	21.93 c	19.26bc	17.60 a	**20.81bc**	14.24bcd	7.72 c	5.12 c	**9.03cde**
Hot water (45°C)	31.36a	23.76cd	22.83bc	20.68ab	17.82 a	**21.27bc**	14.08 cd	6.46 de	4.32 d	**8.28 e**
Chitosan 2%	31.36a	24.36cd	22.15 c	20.86ab	17.60 a	**21.24bc**	15.74abc	7.88 c	5.69 bc	**9.77bcd**
Chitosan 2%+ Citric acid 10%	31.36a	25.44bc	22.81bc	20.51ab	18.56 a	**21.83 b**	16.16abc	8.47 bc	6.03 b	**10.22bc**
Chitosan 2%+ $CaCl_2$ 6%	31.36a	28.32 a	27.12 a	23.20 a	19.21 a	**24.46 a**	17.77 a	11.72 a	7.49 a	**12.33 a**
Chitosan 2%+ Hot water (45°C)	31.36a	26.64ab	25.23ab	22.08ab	19.61 a	**23.39 a**	17.50 ab	9.02 b	6.24 b	**10.92 b**
Mean	**31.36a**	**24.61 b**	**22.88 c**	**20.52 d**	**17.34 e**		**9.39 a**	**9.74 a**	**9.34 a**	

• The means were significantly different at the 0.05 probability level.

reduction of vitamin C compared to the control. **Alizade-Dashqabu *et al.* (2011)** found that treating 'J.H. Hale' peach fruits with 60 mM calcium helped maintain the highest percentage of vitamin C.

Total sugar content (%)

In Table 7 it could be observe that there was an increase in total sugar content in all experimental treatments with increased cold storage duration. The maximum content of total sugar (3.47 and 3.83%) was recorded with untreated fruits in the 2021 and 2022 seasons, but the minimum content (2.64 and 3.12%) was recorded with treated fruits with chitosan 2%+ hot water (45°C) at the end of the cold storage period. Meanwhile, there was no significant difference between chitosan 2%+ hot water (45°C) treatment and either chitosan 2%+ $CaCl_2$ 6% or chitosan 2%+ citric acid 10% treatments in the 2022 season.

Furthermore, during the shelf life period, the chitosan 2% + hot water (45°C) treatment maintained the fruit's total sugar content in the lower level (4.08 and 4.74%), while control fruits had the highest content (5.50 and 6.17%) in 2021 and 2022 seasons, respectively.

The findings suggest that chitosan treatments at 45°C or in combination with 6% $CaCl_2$ were most effective in reducing the total sugar content. Increased sugar content during the storage period may be due to starch being hydrolyzed into sugar and organic acids breaking down into sugars during ripening. It could be attributed to metabolic breakdown and fruit senescence resulting from moisture and firmness loss during storage **(Dorostkar *et al.*, 2022)**. Therefore, delaying fruit ripening and increasing fruit hardness by using chitosan, calcium, and hot water during storage reduces fruit sugar content. Similar findings were obtained in treated date palm fruits with 3 g/L chitosan **(El-Gioushy *et al.*, 2022)**, treated peach fruit with 6% $CaCl_2$ (**Gupta *et al.*, 2011)**, and

Table 7. Effect of some environmentally safe post-harvest treatments on total sugar content (%) during cold storage and shelf life

Treatments	Initial	Cold storage (days)					Shelf life (days)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	2.08 a	2.88 a	3.03 a	3.96 a	4.01 a	**3.47 a**	4.66 a	5.49 a	6.35 a	**5.50 a**
Citric acid 10%	2.08 a	2.60 b	2.79 ab	3.36 b	3.63 bc	**3.09 bc**	4.24 ab	4.91 b	5.67 bc	**4.94 b**
$CaCl_2$ 6%	2.08 a	2.67 ab	2.91 a	3.39 b	3.84 ab	**3.20 b**	4.59 a	4.82 b	5.82 b	**5.08 b**
Hot water (45°C)	2.08 a	2.58 b	2.80 ab	3.15 bc	3.55 cd	**3.02 c**	4.04 bc	4.41 c	5.23 cd	**4.51 c**
Chitosan 2%	2.08 a	2.55 b	2.71abc	3.15 bc	3.57 bc	**3.00 c**	3.88bcd	4.44 c	5.37bcd	**4.62 c**
Chitosan 2%+ Citric acid 10%	2.08 a	2.28 c	2.68abc	3.13 bc	3.50 cd	**2.86 d**	3.67 cd	4.39 c	5.08 de	**4.38 c**
Chitosan 2%+ $CaCl_2$ 6%	2.08 a	2.18 c	2.50 bc	3.10 bc	3.44 cd	**2.85 d**	3.55 d	4.30 c	5.08 de	**4.31 cd**
Chitosan 2%+ Hot water (45°C)	2.08 a	2.04 c	2.34 c	2.93 c	3.26 d	**2.64 e**	3.56 d	4.11 c	4.55 e	**4.08 d**
Mean	**2.08 e**	**2.47 d**	**2.72 c**	**3.27 b**	**3.60 a**		**4.02 c**	**4.61 b**	**5.40 a**	
Season 2022										
Control (Distilled water)	2.80 a	3.32 a	3.51 a	4.22 a	4.27 a	**3.83 a**	5.37 a	5.69 a	7.46 a	**6.17 a**
Citric acid 10%	2.80 a	3.11 ab	3.40 a	3.65 bc	3.95 bc	**3.53 c**	4.62 b	5.02 b	6.92 bc	**5.52 c**
$CaCl_2$ 6%	2.80 a	3.31 a	3.56 a	3.72 b	4.10 ab	**3.67 b**	5.18 a	5.18 b	7.06 ab	**5.81 b**
Hot water (45°C)	2.80 a	3.05 bc	3.38 a	3.63bcd	3.89 bc	**3.49 c**	4.47 bc	4.89 bc	6.72 bc	**5.36 cd**
Chitosan 2%	2.80 a	2.99 bc	3.28 a	3.59bcd	3.86 bc	**3.43 c**	4.17 cd	4.64 cd	6.61 c	**5.14 de**
Chitosan 2%+ Citric acid 10%	2.80 a	2.83 cd	2.94 b	3.41 cd	3.80 bc	**3.25 d**	4.15 cd	4.59 cd	6.50 cd	**5.07 e**
Chitosan 2%+ $CaCl_2$ 6%	2.80 a	2.73 d	2.90 b	3.36 d	3.74 c	**3.18 d**	3.93 d	4.60 cd	6.50 cd	**5.01 e**
Chitosan 2%+ Hot water (45°C)	2.80 a	2.67 d	2.75 b	3.36 d	3.69 c	**3.12 d**	3.82 d	4.31 d	6.10 d	**4.74 f**
Mean	**2.80 e**	**3.00 d**	**3.22 c**	**3.62 b**	**3.91 a**		**4.47 c**	**4.86 b**	**6.73 a**	

▸ The means were significantly different at the 0.05 probability level.

dipped peach fruit in hot water at 50°C **(Sadiqullah *et al.*, 2023)** as compared with the control treatment.

Reducing sugar content (%)

A significant difference in reducing sugar content of peach fruit during the cold storage due to the post-harvest treatments (Table 8). The highest content of reducing sugar between treatments (2.84 and 3.72%) were recorded in untreated fruits (control) in experimental seasons, respectively. The lowest content (2.54 and 3.00%) was recorded in coated fruits with chitosan 2%+ hot water (45°C) in 1st and 2nd seasons, respectively followed by coated fruits with chitosan 2%+ $CaCl_2$ 6%.

During the shelf- life period, the control treatment had the highest content of reducing sugar (3.62 and 5.99%), while treated peach fruit with chitosan 2%+ hot water (45°C) recorded the lowest content (3.16 and 4.96) in the 1st and 2nd seasons. No significant difference was found between chitosan 2%+ hot water (45°C) treatment and Chitosan 2%+ $CaCl_2$ 6% in the 1st season.

Previous results observed that reducing sugar had a direct relation with increasing total sugar content in fruits. The percentage of reducing sugar tends to increase fruit ripens and was decreased with fruit treated with chitosan treatments at 45°C or in combination with 6% $CaCl_2$. The increase in sugar content during storage may be due to starch being converted to sugar and organic acids breaking down storage **(Kaur and Kaur, 2019)**. Chitosan, calcium, and hot water can help delay fruit ripening and increase fruit hardness, thereby reducing sugar content during storage **(El-Shemy, 2020)**. Studies have shown similar findings in treated date palm **(El-Gioushy *et al.*, 2022)** and peach fruits **(Sadiqullah *et al.*, 2023)**.

Table 8. Effect of some environmentally safe post-harvest treatments on reducing sugar content (%) during cold storage and shelf -life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
					Season 2021					
Control (Distilled water)	2.24 a	2.48 a	2.71 a	3.05 a	3.13 a	**2.84 a**	3.31 a	3.54 a	4.01 a	**3.62 a**
Citric acid 10%	2.24 a	2.34 bc	2.63 b	3.00 ab	3.06 ab	**2.76 b**	3.18 ab	3.53 a	3.84 ab	**3.52 b**
$CaCl_2$ 6%	2.24 a	2.36 b	2.62 b	2.98 abc	3.05 ab	**2.75 b**	3.17 ab	3.45 a	3.72 b	**3.44 b**
Hot water (45°C)	2.24 a	2.38 b	2.52 c	2.93 bc	2.97 bc	**2.70 c**	3.13 bc	3.23 bc	3.56 bc	**3.31 c**
Chitosan 2%	2.24 a	2.30 cd	2.51 c	2.89 cd	2.97 bc	**2.66 d**	3.03 bc	3.32 b	3.41 c	**3.25 cd**
Chitosan 2%+ Citric acid 10%	2.24 a	2.31 bcd	2.49 c	2.81 de	2.94 c	**2.64 d**	3.03 bc	3.22 bc	3.39 c	**3.22 cd**
Chitosan 2%+ $CaCl_2$ 6%	2.24 a	2.25 de	2.50 c	2.75 ef	2.82 d	**2.58 e**	2.99 c	3.16 c	3.42 c	**3.19 d**
Chitosan 2%+ Hot water (45°C)	2.24 a	2.22 e	2.48 c	2.67 f	2.81 d	**2.54 f**	3.00 c	3.14 c	3.35 c	**3.16 d**
Mean	**2.24 e**	**2.33 d**	**2.56 c**	**2.88 b**	**2.97 a**		**3.10 c**	**3.32 b**	**3.59 a**	
					Season 2022					
Control (Distilled water)	2.32 a	2.57 a	3.45 a	4.63 a	4.21 a	**3.72 a**	5.48 a	6.05 a	6.45 a	**5.99 a**
Citric acid 10%	2.32 a	2.55 b	3.27 b	4.00 b	4.08 b	**3.47 b**	5.15 b	5.87 b	6.05 b	**5.69 b**
$CaCl_2$ 6%	2.32 a	2.52 c	3.21 c	3.92 b	4.00 c	**3.42 c**	5.17 b	5.64 c	6.09 b	**5.63 c**
Hot water (45°C)	2.32 a	2.50 d	2.96 d	3.83 c	3.88 d	**3.30 d**	5.07 b	5.56 c	5.98 c	**5.53 d**
Chitosan 2%	2.32 a	2.46 e	2.94 e	3.75 d	3.79 e	**3.23 e**	4.78 c	5.62 c	5.98 c	**5.46 e**
Chitosan 2%+ Citric acid 10%	2.32 a	2.50 d	2.75 f	3.53 e	3.76 e	**3.13 f**	4.77 c	5.34 d	5.89 d	**5.33 f**
Chitosan 2%+ $CaCl_2$ 6%	2.32 a	2.49 d	2.59 g	3.47 ef	3.76 e	**3.07 g**	4.58 d	5.37 d	5.59 e	**5.18 g**
Chitosan 2%+ Hot water (45°C)	2.32 a	2.34 f	2.53 h	3.43 f	3.71 e	**3.00 h**	4.30 e	5.01 e	5.57 e	**4.96 h**
Mean	**2.32 e**	**2.49 d**	**2.96 c**	**3.82 b**	**3.89 a**		**4.91 c**	**5.56 b**	**5.95 a**	

▸ The means were significantly different at the 0.05 probability level.

Total anthocyanin content (mg/100 g fresh weight)

According to Table 9, post-harvest treatments had significant effects on the total anthocyanin content. During cold storage, anthocyanin content was lower in all post-harvest treatments compared to untreated fruits. The lowest anthocyanin content (131.50 and 122.00 mg/100g F.W.) was obtained from the chitosan 2%+ hot water (45°C) and chitosan 2%+ $CaCl_2$ 6% treatments, respectively in the first season. In the second season, the chitosan 2%+ hot water (45°C) treatment gave the lowest content (115.89 mg/100g F.W.). The highest anthocyanin content (200.54 and 178.99 mg/100g F.W.) was obtained from the control and citric acid 10%, respectively in the first season, while the control treatment recorded the highest content (180.47 mg/100g F.W.) in the second season.

After 9 days of shelf life, anthocyanin content in all coated fruits increased compared to the uncoated fruits. The results showed that the chitosan 2%+ hot water (45°C) as postharvest treatment had a high effect on anthocyanin content of peach fruit followed by chitosan 2%+ $CaCl_2$ 6% in the 2021 season. The same trend was observed in the second season, where the anthocyanin content was increased to the maximum level by the treatment of chitosan 2%+ hot water (45°C) and chitosan 2%+ $CaCl_2$ 6% treatments. Meanwhile, the lowest anthocyanin content was obtained from the control in the 2021 and 2022 seasons.

Anthocyanins are natural water-soluble pigments that are one of the major groups of flavonoids **(Serradilla *et al.*, 2011)**. Chitosan coating on peach fruits reduced anthocyanin content during the first cold storage period, while $CaCl_2$ maintained fruit hardness and protects organic components from degradation. Conversely, during the shelf-life period anthocyanin content was decreased rapidly in untreated fruits, while the highest values were recorded with chitosan 2%+ $CaCl_2$ 6% treatment. This treatment may have reduced the pigment breakdown. As in the current study, chitosan

Table 9. Effect of some environmentally safe post-harvest treatments on total anthocyanin content (mg/100g F.W.) during cold storage and shelf- life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
				Season 2021						
Control (Distilled water)	90.00a	136.00a	210.86 a	230.00 a	225.33a	**200.54a**	108.00 c	31.33 e	32.70 d	**57.34d**
Citric acid 10%	90.00a	116.00b	201.33 a	216.00ab	182.66b	**178.99a**	119.66 c	53.00 d	68.00 c	**80.22c**
$CaCl_2$ 6%	90.00a	108.20bc	149.00 b	200.00 b	182.00b	**159.80b**	151.00 b	108.66bc	80.66 b	**113.44b**
Hot water (45°C)	90.00a	101.00bc	137.60 b	166.80 c	183.33b	**147.18c**	153.55 b	123.33ab	65.33 c	**114.07b**
Chitosan 2%	90.00a	96.00 bc	136.00 b	200.66 b	226.00a	**164.66 b**	173.66 a	109.33bc	44.00 d	**109.0b**
Chitosan 2%+ Citric acid 10%	90.00a	95.00 bc	149.66 b	167.00 c	182.33b	**148.50 c**	154.00 b	133.66 a	59.33 c	**115.67 b**
Chitosan 2%+ $CaCl_2$ 6%	90.00a	95.33 bc	102.00 c	174.00 c	154.66c	**131.50 d**	169.33 a	92.66 c	97.66 a	**119.89ab**
Chitosan 2%+ Hot water (45°C)	90.00a	89.66 c	112.33 c	150.00 d	136.00c	**122.00 d**	167.33 a	122.00ab	98.00 a	**129.11 a**
Mean	**90.00d**	**104.65 c**	**149.85 b**	**188.06 a**	**184.04a**		**149.57 a**	**96.75 b**	**68.21 c**	
				Season 2022						
Control (Distilled water)	70.00a	94.33 a	150.00ab	174.33 a	303.22a	**180.47 a**	168.33 e	139.56 e	64.03 c	**123.97 d**
Citric acid 10%	70.00a	85.00 ab	159.00 a	156.66ab	270.48b	**167.79 b**	226.70bc	174.13 cd	79.36 c	**160.07 c**
$CaCl_2$ 6%	70.00a	72.00 b	127.00bc	149.60 b	250.33c	**149.73cd**	235.33ab	184.03bcd	109.00b	**176.12 b**
Hot water (45°C)	70.00a	88.46 ab	122.00 c	158.05ab	274.40b	**160.73bc**	249.66 a	171.20 d	111.34b	**177.40 b**
Chitosan 2%	70.00a	78.68 ab	121.66 c	140.00 b	228.50d	**142.21de**	209.00cd	188.60 b	133.86a	**177.15 b**
Chitosan 2%+ Citric acid 10%	70.00a	72.66 b	121.00 c	142.00 b	218.00d	**138.41de**	195.33 d	184.50 bc	132.70a	**170.84 b**
Chitosan 2%+ $CaCl_2$ 6%	70.00a	70.00 b	120.13 c	138.33 b	203.40e	**132.96 e**	193.06 d	214.90 a	134.66a	**180.87 a**
Chitosan 2%+ Hot water (45°C)	70.00a	72.40 b	102.66 c	100.00 c	188.49f	**115.89 f**	237.33ab	172.00 cd	134.84a	**181.39 a**
Mean	**70.00e**	**79.19 d**	**127.93 c**	**144.87 b**	**242.10a**		**214.35 a**	**178.61 b**	**112.47c**	

- The means were significantly different at the 0.05 probability level.

application resulted in a low level of anthocyanin during cold storage of strawberry, while the control treatment led to a high level **(Zam, 2019)**.

Total phenolic content (g/100g F.W.)

Total phenolic content during cold storage was lower in untreated fruits (Table 10). A decline in the total phenolic content of peach fruits was shown during cold storage. Treated peaches with chitosan 2%+ $CaCl_2$ 6% recorded higher average phenolic content (0.511 g/100g F.W.) followed by chitosan 2%+ hot water (45°C) which recorded (0.491 g/100g F.W.) in the first seasons, as compared to other postharvest treatments and control. While treated fruits with chitosan 2%+ $CaCl_2$ 6% and chitosan 2%+ hot water (45°C) treatments recorded higher phenolic content (0.544 and 0.538 g/100g F.W.) in the second season. On the other hand, the lowest phenol content (0.403 and 0.435 g/100g F.W.) in1st and 2nd seasons, respectively were observed in the untreated fruits (control).

Total phenolic content of peach fruits showed a declining trend during the shelf-life period. The control and citric acid 10% treatment decreased the average phenol content to the minimum level (0.187 and 0.206 g/100g F.W.) in the 1st season, respectively. While, in the 2nd season, the untreated fruits recorded the lowest average value (0.278 g/100g F.W.). Meanwhile, the highest fruit contents of total phenolic (0.328 and 0.419 g/100g F.W.) in 1st and 2nd seasons were observed with chitosan 2%+ $CaCl_2$ 6% treatment.

Polyphenols act as antioxidants within fruit cells, helping to limit or prevent damage caused by free radicals **(Peretto *et al.*, 2017)**. The increase in fruit content at the beginning of the cold storage period may be due to the ability of chitosan and calcium to slow down fruit respiration and prevent gaseous exchange, thereby inhibiting the action of enzymes **(Hernandez-Munoz *et al.*, 2006)**. During the shelf life, as the polyphenol-oxidase activity enzyme began to form and its activity increased, it led to

Table 10. Effect of some environmentally safe post-harvest treatments on total phenolic content (mg/100g F.W.) during cold storage and shelf life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
				Season 2021						
Control (Distilled water)	0.337a	0.394 b	0.420 c	0.480 d	0.318 d	**0.403 d**	0.256 d	0.206 d	0.100 d	**0.187 d**
Citric acid 10%	0.337a	0.401 b	0.490 b	0.493 cd	0.446 c	**0.457 c**	0.260 d	0.229cd	0.130cd	**0.206 d**
$CaCl_2$ 6%	0.337a	0.410ab	0.485 b	0.514bcd	0.454 b	**0.466bc**	0.317 c	0.260bc	0.163bc	**0.247 c**
Hot water (45°C)	0.337a	0.409ab	0.484 b	0.532a-d	0.465 b	**0.473bc**	0.313 c	0.260bc	0.160bc	**0.245 c**
Chitosan 2%	0.337a	0.417ab	0.496ab	0.529a-d	0.470 a	**0.478bc**	0.354bc	0.276 b	0.178ab	**0.269bc**
Chitosan 2%+ Citric acid 10%	0.337a	0.425ab	0.503ab	0.547abc	0.471 a	**0.487ab**	0.374ab	0.293 b	0.196ab	**0.288 b**
Chitosan 2%+ $CaCl_2$ 6%	0.337a	0.447 a	0.520 a	0.589 a	0.487 a	**0.511 a**	0.415 a	0.355 a	0.216 a	**0.328 a**
Chitosan 2%+ Hot water (45°C)	0.337a	0.427ab	0.498ab	0.567 ab	0.470 a	**0.491ab**	0.391ab	0.300 b	0.203ab	**0.298 b**
Mean	**0.337e**	**0.416 d**	**0.487 b**	**0.532 a**	**0.448 c**		**0.335 a**	**0.273 b**	**0.168 c**	
				Season 2022						
Control (Distilled water)	0.436a	0.435 c	0.487 f	0.391 e	0.424 f	**0.435 e**	0.363 d	0.260 e	0.212 d	**0.278 f**
Citric acid 10%	0.436a	0.444 c	0.512cd	0.491 d	0.454ef	**0.475 d**	0.370 d	0.313 d	0.267 c	**0.316 e**
$CaCl_2$ 6%	0.436a	0.449bc	0.496ef	0.509 cd	0.472de	**0.482 d**	0.383cd	0.324 d	0.282 c	**0.330de**
Hot water (45°C)	0.436a	0.462 b	0.508de	0.531 cd	0.498cd	**0.500 c**	0.396 c	0.319 d	0.287 c	**0.334 d**
Chitosan 2%	0.436a	0.464ab	0.524bc	0.554 bc	0.510bc	**0.513 b**	0.431 b	0.369 c	0.320 b	**0.373 c**
Chitosan 2%+ Citric acid 10%	0.436a	0.479 a	0.514cd	0.549 bc	0.501cd	**0.511bc**	0.453ab	0.396 b	0.354 a	**0.401 b**
Chitosan 2%+ $CaCl_2$ 6%	0.436a	0.478 a	0.558 a	0.599 a	0.539ab	**0.544 a**	0.445 b	0.431 a	0.381 a	**0.419 a**
Chitosan 2%+ Hot water (45°C)	0.436a	0.479 a	0.535 b	0.584 ab	0.555 a	**0.538 a**	0.471 a	0.410 b	0.359 a	**0.413ab**
Mean	**0.436d**	**0.461 c**	**0.517 a**	**0.526 a**	**0.494 b**		**0.414 a**	**0.353 b**	**0.308 c**	

• The means were significantly different at the 0.05 probability level.

enzymatic oxidation and breakdown of phenolic compounds. **Ramirez *et al.* (2015)** on nectarines, showed that coating peach fruits with chitosan maintained the highest polyphenol content compared to the control. Additionally, **Hajilou and Fakhimrezaei (2013)** indicated that treated apricot with 80 mM $CaCl_2$ exhibited the highest phenol content compared with control during the cold storage period.

Flavonoids (mg/100g F.W.)

In all treatments, the flavonoid content was increased from 0 to 7 days from the cold storage period and then declined towards the end of cold storage (Table 11). The highest average of flavonoid content (1.329 and 1.352 mg/100g F.W.) in 1st and 2nd seasons, respectively, were observed in treated fruits with chitosan 2%+ $CaCl_2$ 6%. No significant difference was shown between chitosan 2%+ $CaCl_2$ 6% and chitosan 2%+ hot water (45°C) in the first season. Meanwhile, the lowest average of flavonoid content (1.311 and 1.332 mg/g F.W.) in 1st and 2nd seasons, respectively, was recorded with control (distilled water).

A similar decline in flavonoid content under cold storage was also shown under shelf-life conditions. Treated fruits with chitosan 2%+ $CaCl_2$ 6% recorded a higher average of flavonoid content (1.307 and 1.317 mg/100g F.W.), whereas a minimum content was observed in the control (1.279 and 1.281 mg/100g F.W.) in 1st and 2nd seasons, respectively.

Flavonoids, an important group of phenolic compounds, showed a similar pattern to phenols, with the lowest values recorded under the control treatment. The treatment of chitosan in combination with calcium or hot water (45°C) preserved the highest flavonoid content, indirectly affecting the preservation of organic components by reducing respiration rate, preventing decay, and maintaining fruit hardness. This was confirmed with **He *et al.* (2018)** on strawberries, who indicated that applicated fruits 50 mg/L of chitosan increased total flavonoid content compared with untreated fruits.

Table 11. Effect of some environmentally safe post-harvest treatments on flavonoid content (mg/100g F.W.) during cold storage and shelf life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	1.324a	1.324 c	1.313 b	1.301 c	1.309 de	**1.311 e**	1.295 c	1.278 c	1.263 f	**1.279 d**
Citric acid 10%	1.324a	1.324 c	1.311 b	1.312 b	1.304 e	**1.312 e**	1.307 b	1.299 b	1.277 e	**1.294 c**
$CaCl_2$ 6%	1.324a	1.326 c	1.311 b	1.312 b	1.312cde	**1.315de**	1.307 b	1.299 b	1.284de	**1.297bc**
Hot water (45°C)	1.324a	1.329 bc	1.320 ab	1.309bc	1.317a-d	**1.319cd**	1.311 b	1.299 b	1.287cd	**1.299bc**
Chitosan 2%	1.324a	1.336 b	1.321 ab	1.314ab	1.320abc	**1.322bc**	1.310 b	1.302ab	1.292bc	**1.301 b**
Chitosan 2%+ Citric acid 10%	1.324a	1.344 a	1.320 ab	1.315ab	1.316bcd	**1.323 b**	1.312 b	1.303ab	1.288cd	**1.301 b**
Chitosan 2%+ $CaCl_2$ 6%	1.324a	1.345 a	1.327 a	1.317ab	1.328 a	**1.329 a**	1.316ab	1.308 a	1.298ab	**1.307 a**
Chitosan 2%+ Hot water (45°C)	1.324a	1.347 a	1.331 a	1.322 a	1.325 ab	**1.332 a**	1.322 a	1.308 a	1.301 a	**1.310 a**
Mean	**1.324a**	**1.335 b**	**1.319 c**	**1.313 d**	**1.316 e**		**1.310 a**	**1.299 b**	**1.286 c**	
Season 2022										
Control (Distilled water)	1.374a	1.355 c	1.344 d	1.318 e	1.311 d	**1.332 e**	1.290 f	1.279 g	1.275 g	**1.281 g**
Citric acid 10%	1.374a	1.356 c	1.347 cd	1.334 d	1.324 c	**1.340 d**	1.302 e	1.298 e	1.292 e	**1.298 e**
$CaCl_2$ 6%	1.374a	1.356 c	1.349bcd	1.332 d	1.329 b	**1.342 d**	1.301 e	1.289 f	1.283 f	**1.291 f**
Hot water (45°C)	1.374a	1.358 bc	1.352 bc	1.337 c	1.337 a	**1.346 c**	1.315cd	1.306 c	1.293 e	**1.305 d**
Chitosan 2%	1.374a	1.359abc	1.356 ab	1.341 b	1.335 a	**1.348 c**	1.314 d	1.302 d	1.296 d	**1.304 d**
Chitosan 2%+ Citric acid 10%	1.374a	1.358 bc	1.356 ab	1.341 b	1.339 a	**1.348bc**	1.316 c	1.311 b	1.301 c	**1.309 c**
Chitosan 2%+ $CaCl_2$ 6%	1.374a	1.363 a	1.361 a	1.347 a	1.339 a	**1.352 a**	1.328 a	1.317 a	1.306 a	**1.317 a**
Chitosan 2%+ Hot water (45°C)	1.374a	1.362 ab	1.356 ab	1.343 b	1.340 a	**1.351ab**	1.324 b	1.316 a	1.304 b	**1.315 b**
Mean	**1.374a**	**1.359 b**	**1.353 c**	**1.337 d**	**1.332 e**		**1.311 a**	**1.302 b**	**1.294 c**	

- The means were significantly different at the 0.05 probability level.

DPPH radical scavenging activity (%)

The scavenging activity (DPPH%) was decreased gradually with increasing cold storage duration from 0 to 28 days. The postharvest treatments showed an increase in scavenging activity (DPPH%) compared with untreated fruits (Table 12). The highest average of DPPH percentage was observed with chitosan 2%+ $CaCl_2$ 6% and chitosan 2%+ hot water (45°C) treatments (46.15 and 46.08%) in the 2021 season, respectively chitosan 2%+ $CaCl_2$ 6% treatment recorded the highest percentage (53.01%) in the 2022 season. The lowest DPPH percentage was found in control (36.54 and 44.63%) after 28 days of cold storage in the 2021 and 2022 seasons, respectively.

Changes in the scavenging activity (DPPH%) of peach fruit continued to decline during the shelf life compared to the cold storage period. Treated fruits with chitosan 2%+ $CaCl_2$ retained higher scavenging activity (36.53, 32.18, and 14.58%) in 2nd season and (42.24, 34.57, and 29.44%) at 3, 6, and 9 days of the shelf-life period as compared to control. The control recorded the lowest average DPPH percentage (13.99 and 19.75%) in 1st and 2nd seasons, respectively.

The DPPH radical scavenging plays a vital role as an antioxidant in reducing oxidative damage caused by reactive oxygen species (ROS). Previous results indicated that the DPPH activity was decreased gradually with a prolonged storage period, especially with untreated fruits. This supports the idea that chitosan plays a crucial role in slowing down the ripening and aging of fruits by decreasing respiration and oxygen absorption rates. $CaCl_2$ has been utilized to delay ripening by preserving fruit firmness and protecting against microbial infection **(El-Shemy, 2020)**. **Mohamed *et al.* (2019)** revealed that treated apricots with chitosan 0.025% recorded higher DPPH activity than the control.

Table 12. Effect of some environmentally safe post-harvest treatments on DPPH radical scavenging activity (%) during cold storage and shelf life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
Season 2021										
Control (Distilled water)	53.43a	45.85c	39.09 c	32.67 d	28.54 e	**36.54 d**	23.70 d	13.70 d	4.58 c	**13.99 e**
Citric acid 10%	53.43a	45.90c	46.36 a	42.39abc	32.97de	**41.91 c**	27.38 c	19.83 cd	9.94 b	**19.05 d**
$CaCl_2$ 6%	53.43a	46.87b	46.37 a	40.33 c	35.74cd	**42.33 c**	32.92 b	22.20 bc	9.73 b	**21.62cd**
Hot water (45°C)	53.43a	46.16b	42.86 b	41.22 bc	37.66cd	**41.97 c**	33.28ab	24.01 bc	11.54ab	**22.94bc**
Chitosan 2%	53.43a	46.42b	47.14 a	41.84abc	38.51bc	**43.48bc**	34.21ab	24.88 bc	10.76ab	**23.28bc**
Chitosan 2%+ Citric acid 10%	53.43a	47.65a	47.19 a	44.92 a	39.46bc	**44.81ab**	35.39ab	26.79abc	11.01ab	**24.39bc**
Chitosan 2%+ $CaCl_2$ 6%	53.43a	47.96a	47.17 a	45.11 a	44.37 a	**46.15 a**	36.53 a	32.18 a	14.58 a	**27.76 a**
Chitosan 2%+ Hot water (45°C)	53.43a	48.99a	48.63 a	43.83 ab	42.86ab	**46.08 a**	35.44ab	29.15 ab	13.11ab	**25.90ab**
Mean	**53.43a**	**46.97b**	**45.60 b**	**41.54 c**	**37.51 d**		**32.35 a**	**24.09 b**	**10.66 c**	
Season 2022										
Control (Distilled water)	59.56a	51.23c	47.09 c	42.96 e	37.25 d	**44.63 d**	29.47 f	19.01 d	10.78 f	**19.75 e**
Citric acid 10%	59.56a	55.76b	51.57 b	45.64 d	42.69 c	**48.92 c**	33.02 e	28.49 c	18.44 e	**26.65 d**
$CaCl_2$ 6%	59.56a	55.88b	52.44ab	47.24 cd	43.76bc	**49.83 c**	34.57de	29.25 bc	19.21 e	**27.68 d**
Hot water (45°C)	59.56a	55.70b	52.03ab	48.57 bc	43.33bc	**49.91 c**	35.10 d	30.07 bc	24.15cd	**29.77 c**
Chitosan 2%	59.56a	57.23a	53.09ab	49.92 b	44.71bc	**51.24 b**	38.59 c	28.74 c	23.32 d	**30.22 c**
Chitosan 2%+ Citric acid 10%	59.56a	57.13a	53.06ab	49.61 b	45.80ab	**51.40 b**	40.37 b	31.89 ab	25.96bc	**32.74 b**
Chitosan 2%+ $CaCl_2$ 6%	59.56a	57.55a	54.10 a	52.17 a	48.21 a	**53.01 a**	42.24 a	34.57 a	29.44 a	**35.42 a**
Chitosan 2%+ Hot water (45°C)	59.56a	58.73a	53.36ab	49.94 b	47.38 a	**52.36ab**	43.12 a	34.43 a	28.13ab	**35.22 a**
Mean	**59.56a**	**56.15b**	**52.09 c**	**48.26 d**	**44.14 e**		**37.06 a**	**29.56 b**	**22.43 c**	

- The means were significantly different at the 0.05 probability level.

Malondialdehyde activity (MDA; Mmole / gm FW)

Different post-harvest treatments showed a significant effect in the accumulation of Malondialdehyde enzyme (Table 13). As increasing time of cold storage from 0 to 28 days MDA content in treated and untreated peach fruits was increased. The chitosan 2%+ $CaCl_2$ 6% treated fruits significantly recorded the lowest MDA content during the whole period of cold storage followed by chitosan 2%+ hot water (45°C) treatment in 1st and 2nd seasons. The increase of MDA content was induced in untreated fruits (control). The control recorded the highest content (0.041 and 0.088 Mmole/gm F.W.) in 1st and 2nd seasons, respectively.

On the same line, during the shelf-life period, the coated fruit with chitosan 2%+ $CaCl_2$ 6% has slowed down the rate of accumulation of the MDA enzyme to the lowest value. The significant minimum MDA content (0.047, 0.083, and 0.109 Mmole/gm F.W.) was observed in the 2021 season with chitosan 2%+ $CaCl_2$ 6% at 3, 6, and 9 days of shelf-life period, respectively. In 2022, it was recorded (0.082, 0.152, and 0.155 Mmole/gm F.W.) at 3, 6, and 9 days of shelf-life period, respectively. The control recorded the highest average MDA content (0.137 and 0.198 Mmole/gm F.W.) in 1st and 2nd seasons, respectively.

Untreated peach fruits undergo a natural ripening process during storage, which involved an increase in respiration and the subsequent oxidation of membrane lipids leading to the formation of the MDA enzyme **(Rosalie *et al.*, 2018)**. This enzymatic activity resulted in softer fruits and the onset of aging, a process that accelerate over time. However, treating fruits with 2% chitosan+6% $CaCl_2$ leads to increase fruit firmness and a reduction in respiration rate. This treatment improved oxidation and reduction processes within the cells, thus reducing the formation of the MDA enzyme. Consequently, the MDA enzyme content was higher in untreated fruits compared to treated fruits with chitosan and

Table 13. Effect of some environmentally safe post-harvest treatments on Malondialdehyde activity (Mmole/gm FW) during cold storage and shelf life

Treatment	Initial	Cold storage (day)					Shelf life (day)			
		7	14	21	28	Mean	3	6	9	Mean
				Season 2021						
Control (Distilled water)	0.092a	0.022 a	0.033 a	0.046 a	0.065 a	**0.041 a**	0.103 a	0.129 a	0.180 a	**0.137 a**
Citric acid 10%	0.092a	0.019 bc	0.023 b	0.033 b	0.049 b	**0.031 b**	0.075cde	0.102 bc	0.153cd	**0.110cd**
$CaCl_2$ 6%	0.092a	0.020 ab	0.032 a	0.047 a	0.058ab	**0.039 a**	0.088 b	0.127 a	0.169ab	**0.128 b**
Hot water (45°C)	0.092a	0.018 c	0.025 b	0.035 b	0.053 b	**0.033 b**	0.081bcd	0.108 b	0.161bc	**0.117 c**
Chitosan 2%	0.092a	0.018 bc	0.025 b	0.032 b	0.051 b	**0.032 b**	0.085 bc	0.107 b	0.158bc	**0.117 c**
Chitosan 2%+ Citric acid 10%	0.092a	0.017 cd	0.023 b	0.030bc	0.048 b	**0.029 b**	0.072 de	0.100 bc	0.143 d	**0.105 d**
Chitosan 2%+ $CaCl_2$ 6%	0.092a	0.013 e	0.016 c	0.023 c	0.033 c	**0.021 c**	0.047 f	0.083 d	0.109 e	**0.079 f**
Chitosan 2%+ Hot water (45°C)	0.092a	0.015 de	0.020bc	0.028bc	0.034 c	**0.024 c**	0.068 e	0.097 c	0.115 e	**0.093 e**
Mean	**0.092a**	**0.018 e**	**0.025 d**	**0.034 c**	**0.049 b**		**0.077 c**	**0.106 b**	**0.149 a**	
				Season 2022						
Control (Distilled water)	0.245a	0.076 a	0.079 a	0.096 a	0.103 a	**0.088 a**	0.142 a	0.200 a	0.250 a	**0.198 a**
Citric acid 10%	0.245a	0.063abc	0.079 a	0.081ab	0.091ab	**0.078bc**	0.127 b	0.180 b	0.211bc	**0.173 b**
$CaCl_2$ 6%	0.245a	0.066 ab	0.074 a	0.085ab	0.093ab	**0.080 b**	0.120 bc	0.176 bc	0.217 b	**0.171 b**
Hot water (45°C)	0.245a	0.059 bc	0.074 a	0.082ab	0.090ab	**0.077bc**	0.118bcd	0.171 bc	0.204bc	**0.164 b**
Chitosan 2%	0.245a	0.056 bc	0.072 a	0.081ab	0.086 b	**0.074bc**	0.109 d	0.168bcd	0.211bc	**0.162 b**
Chitosan 2%+ Citric acid 10%	0.245a	0.055 bc	0.069 b	0.073 b	0.087 b	**0.071cd**	0.111 cd	0.155 de	0.187 c	**0.151 c**
Chitosan 2%+ $CaCl_2$ 6%	0.245a	0.050 c	0.064 b	0.073 b	0.069 c	**0.064 e**	0.082 e	0.152 e	0.155 d	**0.130 d**
Chitosan 2%+ Hot water (45°C)	0.245a	0.054 bc	0.069 b	0.072 b	0.071 c	**0.066de**	0.111 cd	0.163cde	0.155 d	**0.143 c**
Mean	**0.245a**	**0.060 e**	**0.072 d**	**0.080 c**	**0.087 b**		**0.115 c**	**0.170 b**	**0.199 a**	

- The means were significantly different at the 0.05 probability level.

calcium, particularly with long cold storage and shelf-life periods. The results partially agree with **Elmenofy *et al.* (2021)** who found that 2.5% chitosan reduced MDA content in apricots compared to the control treatment during 28 days of cold storage.

Polyphenol-oxidase activity (PPO; unit / mg FW min.$^{-1}$)

The Polyphenol-oxidase activity (PPO) of treated fruits post-harvest treatments were increased during the cold storage period (Table 14). The PPO activity in untreated fruits (control) was higher than the other treatments in the 2021 and 2022 seasons. In 2021, the PPO activity of untreated fruit (control) in the initial experiment (day 0) was 0.011 unit/mg FW min.$^{-1}$, which increased gradually to 0.035, 0.055, 0.070, and 0.099 unit/mg FW min.$^{-1}$ at 7, 14, 21, and 28 days of cold storage period. In 2022, the PPO activity has remained quite stable at 0.065 unit/mg FW min.$^{-1}$ from 0 to 7 days of cold storage, then was increased to 0.079, 0.122, and 0.123 unit/mg FW min.$^{-1}$ at 14, 21, and 28 days of cold storage. While treated fruits with chitosan 2%+ $CaCl_2$ 6% treatment recorded the lowest PPO values.

As for the effect of post-harvest treatments during the shelf-life period, results were cleared that the coating of peach fruit decreased PPO activity in comparison with the control. The chitosan 2%+ $CaCl_2$ 6% treatment recorded the lowest average of the PPO activity (0.123 and 0.169 unit/mg FW min.$^{-1}$) in the 2021 and 2022 seasons. Meanwhile, the highest PPO activity (0.229 and 0.290 unit/mg FW min.$^{-1}$) in the 2021 and 2022 seasons was recorded in the untreated fruits (control).

Based on the previous results, we can conclude that treating the fruits with chitosan in combination with calcium helped maintain the lowest respiration rate, reducing the percentage of oxygen needed for internal physiological reactions. This, in turn, decreased the likelihood of fruit browning due to enzymatic oxidation through the

Table 14. Effect of some environmentally safe post-harvest treatments on Polyphenol-oxidase activity (unit/mg FW min.$^{-1}$) during cold storage and shelf life

Treatments	Initial	Cold storage (days)					Shelf life (days)			
		7	14	21	28	Mean	3	6	9	Mean
				Season 2021						
Control (Distilled water)	0.011a	0.035 a	0.055 a	0.070 a	0.099 a	**0.064 a**	0.152 a	0.223 a	0.314 a	**0.229 a**
Citric acid 10%	0.011a	0.030 b	0.044 b	0.063ab	0.089 b	**0.056 b**	0.123 b	0.160 b	0.288 b	**0.190 b**
$CaCl_2$ 6%	0.011a	0.027bc	0.035 c	0.063ab	0.085 b	**0.052 b**	0.116 b	0.173 b	0.277 b	**0.189 b**
Hot water (45°C)	0.011a	0.028 b	0.035 c	0.055bc	0.070 c	**0.047 c**	0.099 c	0.164 b	0.263 c	**0.175 c**
Chitosan 2%	0.011a	0.024cd	0.031 c	0.048cd	0.065cd	**0.042 d**	0.085de	0.126 c	0.246 d	**0.152 d**
Chitosan 2%+ Citric acid 10%	0.011a	0.023de	0.035 c	0.044cd	0.063cd	**0.042 d**	0.094cd	0.108 d	0.231 e	**0.144 e**
Chitosan 2%+ $CaCl_2$ 6%	0.011a	0.012 f	0.022 d	0.038 d	0.058 d	**0.033 e**	0.074 e	0.098 d	0.196 f	**0.123 f**
Chitosan 2%+ Hot water (45°C)	0.011a	0.020 e	0.031 c	0.048cd	0.065cd	**0.041 d**	0.085de	0.104 d	0.231 e	**0.140 e**
Mean	**0.011e**	**0.025 d**	**0.036 c**	**0.054 b**	**0.074 a**		**0.104 c**	**0.145 b**	**0.256 a**	
				Season 2022						
Control (Distilled water)	0.065a	0.065 a	0.079 a	0.122 a	0.123 a	**0.097 a**	0.198 a	0.293 a	0.378 a	**0.290 a**
Citric acid 10%	0.065a	0.064 a	0.082 a	0.111ab	0.121 a	**0.095 a**	0.158 b	0.230 b	0.341 b	**0.243 b**
$CaCl_2$ 6%	0.065a	0.060ab	0.071 b	0.106bc	0.109 b	**0.087 b**	0.153bc	0.233 b	0.323bc	**0.236bc**
Hot water (45°C)	0.065a	0.054bc	0.064cd	0.097bc	0.094 c	**0.077 c**	0.138cd	0.240 b	0.313 c	**0.230 c**
Chitosan 2%	0.065a	0.053 c	0.068bc	0.092 c	0.089 c	**0.075 cd**	0.137cd	0.179 c	0.299cd	**0.205 d**
Chitosan 2%+ Citric acid 10%	0.065a	0.049cd	0.060de	0.093 c	0.089 c	**0.073cde**	0.124de	0.168cd	0.275de	**0.189 e**
Chitosan 2%+ $CaCl_2$ 6%	0.065a	0.037 e	0.058de	0.090 c	0.087 c	**0.068 e**	0.111 e	0.157 d	0.239 f	**0.169 f**
Chitosan 2%+ Hot water (45°C)	0.065a	0.045 d	0.055 e	0.089 c	0.087 c	**0.069 de**	0.121de	0.150 d	0.272 e	**0.181 e**
Mean	**0.065b**	**0.053 c**	**0.067 b**	**0.100 a**	**0.100 a**		**0.143 c**	**0.206 b**	**0.305 a**	

• The means were significantly different at the 0.05 probability level.

formation of the PPO enzyme **(Jiang *et al.*, 2016)**. The results partially agree with **Ramirez *et al.* (2015)**, who found that treating fruit with 2 g/100 ml of chitosan decreased the PPO activity in nectarine. Also, treated fruits with chitosan 0.025% recorded lower PPO activity than the control treatment **(Mohamed *et al.*, 2019)**.

Shelf Life

The shelf- life significantly extended for all post-harvest treatments compared to the control (Fig. 1). In the first season, the longest shelf life (9 days) after 28 days of cold storage was observed with the chitosan 2%+$CaCl_2$ 6% or Chitosan 2% at 45°C treatments. The same pattern was observed in the second season. Treated fruits with chitosan 2%+$CaCl_2$ 6% or chitosan 2% at 45°C had the highest shelf-life days (8 days). The shortest shelf life (3 days) was recorded with control in both seasons, respectively. The shelf life of peaches is about two to three days at room temperature **(Kader, 2001)**. It's important to preserve fruit quality and freshness by focusing on firmness and preventing microbial decay. This study observed that chitosan, calcium, and hot water treatments had a positive effect on maintaining firmness, reducing respiration rate, preventing spoilage, and delaying fruit senescence (Fig. 2). A similar result was shown by **El-Badawy *et al.* (2012) and Gayed *et al.* (2017)** who reported that the shelf life of peach fruits was extended of 4-5 days when treated fruit with chitosan in combination with $CaCl_2$ treatment.

Conclusions

The study concluded that the treated EarliGrande peaches with a combination of 2% chitosan and 6% $CaCl_2$ or treated with 2% chitosan after being dipped in hot water at 45°C for 10 min, resulted in reduced decay, slowed weight loss, and maintained the highest fruit firmness during the 28 days of cold storage. Furthermore, the use of post-harvest treatment with 2% chitosan and 6% $CaCl_2$ proved to be highly effective in extending the shelf life of peach fruit. This treatment significantly improved various fruit quality parameters, such as total phenol, acidity, ascorbic acid, and DPPH%, while also reducing the formation and activity of MDA and PPO enzymes.

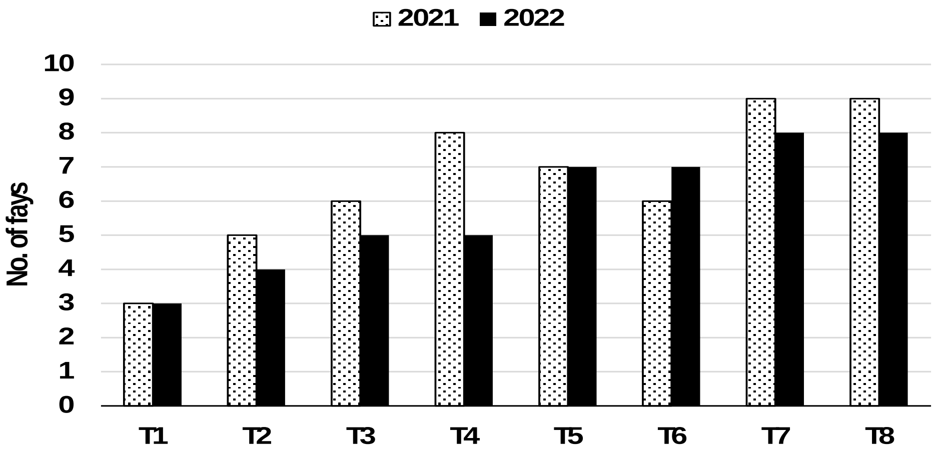

Fig. 1. Effect of some environmentally safe post-harvest treatments on shelf-life after 28 days of cold storage. (T1) Control (Distilled water), (T2) Citric acid 10%, (T3) $CaCl_2$ 6%, (T4) Hot water (45˚C), (T5) Chitosan 2%, (T6) Chitosan 2%+ Citric acid 10%. (T7) Chitosan 2%+ $CaCl_2$ 6%, and Chitosan 2%+ Hot water at 45˚C (T8)

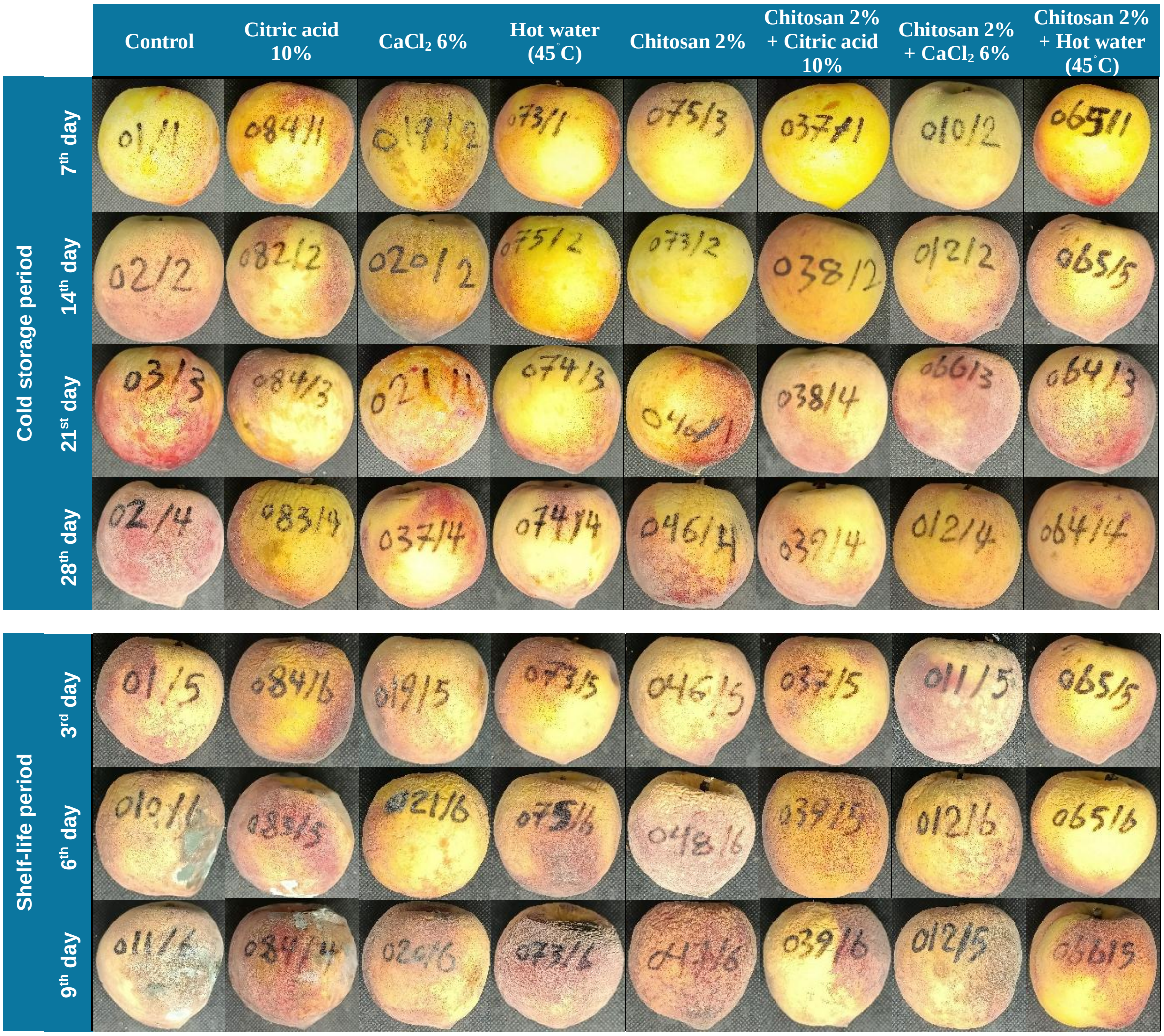

Fig. 2. Appearance of Early-Grand peach fruits treated with some postharvest treatments during cold storage

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الملخص العربي

إطالة مدة تخزين وصلاحية ثمار الخوخ الإيرلي جراند باستخدام بعض معاملات ما بعد الحصاد

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أجريت هذه الدراسة لإطالة مدة تخزين وصلاحية ثمار الخوخ الإيرلي جراند من خلال تطبيق بعض معاملات ما بعد الحصاد الآمنة بيئيًا عند التخزين المبرد. تم غمس ثمار الخوخ في محلول 10% حمض الستريك، محلول 6% كلوريد الكالسيوم، الماء الساخن (45°م)، ومحلول 2% شيتوزان، بشكل منفرد أو في توليفات بالإضافة إلى الماء المقطر "الكنترول" وذلك لمدة 10 دقائق. أظهرت النتائج ارتفاع معدل فقد وزن الثمرة ومحتوى المواد الصلبة الذائبة والسكر الكلي والفينول ونشاط الإنزيمات في جميع المعاملات مع زيادة فترة التخزين المبرد (28 يومًا) وزيادة مدة الصلاحية الى اليوم التاسع، باستثناء محتوى الفينول الذي انخفض عند نهاية فترة الصلاحية. كما انخفضت صلابة الثمار والحموضة والفلافونيدات ونشاط مضادات الأكسدة (DPPH%) وحمض الأسكوربيك تدريجياً مع زيادة التخزين المبرد ومدة الصلاحية. لم يلاحظ أي مظاهر فساد بالميكروبات الدقيقة على الثمار المعاملة وغير المعاملة خلال 28 يومًا من التخزين المبرد، ولكن تلاحظ ظهور نموات فطرية على الثمار خلال مدة الصلاحية. خلال فترة التخزين المبرد، تم الحصول على أقل معدل فقد في الوزن، إلى جانب أعلى قيم لصلابة الثمار، وحمض الأسكوربيك، والفلافونيدات، ومضادات الأكسدة في الثمار المعاملة بالشيتوزان 2%+ كلوريد الكالسيوم 6%. علاوة على ذلك، كان الشيتوزان 2%+الماء الساخن (45°م) متفوقا في منع فساد الثمار إلى أدنى نسبة مئوية خلال مدة الصلاحية. لم يتم ملاحظة اختلاف كبير بين معاملة الشيتوزان 2% + الماء الساخن (45°م) ومعاملة الشيتوزان 2%+كلوريد الكالسيوم 6% بالنسبة لإبطاء معدل فقد الوزن. وأدت معاملة الثمار باستخدام الشيتوزان 2%+كلوريد الكالسيوم 6% إلى تثبيط نشاط إنزيم الـ MDA وPPO بكفاءة، مع الحفاظ أيضًا على أعلى نشاط لمضادات الأكسدة، ومحتوى الفينول، وحمض الأسكوربيك.

الكلمات الاسترشادية: الخوخ، ما بعد الحصاد، التخزين المبرد، مدة الصلاحية.

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