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Fruit Antioxidant Properties of "Costata" Persimmon (*Diospyros kaki Thunb*.) under Different Astringency Removal Treatments

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Abstract

This study evaluated alternative postharvest de-astringency treatments for ‘Costata’ persimmon (*Diospyros kaki Thunb*) fruits to assess total phenols, soluble tannins, carotenoids, vitamin C, and antioxidant activity (reducing power, total antioxidant capacity, and DPPH scavenging) during the shelf life. Experiments were conducted in the 2023 and 2024 seasons using six treatments and a control: distilled water (Tc), calcium carbide (CaC_2) (T1), potassium carbonate (K_2CO_3) at 2.5% (T2) and 5% (T3), sodium bicarbonate ($NaHCO_3$) at 2.5% (T4) and 5% (T5), and 40% ethanol (T6). Results indicated that all antioxidant parameters declined progressively during the shelf-life period, but the rate of decline was significantly affected by the postharvest treatments. Fruits treated with CaC_2 showed rapid de-astringency but exhibited the lowest retention of total phenols, vitamin C, and antioxidant capacity, reflecting accelerated ripening and oxidative degradation. On the other hand, fruits treated with $NaHCO_3$ and K_2CO_3 showed a progressive loss of antioxidant compounds over the course of their shelf life, but they retained higher levels of carotenoids, polyphenols, and radical scavenging activity. Ethanol treatment also delayed antioxidant depletion but was less effective than carbonate treatments. These results validate the use of alkaline treatments, specifically K_2CO_3 at 2.5%, as safe and environmentally beneficial substitutes for CaC_2 in the simultaneous elimination of astringency and maintenance of antioxidant quality in "Costata" persimmon fruits.

Keywords: Antioxidant activity, carotenoids, de-astringency, tannins, polyphenols.

1. Introduction

Persimmon (*Diospyros kaki Thunb*.), a deciduous fruit tree belonging to the family *Ebenaceae*, is widely cultivated in subtropical and temperate regions, particularly in East Asia **(Jain *et al*., 2023).** Globally, China remains the dominant producer, accounting for the majority of the world's supply due to its favorable climate and long-standing cultivation practices **(Giordani, 2022).** The fruit is traditionally classified into two main types, astringent and non-astringent, based on the presence of soluble tannins at harvest **(Han *et al*., 2022).** Non-astringent cultivars can be consumed directly after harvest, whereas astringent ones require postharvest treatments such as exposure to ethanol, CO_2, or chemical agents to remove bitterness **(Zhao *et al*., 2025).** Despite its nutritional richness and consumer appeal, the persimmon has a relatively short shelf life, and the fruit often undergoes rapid softening during postharvest storage and distribution, which limits its marketability. This rapid ripening, coupled with susceptibility to mechanical damage, poses a significant challenge for both local and international marketing **(Chen *et al*., 2021).**

Astringency in persimmon fruit is primarily attributed to the presence of water-soluble tannins, which are stored in large, specialized “tannin cells” dispersed throughout the fruit's flesh **(Mirabello, 2024).** Postharvest treatments such as carbon dioxide exposure, ethanol vapor application, and drying after peeling convert these soluble tannins into insoluble forms, effectively reducing astringency and allowing the fruit to be consumed safely **(Zhao *et al*., 2025).** Persimmons are called "the fruit of the gods" because of their importance and nutritional value. Fruits are rich in various nutrients and phytochemicals, such as carbohydrates, organic acids, vitamins, tannins, polyphenols, dietary fiber, triterpenoids, and carotenoids, which contribute significantly to their taste, color, and nutritional and medicinal value **(Altuntas *et al*., 2011).**

Egypt has recently introduced the persimmon, a horticultural crop with promising export development prospects to other markets in the world. The cultivated area of approximately 1,420 feddan produced approximately 8,516 tons of persimmons **(Gabr and Rabie 2023).** Dakahlia Governorate has occupied about 750 feddan from the total area cultivated **(Eliwa *et al.,* 2003).** Costata, as an astringent cultivar, is the leading persimmon variety progressively consumed in the Egyptian market and for exportation **(Eliwa *et al.,* 2003; Ahmed and Sobieh, 2007).** The physicochemical and physiological changes induced by deastringency treatment in intact persimmons vary according to the fruit variety and deastringency methods, which include warm water treatment **(Jia *et al*., 2024),** ethanol treatment **(Chung *et al*., 2015)**, high CO_2 treatment **(Sanchís Soler, 2016)**, and modified atmosphere packaging **(Novillo Borrás, 2016; Jia *et al*., 2024)**. Freezing treatment **(Chung *et al*., 2015).**

Persimmons are recognized for their high antioxidant capacity, which contributes to their potential protective effects against oxidative stress in humans. These bioactive compounds make persimmons particularly valuable in managing lifestyle-related diseases such as cardiovascular disorders and diabetes mellitus **(Jiao *et al*., 2022).** Among their key phytochemicals, tannins are especially notable for their free radical scavenging ability. Traditionally, persimmons have held a prominent place in Chinese medicine, where they were used to treat a variety of ailments, including paralysis, frostbite, burns, and hemorrhages **(Al-Qaisi *et al*., 2025).** The antioxidant compounds in persimmons, particularly tannins, phenolics, carotenoids, and vitamin C, play a critical role in neutralizing reactive oxygen species and preventing lipid peroxidation, thereby reducing cellular damage **(Yaqub *et al.,* 2016).** Studies have demonstrated that both pulp and peel extracts exhibit strong DPPH radical scavenging activity, reducing power, and total antioxidant capacity, highlighting their potential use in functional foods and nutraceuticals **(Salazar-Bermeo *et al*., 2023)**. Moreover, the presence of carotenoids such as β-carotene and lycopene further enhances the fruit's antioxidant potential, contributing to improved cardiovascular health and reduced inflammation **(Yaqub *et al*., 2016).**

Calcium carbide (CaC_2) is commonly used to artificially accelerate the ripening of fruits, as it releases acetylene gas upon contact with moisture. Acetylene acts similarly to ethylene, the natural ripening hormone, by promoting softening and color development. However, this method often results in uneven ripening, where fruits exhibit a ripe appearance externally while remaining immature and underdeveloped internally. More importantly, calcium carbide treatment has been shown to negatively affect the nutritional quality of fruits. For example, a study on bananas found that calcium carbide treatment compromised the activity levels of antioxidant enzymes: peroxidase, ascorbate peroxidase, and catalase all decreased significantly compared to naturally ripened fruits **(Vidhya *et al., 2025).*** In ripened mangoes treated with calcium carbide, the vitamin C content dropped significantly as compared to naturally ripened controls **(Hussain *et al.*, 2024)** Health concerns are further heightened by the fact that commercial-grade calcium carbide often contains hazardous contaminants such as arsenic and phosphorus. These toxic substances may lead to acute irritation of the mouth and nasal passages, vomiting, skin ulcers, and even kidney damage. In addition, the accumulation of acetylene gas within fruit tissues poses a risk of neurological damage, especially with frequent consumption of contaminated produce **(Vidhya *et al.*, 2025).**

Carbonates and bicarbonates are eco-friendly, low-cost alternatives for postharvest disease control and quality preservation in fruits. These alkaline salts inhibit major pathogens like *Penicillium* and *Botrytis* by raising surface pH and disrupting fungal membranes. They also delay fruit senescence by reducing respiration and preserving organic acids **(Youssef *et al.*, 2014).** Due to their low toxicity and Generally Recognized as Safe (GRAS) status, they are promising tools in postharvest management strategies**. Ahmed *et al.*, 2007; D'Aquino *et al.*, 2022; Zhao *et al.*, 2025.**

This study aimed to evaluate the effectiveness of different postharvest treatments, calcium carbide (CaC_2), potassium carbonate (K_2CO_3), sodium bicarbonate ($NaHCO_3$), and ethanol vapor, on the removal of astringency and the preservation of antioxidant properties of 'Costata' persimmon fruits at room temperature. Particular emphasis was placed on assessing the treatments' impact on antioxidant-related parameters such as total polyphenol content, soluble tannins, flavonoids, and vitamin C over eight days of shelf life period.

2. Materials and Methods

The current study was conducted during two successive seasons (2023 and 2024) on persimmon (*Diospyros kaki Thunb.)*, cv. costata fruit. Trees were 10 years old, budded on *Diospyros virginiana* rootstock, planted at 4x4 m apart, and grown in a clay loamy soil at a private orchard in Fisha-Bana Village, Aga Center, El-Dakahlia Governorate, Egypt. Costata cultivar belongs to the astringent group of cultivars with no changes in flesh color with pollination (APC). Plant experimental research, including the gathering of plant material, was carried out in compliance with the applicable laws and regulations.

2.1. Plant materials

Fruits were collected in the early morning at the middle of October (2023 and 2024 seasons), with uniform sizes (110 ± 5 g), shape, and yellow-green color stage, and inspected for mechanical injuries, diseases, and pests. The harvested fruits were immediately transported (at ambient temperature) to the Laboratory of the Pomology Department, Faculty of Agriculture, University of Damietta. The fruits were cleaned with a cotton cloth to reduce the microbial load on the fruit surface and then divided into 7 groups of 45 fruits per treatment, with 15 fruits in each measure day (5 fruits X 3 replicates). Each group received one of the following artificial ripening treatments:

T_c: Soaking fruits with distilled water for 24 hours (Control).

T_1: Calcium carbide (CaC_2); fruits exposed to the gases resulted from the interaction between calcium carbide at 0.5 g/ml water in a closed chamber for 24 hours as described by **Eliwa et al. (2025).**

T_2: Soaking in potassium carbonate (K_2CO_3) with concentrations of 2.5% for 24 hours.

T_3: Soaking in potassium carbonate (K_2CO_3) with concentrations of 5% for 24 hours.

T_4: Soaking in sodium bicarbonate ($NaHCO_3$) with concentrations of 2.5% for 24 hours.

T_5: Soaking in sodium bicarbonate ($NaHCO_3$) with concentrations of 5% for 24 hours.

T_6: laying fruits in layers of paper moistened with ethyl alcohol at a concentration of 40% for 24 hours.

The fruits were packed in one layer in carton boxes. The experiment was carried out at room temperature to determine the effect of treatments on fruit quality characteristics, and samples were taken every three days during the experiment (2, 5, and 8 days). The following assessments were determined:

2.2. Assessment of Antioxidant

2.2.1. Total polyphenolic Content (mg/g)

Total polyphenolic content was determined using the Folin–Ciocalteu method described by **Singleton and Rossi (1965).** Fruit extract prepared in methanol (99.9%) was reacted with diluted Folin–Ciocalteu reagent and sodium carbonate (2%), incubated for 30 min in the dark, and absorbance was measured at 750 nm. Results were expressed as mg Gallic acid equivalents (GAE) per g fresh weight.

2.2.2. Soluble Tannin Content

Soluble tannin content was determined using the Folin–Ciocalteu method as described by **Hoff and Singleton (1977).** Fruit tissue (1.25 g) was extracted with 80% methanol, centrifuged at 6000 rpm for 15 min at 4°C, and the supernatant was collected. An aliquot of the extract was mixed with Folin reagent and sodium carbonate, and absorbance was measured at 765 nm. Tannin concentration was calculated from a Gallic acid calibration curve and expressed as mg Gallic acid equivalents (GAE) per g fresh weight.

2.2.3. Total Carotenoids (mg/100 mL)

Total carotenoids were quantified as described by **Wellburn (1994)**, using the following equation:

$$C = \frac{A \times V_{extract} \times 10^6}{A_{1\%} \times W_{sample}}$$

Where:

- **C** = carotenoid concentration (µg/g)
- **A** = absorbance at 480 nm
- **$V_{extract}$** = extract volume (mL)
- **A1%** = specific absorption coefficient (typically 2500)
- **W_{sample}** = sample weight (g)

2.2.4. Vitamin C Content (mg/100 mL Juice)

Ascorbic acid was measured using the 2, 6-dichlorophenol-indophenol titration method according to **AOAC (2000).** It was calculated using:

$$Vitamin\ C\ (mg/100\ mL) = \frac{Titration\ volume \times Dye\ factor \times 100}{Sample\ volume}$$

2.2.5. Reducing Power

The reducing power of persimmon extracts was determined according to **Oyaizu (1986).** Fruit samples (0.1 g) were extracted with methanol (99.9%). The reaction mixture containing extract, phosphate buffer (0.2 M, pH 6.6), and potassium ferricyanide (1%) was incubated at 50 °C for 20 min, followed by the addition of trichloroacetic acid (10%) and centrifugation. The supernatant was mixed with ferric chloride (0.1%), and absorbance was measured at 700 nm, and results were expressed as absorbance

2.2.6. Total Antioxidant Capacity

Total antioxidant capacity was determined using the phosphomolybdenum method described by **Prieto et al. (1999).** Fruit extract (0.1 g in 10 mL methanol, 99.9%) was mixed with phosphomolybdenum reagent and incubated at 37°C for 90 min. The absorbance of the developed green color was measured at 695 nm, and the results were expressed as absorbance.

2.2.7. Radical Scavenging Activity (DPPH Assay)

Assessed using DPPH radical according to **Ribeiro *et al.* (2007).** Inhibitions (%) were calculated by:

$$\text{Inhibitions (\%)} = (\frac{A_0 - A_s}{A_0}) \times 100$$

Where:

- **A_0** = absorbance of the control (DPPH only)
- **As** = absorbance with sample extract

2.3. Statistical Analysis

This study was carried out as a factorial experiment (treatments x shelf life duration) in a completely randomized Design (CRD), and the outcomes were confirmed by repeating them over two seasons. Each treatment had 45 fruit, with three replicates, each containing 5 fruit on each measurement day. For each date during the shelf life, average data regarding the effects of treatments was analyzed using CoStat Computer Software (version 6.311). Mean differences were evaluated using the least significant difference (LSD) test at $p \leq 0.05$ (**Steel et al., 1997**).

3. Results and discussions

3.1.1. Total polyphenolic content (TPC):

In **Table (1a) and Figure (1a),** total polyphenolic content gradually declined as the shelf life progressed from 2 to 8 days across all treatments. Regarding the treatments, it could be noticeable that the control (T_c; distilled water) showed the highest significant mean value (8.89 mg/g), followed by K_2CO_3 treatments (T_2: 2.5% and T_3: 5%) and $NaHCO_3$ (T_4: 2.5% and T_5: 5%), which recorded 7.66 and 7.25 mg/g, respectively. Whereas the lowest treatment was recorded in CaC_2-treated fruits (T_1) with a mean of 3.97 mg/g. For the interaction of the treatments and shelf-life duration, the highest significant mean value (9.00 mg/g) was recorded with T_c on the second day of shelf life, but the lowest significant mean value (1.34 mg/g) was recorded with T_1 on the eighth day during the shelf life. These results are consistent with **Ebrahimi *et al.* (2024)**, who found that potassium nano-carbonate coatings helped preserve antioxidant compounds and delay oxidative damage in grapefruit.

3.1.2. Soluble tannin content:

Soluble tannins decreased significantly during the shelf-life period due to polymerization into insoluble forms during the de-astringency process, as shown in **Table (1b) and Figure (1b)**. Regarding the treatments, it could be noticeable that the control (T_c) recorded the highest mean tannin content (2.32 mg/g), followed by $NaHCO_3$ 5% (T_5; 1.97 mg/g) and K_2CO_3 2.5% (T_2; 1.88 mg/g). The lowest value was obtained in CaC_2-treated fruits (T_1; 0.65 mg/g), confirming the rapid de-astringency effect of acetylene gas. For the interaction of the treatments and shelf-life duration, the highest significant mean value was recorded with T_c (2.91 mg/g) on the second day of shelf life, but the lowest significant mean value (0.32 mg/g) with T_1 on the eighth day during the shelf life. This decline in tannin levels reflects progressive ripening and reduced astringency, which may enhance consumer acceptability and fruit quality **(Aharoni et al., 1997).**

3.1.3. Total carotenoids:

Table (1c) and **Figure (1c)** showed that carotenoid concentration increased gradually with extended shelf life. Regarding the treatments, it could be noticeable that the highest mean value is in CaC_2-treated fruits (T_1; 2.66 mg/100 mL), followed by ethanol treatment (T_6, 2.15 mg/100 mL). The lowest carotenoid levels were observed in the control (T_c; 1.59 mg/100 mL) and $NaHCO_3$ 2.5% (T_4; 1.57 mg/100 mL). The increase in carotenoid content under CaC_2 treatment could be linked to accelerated pigment biosynthesis followed by rapid senescence, as suggested by **Zhao *et al.* (2025).** For the interaction of the treatments and shelf-life duration, the highest significant mean value was recorded with T_1 (2.90 mg/100 mL) on the eighth day of shelf life, but the lowest significant mean value (1.50 mg/100 mL) was with T_c on the second day during the shelf life.

Table (1): Effect of different postharvest treatments and shelf life on antioxidant concentration (a: Total polyphenolic, b: Soluble tannin, c: Total carotenoid, and d: Vitamin C contents) of ‘Costata’ persimmon fruits.

Treatment	**Shelf life (days)**			**Mean**	**Shelf life (days)**			**Mean**
	2	**5**	**8**		**2**	**5**	**8**	
(a)	**Total polyphenolic content (mg/g)**				**(b)**	**Soluble tannin Content (mg/g)**		
T_c	9.00^{a}	8.89^{a}	8.77^{ab}	**8.89^{A}**	2.91^{a}	2.35^{b}	1.72^{cd}	**2.32^{A}**
T_1	6.71^{f}	3.85^{j}	1.34^{l}	**3.97^{F}**	0.92^{fg}	0.71^{fgh}	0.32^{h}	**0.65^{G}**
T_2	8.72^{abc}	5.65^{h}	2.83^{k}	**5.74^{D}**	2.56^{ab}	1.37^{de}	0.41^{h}	**1.45^{E}**
T_3	8.36^{bc}	4.99^{i}	2.93^{k}	**5.43^{E}**	2.31^{b}	1.03^{efg}	0.65^{gh}	**1.33^{F}**
T_4	8.93^{a}	7.81^{d}	6.24^{g}	**7.66^{B}**	2.81^{a}	1.76^{cd}	1.08^{ef}	**1.88^{C}**
T_5	8.32^{c}	7.30^{e}	6.12^{g}	**7.25^{C}**	2.93^{a}	1.87^{c}	1.11^{ef}	**1.97^{B}**
T_6	8.88^{a}	7.36^{e}	5.30^{hi}	**7.18^{C}**	2.80^{a}	1.65^{cd}	0.71^{fgh}	**1.72^{D}**
Mean	**8.42^{A}**	**6.55^{B}**	**4.79^{C}**		**2.46^{A}**	**1.53^{B}**	**0.86^{C}**	
(c)	**Total Carotenoids (mg/100 mL)**				**(d) vitamin C content (mg/100 ml juice)**			
T_c	1.50^{n}	1.60^{lm}	1.68^{jk}	**1.59^{E}**	54.30^{a}	51.28^{c}	47.00^{e}	**50.86^{A}**
T_1	2.43^{d}	2.67^{b}	2.90^{a}	**2.66^{A}**	41.30^{i}	31.65^{n}	25.60^{p}	**32.85^{G}**
T_2	1.74^{ij}	2.00^{g}	2.55^{c}	**2.10^{C}**	42.23^{h}	34.60^{m}	28.53^{o}	**35.12^{F}**
T_3	1.84^{h}	2.05^{fg}	2.31^{e}	**2.07^{C}**	45.63^{f}	36.70^{l}	28.90^{o}	**37.08^{E}**
T_4	1.45^{n}	1.58^{m}	1.67^{jkl}	**1.57^{E}**	53.13^{b}	48.58^{d}	40.20^{k}	**47.31^{B}**
T_5	1.67^{jkl}	1.80^{hi}	1.99^{g}	**1.82^{D}**	51.20^{c}	46.77^{e}	40.70^{j}	**46.22^{C}**
T_6	1.65^{klm}	2.08^{f}	2.71^{b}	**2.15^{B}**	48.70^{d}	44.37^{g}	40.50^{jk}	**44.52^{D}**
Mean	**1.75^{C}**	**1.97^{B}**	**2.26^{A}**		**48.07^{A}**	**41.99^{B}**	**35.92^{C}**	

*Using the same letters, the LSD test shows that, at $P \leq 0.05$, there is no significant difference between the means of each factor and their interaction.

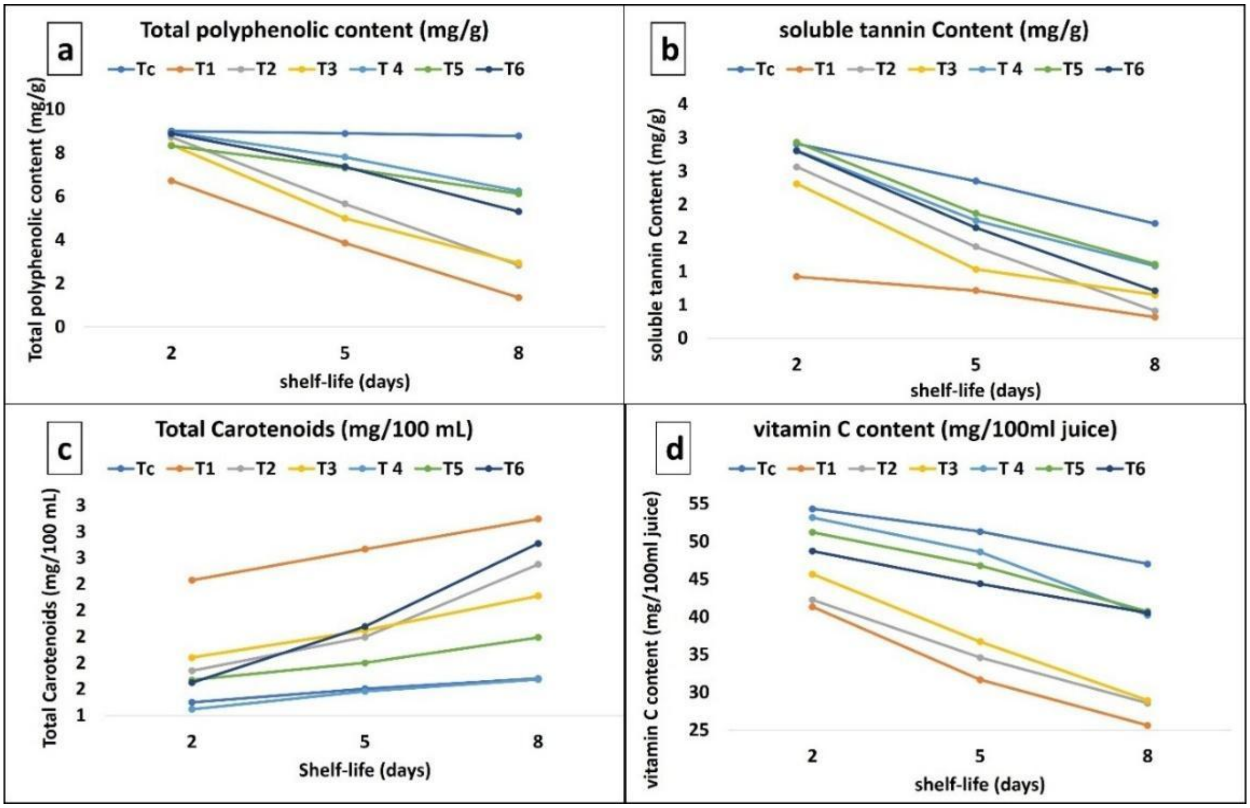

Figure (1): Effect of different postharvest treatments and shelf-life on antioxidant concentration (a: Total polyphenolic, b: Soluble tannin, c: Total carotenoid, and d: Vitamin C contents) of ‘Costata’ persimmon fruits.

3.1.4. Vitamin C content:

Table (1d) and **figure (1d)** showed that vitamin C decreased markedly with prolonged shelf life, indicating oxidative degradation of ascorbic acid. Regarding the treatments, it could be noticeable that the highest mean value was recorded in the control (50.86 mg 100 mL^{-1}), followed by K_2CO_3 2.5% (T_2; 47.31 mg/100 ml juice) and $NaHCO_3$ 5% (T_5; 46.22 mg/100 ml juice). The lowest level was found in CaC_2-treated fruits (T_1; 32.85 mg/100 ml juice), reflecting accelerated oxidative degradation (Patoare *et al*., 2007). The higher vitamin C retention in carbonate-treated fruits compared with CaC_2 may be attributed to reduced oxidative stress and slower ripening **(Fenech *et al.*, 2019).** For the interaction of the treatments and shelf-life duration, the highest significant mean value was recorded with T_c (54.30 mg/100 ml juice) on the second day of shelf life, but the lowest significant mean value (25.60 mg/100 ml juice) was with T_1 on the eighth day during the shelf life.

3.1.5. Reducing power (RP)

Reducing power (RP) provides an additional measure of antioxidant potential by assessing electron-donating ability. Data as average of two seasons **(Table (2) and figure (2)** demonstrated a progressive decrease in reducing power as storage advanced. The control (T_c) retained the highest RP at the highest concentration tested (150 µg/ml), with absorbance values of 2.29 by the day 8, followed closely by $NaHCO_3$-treated fruits (T_4, T_5), which recorded average values of 2.58-2.63 (150 µg/ml at the day 5).

In contrast, CaC_2-treated fruits (T_1) consistently showed the lowest RP with an absorbance average value at 150 µg/ml as low as 0.55 by day 8. These low values are associated with the sharp loss of antioxidant compounds due to rapid ripening and senescence. K_2CO_3 treatments (T_2 and T_3) displayed moderate values that were significantly higher than T_1 but lower than T_c and $NaHCO_3$, suggesting partial preservation of reducing compounds. Overall, the better performance of $NaHCO_3$ treatments correlates with their ability to maintain higher polyphenol and vitamin C levels during storage **(D'Aquino *et al.*, 2022),** who reported that sodium bicarbonate improves the fruit quality of mandarins.

Table (2): Effect of postharvest treatments on reducing power of 'costata' persimmon fruits during shelf life.

Reducing power											
Absorbance											
Shelf life (days)		2			5			8			Aver.
Concentration (µg/ml)		50	100	150	50	100	150	50	100	150	
Treatments	T_c	1.45^{r}	1.71^{o}	2.80^{e}	1.19^{u}	1.64^{p}	2.77^{e}	0.73^{z}	1.17^{uv}	2.29^{j}	1.75^{A}
	T_1	0.24^{e-g}	0.43^{c}	0.62^{a}	0.18^{hi}	0.36^{d}	0.53^{b}	0.07^{kl}	0.23^{e-h}	0.55^{b}	0.36^{F}
	T_2	0.61^{a}	2.02^{l}	2.86^{d}	0.51^{b}	1.70^{o}	2.37^{i}	0.24^{e-g}	0.73^{z}	1.02^{w}	1.34^{D}
	T_3	0.96^{x}	2.09^{k}	2.99^{c}	0.92^{x}	1.72^{o}	2.47^{h}	0.84^{y}	1.40^{st}	1.73^{o}	1.68^{B}
	T_4	1.34^{t}	1.94^{m}	3.10^{b}	1.12^{v}	1.41^{rs}	2.58^{g}	0.05^{l}	0.18^{g-i}	0.25^{ef}	1.33^{D}
	T_5	1.39^{st}	2.35^{i}	3.17^{a}	1.16^{uv}	1.96^{m}	2.63^{f}	0.07^{kl}	0.20^{f-i}	0.28^{e}	1.47^{C}
	T_6	0.12^{j}	0.55^{b}	1.83^{n}	0.12^{j}	0.87^{y}	1.51^{q}	0.05^{l}	0.16^{ij}	0.22^{f-h}	0.60^{E}
Aver.		1.65^{A}			1.42^{B}			0.59^{C}			

*Using the same letters, the LSD test shows that, at $P \leq 0.05$, there is no significant difference between the means of each factor and their interaction.

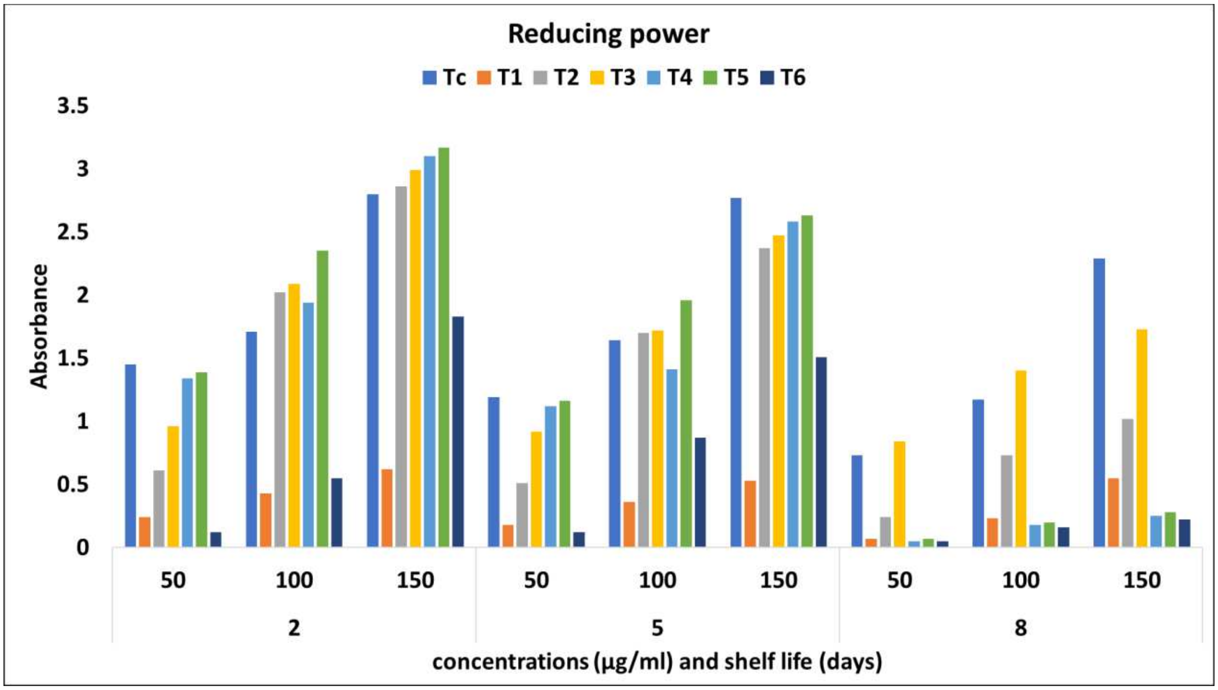

Figure (2): Effect of postharvest treatments on Reducing Power of 'Costata' persimmon fruits during shelf Life.

3.1.6. Total antioxidant capacity (TAC)

Total antioxidant capacity (TAC) measured by the phosphomolybdenum assay also declined significantly in all treatments as storage progressed **(Table (3) and Figure (3).** This reduction reflects the cumulative degradation of antioxidant compounds such as polyphenols, carotenoids, and vitamin C during fruit ripening and senescence. The control (T_c) exhibited the highest final TAC, with absorbance value reaching 0.31 at 750 µg/ml by day 8, followed by $NaHCO_3$ treatments (T_4 and T_5), which maintained significantly higher TAC values (0.18 and 0.22 absorbance units at 750 µg/ml by day 5) compared to other treatments.

CaC_2-treated fruits (T_1) consistently recorded the lowest antioxidant capacity, dropping to 0.19 absorbance units (750 µg/ml) by day 8. Whereas, K_2CO_3 treatments (T_2 and T_3) showed moderate performance, with higher values than T_1 but lower than T_4/T_5 and T_c. These results highlight the cumulative effect of antioxidant degradation under faster ripening conditions. The superior performance of $NaHCO_3$ is consistent with its ability to slow down metabolic activity, thereby delaying antioxidant depletion **(Aharoni *et al*., 1997; Ahmed *et al*., 2007).**

Table (3): Effect of postharvest treatments on total antioxidant capacity of 'costata' persimmon fruits during shelf life.

Total antioxidant capacity											
Absorbance											
Storage period (days)		2			5			8			Aver.
Concentration (µg/ml)		250	500	750	250	500	750	250	500	750	
Treatments	T_c	0.50^{s}	1.26^{b}	1.71^{a}	0.22^{cd}	0.52^{r}	0.75^{m}	0.10^{l}	0.23^{c}	0.31^{b}	0.62^{A}
	T_1	0.31^{ab}	0.80^{k}	1.04^{e}	0.15^{j}	0.32^{za}	0.59^{p}	0.06^{o}	0.14^{k}	0.19^{ef}	0.40^{F}
	T_2	0.38^{v}	0.90^{j}	1.18^{c}	0.17^{hi}	0.50^{s}	0.60^{p}	0.07^{no}	0.16^{h-j}	0.21^{d}	0.46^{B}
	T_3	0.42^{t}	0.90^{j}	0.99^{g}	0.18^{g}	0.35^{x}	0.57^{q}	0.08^{n}	0.13^{k}	0.18^{g}	0.42^{D}
	T_4	0.36^{w}	0.92^{i}	1.16^{d}	0.16^{h-j}	0.38^{v}	0.62^{o}	0.07^{no}	0.17^{h}	0.22^{cd}	0.45^{C}
	T_5	0.35^{x}	0.74^{m}	0.94^{h}	0.17^{h}	0.33^{z}	0.34^{y}	0.09^{m}	0.19^{fg}	0.20^{e}	0.37^{G}
	T_6	0.39^{u}	0.78^{l}	1.01^{f}	0.19^{fg}	0.32^{za}	0.63^{n}	0.08^{mn}	0.14^{k}	0.19^{ef}	0.41^{E}
Aver.		0.81^{A}			0.38^{B}			0.15^{C}			

*Using the same letters, the LSD test shows that, at $P \leq 0.05$, there is no significant difference between the means of each factor and their interaction.

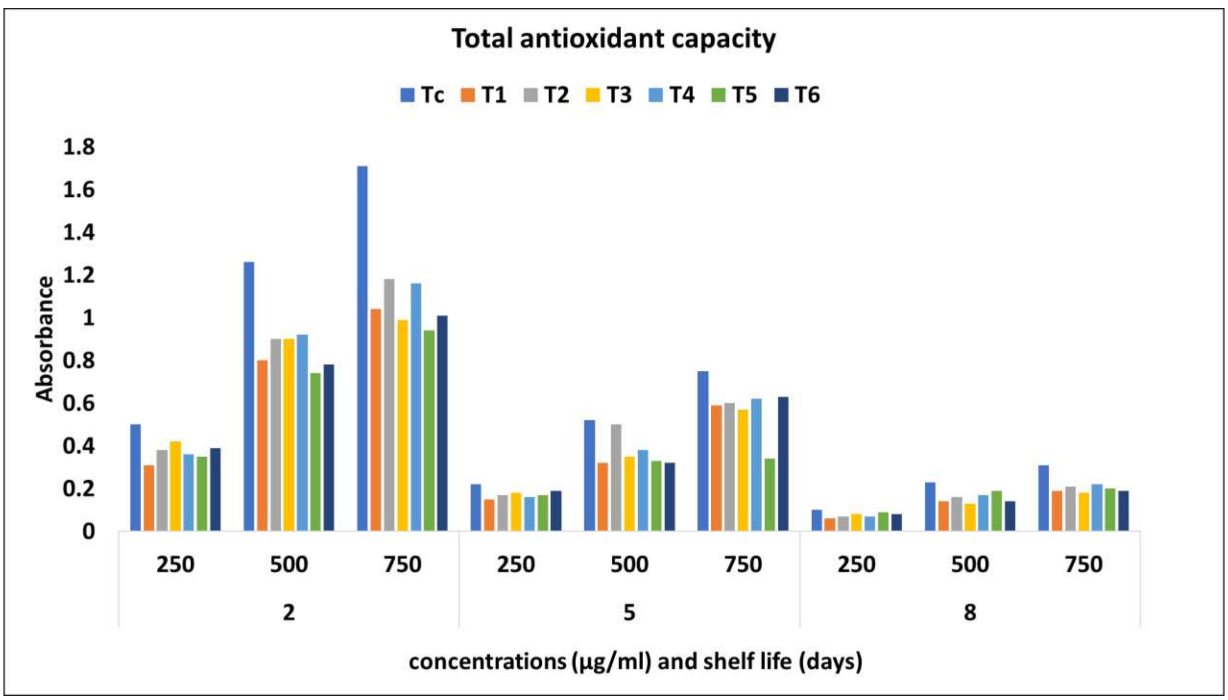

Figure 3: Effect of postharvest treatments on total antioxidant capacity of 'costata' persimmon fruits during shelf life.

3.1.7. Analysis of radical scavenging activity

DPPH radical scavenging activity is an important indicator of antioxidant capacity in fruits, as it reflects the availability of free radical-neutralizing compounds such as polyphenols and vitamin C. Results from both seasons **(Table 4** and **Figure 4)** revealed a significant reduction in radical scavenging activity as storage progressed, consistent with the decline in total polyphenols and vitamin C. The control (T_c) exhibited the highest antioxidant activity across all storage days, reaching values of 99.03% at 150 µg/ml by day 2 and remaining significantly higher than other treatments by day 8 (93.8% at 150 µg/ml).

Fruits treated with CaC_2 (T_1) showed a sharper decline in DPPH activity, especially at higher storage intervals, with final values as low as 28.08% (T_1, 150 µg/ml, day 8). This decline is linked to the accelerated metabolic activity and faster depletion of bioactive antioxidants induced by this treatment. In contrast, $NaHCO_3$ (T_4 and T_5) was the most effective at preserving antioxidant activity during storage (54.80% and 52.40% at 150 µg/ml by day 8, respectively). K_2CO_3 treatments (T_2 and T_3) maintained moderate radical scavenging activity at all storage periods, averaging 47.07–56.12% at 150 µg/ml by day 8, suggesting a better preservation of antioxidant compounds compared to CaC_2. Ethanol treatment (T_6) showed intermediate performance, with antioxidant activity values higher than T_1 but lower than T_4/T_5. These results confirm that alkaline treatments are more effective at preserving functional antioxidant quality during storage **(Anjum *et al*., 2025).**

Collectively, the antioxidant parameters (**RP**, TAC, and DPPH radical scavenging activity) showed that treatments capable of slowing ripening, particularly $NaHCO_3$ (T_4 and T_5), were the most effective at preserving antioxidant capacity during storage. Control fruits (T_c) maintained the highest initial values but did not achieve sufficient de-astringency for consumer acceptability. K_2CO_3 (T_2, T_3) has moderate ripening with effective preserving antioxidant capacity. Conversely, CaC_2 (T_1) promoted rapid antioxidant depletion, limiting their effectiveness in preserving functional quality despite efficient de-astringency. K_2CO_3 (T_2, T_3) has moderate ripening with effective preserving antioxidant capacity.

Table (4): Effect of postharvest treatments on dpph radical scavenging activity of 'costata' persimmon fruits during shelf life.

DPPH radical scavenging activity (%)											
Inhibitions (%)											
Storage period (days)		2			5			8			Aver.
Concentration (µg/ml)		50	100	150	50	100	150	50	100	150	
Treatments	T_c	44.12^{x}	78.83^{g}	99.03^{b}	16.27^{s}	76.17^{h}	97.25^{c}	45.77^{w}	76.03^{h}	93.80^{d}	**72.41^{A}**
	T_1	16.27^{s}	41.30^{ab}	55.95^{q}	18.52^{p}	39.67^{de}	53.40^{s}	9.63^{u}	21.30^{n}	28.08^{i}	**31.32^{G}**
	T_2	26.10^{k}	45.87^{w}	57.33^{p}	24.03^{m}	41.70^{a}	55.23^{r}	9.45^{u}	33.28^{f}	47.07^{v}	**37.17^{F}**
	T_3	27.35^{j}	62.53^{l}	83.25^{f}	17.90^{q}	45.48^{w}	58.07^{o}	14.77^{t}	40.93^{bc}	56.12^{q}	**45.84^{D}**
	T_4	14.7^{8t}	40.93^{bc}	56.18^{q}	25.60^{l}	47.88^{u}	65.42^{k}	20.47^{o}	42.20^{z}	54.80^{r}	**40.06^{E}**
	T_5	39.40^{e}	66.77^{j}	82.83^{f}	30.33^{g}	64.97^{k}	88.00^{e}	18.60^{p}	39.90^{d}	52.40^{t}	**53.16^{C}**
	T_6	28.80^{h}	75.33^{i}	102.67^{a}	30.33^{g}	60.93^{m}	78.93^{g}	16.80^{r}	43.37^{y}	58.90^{n}	**55.12^{B}**
Aver.		54.55^{A}			49.83^{B}			39.22^{C}			

*Using the same letters, the LSD test shows that, at $P \leq 0.05$, there is no significant difference between the means of each factor and their interaction.

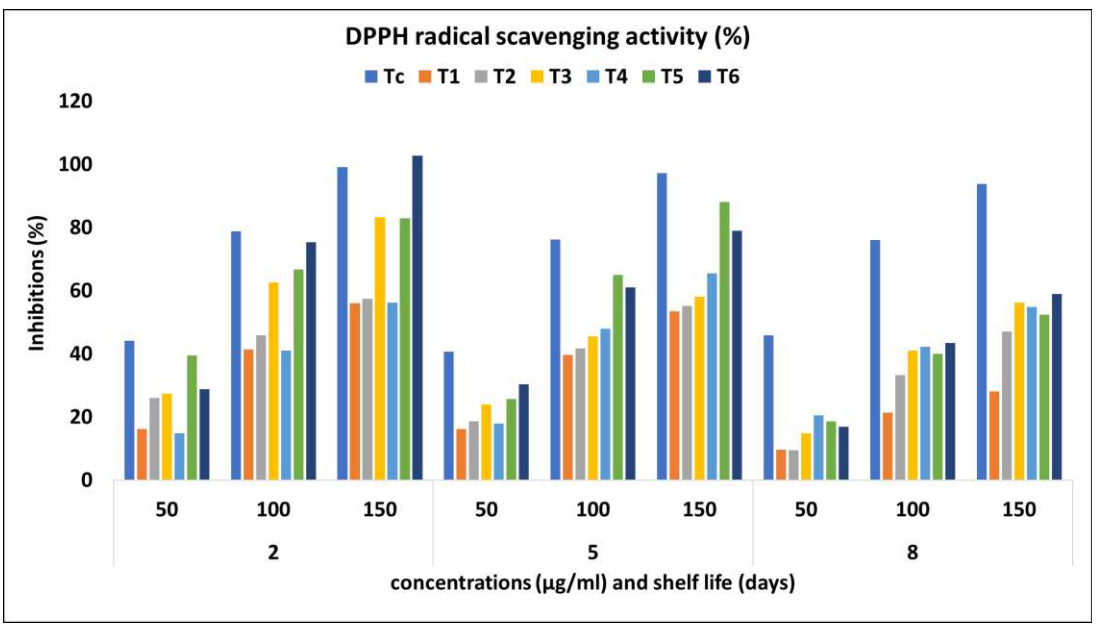

Figure (4): Effect of postharvest treatments on DPPH radical scavenging activity of 'costata' persimmon fruits during shelf life.

4. Conclusions

The findings of this study confirm that sodium bicarbonate and potassium carbonate are promising, safe alternatives to calcium carbide for postharvest astringency removal in ‘Costata’ persimmon fruits. Although CaC_2 effectively eliminated astringency, it led to a decline in antioxidant content. Conversely, treatments with $NaHCO_3$ and K_2CO_3 successfully maintained higher levels of vitamin C, polyphenols, and antioxidant activity, thereby enhancing fruit quality. Noticeably, potassium carbonate treatments exhibited superior effectiveness in preserving antioxidant compounds. These results advocate for the adoption of carbonate-based treatments as eco-friendly, non-toxic postharvest solutions to improve the nutritional quality, safety, and commercial value of astringent persimmons.

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Author contributions

GIE and MSA conceptualized, carried out, and supervised the experiments; SAE collected the data; GIE and SAE analyzed the data; GIE and SAE prepared the manuscript; GIE, MSA, and SAE wrote, reviewed, and edited it; and all authors have read and approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability declaration

The authors affirm that the article contains all pertinent information. Data from this study can be requested by contacting Galal Eliwa at geliwa2002@du.edu.eg

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