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Mitigation of Chilling Injury Symptoms and Extending the Storage Life of Cantaloupes by Some Postharvest Applications

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ABSTRACT

This study was conducted on cantaloupe fruits (cv. Primal Galia type) during two consecutive seasons in 2020 and 2021 to investigate the impact of postharvest treatments with hot water, spermine, putrescine, salicylic acid, and potassium silicate on decreasing chilling injury and preserving fruit quality in comparison to a control treatment during cold storage at 1±0.5ºC for twenty days in addition to two days at 15ºC (shelf life). The findings showed that all postharvest treatments outperformed the control treatment in decreasing weight loss, decay, chilling injury, firmness loss, change of color, and electrolyte leakage of fruits and maintaining ascorbic acid, total phenolics, total sugars, antioxidant activity, and overall appearance of fruits. Furthermore, cantaloupe fruits dipped in spermine or salicylic acid materials were effective in not showing any chilling injury symptoms throughout cold storage periods in addition to shelf life. Putrescine and hot water treatments delayed the beginning of chilling injury symptoms and recorded a low score of symptoms at the end of cold storage duration in addition to shelf life. However, spermine and salicylic acid treatments were the most efficient in preserving overall quality attributes and giving fruits a good overall appearance without any chilling injury symptoms or decay after twenty days of storage at 1±0.5ºC in addition to two days at 15ºC.

KEYWORDS: cantaloupe, chilling injury, hot water, polyamines, salicylic acid, potassium silicate, storability.

1. INTRODUCTION

Cantaloupe has typical climacteric behavior that includes increased respiration rate and ethylene production during storage (Kader, 2002). Ethylene production is usually associated with a short shelf life, a soft texture, color change, and the acceleration of maturation, ripening, and senescence processes (Baraka, 2009), but storage at a lower temperature preserves quality and extends the shelf life of fruits by reducing metabolism processes (Park *et al.*, 2020). However, cantaloupe is a tropical crop sensitive to chilling injury if stored at low temperatures around 2ºC for a few days (Flores *et al.*, 2004).

Therefore, quick precooling in conjunction with transportation and storage of cantaloupe fruits at optimum temperatures around 2.2 to 5ºC and 95% relative humidity was recommended for maximum fruit preservation and avoid chilling injury (Suslow *et al*., 2000).

Chilling injury (CI) symptoms can exhibit on sensitive crops to chilling either when being stored at chilling temperatures or afterwards while being marketed at non-chilling temperatures. The main chilling injury symptoms in cantaloupe fruits include surface discoloration, sunken areas, pitting, brown spots, and other changes that may be attributed to the deterioration and decay of the surface (Krarup *et al*., 2009). The developing CI symptoms result in reduced postharvest life, increased losses in quality, and reduced consumer acceptance of the fruit (Mao *et al*., 2007).

Chilling injury symptoms can be alleviated by enhancing bioactive substances that scavenge reactive oxygen species (ROS). One of the most bioactive substances in preventing oxidative damage to fruit is antioxidants, which include antioxidant enzymes like superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT) and non-enzymatic ones like phenolic compounds, ascorbic acid, anthocyanin, and carotenoids, which inhibit ROS, decreasing lipid peroxidation and damage to cells (Zhao-Liang *et al*., 1998).

Many different methods, such as hot water, polyamines, salicylic acid, and potassium silicate treatments, have been applied to reduce chilling injury and increase shelf life of fruits.

Hot water (HW) is an effective technique to decrease the development of CI symptoms. HW treatment can induce tolerance to too much cold by activating enzymatic antioxidants, including SOD, POD, and CAT, and maintaining total phenolic and ascorbic acid contents, which scavenge ROS, alleviate chilling injury, preserve fruit quality, and extend the postharvest life (Gabriela *et al*., 2021). Many studies have proven the beneficial effect of hot water treatment in reducing CI symptoms, including tomato (Tadesse and Abtew, 2016) and bell pepper (Gabriela *et al*., 2021), reducing decay and maintaining the quality of cantaloupe fruits (Ukuku *et al*., 2004).

Polyamines (PAs), such as putrescine (PUT), spermine (SPE), and spermidine (SPD), are natural substances essential in regulating the ripening and senescence processes of fruits by decreasing respiration rate, ethylene production, delaying senescence, retarding color change, enhancing fruit firmness, extending the postharvest life, and reducing CI symptoms in many vegetables and fruits (Valero *et al*., 2002). Several researchers have demonstrated the efficiency of the application of PAS in increasing resistance to CI and reducing CI symptoms in horticultural crops, including pomegranate (Mirdehghan *et al*., 2007), mango (Bhat *et al*., 2014), and okra (Phornvillay *et al*., 2019).

Salicylic acid (SA) is a natural simple phenolic compound that is crucial in regulating stress resistance (Han *et al*., 2017). SA shows a lot of potential to be very effective in reducing losses of fruit after harvest due to its ability to inhibit emission of ethylene, reduce microbial load and fungal dispersion (Asghari and Aghdam, 2010), retard chilling injury, and adjust to cold resistance (Aghdam *et al*., 2014). According to studies, SA enhances chilling tolerance in cold-stored cucumber (Cao *et al*., 2009) and tomato (Aghdam *et al*., 2014).

Silicon (Si) is a secure and efficient source of antioxidants and has an effect on the activity of important enzymatic antioxidants that participate in the defense mechanisms against stress conditions (Crusciol *et al*., 2009). Moreover, Si applications had a positive influence on decreasing weight loss and electrolyte leakage and preserving the firmness of fruits (Mditshwa, 2012). Several studies demonstrated that the application of potassium silicate as a postharvest treatment reduced CI symptoms in horticultural crops, including cucumber (Saad, 2019) and orange (Mshraky *et al*., 2016).

The goal of current research was to assess the influence of hot water, spermine, putrescine, salicylic acid, and potassium silicate on alleviating chilling injury symptoms and preserving the quality of cantaloupes throughout cold storage at 1±0.5ºC for twenty days plus two days at 15ºC (shelf life).

2. MATERIALS AND METHODS

Cantaloupe fruits (*Cucumis melo* L. cv. Primal Galia type) used in this investigation were picked at the yellowish-green color stage from a commercial farm in El-Fayoum Governorate on October 19th and 24th in the 2020 and 2021 seasons, respectively, and were then transported to the laboratory of Vegetable Handling Research Department, Horticultural Research Institute, Agricultural Research Center, Giza, Egypt. Fruits that are healthy and uniform in size and weight (750–800 g), color, and free from damage or any visual defects were chosen and divided into six different treatments.

Cantaloupe fruits were dipped for 5 minutes in the following treatments: hot water at 45ºC, spermine at 100 ppm, putrescine at 100 ppm, salicylic acid at 100 mg / L, and potassium silicate at 100 mg / L, as well as distilled water as a control treatment.

After drying the fruits, they were placed in carton boxes (20×15×10 cm). Each box contains three fruits, represented as experimental unit (EU). Fifteen EUs were prepared from each treatment, and stored at 1±0.5ºC and 90-95% relative humidity in addition to two days at 15ºC as a shelf life. A completely randomized design was used to organize the samples in each treatment, which were taken randomly in three replicates to be evaluated. Measurements were evaluated after harvest and every five days of storage at 1±0.5ºC for twenty days plus two days at 15ºC to determine the following characteristics:

1. **Weight loss percentage** was determined using the formula = $((W_1 - W_2)/ W_1) \times 100$.

Where, W_1 is the starting fruit weight and W_2 is the sample fruit weight.

2. **Overall appearance** has been assessed using a scale of 9 to 1, with 9 as excellent, 7 as good, 5 as fair, 3 as poor, and 1 as unsalable; fruits rated 5 or lower were regarded as unmarketable, in accordance with Kader *et al*. (2002).
3. **Decay** was measured using a scale from 1 to 5, where 1 refers to no decay, 2 refers to slight decay, 3 refers to moderate decay, 4 refers to severe decay, and 5 refers to extreme decay, in accordance with Wang and Qi (1997).
4. **Chilling injury** was assessed as a percentage of the area infected by chilling injury symptoms using a scale from 1 to 5, where 1 refers to not showing any symptoms (no pitting or brown spots), 2 refers to low symptoms (<10% of the peel infected), 3 refers to moderate symptoms (11-25% of the peel infected), 4 refers to high symptoms (26–50% of the peel infected), and 5 refers to extreme symptoms (> 50% of the peel infected), as described Krarup *et al*. (2009).
5. **Firmness** was assessed by using a hand pressure tester (The Italian model) with an 8 mm plunger expressed in kg/cm^2 (Abbott, 1999).
6. **Color** was measured external surface color by a Minolta CR-400 Chroma Meter (Minolta Co., Ltd., Osaka, Japan). Lightness (L* value) was used to express the measure of gloss and skin color (McGuire, 1992).
7. **Electrolyte leakage** (%) was assessed in accordance with Zhu *et al*. (2004).
8. **Ascorbic acid** (mg / 100 g fresh weight) was assessed in accordance with AOAC (1990).
9. **Total phenolic content** (mg / 100 g fresh weight) was assessed in accordance with Singleton *et al*. (1999).
10. **Total sugars** (%) were measured in accordance with Malik and Singh (1980).
11. **Antioxidant activity** was assessed by determining the free radical scavenging activity by using 2.2-diphenyl-1-picrylhydrazyl (DPPH), in accordance with Sánchez-Moreno *et al*. (2003).

2.1. Statistical analysis

The data were statistically analyzed in a factorial complete randomized design with three replicates using the MSTAT-C software program, and the means of the different treatments were compared using LSD at the 0.05 level, in accordance with Snedecor and Cochran (1980).

3. RESULTS AND DISCUSSION

3.1.Weight loss

According to Table (1) the percentage loss of fruit weight increased considerably with increasing storage durations in addition to shelf life in both seasons; these findings are consistent with those of Ning *et al*. (2022). This decline may be attributed to cell degradation, loss of integrity of the membranes, or removing the epicuticular wax layer, which is known to reduce water loss (Nilprapruck *et al*., 2017). Additionally, this may also be due to metabolic activities connected to senescence, such as respiration and transpiration (Bhat *et al*., 2014).

In comparison to the control treatment, all applied treatments revealed a considerably decreased percentage loss of fruit weight throughout cold storage durations in addition to shelf life. Moreover, the treatments with spermine (SPE) and salicylic acid (SA) were the most efficient in decreasing the loss of fruit weight with significant variations between them, followed by putrescine (PUT) and hot water (HW) with no significant variations between them. Whereas potassium silicate (PS) treatment was the least effective in this respect. As opposed to that, the control treatment recorded the greatest percentage loss of weight. These findings were obtained in both seasons and are consistent with those of Mshraky *et al*. (2016), Tadesse and Abtew (2016), Nilpraprucк *et al*. (2017), and Minh (2022).

The positive effect of polyamines (PAs) and SA treatments may be because these substances slow down the respiration process, reduce ethylene production and membrane permeability, and increase membrane stability and integrity, thus preventing water losses from fruits and reducing weight loss (Srivastava and Dwivedi, 2000 and Bhat *et al*., 2014). Moreover, PAs protect cell membranes and maintain cell integrity, thus preventing cell membrane damage when exposed to chilling temperatures, where PAs bind to the membranes of cells and protect the layers of cuticle wax, and reducing evaporation of water from fruits, which explains the ability of PAs to suppress weight loss in fruits (Mirdehghan *et al*., 2007).

There were significant variations in the interaction among all treatments and all storage durations in both seasons. After twenty days of storage at 1±0.5°C in addition to two days at 15°C, data reveal that cantaloupe fruits dipped in SPE or SA have a significant effect on decreasing weight loss (2.42 & 3.07%, the average of both seasons), respectively, with no significant variations between them in the first season, followed by PUT and HW treatments (3.79 & 3.86%, the average of both seasons), respectively, with no significant variations between them in the two seasons. Whereas the control treatment gave the highest value of weight loss (6.51%, the average of both seasons) over the same duration.

3.2.Overall appearance (score)

According to Table (2) the score of overall appearance significantly decreased when storage duration increased; These findings were obtained in both seasons and consistent with those of Park *et al*. (2020). This decline may be due to pitting, shriveling, decay, and discoloration (Saad, 2019). The overall appearance of cantaloupe fruits dipped in all postharvest treatments was better than that obtained from untreated fruits throughout the storage duration in addition to shelf life. However, SPE and SA were the most efficient materials for preserving overall fruit appearance and recorded the highest score of overall appearance with no significant variations between them. This was followed by the PUT and HW treatments with no significant variations between them. The PS treatment was the least effective in this respect, whereas the control treatment gave the lowest score for overall appearance. These findings were obtained in both seasons and are consistent with those of Deepthi *et al*. (2016) and Saad (2019). This sharp decline in sensory quality of fruits in the control treatment may perhaps be due to deterioration, early senescence, and extreme overripening, which cause the fruits to appear dull, excessively soft, and have a bad flavor and taste (Deepthi *et al*., 2016).

The beneficial impact of PAs application on extending the shelf life of fruits and preserving their quality parameters is potentially due to their ability to slow down respiration rate, reduce ethylene production, keep fruit firmness, inhibit cell wall degrading enzymes, enhance the mechanism of antioxidant enzymes, stabilize the lipid bilayer, and prevent membrane deterioration (Sharma *et al*. 2017). Moreover, the superiority of SPE over PUT in preserving the quality of fruits may be because SPE contains a tetra-amine structure, which has a very high potential for decreasing the respiration rate and retarding senescence compared with PUT, which contains di-amine (Deepthi *et al*., 2016).

Table 1. Influence of some postharvest applications on weight loss (%) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean	Storage durations 2021					Mean
	0+2	5+2	10+2	15+2	20+2		0+2	5+2	10+2	15+2	20+2	
Hot water	0.81 m-p	1.10 k-p	1.80 f-k	2.54 d-f	3.60 bc	1.97 C	0.93 n-q	1.21 m-p	2.00 i-k	2.88 e-g	4.11 c	2.23 C
Spermine	0.40 p	0.69 n-p	1.09 k-p	1.57 h-l	2.23 e-i	1.20 E	0.55 q	0.87 o-q	1.37 l-o	2.06 h-k	2.61 g-i	1.49 E
Putrescine	0.86 l-p	1.10 k-p	1.78 g-k	2.51 d-g	3.50 bc	1.95 C	0.92 o-q	1.19 m-p	1.86 j-l	2.87 e-g	4.08 c	2.18 C
Salicylic acid	0.55 op	0.97 l-p	1.51 i-m	2.11 f-i	2.90 c-e	1.61 D	0.76 pq	1.11 m-q	1.54 k-n	2.45 g-j	3.24 d-f	1.82 D
Potassium silicate	1.03 l-p	1.36 j-n	2.08 f-j	3.00 cd	4.21 b	2.34 B	1.12 m-q	1.56 k-m	2.30 g-j	3.41 de	4.87 b	2.65 B
Control	1.21 k-o	1.53 i-m	2.31 d-h	3.64 bc	6.42 a	3.02 A	1.38 l-o	1.87 j-l	2.66 f-h	3.85 cd	6.60 a	3.27 A
Mean	0.81 E	1.13 D	1.76 C	2.56 B	3.81 A		0.94 E	1.30 D	1.95 C	2.92 A	4.25 A	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

Table 2. Influence of some postharvest applications on the overall appearance (score) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean	Storage durations 2021					Mean
	0+2	5+2	10+2	15+2	20+2		0+2	5+2	10+2	15+2	20+2	
Hot water	9.00 a	9.00 a	9.00 a	7.00 cd	6.33 d	8.07 B	9.00 a	9.00 a	8.33 ab	7.00 cd	5.67 e	7.80 B
Spermine	9.00 a	9.00 a	9.00 a	9.00 a	7.67 bc	8.73 A	9.00 a	9.00 a	9.00 a	9.00 a	7.67 bc	8.73 A
Putrescine	9.00 a	9.00 a	9.00 a	7.67 bc	6.33 d	8.20 B	9.00 a	9.00 a	8.33 ab	7.67 bc	6.33 de	8.07 B
Salicylic acid	9.00 a	9.00 a	9.00 a	9.00 a	7.67 bc	8.73 A	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 bc	8.60 A
Potassium silicate	9.00 a	8.33 ab	7.67 bc	6.33 d	3.00 f	6.87 C	9.00 a	8.33 ab	7.00 cd	5.67 e	2.33 g	6.47 C
Control	9.00 a	6.33 d	5.00 e	3.67 f	1.00 g	5.00 D	9.00 a	5.67 e	4.33 f	3.00 g	1.00 h	4.60 D
Mean	9.00 A	8.44 B	8.11 B	7.11 C	5.33 D		9.00 A	8.33 B	7.67 C	6.78 D	5.11 E	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

Also, SA material demonstrated the ability to maintain fruit quality and reduce deterioration, where it mainly works by retaining the ability to prevent accumulation of O_2 and improving enzymatic antioxidant capacity, as well as increasing the production of proteins related to senescence or defense proteins to preserve the high quality of fruits throughout storage (Tareen *et al*., 2012). In addition, SA may reduce respiration rate and the loss of water by limiting cell wall breakdown and lowering ethylene production, thus delaying fruit ripening, improving shelf life, and preserving overall quality parameters (Srivastava and Dwivedi, 2000).

There were significant variations in the interaction among all treatments and all storage periods in addition to the shelf life for both seasons. Data showed that SPE and SA materials recorded an excellent overall appearance until fifteen days of cold storage in addition to two days of shelf life and gave a good overall appearance after twenty days of cold storage in addition to two days of shelf life, with no significant variations between them in both seasons. Whereas the control treatment had an unacceptable appearance of fruits at the same time for both seasons.

3.3. Decay (score)

According to Table (3), the score of decay increased considerably with prolongation of storage duration in addition to shelf life for both seasons; these findings matched those of Ning *et al*. (2022). This could be because of the continual biochemical and chemical changes in the fruits, which result in some reactions such as the transformation of molecules from a complex form into a simple form, which increases their susceptibility to fungus infection (Wills *et al*., 1998). During storage, the epidermal tissue softens and cracks appear, eventually leading to fruit decay (Krarup *et al*., 2009).

There was a considerable reduction in the decay score for all postharvest treatments in comparison to the control treatment. Moreover, fruits treated with SPE or SA materials don't exhibit any signs of decay until the end of the storage duration in addition to the shelf life with no significant variations between them. PUT and HW treatments reduce the incidence of decay with no significant variations between them. PS material was the least effective in this respect, whereas the control treatment recorded the greatest score of decay throughout storage in addition to shelf life in both seasons**.** These findings were obtained in both seasons and are consistent with those of Bhat *et al*. (2014), Mshraky *et al*. (2016), Saad (2019), and Minh (2022).

The greatest score of decay in the control treatment could be attributed to increased respiration rate and ethylene emission, causing early ripening and a high incidence of diseases due to susceptibility to infection by diseases rising with ripening. Whereas SPE or SA materials don't exhibit any signs of decay throughout all storage times, this may be primarily attributed to the delayed fruit ripening, where SPE increases the endogenous free polyamine levels in fruits, reduces ethylene production, delays ripening, and improves the defense system against potential diseases (Deepthi *et al*., 2016). Also, the positive impact of SA may be due to its antifungal effect, as well as enhances the activities of enzymatic antioxidant like peroxidase enzyme and decreases the activities of the polyphenol oxidase (PPO) enzyme (Yao and Tian, 2005).

There were significant variations in the interaction among all treatments and all storage times, in addition to the shelf life for both seasons. Cantaloupe fruits dipped in SPE or SA treatments do not show any decay throughout all storage times for both seasons, and the other treatments recorded significantly lower decay in comparison to those obtained from the control treatment. Whereas untreated fruits started to show signs of decay after ten days of storage and recorded the highest score of decay (4.33) after twenty days of cold storage at 1±0.5°C in addition to two days at 15°C for both seasons.

3.4.Chilling injury (score)

In this study, the presence of chilling injury (CI) on cantaloupe fruits was assessed in terms of its severity two days after transferring the fruit from 1±0.5°C to 15°C. According to Table (4), the differences in CI severity among the various treatments became clearer with increasing the

Table 3. Influence of some postharvest applications on the score of decay of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean	Storage durations 2021					Mean
	0+2	5+2	10+2	15+2	20+2		0+2	5+2	10+2	15+2	20+2	
Hot water	1.00 f	1.00 f	1.00 f	1.00 f	2.33 d	1.27 C	1.00 e	1.00 e	1.00 e	1.00 e	2.67 c	1.33 C
Spermine	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 D	1.00 e	1.00 e	1.00 e	1.00 e	1.00 e	1.00 D
Putrescine	1.00 f	1.00 f	1.00 f	1.00 f	2.00 e	1.20 C	1.00 e	1.00 e	1.00 e	1.00 e	2.00 d	1.20 C
Salicylic acid	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 D	1.00 e	1.00 e	1.00 e	1.00 e	1.00 e	1.00 D
Potassium silicate	1.00 f	1.00 f	1.00 f	2.00 e	3.33 b	1.67 B	1.00 e	1.00 e	1.00 e	2.33 cd	3.67 b	1.80 B
Control	1.00 f	1.00 f	2.00 e	3.00 c	4.33 a	2.27 A	1.00 e	1.00 e	2.33 cd	3.33 b	4.33 a	2.40 A
Mean	1.00 D	1.00 D	1.17 C	1.50 B	2.33 A		1.00 D	1.00 D	1.22 C	1.61 B	2.44 A	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

Table 4. Influence of some postharvest applications on chilling injury (score) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean	Storage durations 2021					Mean
	0+2	5+2	10+2	15+2	20+2		0+2	5+2	10+2	15+2	20+2	
Hot water	1.00 f	1.00 f	1.00 f	1.00 f	2.33 d	1.27 C	1.00 e	1.00 e	1.00 e	1.00 e	2.33 d	1.27 C
Spermine	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 D	1.00 e	1.00 e	1.00 e	1.00 e	1.00 e	1.00 D
Putrescine	1.00 f	1.00 f	1.00 f	1.00 f	2.00 de	1.20 C	1.00 e	1.00 e	1.00 e	1.00 e	2.00 d	1.20 C
Salicylic acid	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 D	1.00 e	1.00 e	1.00 e	1.00 e	1.00 e	1.00 D
Potassium silicate	1.00 f	1.00 f	1.00 f	2.33 d	3.33 bc	1.73 B	1.00 e	1.00 e	1.00 e	2.33 d	3.67 c	1.80 B
Control	1.00 f	1.67 e	3.00 c	3.67 b	4.67 a	2.80 A	1.00 e	2.00 d	3.33 c	4.33 b	5.00 a	3.13 A
Mean	1.00 D	1.11 D	1.33 C	1.67 B	2.39 A		1.00 E	1.17 D	1.39 C	1.78 B	2.50 A	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

storage duration; these results were consistent with Krarup *et al*. (2009). The overproduction of reactive oxygen species (ROS), like $O_2^{\cdot-}$, H_2O_2, and OH, is one of the main reasons for the occurrence of CI. If the excess ROS are not quickly and efficiently eliminated, this results in lipid peroxidation (Chen and Li, 2001).

Fruits dipped in all postharvest treatments prior to storage at low temperatures were effective treatments in reducing CI severity, while CI severity developed rapidly in untreated fruits with the main symptoms being pitting and brown spots. In other words, traces of pitting and brown spots were observed on the cantaloupe peel in untreated fruits after five days of cold storage in addition to two days of shelf life, and these symptoms were more obvious in fruits after ten days of cold storage in addition to two days of shelf life and reached the extreme score (4.84, the average of both seasons) after twenty days at 1±0.5ºC plus two days at 15ºC. However, fruits dipped in SPE or SA appeared normal without any symptoms of CI throughout all storage times. PUT and HW treatments delayed the beginning of CI symptoms in fruits and recorded low scores (2.00 & 2.33, the average of both seasons), respectively, after twenty days of cold storage in addition to two days of shelf life, while PS treatment recorded a moderate score (3.50, the average of both seasons) at the same duration. These findings were consistent with those of Aghdam *et al*. (2014), Bhat *et al*. (2014), Mshraky *et al*. (2016), and Tadesse and Abtew (2016).

It has been mentioned that PAs have the potential for protecting the cell membranes and keeping cell integrity from varying stresses through binding with negatively charged molecules like phospholipids, as well as exhibiting antioxidant properties, thus preventing cell membrane damage when exposed to chilling temperatures, which explains the ability of PAs to suppress CI (Mirdehghan *et al*., 2007). Also, PAs contain antioxidant characteristics that act as ROS scavenging agents and maintain higher enzymatic antioxidant activities like superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), and ascorbate peroxidase (APX), as well as antioxidant compounds effective in reducing oxidative stress and improving fruits ability to tolerate chilling (Yang *et al*., 2016). Additionally, PAs strengthen the cell walls and reduce PPO activity by keeping phenolics and PPO separate, thus preventing the oxidation of phenols and minimizing the browning of fruits during storage at low temperatures (Nilprapruck *et al*., 2017).

The effectiveness of SA in lowering CI symptoms may be attributed to increasing heat shock protein gene expression and antioxidant activity, maintaining membrane integrity, reducing PPO enzyme activity, and slowing down the browning process (Guan *et al*., 2019). Also, SA application increased the activity of enzymatic antioxidants (SOD, POD, CAT, and APX) and decreased the activity of lipoxygenase (LOX). Where LOX is accountable for producing a superoxide radical, which is transformed to H_2O_2 by the action of the SOD enzyme. H_2O_2 can be removed by the activities of the CAT and APX enzymes (Cao *et al*., 2009). Additionally, SA therapy reduces lipid peroxidation, preserves cell membrane integrity, and alleviates CI (Aghdam *et al*., 2014).

3.5.Firmness

According to Table (5), a significant loss in fruit firmness has occurred by prolonging storage duration and shelf life; these findings were obtained in both seasons and are consistent with those of Ning *et al*. (2022).

This decline may be attributed to the changes that occur in the structure of the cell wall, such as decreased pectin and hemicellulose, due to the increased activity of the enzymes that degrade the cell wall, like polygalacturonase (PG), pectin methyl esterase (PME), pectin esterase (PE), and cellulose (Sharma *et al*., 2017). Additionally, fruit tissues become softer because of the rapid production of ROS (Cheng *et al*., 2008).

All treatments significantly decreased the firmness loss in fruit in comparison to the control treatment. However, SPE was the most efficient material in decreasing the firmness losses throughout storage in addition to shelf life and recorded the greatest value of firmness, followed by SA and PUT treatments with significant variations between them. The HW and PS treatments were the least effective in this respect with significant variations between them, whereas

Table 5. Influence of some postharvest applications on firmness (kg/cm^2) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations					Mean
	2020					
	0+2	5+2	10+2	15+2	20+2	
Hot water	19.17 b-d	18.24 d-g	16.62 i-k	14.57 no	12.10 pq	16.14 D
Spermine	20.44 a	19.57 a-c	18.38 d-g	17.06 h-j	15.22 l-o	18.13 A
Putrescine	19.52 a-c	18.54 c-f	17.00 i-k	15.49 l-n	12.95 p	16.70 C
Salicylic acid	20.00 ab	18.82 c-e	17.45 g-i	16.01 j-k	14.90 no	17.44 B
Potassium silicate	18.77 c-e	17.52 f-i	15.97 k-m	14.21 o	11.58 q	15.61 E
Control	18.06 e-h	16.91 i-k	14.92 m-o	12.56 pq	10.12 r	14.52 F
Mean	19.33 A	18.27 B	16.72 C	14.98 D	12.81 E	
Treatment	**Storage durations**					**Mean**
	2021					
	0+2	**5+2**	**10+2**	**15+2**	**20+2**	
Hot water	17.89 a-c	16.60 de	14.88 g-i	13.18 j-l	11.04 n-p	14.72 D
Spermine	18.92 a	18.01 a-c	16.56 de	15.08 f-h	13.37 jk	16.39 A
Putrescine	18.02 a-c	16.87 cd	15.67 e-g	13.86 ij	11.91 m-o	15.27 C
Salicylic acid	18.25 ab	17.19 b-d	16.17 d-f	15.31 fg	12.16 l-n	15.82 B
Potassium silicate	17.13 b-d	15.71 e-g	14.10 h-j	12.25 k-m	10.17 p	13.87 E
Control	16.95 cd	15.03 f-h	13.16 j-l	11.00 op	8.78 q	12.98 F
Mean	17.86 A	16.57 B	15.09 C	13.45 D	11.24 E	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

the control treatment recorded the least value of firmness. These findings were obtained in both seasons and are consistent with those of Bhat *et al*. (2014), Tadesse and Abtew (2016), Saad (2019), and Minh (2022).

The favorable impact of PAs in preserving firmness may be due to the cross-linking of polyamine to the carboxylate (-COO-) group of the pectic compounds in the cell wall, leading to its rigidification. This binding also prevents the enzymes that breakdown the cell wall from accessing it, like PE, PG, and PME, thus slowing the softening of fruits (Razzaq *et al*., 2014). Also, SA treatment reduces ethylene production and lowers the activity of cell wall breakdown enzymes such as PME and PG, thus reducing softening and maintaining firmness (Srivastava and Dwivedi, 2000).

There were significant variations in the interaction among all treatments and all storage durations, in addition to the shelf life for both seasons. After twenty days of cold storage at 1±0.5°C plus two days at 15°C, these findings reveal that fruits dipped in SPE and SA had significantly higher fruit firmness (14.30 & 13.53 kg/cm^2, the average of both seasons), respectively, with no significant variations between them in the first season. Whereas the control treatment recorded the lowest values of firmness (9.45 kg/cm^2, the average of both seasons) over the same duration.

3.6. Color (L value)

Fruit color is one of the most critical quality considerations for consumers. The lightness (L* value) of the peel is a crucial consumer choice criterion because it indicates the level of ripening in the fruit. As indicated in Table (6), the lightness of the fruit gradually decreased with increasing storage times for all treatments, resulting in a darker peel color. These findings were obtained in both seasons and are in agreement with Atress and Attia (2011). Increased activity of enzymes degrading chlorophyll, such as chlorophyll oxidase, chlorophyllase, and peroxidase, may be responsible for the decrease in skin lightness during ripening (Jain *et al*., 2001).

Table 6. Influence of some postharvest applications on color (L* value) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean
	0+2	5+2	10+2	15+2	20+2	
Hot water	70.93 a-c	69.41 d-g	67.64 h-j	64.55 m-o	61.00 q	66.70 C
Spermine	71.86 a	71.05 a-c	69.88 c-f	66.93 i-k	63.92 n-p	68.73 A
Putrescine	71.29 a-c	70.62 a-d	68.46 f-h	65.24 l-n	61.23 q	67.37 C
Salicylic acid	71.60 ab	70.97 a-c	68.8 e-h	66.02 k-m	62.92 p	68.06 B
Potassium silicate	70.59 a-d	68.82 e-h	66.19 j-l	63.46 op	60.09 q	65.83 D
Control	70.16 b-e	68.04 g-i	65.27 l-n	60.88 q	54.69 r	63.81 E
Mean	71.07 A	69.82 B	67.71 C	64.51 D	60.64 E	
Treatment	**Storage durations 2021**					**Mean**
	0+2	**5+2**	**10+2**	**15+2**	**20+2**	
Hot water	70.11 ab	68.44 b-e	66.33 f-h	63.49 lm	62.13 m	66.10 C
Spermine	70.69 a	70.01 ab	69.12 a-d	67.45 d-g	64.00 j-l	68.25 A
Putrescine	70.05 ab	69.16 a-d	67.12 e-h	64.42 i-l	61.82 mn	66.51 C
Salicylic acid	70.12 ab	69.41 a-c	67.97 c-f	65.87 g-i	63.62 lm	67.40 B
Potassium silicate	69.65 a-c	67.53 d-g	65.41 h-k	63.22 lm	60.02 no	65.17 D
Control	69.12 a-d	67.86 g-i	65.58 h-j	59.66 o	53.50 p	63.14 E
Mean	69.96 A	68.73 B	66.92 C	64.02 D	60.85 E	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

All treatments significantly maintained L values in comparison to the control treatment. However, SPE and SA were the best materials for decreasing L value losses, indicating that lighter fruits (high L value) with significant variations between them, followed by PUT and HW with no significant variations between them. PS material was the least successful in this respect. Whereas the lower L value was found in the control treatment, indicating that darker fruits (low L value). These findings were obtained in both seasons and correspond with those of Deepthi *et al*. (2016), Mshraky *et al*. (2016), and Saad (2019).

The larger loss of lightness in untreated fruits was perhaps attributable to the increase in water loss from the fruits. Furthermore, the failure of ripening in untreated fruits may be due to a halt in the process of transformation of chloroplasts to chromoplasts caused by the breakdown of plastids during storage at low temperatures (Tadesse and Abtew, 2016).

The delay in color development by PAs treatments may be due to delayed ethylene production and senescence, which decrease the degradation of chlorophyll and delay the biosynthesis of carotenoids.

Furthermore, PAs treatments reduce peroxidation of membranes and increase chlorophyll retention (Deepthi *et al*., 2016). Also, the lower change in the lightness (L* value) after the applications of PAs and SA could be attributed to the fact that these materials reduced the respiration process and the ethylene emission, resulting in decreased activity of the chlorophyllase enzyme and degradation of chlorophyll; therefore, the fruit color was lighter than that of the control treatment (Saad, 2019 and Barman *et al*., 2014).

The interaction among all treatments and all storage durations in addition to shelf life was significant over both seasons. Fruits dipped in SPE and SA treatments had significantly greater L values (63.96 & 63.27, the average of both seasons), respectively, with no significant variations between them after twenty days of cold storage plus two days of shelf life. Whereas the control treatment had the lowest value (54.10, the average of both seasons) over the same duration.

3.7. Electrolyte leakage (%)

One of the most common signs of chilling injury in horticultural crops is electrolyte leakage. Increased electrolyte leakage has been linked with the emergence of chilling injury symptoms (Vicente *et al*., 2005). As indicated in Table (7), a considerably increased electrolyte leakage percentage was obtained with increasing storage duration and shelf life; these findings were obtained in both seasons and correspond with Flores *et al*. (2004). The substantial electrolyte leakage shown during cold storage could be because of membrane degradation and cell membrane integrity loss (Nilprapruck *et al*., 2017). Chilling injury induces solute leakage and a rise in the quantity of H_2O_2 by damaging cell organelles and membranes (Sharma *et al*., 2017).

All applied treatments significantly decreased electrolyte leakage in comparison to the control treatment throughout cold storage durations plus shelf life. Furthermore, SPE material had the lowest value of electrolyte leakage, followed by SA material with significant variations between them. PUT and HW treatments were the least effective in this respect with no significant variations between them. While the control and PS treatments gave the greatest values of electrolyte leakage with significant variations between them. These findings were obtained in both seasons and correspond with Mditshwa (2012), Ezzat *et al*. (2017), Nilprapruck *et al*. (2017), and Emongor *et al*. (2020).

Polyamines contribute most to the stabilization of membranes by directly interacting with membranes, preventing trans-bilayer movement of phospholipids, and scavenging free radicals. Additionally, PAs maintain the stability of molecular complexes in membranes, decreasing the damage to membranes by LOX enzyme activity, providing leaky resistance, preventing the development of ROS, and lowering CI (Sharma *et al*., 2017). Also, SA treatment reduces phospholipase D and lipoxygenase activities and ROS production, weakens lipid peroxidation, and maintains cell membrane integrity, thus leading to lower electrolyte leakage and lowering CI (Aghdam *et al*., 2014).

There were significant variations in the interaction among all treatments and all storage durations in addition to shelf life in both seasons. After twenty days at 1±0.5°C in addition to two days at 15°C, SPE and SA treatments gave the lowest values of electrolyte leakage (44.58 & 45.50%, the average of both seasons), respectively, with no significant variations between them. While the control treatment had the greatest value (65.62%, the average of both seasons) over the same duration.

3.8.Ascorbic acid

Ascorbic acid is one of the antioxidant compounds in fruits and could be used to remove ROS (Hosseini *et al*., 2018). As noted in Table (8), ascorbic acid content significantly decreased with increasing storage times in both seasons; these findings are consistent with Minh (2022). This reduction in ascorbic acid content may be attributed to the oxidative transformation of dehydroascorbic acid to diketogluconic acid (Ishaq *et al*., 2009) and the activity of ascorbic acid oxidase (Hosseini *et al*., 2018). Also, losses in ascorbic acid content were connected with the senescence and deterioration of fruit during storage (Wills *et al*., 1998).

All postharvest treatments significantly maintained ascorbic acid content throughout cold storage durations in addition to shelf life in comparison to the control treatment. However, the SPE treatment recorded the greatest value of ascorbic acid, followed by SA and PUT materials with significant variations among them in both seasons. While the least value was found in untreated fruits. These findings were obtained in both seasons and are consistent with Erkan *et al*. (2005), Mshraky *et al*. (2016), Sharma *et al*. (2017), and Minh (2022).

Polyamine applications inhibit ascorbic acid oxidation by reducing water loss and preserving cell membrane integrity (Mirdehghan *et al*., 2007). Also, the reduction of ascorbic acid loss by using PAs and SA may be attributed to a reduced respiration rate as well as diminished ethylene production and metabolic activity, lower ascorbic acid oxidation, and delayed ascorbic acid degradation (Wang *et al*., 2019 and Rao *et al*., 2011).

Table 7. Influence of some postharvest applications on electrolyte leakage (%) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean	Storage durations 2021					Mean
	0+2	5+2	10+2	15+2	20+2		0+2	5+2	10+2	15+2	20+2	
Hot water	32.83 qr	34.83 n-p	37.98 kl	41.63 i	47.58 e	38.97 C	34.54 op	36.91 l-n	39.04 jk	41.93 hi	47.74 e	40.03 C
Spermine	32.16 r	33.41o-r	35.00 no	37.94 kl	44.46 gh	36.59 E	34.04 p	34.97 n-p	36.84 l-n	39.46 jk	44.70 fg	38.00 E
Putrescine	32.70 qr	34.17 o-q	37.23 lm	41.22 ij	47.00 ef	38.46 C	34.41 op	36.53 m-o	38.86 j-l	41.72 i	47.01 e	39.71 CD
Salicylic acid	32.38 qr	33.93 o-q	36.04 mn	39.58 jk	45.22 f-h	37.43 D	34.10 p	36.06 m-p	38.15 k-m	40.91 ij	45.77 e-g	39.00 D
Potassium silicate	33.13 p-r	38.49 kl	44.26 h	50.60 d	58.15 b	44.92 B	34.87 n-p	39.17 jk	44.00 gh	50.34 d	57.82 b	45.24 B
Control	33.45 o-r	39.61 jk	46.27 e-g	54.72 c	65.96 a	48.00 A	35.16 n-p	40.35 ij	46.81 ef	54.92 c	65.27 a	48.50 A
Mean	32.78 E	35.74 D	39.46 C	44.28 B	51.39 A		34.52 E	37.33 D	40.62 C	44.88 B	51.39 A	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

Table 8. Influence of some postharvest applications on ascorbic acid content (mg / 100 g fresh weight) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean	Storage durations 2021					Mean
	0+2	5+2	10+2	15+2	20+2		0+2	5+2	10+2	15+2	20+2	
Hot water	31.94 a-c	29.49 ef	25.92 hi	22.13 mn	18.28 p	25.55 D	28.64 a-d	26.75 ef	24.45 hi	21.72 l-n	18.75 pq	24.06 D
Spermine	32.85 a	31.02 cd	28.96 e-g	26.68 h	24.21 j-l	28.74 A	29.68 a	28.52 a-d	26.92 ef	24.94 g-i	22.84 j-l	26.58 A
Putrescine	32.02 a-c	29.95 de	26.84 h	23.09 lm	19.22 p	26.22 C	28.95 a-c	27.66 de	25.29 gh	22.52 kl	19.59 op	24.80 C
Salicylic acid	32.38 ab	30.85 cd	28.20 g	24.93 i-k	21.43 no	27.56 B	29.14 ab	28.17 b-d	26.13 fg	23.80 ij	21.17 mn	25.68 B
Potassium silicate	31.25 bc	29.03 e-g	24.98 ij	20.92 o	16.38 q	24.51 E	28.61 a-d	26.80 ef	23.74 i-k	20.54 no	16.20 r	23.18 E
Control	30.87 cd	28.65 fg	23.78 kl	18.75 p	13.56 r	23.12 F	27.92 c-e	25.87 fg	21.95 lm	17.74 q	13.17 s	21.33 F
Mean	31.89 A	29.83 B	26.45 C	22.75 D	18.85 E		28.82 A	27.30 B	24.75 C	21.88 D	18.62 E	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

Additionally, PAs increased the activity of enzymatic antioxidants involved in the ascorbate-glutathione cycle and increased ascorbic acid content (Yang *et al*., 2016).

There were significant variations in the interaction among all treatments and all storage durations in addition to shelf life in both seasons. Cantaloupe fruits dipped in SPE had a significantly higher value of ascorbic acid (23.53 mg / 100 g fresh weight, the average of both seasons), followed by SA treatment (21.30 mg / 100 g fresh weight, the average of both seasons) after twenty days of cold storage at 1±0.5°C plus two days at 15°C. Whereas untreated fruits gave the least value (13.37 mg / 100 g fresh weight, the average of both seasons) over the same duration.

3.9.Total phenolic content

Phenolics are a natural resource for antioxidants, and they are accountable for increasing the capacity of antioxidants in fruits. They are very effective in scavenging ROS, which are the primary cause of chilling injury in fruit (Ayaz *et al*., 2005). According to Table (9), a significantly reduced total phenolic content was observed with increased storage durations in both seasons; these findings are consistent with Minh (2022). The breakdown of cell structure and phenolic compounds because of polyphenol oxidase enzyme activity leads to a rapid reduction in total phenolics (Arendse *et al*., 2014). Additionally, the decline in total phenolics was connected with the consumption of phenolics for scavenging free radicals in cold storage (Mphahlele *et al*., 2014).

All postharvest treatments considerably maintained the total phenolic content during storage durations in comparison to the control treatment. Moreover, SPE was the most successful material in preserving total phenolic content and gave the highest value in this respect, followed by SA and PUT materials with significant variations between them. However, HW and PS treatments were less successful in this respect with significant variations between them, while the lowest value of total phenolic content was found in untreated fruits. These findings were obtained in both seasons and are consistent with Mditshwa (2012), Sharma *et al*. (2017), Killadi *et al*. (2021), and Minh (2022).

Table 9. Influence of some postharvest applications on total phenolic content (mg / 100 g fresh weight) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean
	0+2	5+2	10+2	15+2	20+2	
Hot water	149.23 a-e	147.32 e-h	144.74 jk	141.51 lm	138.81 n	144.32 D
Spermine	150.88 a	149.54 a-d	147.96 b-f	145.84 g-j	143.41 kl	147.53 A
Putrescine	149.82 a-c	147.80 c-g	145.52 h-j	143.04 kl	140.69 mn	145.38 C
Salicylic acid	150.05 ab	148.64 b-f	147.00 f-i	144.96 i-k	141.51 lm	146.43 B
Potassium silicate	148.74 b-f	147.68 d-g	143.95 jk	139.92 mn	134.26 o	142.91 E
Control	148.41 b-f	145.01 i-k	140.48 mn	135.24 o	129.19 p	139.67 F
Mean	149.52 A	147.66 B	144.94 C	141.75 D	137.98 E	

Treatment	Storage durations 2021					Mean
	0+2	5+2	10+2	15+2	20+2	
Hot water	148.13 a-d	145.48 f-h	143.92 hi	141.45 k	138.17 l	143.43 D
Spermine	149.93 a	148.77 a-c	147.50 c-e	145.26 gh	142.90 ij	146.87 A
Putrescine	148.60 a-c	147.42 c-e	145.40 gh	142.76 ij	139.70 kl	144.78 C
Salicylic acid	149.54 ab	147.87 b-e	146.31 d-g	144.06 hi	141.29 jk	145.82 B
Potassium silicate	147.80 b-e	146.20 e-g	144.27 hi	140.12 k	134.41 m	142.56 E
Control	147.38 c-f	145.40 gh	140.45 k	135.35 m	128.93 n	139.50 F
Mean	148.57 A	146.86 B	144.64 C	141.50 D	137.57 E	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

The reduction in loss of phenolics in fruits treated with PAs materials may be attributed to the significant contribution of PAs in lowering PPO activity, which is connected to a drop in respiration and senescence processes in fruit, thus maintaining the total phenolics. Also, PAs have antioxidants, and studies have discovered that there is a linear link between the concentration of phenolics and the activity of antioxidants in fruits (Razzaq *et al*., 2014).

Salicylic acid treatment is effective in stimulating phenylalanine ammonia-lyase enzyme activity, which is an essential enzyme in the manufacture of phenolics. Thus, SA treatment can inhibit oxidative stress and reduce chilling injury by increasing phenylpropanoid enzymes and antioxidant enzymes (Asghari and Aghdam, 2010).

There were significant variations among all treatments, all storage durations, and their interactions between them. Data show that fruits dipped in SPE and SA materials gave the greatest values of total phenolic content (143.16 & 141.40 mg / 100 g fresh weight, the average of both seasons), respectively, with no significant variations between them in both seasons after twenty days of cold storage plus two days of shelf life. Whereas untreated fruits recorded the least value in this concern (129.06 mg / 100 g fresh weight, the average of both seasons) over the same duration.

3.10. Total sugars

The percentage of total sugars significantly decreased with increasing storage durations in the two seasons, as indicated in Table 10. These findings are consistent with those of Atress and Attia (2011); this decline may be attributed to the respiration-induced consumption of sugars (Wills *et al*., 1998). Additionally, the sugar content significantly decreases with increased development of the chilling injury (Couee *et al*., 2006).

Table 10. Influence of some postharvest applications on the percentage of total sugars (%) in cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean
	0+2	5+2	10+2	15+2	20+2	
Hot water	9.30 b-e	9.04 c-f	8.53 f-i	7.71 lm	7.00 no	8.31 C
Spermine	9.92 a	9.67 ab	9.41 a-d	8.97 c-g	8.36 h-k	9.27 A
Putrescine	9.46 a-c	9.18 b-e	8.80 e-h	8.35 h-k	7.86 kl	8.73 B
Salicylic acid	9.51 a-c	9.20 b-e	8.87 d-h	8.44 g-j	8.00 i-l	8.80 B
Potassium silicate	9.24 b-e	8.50 f-i	7.89 j-l	7.20 mn	6.49 op	7.87 D
Control	9.02 c-f	8.34 h-k	7.44 l-n	6.43 p	5.41 q	7.33 E
Mean	9.41 A	8.99 B	8.49 C	7.85 D	7.19 E	

Treatment	Storage durations 2021					Mean
	0+2	5+2	10+2	15+2	20+2	
Hot water	9.00 a-d	8.56 b-f	8.08 e-i	7.47 g-k	6.79 lm	7.98 C
Spermine	9.52 a	9.27 d-h	9.01 a-d	8.71 b-e	8.28 d-h	8.96 A
Putrescine	9.16 a-c	8.72 b-e	8.40 d-g	8.07 e-i	7.58 h-k	8.39 B
Salicylic acid	9.18 a-c	8.80 a-e	8.53 b-f	8.45 c-f	7.67 g-k	8.53 B
Potassium silicate	8.64 b-e	8.16 e-i	7.63 h-k	7.04 k-m	6.40 m	7.57 D
Control	8.28 d-h	7.84 f-j	7.32 j-l	6.80 lm	5.34 n	7.12 E
Mean	8.97 A	8.56 B	8.16 C	7.76 D	7.01 E	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

All treatments preserved the percentage of total sugars in comparison to the untreated fruits. Moreover, spermine treatment seems to be the most successful in preserving the total sugar, followed by salicylic acid and putrescine with no significant variations between them in both seasons. Whereas untreated fruits had the least value in total sugars. These findings were obtained in both seasons and are in conformity with those of Koyuncu *et al*. (2019) and Mditshwa (2012).

The positive impact of PAs and SA materials in preserving total sugars in fruits may be due to decreased ethylene emission, respiration rate, senescence, metabolic changes in organic acids and carbohydrates, decreasing the consumption of sugars, and thus reducing the loss of total sugar content (Valero *et al*., 2002 and Rao *et al*., 2011).

After twenty days of cold storage at 1±0.5°C plus two days at 15°C, data reveal that spermine, salicylic acid, and putrescine treatments gave the greatest values of total sugars (8.32, 7.84 & 7.72%, the average of both seasons), respectively, with no significant variations between them in both seasons, followed by hot water and potassium silicate treatments (6.90 & 6.45%, the average of both seasons), respectively, with no significant variations between them in both seasons. Whereas untreated fruits had the least value (5.38%, the average of both seasons) over the same duration.

3.11. Antioxidant activity (DPPH radical scavenging activities %)

DPPH free radical scavenging activity is commonly used to assess antioxidant activity, which is connected to antioxidant component contents in fruit, such as phenolics and ascorbic acid (Cantin *et al*., 2009). According to Table (11), antioxidant activity percentage in fruits considerably reduced with increased storage durations and shelf life in both seasons; these findings are consistent with those of Lecholocholo *et al*. (2022). The reduction in antioxidant activity may be due to phenolics oxidized by the PPO enzyme (Kubota *et al*., 2001) as well as the oxidative degradation of ascorbic acid (Zhao-Liang *et al*., 1998). Furthermore, antioxidants play an important role in scavenging ROS created under stress conditions and senescence, which causes their amounts to drop in the initial period of storage (Hounsome *et al*., 2009). Also, under different stress conditions and storage at low temperatures, the level of release of ROS rises above the antioxidant defense ability of the cell, leading to cell degradation and thus a decrease in antioxidant content (Lemoine *et al*., 2010).

All postharvest treatments considerably maintain the percentage of antioxidant activity in comparison to the control treatment. Moreover, the application of SPE treatment recorded the greatest value of antioxidant activity, followed by SA treatment with significant variations between them. PUT and HW treatments were the least effective in this respect with no significant variations between them. Whereas the control and PS treatments gave the lowest values with significant variations between them, these findings were obtained in both seasons and are in conformity with Mditshwa (2012), Ezzat *et al*. (2017), Phornvillay *et al*. (2019), and Gabriela *et al*. (2021).

PAs and SA applications enhanced the antioxidant activity by maintaining the high level of phenolics and ascorbic acid and contributed to activating the enzymatic antioxidants such as SOD, POD, CAT, and APX, which led to the mitigation of oxidative stress by decreasing H_2O_2 and $O_2^{\cdot-}$, thus reducing the susceptibility to CI and maintaining quality (Guan *et al*., 2019 and Phornvillay *et al*., 2019). According to previous findings, the treatments that recorded higher total phenolics and ascorbic acid contents also had higher antioxidant activity, thereby exhibiting more advanced DPPH radical scavenging activity (Gil *et al*., 2006).

There were significant variations in the interaction among all treatments and all storage durations in addition to shelf life in both seasons. After twenty days of cold storage at 1±0.5°C plus two days at 15°C, SPE or SA treatments recorded the highest values of antioxidant activity (48.63 & 46.57%, the average of both seasons), respectively, with no significant variations between them. Whereas the control treatment showed the least value of antioxidant activity (23.51%, the average of both seasons) during the same duration.

Table 11. Influence of some postharvest applications on antioxidant activity (%) of cantaloupes throughout storage durations (days) in the 2020 and 2021 seasons.

Treatment	Storage durations 2020					Mean
	0+2	5+2	10+2	15+2	20+2	
Hot water	54.23 a-d	53.02 a-e	50.24 e-i	45.81 j-m	42.36 no	49.13 C
Spermine	56.20 a	55.91 ab	54.14 a-d	52.55 b-f	49.11 g-j	53.58 A
Putrescine	54.91 a-c	53.18 a-e	51.33 d-h	48.07 h-k	45.52 k-n	50.60 BC
Salicylic acid	55.00 a-c	53.98 a-d	52.41 c-g	50.52 e-i	48.14 h-k	52.01 B
Potassium silicate	49.30 f-i	47.22 i-l	44.34 l-o	41.20 o	36.73 p	43.76 D
Control	45.84 j-m	42.72 m-o	37.74 p	30.94 q	23.81 r	36.21 E
Mean	52.58 A	51.01 B	48.37 C	44.85 D	40.95 E	
Treatment	**Storage durations 2021**					**Mean**
	0+2	**5+2**	**10+2**	**15+2**	**20+2**	
Hot water	51.34 a-c	49.34 b-e	46.91 e-h	43.84 g-i	41.14 i-k	46.51 C
Spermine	53.82 a	52.56 ab	51.21 a-d	49.84 a-e	48.14 c-f	51.12 A
Putrescine	51.48 a-c	50.11 a-e	47.44 c-g	44.49 f-i	43.14 h-j	47.33 C
Salicylic acid	52.53 ab	51.43 a-c	49.64 a-e	47.48 c-g	45.00 f-i	49.22 B
Potassium silicate	47.02 d-h	44.65 f-i	42.20 i-k	39.61 j-l	36.51 lm	42.00 D
Control	41.37 i-k	38.26 k-m	34.20 m	29.11 n	23.20 o	33.23 E
Mean	49.59 A	47.73 B	45.27 C	42.40 D	39.52 E	

The similar capital or small letters in the columns and rows indicate there are no significant variations among treatments, storage durations, and their interactions at level 0.05.

4. CONCLUSION

According to the findings, all postharvest treatments applied in this study (hot water, spermine, putrescine, salicylic acid, and potassium silicate) outperformed the control treatment in decreasing weight loss, decay, chilling injury, firmness loss, change of color, and electrolyte leakage of fruits and maintaining ascorbic acid, total phenolics, total sugars, antioxidant activity, and overall appearance of cantaloupe fruits. However, spermine and salicylic acid were the most efficient materials for preserving all fruit quality parameters and giving fruits a good overall appearance at the end of storage duration and shelf life (twenty days of cold storage at 1±0.5°C plus two days at 15°C) without any chilling injury symptoms or decay. Therefore, this study recommends using spermine and salicylic acid materials to reduce chilling injury, maintain overall quality attributes, and extend the storability of cantaloupe fruits during cold storage.

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الملخص العربي

تخفيف أعراض أضرار البرودة وإطالة عمر تخزين ثمار الكانتلوب عن طريق بعض تطبيقات ما بعد الحصاد

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قسم بحوث تداول الخضر – معهد بحوث البساتين – مركز البحوث الزراعية – الجيزة – مصر

أجريت هذه الدراسة على ثمار الكانتلوب (صنف بريمال – طراز جاليا) خلال موسمين متتاليين ٢٠٢٠ و ٢٠٢١ لبحث تأثير معاملات ما بعد الحصاد بالماء الساخن، الاسبيرمين، البوترسين، حمض الساليسيليك وسيليكات البوتاسيوم على تقليل اضرار البرودة و المحافظة على جودة الثمار مقارنة بالمعاملة الكنترول خلال التخزين المبرد على ١ ± ٠,٥ °م لمدة ٢٠ يوم + ٢ يوم على درجة ١٥ °م (فترة العرض). أظهرت النتائج أن جميع معاملات ما بعد الحصاد تفوقت على المعاملة الكنترول في تقليل الفقد فى الوزن، التالف، اضرار البرودة، الفقد فى الصلابة، التغيير فى اللون والتسرب الكهربي للثمار، والمحافظة على محتوى حمض الأسكوربيك، الفينولات الكلية، السكريات الكلية، نشاط مضادات الأكسدة و المظهر العام للثمار. علاوة على ذلك، الثمار المعاملة بالاسبيرمين او حمض الساليسيليك كانت فعالة فى عدم ظهور اى أعراض لأضرار البرودة طوال فترات التخزين بالاضافة الى فترة العرض. أدت المعاملة بالبوترسين والماء الساخن إلى تأخير بداية ظهور أعراض أضرار البرودة وسجلت أعراض بسيطة في نهاية فترة التخزين بالإضافة إلى فترة العرض. ومع ذلك، كانت المعاملة بالاسبيرمين وحمض الساليسيليك الأكثر فاعلية في المحافظة على جميع صفات الجودة وأعطت مظهرًا جيدًا للثمار بدون أي أعراض لأضرار البرودة أو تالف بعد عشرين يوم من التخزين على ١ ± ٠,٥ °م + يومين على درجة ١٥ °م. لذلك، توصى هذه الدراسة باستخدام مادة الاسبيرمين وحمض الساليسيليك فى تقليل أضرار البرودة والمحافظة على صفات الجودة وزيادة القدرة التخزينية لثمار الكانتلوب اثناء التخزين المبرد.

الكلمات المفتاحية: كانتلوب – اضرار البرودة – ماء ساخن – البوليامين – حمض الساليسيليك – سيليكات بوتاسيوم – القدرة التخزينية.