Impact of Postharvest application with Nano chitosan and Nano salicylic acid on reducing chilling injury and Quality maintenance of Sweet Pepper Fruits during cold storage

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ABSTRACT

The current study was carried out during 2020 and 2021 seasons on sweet pepper variety: Taison. Its objective was to assess the impact of coating fruits with a solution of nano-salicylic acid (Nano-SA) at 100 and 200 ppm, nano-chitosan (Nano-SC) at 125 and 500 ppm, salicylic acid (SA) at 200 ppm and chitosan at 500 ppm for 5 min, in addition to untreated fruits (control) during storage at 5°C for 35 days plus 2 days at 20°C (shelf life) on alleviating chilling injury and preserve fruit quality attributes. Results indicate that sweet pepper fruits treated with all postharvest treatments had significantly less fruit weight loss, retained their firmness, L* value, and ascorbic acid, alleviated chilling injury retained total antioxidants and total phenol and the overall appearance of fruits. Also, the lowest accumulation of carotenoids content during all storage period as compared with control. Fruits treated with Nano-SA at 100 ppm or Nano-SC at 125 ppm treatments were the most effective treatments in preserving all the quality attributes of fruits, and gave good appearance of fruits for 35 days without any decay or chilling injury, while Nano-SA at 200 ppm and Nano-SC at 500 ppm treatments gave a good appearance of fruits for 28 days at 5°C plus 2 days at 20°C, but Bulk-SA and SC treatments gave a good appearance of fruits for only 14 days at the same storage condition.

Keywords: Chilling injury-Nanotechnology- Sweet Pepper- Salicylic Acid- Chitosan.

INTRODUCTION

One of the most popular methods for prolonging the post-harvest period of horticultural products is cold storage, which slows down respiration and other metabolic activities. Due to their tropical origin, sweet pepper fruits are susceptible to chilling damage if they are kept for longer than three days at a temperature below 7ºC (Fallik et al., 2009). The optimum storage temperature from 7 to 10ºC is recommended for fresh sweet pepper during postharvest to avoid chilling injury (Kader, 2002). chilling injury symptoms in sweet pepper fruits include pitting, poor ripening, surface discoloration, collapse of structural integrity, development of off-flavors, the formation of sunken, calyx darkening, seed browning and darkening and increased susceptibility to decay and fungal growth (Aghdam et al., 2011). These symptoms often develop after transfer of the chilled sweet pepper fruit to non-chilling temperature (Ge et al., 2020). Therefore, it is necessary to use some techniques to alleviate chilling injury and preserve the quality of sweet pepper fruits during stored in the cold. As a result, it is vital to employ specific strategies to reduce chilling harm and preserve the quality of sweet pepper fruits during cold storage. With the widespread use of cold chain storage during the transit of horticultural products post-harvest, novel strategies to prevent chilling injury are continually in demand. The recent use of innovative techniques, such as nanotechnology, in the post-harvest of fruits and vegetables warrants additional exploration. Nanotechnology, which improves a material's physical and chemical properties, also possesses strong antifungal and antiviral effects (Babalar, 2007). Generally, nanotechnology is concerned with the characterization and utilization of nanoparticles (NPs) with sizes between 1 and 100 nm. Edible nano-coatings could be used on fruit and vegetables to create a barrier to moisture and gas exchange, as well as a vehicle for colors, tastes, antioxidants, and enzymes, and can also raise the shelf life of produced foods (Azeredo et al., 2009). This might be due to nanoparticles having been found to zigzag in the new film and protecting against the transmission of oxygen as a barrier. In other words, the oxygen for entrance into film should during a longer path, and because of the longer route for oxygen molecules, food may spoil later. Chitosan nanoparticles act as both biopolymers and nanoparticles, with quantum size effects, and have numerous applications in antimicrobial therapies (Kalaivani et al., 2020). But more recently, chitosan has been applied on a nanometric scale, which has increased the surface area of interaction and proven to be even more effective (Duan et al., 2019). Chitosan has been dubbed the most significant polymer in agricultural nanotechnology because of its qualities, which include its antibacterial qualities, nontoxicity, economic accessibility, and biodegradability (Saharan et al., 2015). Because of its higher dispersion capacity, chitosan is said to be far more effective when present in nanostructures than when it is in macro-size (Sampathkumar et al., 2020). To improve the performance of edible coatings, some can be transformed to nanoscale. Because of the presence of amino and hydroxyl groups on the chitosan polymeric network, it is easily converted to chitosan nano particles (CSNPs). CSNPs are also an edible coating used to extend the shelf-life period and maintain the quality of banana fruits (Lustriane et al., 2018). Moreover, postharvest application of CSNPs was highly in cadence and maintains quality of cold storage banana fruit at 20 days (Elbagoury et al., 2022). Edible chitosan-based coatings were able to reduce the chilling injury and maintaining the quality characteristics of sweet pepper during storage. The chitosan coating could reduce the cell damage, intracellular compartmentation disruption, and release of the phenolic substrates from vacuoles during the storage days of the fruits (Emadifar et al., 2024)._Salicylic acid (SA), has potential postharvest applications be alleviating chilling injury, maintain quality, reducing decay and increasing fruit resistance to pathogens (Chan et al., 2007), As a result, SA plays a significant role in fruit quality attributes like firmness, taste, aroma, and color, inhibiting the production of ethylene, respiration and senescence (Siriamornpun and Niwat, 2017).

A few studies have found that exogenous SA can induce resistance to chilling injury in post-harvest horticultural crops, including sweet peppers (Mohamed, 2020). Therefore, the current study's goal was to evaluate the impact postharvest Therefore, chitosan and salicylic acid without and with nanotechnology application on reducing the chilling injury and maintaining the overall quality attributes of sweet pepper fruits during cold storage at 5°C (chilling temperature) plus 2 days at 20° C (shelf life).

MATERIALS AND METHODS

Sweet pepper (*Capsicum annuum L.*) variety: Taison. were harvested at 3/4 red color stage of the fruit surface on 16th and 19th of January in 2020 and 2021 seasons, respectively, from a private farm in Abo sultan 1 - Ismailia Governorate – Egypt, during winter seasons and then the fruits were transported the laboratory of Vegetable Handling Research Department, Horticultural Research Institute, Agricultural Research Center, Giza, Egypt. Only fruits of uniform size, weight, and color with a short calyx (1cm) that were sound, healthy and free from any visible defects were selected for the storage experiment.

1. Chitosan nanoparticle preparation: Based on the ionic gelation of chitosan with TPP anions, chitosan nanoparticles were created. The method used was described by Calvo et al. (1997), with some changes by Mohamed (2017).

2. **Preparation protocol of salicylic acid nanoparticles**: Salicylic acid-loaded chitosan nanoparticles were synthesized in accordance with Taghizadeh and Raveled (2010)**.**
3. **Laboratory Characterization and identification of nanoscale chitosan and salicylic acid particles**

3.1. High-resolution transmission electron microscope (TEM): The diameter of chitosan and salicylic acid nanoparticles was measured using a TEM (200 kV, Tecnai G2 S-Twin model FEL Company, Netherlands).

3.2. Diffraction of X-rays (XRD): The chemical determine of the nanomaterials was ascertained using X-ray diffraction (x'pert pro model Panalytical Company Netherland).

3.3. Zeta Sizer (ZS): Dynamic light scattering (DLS) was used to determine particle size distribution using Nano ZS equipment (Malvern Instruments, U.K). Measurements were taken at 25 ºC and began 2 minutes after the cuvette was placed in the apparatus to allow for temperature equilibration. Electrophoretic light scattering experiments were carried out in aqueous solution to evaluate the zeta potential. The Agricultural Research Center in Egypt's Nanotechnology and Advanced Materials Central Lab (NAMCL) was the site of all the preparation and characterization procedures.

The experiment contained seven treatments which applied as follows: Sweet pepper fruits were dipped for 5 minutes on the following treatments chitosan (SC) at 500 ppm, Nano-Chitosan (Nano-SC) at 500 ppm and 125 ppm, salicylic acid (SA) at 200 ppm, Nano-salicylic acid (Nano-SA) at 200 ppm and100 ppm, Untreated fruits dipped (in distilled water) control.

All fruit treatments were dipped in different solutions at room temperature (20± 5° C) allowed to air dry, and then packed in carton boxes (30×20×15cm). Each box contains three fruits represented as experimental units (EU). Eighteen EU were prepared for each treatment and stored at 5ºC and 95% relative humidity (RH). Samples were taken randomly in three replicates EU and were arranged in complete randomized design. Measurements were examined immediately after harvest and at 7 days intervals (0, 7, 14, 21, 28 and 35 days) of storage at 5º C (chilling injury conditions) plus, two days at 20˚C and RH 85% (shelf-life conditions).

The following characters in the storage experiment were examined:

1. **Weight loss percentage**: Equation was used to determine it: Weight loss% = [(A – B) / A]*100.

Where: A = the initial weight, B = Weight at inspection date

2. **General appearance:** General appearance was evaluated using a scale from (1-9) with 9=excellent, 7=good, 5=fair, 3=poor, 1=unsalable and fruits rating (5) or below were considered unmarketable according to **Kader *et al*. (2002)**.
3. **The decay score** was calculated as follows: 1=no decay, 2=slight, 3=moderate, 4=sever and 5=extreme **(Wang and Qi, 1997).**
4. **Chilling injury** was determined based on a five scale: 0 = no injury; 1 = <10%; 2 = 11v to 25%; 3 = 26–40% and 4 = > 40%**.** The severity of the symptoms was assessed visually according to Vega-García et al. (2010), 5 parameters: surface pitting, shriveling, water-soaked areas, uneven ripening and color development and decay, calyx darkening, seed browning and darkening.
5. **External surface color: it** was evaluated by using a Minolta CR-400 Chroma Meter (Minolta Co., Ltd., Osaka, Japan) to measure the L* describes lightness (L*=0 for black, L*=100 for white) according to McGuire (1992).
6. **Fruit firmness:** Fruit firmness was measured in Lp/inch^2 by a hand pressure tester (Italian model) with an 8 mm

plunger expressed in kg/cm2 (Abbott, 1999).

7. Ascorbic acid content (V.C.): vitamin (C) was determined as (mg/100g fruit fresh weight) by titration method using 2, 6 dichloro-phenol-indo-phenol the dye as described in A.O.A.C (1990).

8. Total carotenoids content: it was determined according to A.O.A.C (1990), as (mg/100g fresh weight).

9. Total phenolic content: it was measured by the Folin Ciocalteu method, according to Singleton et al., (1999), as (mg/100g fresh weight).

10. Antioxidant activity (%): it was measured by determining of the free radical scavenging activity evaluated by 2.2-diphenyl-1-picrylhydrazyl (DPPH), according to Sánchez-Moreno et al. (2003).

The Statistical design: The experiments were conducted completely randomized in factorial design with three replicates.

11. Statistical analysis: All data were statistically analyzed as described by Snedecor and Cochran (1980), and the Duncan's multiple range test method was used to compare the means.

RESULTS DISCUSSION

a. Characterization of synthesized chitosan nanoparticles:

Hydrodynamic diameter and surface charge were measured in the nanoscale range using the particle size (DLS) and zeta potential. Nano-CS was measured to have a size of 36.45 nm **Fig. (1)** and a zeta of + 43.7 mV **Fig. (2).**

The size of particles plays an important role in the determination of antimicrobial activity of nanoparticles as they enter the cell walls of microbes through carrier proteins or ion channel. Therefore, the smaller particle size will result in a better uptake of nanoparticles into a microbial cell as mentioned by Sharma et al. (2010). Zeta potential of CSNPs is equal to + 44.7 mV, which due to excess positive charge of chitosan molecules after interaction with sodium tripolyphosphate (TPP). Chitosan is a polycationic electrolyte with amino groups, while TPP is a polyanionic electrolyte with phosphate groups. The zeta potentials between +20 and +60mV for chitosan nanoparticles as reported by Shukla et al. (2013).

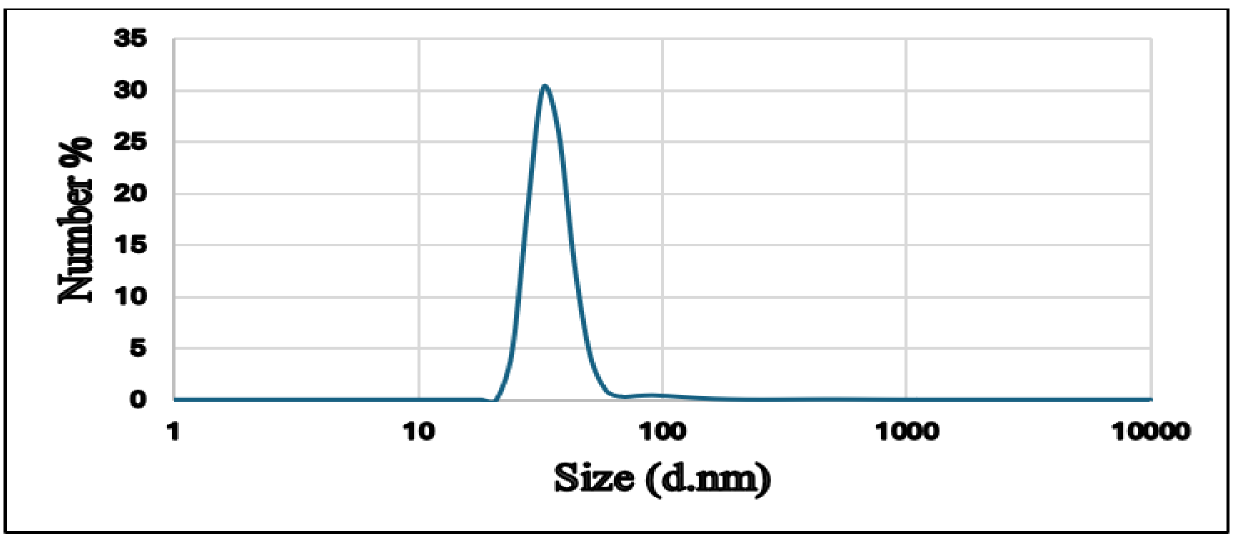

Fig. (1): The particle size distribution of prepared Nano-CS

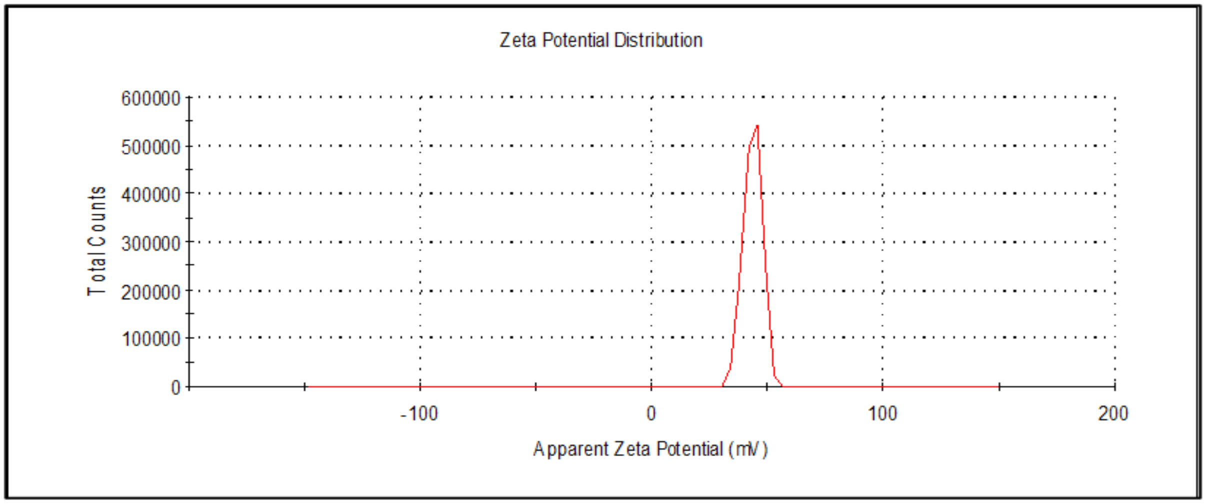

Fig. (2): the Zeta potential of prepared Nano-CS showing surface charge, zeta-potential

b. Characterization of Salicylic acid-loaded chitosan nanoparticles (SA/CS NPs**).**

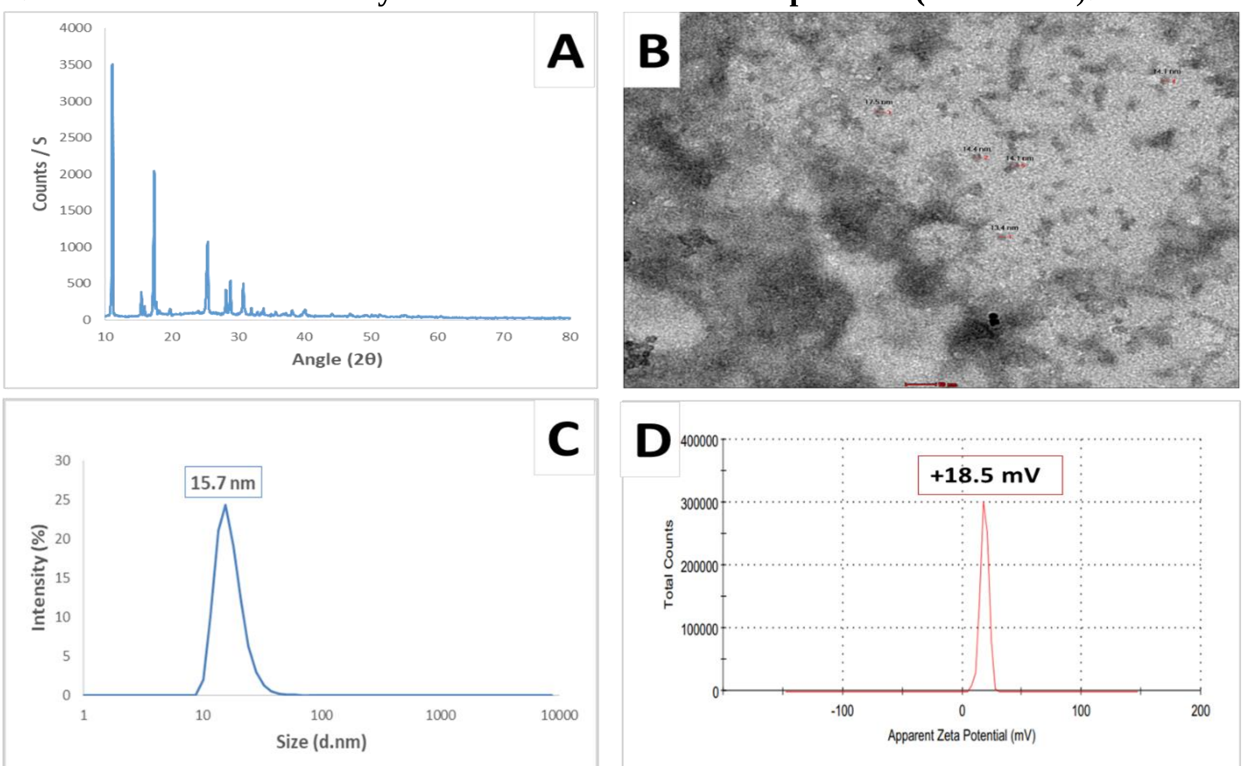

Fig 3. Characterization of Salicylic acid-loaded chitosan nanoparticles (SA/CS NPs). **(A)**: XRD pattern analysis indicating the formation of SA/CS NPs **(B):** HR-TEM image showing nearly spherical shape of prepared SA/CS NPs with average size 14.7 nm. **(C):** Particle size distribution of prepared SA/CS NPs showing the average size of 15.7 nm. **(D):** Zeta potential of prepared SA/CS NPs CS nanoparticles showing surface charge, zeta potential, +18.5 mV**.**

1. Weight loss percentage:

The data shown in **Table (1)** indicates that all samples experienced a gradual increase in weight loss (%) as the storage period and shelf life lengthened during the two seasons. These findings are consistent with Mohamed (2020). Weight loss during storage may be caused by respiration, transpiration, and other senescence-related metabolic activities (Amarante et al., 2001).

Results show also that all postharvest treatments decreased the percentage of weight loss when compared to the untreated control during storage period and shelf life. After 35 days of storage at 5°C plus 2 days at 20°C. Sweet pepper fruits treated with Nano-SA at 100 ppm and Nano-CS at 125 ppm were the most effective treatment in reducing weight loss percentage of fruits, with non-significant deference between them. The other treatments were less effective in these concerns. Highest value of weight loss was seen in control treatment. These results and agree with (Safitri et al., 2021 and Abdelkader et al., 2022).

The nanoparticles in the coatings are responsible for forming a zigzag in the film structure (raising surface area), as well as a crosslinked-like structure that acts as a barrier to the transfer of oxygen. In other words, oxygen should enter the film via a longer path than water vapor (Harnkarnsujarit and Li, 2017). This slows down the rate of all vital processes and activities that take place inside the fruits, as well as the rate of respiration, resulting in a lower weight loss percentage during storage and a slower rate of respiration and decay (Heena et al., 2013). Fruit preservation coating technology has been improved using nanotechnology and a variety of nano-systems, including nanoparticles. According to Algarni et al. (2022), CSNP treatment increased the fruit's shelf life and decreased fresh apricot fruit weight loss during cold storage. Salicylic acid improved fruit firmness by maintaining cell membrane integrity, resulting in decreased water loss and shriveling (Yanthan et al., 2019).

Table (1): Effect of edible coating chitosan and salicylic acid nanoparticles on weight loss percentage of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20ºC (shelf life) during 2020 & 2021 seasons.

Treatments (ppm)	Weight loss (%) Storage period (days)						Mean
	0+2	7+2	14+2	21+2	28+2	35+2	
				2020			
Control	0.16 rs	2.25 e-h	3.58 d	5.27 c	6.26 b	7.43 a	**4.16 A**
CS 500	0.05 s	0.39 q-s	0.97 m-p	1.90 g-j	2.39 e-g	3.58 d	**1.55 B**
Nano-CS 500	0.04 s	0.56 p-r	1.17 l-o	2.08 e-i	2.45 ef	3.15 d	**1.58 B**
Nano-CS 125	0.04 s	0.48 p-s	0.81 n-q	1.42 j-m	1.80 h-k	2.35 e-g	**1.15 C**
SA 200	0.04 s	0.63 p-r	1.33 k-m	1.94 g-i	2.47 e	3.34 d	**1.62 B**
Nano-SA 200	0.05 s	0.71 o-q	1.30 k-n	1.89 g-j	2.35 e-g	3.53 d	**1.64 B**
Nano-SA 100	0.05 s	0.41 q-s	0.79 o-q	1.62 i-l	1.96 f-i	2.27 e-h	**1.18 C**
Mean	**0.06 F**	**0.77 E**	**1.42 D**	**2.30 C**	**2.81 B**	**3.66 A**	
				2021			
Control	0.25 uv	1.37 n-s	2.89 e-h	4.95 c	6.23 b	8.02 a	**3.95 A**
CS 500	0.12 v	0.59 s-v	1.18 o-t	2.05 i-n	3.30 d-g	3.98 d	**1.87 B**
Nano-CS 500	0.10 v	0.42 t-v	0.95 q-u	1.78 j-p	2.53 g-k	3.52 de	**1.55 BC**
Nano-CS 125	0.11 v	0.42 t-v	1.36 n-s	1.65 l-q	2.25 h-m	2.56 f-j	**1.39 CD**
SA 200	0.11 v	0.65 s-v	1.02 p-u	1.74 k-q	2.57 f-j	3.45 de	**1.59 BC**
Nano-SA 200	0.09 v	0.46 t-v	1.13 o-t	1.82 j-o	2.62 f-i	3.34 d-f	**1.58 BC**
Nano-SA 100	0.11 v	0.41 t-v	0.81 r-v	1.48 m-r	2.00 i-n	2.34 h-l	**1.19 D**
Mean	**0.13 F**	**0.62 E**	**1.33 D**	**2.21 C**	**3.07 B**	**3.89 A**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

2. General appearance (GA):

The results in **Table (2)** showed that (GA) of sweet pepper fruits decreased with the prolongation of storage period plus shelf life. This might be due to shriveling, pitting, color change of fruits and decay (Mohamed, 2020). However, all postharvest treatments had significantly the highest score of appearance as compared with untreated control. Fruits dipped in Nano-SA at 100 ppm showed the best appearance which did not exhibit any changes in GA till 28 days at storage period plus shelf life and give a good appearance at the end of storage while Nano-SA at 200 ppm and Nano-SC at 125 ppm give a good appearance at the end of storage. Nano-Sc at 500 ppm treatment rated good appearances after 21 days at 5ºC + 2 days at 20 ºC in the two seasons. On the other hand, untreated control had an unsalable appearance at the end of storage period plus shelf life. These results were achieved in the two seasons and agreed with SA (Mohamed, 2020) and Nano-CS (Algarni et al., 2022).

The nanoscale coatings have additional advantages, such as a decrease in moisture loss and consequent preservation of texture, flavor, and appearance. Because of their smaller size and greater surface area, NPs have different properties from bulk materials. This means that they are more soluble and have a higher surface reactivity. SA treatment may be used as an efficient biomolecule for protecting tomato fruits encountered with frost or chilling and/or any other stress condition affect cell architecture and membrane (Aghdam et al., 2012) and increase resistance to postharvest diseases and chilling injury in horticultural crops, including sweet pepper (Mohamed, 2020). Chitosan as a coating preserved greater firmness, inhibited weight loss, reduced the increase in lipid peroxidation (MDA concentration), and relieved symptoms of CI in cucumbers. (Hashim et al., 2017).

Table (2): Effect of edible coating chitosan and salicylic acid nanoparticles on general appearance (score) of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20 ºC (shelf life) during 2020 & 2021 seasons.

Treatments (ppm)	General appearance (%) Storage period (days)						Mean
	0+2	7+2	14+2	21+2	28+2	35+2	
				2020			
Control	9.00 a	7.00 b-d	5.67 d-f	4.33 f	2.33 g	1.00 g	**4.89 D**
CS 500	9.00 a	8.33 ab	7.00 b-d	6.33 c-e	5.67 d-f	4.33 f	**6.78 C**
Nano-CS 500	9.00 a	9.00 a	8.33 ab	7.67 a-c	6.33 c-e	5.00 ef	**7.56 B**
Nano-CS 125	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 a-c	7.00 b-d	**8.33 A**
SA 200	9.00 a	8.33 ab	7.67 a-c	6.33 c-e	5.67 d-f	5.00 ef	**7.00 BC**
Nano-SA 200	9.00 a	9.00 a	9.00 a	7.67 a-c	7.67 a-c	7.00 b-d	**8.22 A**
Nano-SA 100	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 a-c	**8.67 A**
Mean	**9.00 A**	**8.52 A**	**7.95 B**	**7.10 C**	**6.24 D**	**5.29 E**	
				2021			
Control	9.00 a	7.00 b-d	6.33 c-e	4.33 f	2.33 g	1.00 g	**5.00 D**
CS 500	9.00 a	8.33 ab	7.67 a-c	5.67 d-f	5.67 d-f	5.00 ef	**6.89 C**
Nano-CS 500	9.00 a	9.00 a	8.33 ab	7.67 a-c	7.00 b-d	5.67 d-f	**7.78 B**
Nano-CS 125	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 a-c	7.00 b-d	**8.33 AB**
SA 200	9.00 a	8.33 ab	7.67 a-c	6.33 c-e	5.67 d-f	5.00 ef	**7.00 C**
Nano-SA 200	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 a-c	7.00 b-d	**8.33 AB**
Nano-SA 100	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 a-c	**8.67 A**
Mean	**9.00 A**	**8.52 AB**	**8.14 B**	**7.10 C**	**6.33 D**	**5.48 E**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

3. Decay Score:

The decay score of sweet pepper fruits significantly increased as the storage period and shelf life were extended during the two seasons, as shown in **Table. (3).** Certain reactions could be brought on by the ongoing biochemical and chemical alterations that fruits go through, such as the breakdown of complex chemicals into simpler ones and a faster rate of ripening that increases their susceptibility to fungus. At the end of storage period and shelf life, no decay was observed in sweet peppers treated with Nano-SC at 125 and Nano-SA at 100 or 200 ppm while Nano-SC 500 ppm and Nano-SA at 200 ppm gave a slight decay at the same period. The highest value of decay were observes from untreated control. These results agree with Mohamed (2020) and Algarni et al. (2022). Regarding Nano-CS, Nanoscale materials have surfaced as innovative antimicrobial agents, with chitosan nanoparticles demonstrating efficacy against pathogenic microorganisms. Apricots coated with Nano-CS after harvest control decay, preserve quality and prolong fruit shelf life. SA can improve disease resistance and is an endogenous signal that triggers certain plant defense responses (Yao and Tian, 2005). The decrease in PPO Valencia orange activity during cold storage and the rise in POX enzyme activity could be the causes of the decline in decaying fruits treated with SA.

Table (3): Effect of edible coating chitosan and salicylic acid nanoparticles on decay (score) of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20 ºC (shelf life) during 2020 & 2021 seasons.

Treatments (ppm)	Decay (%)						Mean
	Storage period (days)						
	0+2	7+2	14+2	21+2	28+2	35+2	
				2020			
Control	1.00 f	1.33 ef	1.33 ef	2.33 c	3.33 b	4.00 a	**2.22 A**
CS 500	1.00 f	1.00 f	1.00 f	1.33 ef	1.67 de	2.33 c	**1.39 B**
Nano-CS 500	1.00 f	1.00 f	1.00 f	1.00 f	1.33 ef	2.00 cd	**1.22 B**
Nano-CS 125	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	**1.00 C**
SA 200	1.00 f	1.00 f	1.00 f	1.33 ef	1.67 de	2.00 cd	**1.33 B**
Nano-SA 200	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	**1.00 C**
Nano-SA 100	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	**1.00 C**
Mean	**1.00 D**	**1.05 D**	**1.05 D**	**1.29 C**	**1.57 B**	**1.91 A**	
				2021			
Control	1.00 f	1.33 ef	1.33 ef	2.33 c	3.33 b	4.00 a	**2.22 A**
CS 500	1.00 f	1.00 f	1.00 f	1.67 de	1.67 de	2.00 cd	**1.39 B**
Nano-CS 500	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.67 de	**1.11 C**
Nano-CS 125	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	**1.00 C**
SA 200	1.00 f	1.00 f	1.00 f	1.33 ef	1.67 de	2.00 cd	**1.33 B**
Nano-SA 200	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	**1.00 C**
Nano-SA 100	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	**1.00 C**
Mean	**1.00 D**	**1.05 D**	**1.05 D**	**1.33 C**	**1.52 B**	**1.81 A**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

4. Chilling injury (CI):

CI symptoms in sweet pepper fruits include pitting, poor ripening, surface discoloration, collapse of structural integrity, development of off-flavors, the formation of sunken, calyx darkening, seed browning and darkening. Data in **Table (4)** show that CI severity increased gradually with the prolongation of storage duration in the two seasons and in agreement with (Mohamed, 2020). At the end storage plus shelf-life, all postharvest treatments had significantly the lowest score of CI as compared with untreated control. However, sweet pepper fruits treated with Nano-SA at 100 ppm appeared normal without any symptoms of CI throughout all storage times and recorded low score 0 the average of the two seasons after 35 days at 5˚ C plus 2 days at 20˚ C, followed by Nano-SC at 125 ppm and Nano-SA at 200 ppm with no significant between them, while untreated control records the highest of the two seasons at the same duration. The application of CSNP coatings may protect banana fruits from membrane damage, lowering CI in fruits by increasing the activity of the phenylalanine ammonia-lyase (PAL) enzyme, total phenolic content (TPC), and total antioxidant activity (TAA) in the flavedo tissue (Elbagoury et al., 2022). Chitosan's effect on chilling resistance in fruits could be attributed to its ability to protect tissue membranes from oxidative damage by producing higher CAT and APX activities (Wang et al., 2021). A therapy prevented CI-induced membrane degradation, as evidenced by reduced electrolyte leakage and malondialdehyde concentration. Furthermore, low field-nuclear magnetic resonance and proline content analysis suggested that SA treatment reduced CI via improving water retention in pepper fruits. Our findings may help optimize low-temperature storage conditions for post-harvest peppers during cold stress at 4 ˚C for 25 days (Ge et al., 2020). Luo et al. (2011) discovered that SA treatment dramatically reduced the CI impact in plum fruits, which related to increased endogenous polyamine accumulation and a reduction in MDA, which is associated with improved cell membrane integrity.

Table (4): Effect of edible coating chitosan and salicylic acid nanoparticles on chilling injury (score) of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20 ºC (shelf life) during 2020 & 2021 seasons.

Treatments (ppm)	Chilling injury (CI) Storage period (days)						Mean
	0+2	7+2	14+2	21+2	28+2	35+2	
				2020			
Control	0.00 f	0.67 de	1.00 cd	1.33 c	2.33 b	4.00 a	**1.56 A**
CS 500	0.00 f	0.00 f	0.00 f	0.33 ef	0.67 de	1.33 c	**0.39 B**
Nano-CS 500	0.00 f	0.00 f	0.00 f	0.00 f	0.33 ef	1.00 cd	**0.22 BC**
Nano-CS 125	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	0.33 ef	**0.06 CD**
SA 200	0.00 f	0.00 f	0.00 f	0.33 ef	0.67 de	1.00 cd	**0.33 B**
Nano-SA 200	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	0.33 ef	**0.06 CD**
Nano-SA 100	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	**0.00 D**
Mean	**0.00 D**	**0.10 CD**	**0.14 CD**	**0.29 C**	**0.57 B**	**1.14 A**	
				2021			
Control	0.00 f	0.33 ef	0.33 ef	1.33 c	2.00 b	3.67 a	**1.28 A**
CS 500	0.00 f	0.00 f	0.00 f	0.67 de	1.00 cd	1.33 c	**0.50 B**
Nano-CS 500	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	0.67 de	**0.11 C**
Nano-CS 125	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	**0.00 C**
SA 200	0.00 f	0.00 f	0.00 f	0.33 ef	0.67 de	1.33 c	**0.39 B**
Nano-SA 200	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	0.33 ef	**0.06 CD**
Nano-SA 100	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	0.00 f	**0.00 C**
Mean	**0.00 C**	**0.05 C**	**0.05 C**	**0.33 B**	**0.52 B**	**1.05 A**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

5. Color (L* value):

Data in **Table (5)** indicate that there was a significant decrease in L* value with an increasing storage period of sweet pepper fruits in the two seasons. These results agree with Abou-Zaid et al. (2020). The rate of respiration and transpiration could be the cause of this (Safitri et al., 2021). All postharvest treatments, however, considerably decreased the L value loss when compared to the untreated control fruits. Moreover, after 35 days at storage period at 5° C + 2 day at 15° C, data reversed that sweet pepper fruits dipped in Nano-SC at 125 ppm and Nano-SA at 100 ppm treatments had considerably increased fruit lightness as compared with the other treatments or untreated control in the season 2020. According to Tareen et al (2012), peach fruits showed that submerging them in

SA solution prevented color changes and preserved their lightness during cold storage. Moreover, the delayed color shift of chitosan-coated fruit is mediated by metabolic activity inhibition (Kumar et al., 2017). Carotenoids will be degraded by oxidation during storage. Since nano chitosan is selectively permeable to oxygen, it inhibits the carotenoid breakdown process (Zambrano-Zaragoza et al., 2014).

Table (5): Effect of edible coating chitosan and salicylic acid nanoparticles on L* Value of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20ºC (shelf life) during 2020 and 2021 seasons.

Treatments (ppm)	L* value						Mean
	Storage period (days)						
	0+2	7+2	14+2	21+2	28+2	35+2	
				2020			
Control	50.71 a-h	48.99 b-j	47.20 h-j	42.13 kl	38.99 lm	37.80 m	**44.30 E**
CS 500	51.41 a-f	48.46 d-j	46.07 i-k	49.64 a-i	48.56 c-j	47.38 g-j	**48.59 D**
Nano-CS 500	51.67 a-e	51.42 a-f	51.20 a-g	48.19 d-j	47.62 f-j	47.83 e-j	**49.66 B-D**
Nano-CS 125	51.81 a-d	51.26 a-g	51.46 a-f	50.57 a-h	51.77 a-e	49.98 a-i	**51.14 AB**
SA 200	51.47 a-f	50.70 a-h	49.01 b-j	48.29 d-j	47.59 f-j	45.28 jk	**48.72 CD**
Nano-SA 200	52.44 a-c	50.77 a-h	50.61 a-h	49.56 a-i	49.88 a-i	48.48 c-j	**50.29 A-C**
Nano-SA 100	53.14 a	52.84 ab	51.79 a-e	51.21 a-g	50.25 a-h	49.55 a-i	**51.46 A**
Mean	**51.81 A**	**50.64 AB**	**49.62 BC**	**48.51 CD**	**47.81 DE**	**46.62 E**	
				2021			
Control	50.78 a-e	48.66 a-g	46.53 c-g	41.13 h-j	39.99 ij	38.80 j	**44.32 D**
CS 500	51.11 a-d	47.93 a-g	45.77 e-h	49.64 a-f	45.23 f-i	44.05 g-j	**47.29 C**
Nano-CS 500	51.81 ab	50.96 a-e	51.72 a-c	50.57 a-e	49.11 a-g	46.31 d-h	**50.08 AB**
Nano-CS 125	51.67 a-c	51.39 a-d	50.87 a-e	48.19 a-g	47.62 a-g	47.83 a-g	**49.60 AB**
SA 200	51.14 a-d	50.03 a-f	48.68 a-g	47.62 a-g	47.49 b-g	44.28 g-i	**48.21 BC**
Nano-SA 200	52.11 ab	50.21 a-f	50.48 a-f	49.29 a-g	49.82 a-f	47.82 a-g	**49.95 AB**
Nano-SA 100	52.81 a	52.68 ab	51.45 a-d	51.04 a-d	49.92 a-f	49.22 a-g	**51.19 A**
Mean	**51.63 A**	**50.26 AB**	**49.36 BC**	**48.21 CD**	**47.02 DE**	**45.47 E**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

6. Fruit firmness:

The data in **Table (6)** showed that fruit firmness continually declined over the course of the storage period, reaching its lowest point at its conclusion. These findings corroborate those of Abdullah and Srour (2019) and were accurate in both seasons. Changes in the mechanical strength of the fruit's cell wall during storage are linked to the loss of firmness (Valero and Serrano, 2010). Additionally, fruit softened because of the breakdown of the middle lamellae, which is closely linked to the hydrolytic enzyme that converts insoluble protopectin into water soluble pectin. This process decreased the rigidity of the cell walls (Luo et al., 2015). In comparison to the untreated control group, all postharvest treatments significantly impacted the firmness of the fruit during storage and shelf life. However, sweet pepper fruits treated with Nano-SA at 100 ppm Nano-SC at 125 ppm were the most effective treatments in reducing the loss of firmness during storage plus shelf-life with no significant differences between them until the end of the storage period in the two seasons, followed by Nano-CS at 500 ppm and Nano-SA at 200 ppm lowest values of fruit firmness was obtained in control treatment at the same duration. According to (Elbagoury et al., 2022), banana fruits coated with CS or CSNPs showed noticeably more firmness than those of the control during low and ideal temperature storage, as well as after moving fruits on days 5, 10, 15 and 20 from cold storage to ripening at 22 ± 2 °C. A substantial difference was observed between CS or CSNP treatments during ripening intervals where CSNPs had higher firmness in fruits moved from days 15 at 10 ± 2 °C and day 5 of optimal temperature storage at 14 ± 2 °C. The CSNP treatment extended the storage life and preserved higher firmness values of apricot fruits during cold storage (Kamil et al., 2019), and strawberry fruits (Eshghi et al., 2014). The reduction of ethylene production by salicylic acid, which in turn decreased the activity of cell wall degrading enzymes and helped to keep the firmness, may be responsible for the higher degree of firmness in the salicylic acid-treated sweet pepper (Fung et al., 2004).

Table (6): Effect of edible coating chitosan and salicylic acid nanoparticles on firmness (kg/cm^2) of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20ºC (shelf life) during 2020 & 2021 seasons.

Treatments (ppm)	Firmness (kg/cm^2) Storage period (days) 0+2	7+2	14+2	21+2	28+2	35+2	Mean
				2020			
Control	4.05 h-m	3.79 m-o	3.57 n-p	3.38 o-q	3.35 pq	3.14 q	3.55 D
CS 500	4.15 f-m	4.09 g-m	4.04 i-m	4.04 i-m	4.02 i-m	4.01 i-m	4.06 C
Nano-CS 500	4.25 c-l	4.20 d-m	4.10 g-m	4.17 f-m	3.98 j-n	3.88 l-n	4.10 BC
Nano-CS 125	4.90 a	4.65 a-c	4.63 a-c	4.61 a-d	4.59 a-e	4.50 a-g	4.65 A
SA 200	4.43 b-i	4.33 b-k	4.18 e-m	4.15 f-m	4.02 i-m	3.93 k-n	4.17 BC
Nano-SA 200	4.55 a-f	4.35 b-j	4.33 b-k	4.17 f-m	4.16 f-m	4.03 i-m	4.27 B
Nano-SA 100	4.75 ab	4.75 ab	4.66 a-c	4.47 b-h	4.38 b-j	4.20 d-lm	4.54 A
Mean	**4.44 A**	**4.31 AB**	**4.22 BC**	**4.14 C**	**4.07 CD**	**3.96 D**	
				2021			
Control	4.05 h-m	3.79 m-o	3.57 n-p	3.38 o-q	3.35 pq	3.14 q	3.55 D
CS 500	4.15 f-m	4.09 g-m	4.04 i-m	4.04 i-m	4.02 i-m	4.01 i-m	4.06 C
Nano-CS 500	4.25 c-l	4.20 d-m	4.10 g-m	4.17 f-m	3.98 j-n	3.88 l-n	4.10 BC
Nano-CS 125	4.75 ab	4.75 ab	4.66 a-c	4.47 b-h	4.38 b-j	4.20 d-m	4.54 A
SA 200	4.43 b-i	4.33 b-k	4.18 e-m	4.15 f-m	4.02 i-m	3.93 k-n	4.17 BC
Nano-SA 200	4.55 a-f	4.35 b-j	4.33 b-k	4.17 f-m	4.16 f-m	4.03 i-m	4.27 B
Nano-SA 100	4.90 a	4.65 a-c	4.63 a-c	4.61 a-d	4.59 a-e	4.50 a-g	4.65 A
Mean	**4.44 A**	**4.31 AB**	**4.22 BC**	**4.14 C**	**4.07 CD**	**3.96 D**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

7. Ascorbic acid content (V.C.):

Data in **Table (7)** showed that as the storage period was extended, the content of ascorbic acid decreased progressively significantly in all treatments, and this could be caused by the oxidation of dehydroascorbic to diketogulonic acid (Ishaq et al., 2009). Additionally, the drop in V.C. concentration during storage could be attributed to increased respiration and oxidation of acids into sugars After 35 days of storage at 5°C and 2 days of shelf life at 20 °C, sweet pepper fruit dipped in Nano-SA at 100 ppm resulted in higher AA content, followed by Nano-SC at 125 with significant difference between them in the two seasons, while untreated control gave the lowest ones. Reduced or delayed ascorbate oxidase activity could explain the action of chitosan and its nanoparticles (Ishaq et al., 2009). These findings are consistent with those of Algarni et al. (2022), who found that Nano-CS treatments may decrease the ripening process and maintain high ascorbic acid levels by reducing oxygen transport. Compared to the control fruits and the chitosan treatments used in this study, Nano-CS treatments were substantially more effective at preserving the fruits' ascorbic acid levels throughout storage. Reducing AAO enzyme activity with SA treatment was beneficial for maintaining nutrition and organoleptic quality by maintaining AA content, which contributes significantly to antioxidant capacity (Gao et al., 2011), as well as reducing the oxidation process (Rasouli et al., 2019). Furthermore, AA is a component of the non-enzymatic antioxidant system that aids in ROS scavenging (Aghdam et al., 2018).

Table (7): Effect of edible coating chitosan and salicylic acid nanoparticles on ascorbic acid content (mg/100 gm F.W.) of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20ºC (shelf life) during 2020 and 2021 seasons.

Treatments (ppm)	Ascorbic acid content (mg/100 gm F.W.) "V. C." Storage period (days)						Mean
	0+2	7+2	14+2	21+2	28+2	35+2	
				2020			
Control	131.50 a	129.80 de	127.40 kl	125.80 q	123.90 t	120.60 w	**126.50 G**
CS 500	131.30 ab	129.80 de	128.00 hi	126.60 op	124.80 s	122.30 v	**127.10 F**
Nano-CS 500	130.90 c	129.90 de	128.40 h	127.20 lm	125.80 q	124.00 t	**127.70 D**
Nano-CS 125	130.90 bc	130.10 d	129.20 fg	127.90 ij	126.70 no	125.20 r	**128.30 B**
SA 200	130.90 c	129.80 de	128.20 hi	126.90 m-o	125.40 r	123.10 u	**127.40 E**
Nano-SA 200	130.90 c	130.00 d	129.00 g	127.60 jk	126.30 p	124.60 s	**128.10 C**
Nano-SA 100	130.80 c	130.10 d	129.50 ef	128.20 hi	127.10 l-n	125.80 q	**128.60 A**
Mean	**131.00 A**	**129.90 B**	**128.50 C**	**127.20 D**	**125.70 E**	**123.70 F**	
				2021			
Control	133.40 a	132.00 d	131.10 h	128.20 m	125.20 r	122.20 t	**128.70 F**
CS 500	132.90 bc	132.00 d	131.10 gh	128.90 l	126.00 p	124.50 s	**129.20 E**
Nano-CS 500	132.70 bc	132.10 d	131.40 f-h	129.40 k	126.70 o	125.40 qr	**129.60 D**
Nano-CS 125	133.00 ab	132.10 d	131.60 ef	130.00 j	128.10 m	126.20 p	**130.20 B**
SA 200	132.80 bc	132.00 d	131.20 f-h	129.00 l	126.20 p	125.00 r	**129.40 E**
Nano-SA 200	132.60 c	132.00 d	131.50 e-g	129.90 j	127.30 n	125.80 pq	**129.80 C**
Nano-SA 100	132.60 c	132.10 d	131.90 de	130.50 i	128.80 l	127.00 no	**130.50 A**
Mean	**132.90 A**	**132.10 B**	**131.40 C**	**129.40 D**	**126.90 E**	**125.20 F**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

8. Total carotenoids:

Data in **Table (8)** showed that carotenoid accumulation was observed throughout storage period plus shelf life. During onset of ripening and sweet pepper development distraction of food pigments (chlorophyll) occurs and hence carotenoids content increase. Carotenoids content increase with advancement in storage conditions (Mohamed, 2020). All postharvest treatments decreased the accumulation of carotenoids content compared with untreated control. However, at the end of the storage period plus shelf-life, the lowest accumulation of carotenoids content was found in Nano-SA at 100 ppm then Nano-CS at 125 ppm with no significant difference between them in the second. Season. Untreated control gave the highest values in this concern. These results agreed with Algarni et al. (2022) and Mohamed et al. (2016). To improve the performance of edible coatings, some can be transformed to nanoscale. Because of the presence of amino and hydroxyl groups on the chitosan polymeric network, it is easily transformed to chitosan nano particles (Nano-CS), an edible coating used to extend the shelf life and quality of banana fruits (Lustriane et al., 2018). The fruits' reddish orange color was evaluated during postharvest treatments and during the storage periods. This is because the fruits contain anthocyanin and carotenoid pigments, which cause carotenoids to oxidize and break down during storage. Haghighi et al. (2020) have reported that nano chitosan slows the degradation of carotenoid because it is selectively permeable to oxygen. According to Aghdam et al. (2012), the lowest carotenoids content in SA is due to these materials' lower respiration activities and suppression of enzyme activities, which reduces the accumulation of carotenoids content during storage.

Table (8): Effect of post-harvest treatments on Total carotenoids content (mg/100 gm F.W.) of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20 ºC (shelf life) during 2020 and 2021 seasons.

Treatments (ppm)	Carotenoids content (mg/100 gm F.W.) Storage period (days)						Mean
	0+2	7+2	14+2	21+2	28+2	35+2	
				2020			
Control	2.76s	2.85 no	3.08 ijk	3.24 ef	3.49 b	3.57 a	**3.16 A**
CS-500	2.78q-s	2.82 o-r	2.97 l	3.23 ef	3.40 cd	3.44 bc	**3.11 B**
Nano-CS-500	2.81o-s	2.85 no	2.94 lm	3.10 h-j	3.35 d	3.39 d	**3.08 C**
Nano-CS-125	2.79 p-s	2.81 o-r	2.90 mn	3.04 k	3.15 gh	3.24 ef	**2.99 E**
SA-200	2.80 o-s	2.83 o-q	2.96 l	3.20 fg	3.36 d	3.39 d	**3.09 BC**
Nano-SA-200	2.77 rs	2.84 op	2.94 lm	3.10 ij	3.21 f	3.28 e	**3.02 D**
Nano-SA-100	2.77 rs	2.79 p-s	2.83 o-q	2.98 l	3.06 jk	3.12 hi	**2.93 F**
Mean	**2.79 F**	**2.83 E**	**2.95 D**	**3.13 C**	**3.29 B**	**3.35 A**	
				2021			
Control	2.93 s	3.05 no	3.38 gh	3.52 b-d	3.63 a	3.66a	**3.36A**
CS-500	2.95 rs	3.01 o-q	3.31 ij	3.48 c-e	3.54 b	3.53bc	**3.30B**
Nano-CS-500	2.94 rs	3.05 no	3.24 kl	3.39 gh	3.48 c-e	3.50b-d	**3.27CD**
Nano-CS-125	2.93 s	3.03 n-p	3.21 lm	3.34 hi	3.41 fg	3.45ef	**3.23E**
SA-200	2.96 rs	3.07 n	3.27 jk	3.41 fg	3.51 b-d	3.47de	**3.28BC**
Nano-SA-200	2.97 q-s	3.02 n-p	3.24 kl	3.35 hi	3.45 ef	3.48c-e	**3.25D**
Nano-SA-100	2.92 s	2.99 p-r	3.18 m	3.30 ij	3.34 hi	3.40fg	**3.19F**
Mean	**2.94E**	**3.03D**	**3.26C**	**3.40B**	**3.48A**	**3.50A**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

9. The total phenolic content (TPC):

The results in **Table (9)** show that (TPC) significantly decreased until the end of the storage time in both seasons, and these agree with Singh et al. (2020). The decline in total phenolics during storage was associated with their consumption to inhibit free radicals under cold-stress conditions (Naser et al., 2018). Interaction had significant effect of carotenoids and data showed that after 35 days of storage at 5°C plus 2 days at 20 °C, sweet pepper fruits dipped in low concentration for Nano-SA and Nano-SC were the highest value TPC with no significant difference between them in the second season followed by Nano-CS at 500 ppm and Nano-SA at 200 ppm, the low value of TPC was recorded from untreated control. These results agree with (Algarni et al., 2022 and Mohamed et al., 2016). In comparison to the control samples, the application of CS or CSNPs reduced CI while increasing TPC. Tolerance to CI may occur because to increased antioxidant capacity, including total phenolic substances and antioxidant enzymes that prevents excessive ROS production (Jiao et al., 2018). CS-Nps enhanced phenolic compounds (Wang et al., 2021). Fruits coated with CSNPs showed significantly greater TPC ($P \leq 0.05$) than those coated with CS (Elbagoury et al., 2022). Fruits coated with CS and SA may contain more phenolic compounds due to increased PAL activation and decreased polyphenol oxidase (PPO) activation (Romanazzi et al., 2017). According to Sayyari et al. (2011), higher anthocyanins and total phenolic accumulation may be attributed to increased ratio of PAL/PPO enzymatic activity caused by chitosan and salicylic acid interactions. Also, this could be attributed to the senescence caused by the disintegration of cell construction and phenolic oxidation by enzymatic activities such as PPO (Razzaq et al., 2014).

Table (9): Effect of edible coating chitosan and salicylic acid nanoparticles on total phenolic content (mg/100g F.W.) of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20ºC (shelf life) during 2020 and 2021 seasons.

Treatments (ppm)	Total phenolic content (mg/100g F.W.) Storage period (days)						Mean
	0+2	7+2	14+2	21+2	28+2	35+2	
				2020			
Control	18.94 a	17.75 q	18.22 jk	18.01 n	17.28 u	16.81 v	**17.83 G**
CS 500	18.93 a	17.78 q	18.32 gh	18.15 l	17.40 t	17.31 u	**17.98 F**
Nano-CS 500	18.94 a	17.78 q	18.40 ef	18.26 ij	17.77 q	17.40 t	**18.09 D**
Nano-CS 125	18.91 a	18.80 b	18.53 d	18.31 g-i	17.92 o	17.58 r	**18.34 B**
SA 200	18.92 a	17.79 q	18.36 fg	18.18 kl	17.51 s	17.32 u	**18.01 E**
Nano-SA 200	18.93 a	18.80 b	18.45 e	18.29 hi	17.86 p	17.46 s	**18.30 C**
Nano-SA 100	18.93 a	18.81 b	18.61 c	18.42 e	18.09 m	17.76 q	**18.43 A**
Mean	**18.93 A**	**18.22 C**	**18.41 B**	**18.23 C**	**17.69 D**	**17.38 E**	
				2021			
Control	19.26 a	19.10 bc	18.57 g-i	18.01 o	17.62 q	17.02 r	**18.27 E**
CS 500	19.22 ab	19.13 a-c	18.66 g-i	18.19 mn	18.00 o	17.56 q	**18.46 D**
Nano-CS 500	19.23 ab	19.15 a-c	18.38 jk	18.35 kl	18.18 mn	17.80 p	**18.51 D**
Nano-CS 125	19.22 ab	19.15 a-c	18.93 de	18.68 f-h	18.38 jk	18.09 no	**18.74 B**
SA 200	19.21 ab	19.14 a-c	18.70 fg	18.31 k-m	18.03 o	17.61 q	**18.50 D**
Nano-SA 200	19.23 ab	19.15 a-c	18.88 de	18.55 hi	18.20 mn	17.82 p	**18.64 C**
Nano-SA 100	19.21 ab	19.16 a-c	19.02 cd	18.82 ef	18.52 ij	18.21 l-n	**18.82 A**
Mean	**19.23 A**	**19.14 B**	**18.74 C**	**18.41 D**	**18.13 E**	**17.73 F**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

10. Antioxidant activity:

As a result, **Table (10)** the contents of antioxidant activity terms of DPPH scavenging activity gradually decreased in treated as well as untreated control sweet pepper fruits. Like previous research by Xing et al. (2021). Reduced amounts of antioxidants may result from senescence and decay of individual phenolics and polyphenols, such as hydrolysable tannins, anthocyanins, and flavonoids (Mohammadi et al., 2016). Antioxidant agents in food products block many of the oxidation events brought on by free radicals, lowering the risk of tissue damage and the loss of functional and nutritional qualities. A decline in antioxidant enzyme activity may be the cause of the changes in chlorophyll compartments over time (Lo'ay et al., 2021). More ROS are produced as a result, which raises the rate of oxidative processes such protein and lipid oxidation. Culminating in the death of cells (Taher et al., 2022). However, sweet pepper treated displayed higher DPPH-RSA retention as compared to untreated control fruits. At the end of the storage period plus shelf life, Nano-SA at 100 ppm treatment significantly contributed to preserving the antioxidant activity of fruits, followed by Nano-SC at 125 ppm treatment. While the untreated fruits had the lowest values of antioxidant activity in both seasons, and these results agree with Xing et al. (2021). According to reports, chitosan coating increases the antioxidant capacity and phenolic components in mango fruits while also inducing ROS scavenging activity (Jongsri et al., 2016). Furthermore, during storage, strawberries coated with Nano-chitosan exhibited marginally increased antioxidant activity when compared with the control of fruits (Eshghi et al., 2014).

The previous study showed that there was a significant positive correlation between total phenolic, ascorbic acid contents and DPPH scavenging capacity (Safariet et al., 2021). SA controls multiple physiological and biochemical paths in cells (Khan et al., 2003). It inhibits the harmful effects of these ROS by enhancing antioxidant activities, such as lowering H_2O_2 levels through the action of ascorbate (APX) (Hayat et al., 2010).

Table (10): Effect of edible coating chitosan and salicylic acid nanoparticles on antioxidant activity (DPPH scavenging %) of sweet pepper fruits stored at 5ºC and RH 90-95% plus 2 days at 20 ºC (shelf life) during 2020 and 2021 seasons.

Treatments (ppm)	Antioxidant activity - Storage period (days) 0+2	7+2	14+2	21+2	28+2	35+2	Mean
				2020			
Control	20.00 d-m	19.04 h-o	17.85 k-p	16.33 o-q	15.20 pq	14.54 q	**17.16 E**
CS 500	20.33 d-l	19.38 g-n	18.73 i-o	18.15 j-o	17.43 m-p	16.96 n-q	**18.50 D**
Nano-CS 500	22.00 a-g	21.11 b-i	20.89 b-j	20.35 d-l	19.86 e-m	19.20 g-n	**20.57 BC**
Nano-CS 125	23.33 a-c	22.38 a-f	21.86 a-h	21.50 a-i	20.67 c-k	19.99 d-m	**21.62 AB**
SA 200	22.00 a-g	20.99 b-i	20.19 d-m	19.67 f-n	19.00 i-o	17.67 l-p	**19.92 C**
Nano-SA 200	22.67 a-e	21.99 a-g	21.36 a-i	20.95 b-j	20.52 c-k	19.98 d-m	**21.25 B**
Nano-SA 100	24.00 a	23.54 ab	22.73 a-d	22.62 a-e	21.99 a-g	21.36 a-i	**22.71 A**
Mean	**22.05 A**	**21.20 AB**	**20.52 BC**	**19.94 CD**	**19.24 DE**	**18.53 E**	
				2021			
Control	21.33 b-g	19.54 e-j	18.05 h-k	17.34 j-l	15.70 kl	14.88 l	**17.81 E**
CS 500	22.33 a-e	21.41 a-g	20.92 b-h	20.43 c-i	19.83 d-j	18.71 g-j	**20.61 CD**
Nano-CS 500	21.00 b-h	20.08 c-j	22.65 a-d	18.82 g-j	17.79 i-l	17.20 j-l	**19.59 D**
Nano-CS 125	23.67 ab	23.04 a-c	22.36 a-e	21.86 a-f	21.33 b-g	20.91 b-h	**22.20 AB**
SA 200	21.67 a-g	20.99 b-h	20.19 c-j	19.63 e-j	18.89 f-j	17.33 j-l	**19.78 D**
Nano-SA 200	22.83 a-c	22.29 a-e	21.68 a-g	21.48 a-g	20.98 b-h	20.69 b-i	**21.66 BC**
Nano-SA 100	24.33 a	23.59 ab	23.05 a-c	22.67 a-d	22.32 a-e	21.62 a-g	**22.93 A**
Mean	**22.45 A**	**21.56 AB**	**21.27 BC**	**20.32 CD**	**19.55 DE**	**18.76 E**	

Values with letters in the same column, the same row and interaction are not statistically different, at 0.05 level according to Duncan's multiple range test. Control = Distilled water, spraying, Nano-CS = chitosan nanoparticles, Nano-SA = Salicylic acid nanoparticles.

Conclusion

From the previous results, it could be concluded that, sweet pepper fruits treated with Nano-SA at 100 ppm or Nano-SC at 125 ppm treatments were the most effective treatments in preserving all tested quality attributes of fruits, and gave a good appearance of fruits for 35 days at 5°C plus 2 days at 20°C without any decay or chilling injury, while bulk-SA or SC treatments gave a good appearance of fruits for only 14 days at the same storage condition.

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الملخص العربى

تاثير المعامة بالنانو-كيتوزان ونانو-حمض الساليسيليك بعد الحصاد على تقليل أضرار البرودة والحفاظ على جودة ثمار الفلفل الحلو أثناء التخزين المبرد.

صفاء زكريا، خالد يحي فروح و محمد أحمد عبدالله

قسم بحوث تداول الخضر معهد بحوث البساتين مركز البحوث الزراعية الجيزة مصر
المعمل المركزي للنانوتكنولوجيا والمواد المتقدمه مركز البحوث الزراعية مصر

أجريت هذه الدراسة خلال موسمي 2020 & 2021، على ثمار الفلفل الحلو صنف Taison. لهدف تقييم تأثير معاملة الثمار في محلول النانو-حمض الساليسيليك تركيز 100 و200 جزء فى المليون، والنانو-كيتوزان تركيز 125 و500 جزء فى المليون، وحمض السالسيلك 200 جزء فى المليون والكيتوزان 500 جزء فى المليون لمدة 5 دقائق، بالاضافة الي معاملة الكنترول (المعاملة بالمياه) خلال التخزين المبرد على درجة 5°م لمدة 35 يوم بالاضافة إلى يومين على درجة 20°م (فترة العرض) على تخفيف أضرار البرودة والحفاظ على خصائص جودة الثمار.

أشارت النتائج إلى أن ثمار الفلفل الحلو المعاملة بجميع معاملات ما بعد الحصاد بالتجربة كانت معنوية في تقليل الفقد فى الوزن، والحفاظ على الصلابة ودرجة اللمعان و حمض الأسكوربيك، وتخفيف أضرار البرودة والحفاظ على الفينولات الكلية ومضادات الأكسدة مع أقل تراكم لمحتوي الكاروتينات للثمرة خلال كل فترات التخزين مقارنة بالكنترول. والثمار المعاملة بالنانو-حمض الساليسيليك بتركيز 100 جزء فى المليون أو النانو-كيتوزان تركيز 125 جزء فى المليون هما المعاملات الأكثر فعالية فى الحفاظ على جميع صفات جودة الثمار، وأعطت مظهرًا جيداً للثمار لمدة 35 يوم من التخزين على درجة 5 °م بالإضافة إلى يومين على درجة 20 °م، بدون ظهور أي أعراض للعفن أو أضرار البرودة، بينما معاملات نانو حمض الساليسيليك تركيز 200 جزء فى المليون والنانو كيتوزان تركيز 500 جزء فى المليون أعطت مظهراً جيد للثمار لمدة 28 يوم ، ولكن حمض الساليسيليك تركيز 200 جزء فى المليون وكيتوزان تركيز 500 جزء فى المليون أعطت مظهراً جيد للثمار لمدة 14 يوم فقط على درجة 5 °م بالإضافة إلى يومين على درجة 20 °م.