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Physicochemical changes of fig fruits quality as affected by Post-harvest Nano Chitosan Treatments

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Abstract
The storage of fig fruits has garnered significant attention in the Egyptian market due to concerns about post-harvest quality. In this study, we evaluated the effectiveness of post-harvest chitosan and Nano-chitosan sprays on quality attributes and storability of fig fruits. *Ficus carica L.* figs were sprayed with 0.5% chitosan and Nano chitosan compared to respective controls. At 5-day intervals, the physical and chemical properties of the fruit were evaluated. As a result, nano-chitosan at 0.5% exhibited significant effect as post-harvest treatment. In general, treatment enhanced different properties including reducing weight losses and decay, moreover to preserving maximum firmness and extending shelf life. However, the chemical properties were also indicated that both applied treatments significantly increased the total soluble solids (TSS), total flavonoid contents, total ascorbic acid content, and total phenolic content. In addition to, decreasing the titratable acidity.
Keywords: Ficus carica; Fig Fruit; Nano-Chitosan; shelf life and post-harvest.

1.1. Introduction
The fig is a fruit that is abundant in fiber, vitamins, amino acids, antioxidants, potassium, calcium, and iron [1]. Fig fruits are difficult to keep because of their limited postharvest life. Perfect to overripe fruit ripens quickly, they shrivel and lose water readily, they are attacked and destroyed by fruit-rotting organisms, and finally they go through internal disintegration that makes them unsellable. The development of safe alternative chemicals that can be stored for long periods of time without losing their marketability has resulted from growing consumer concerns about the safety of food and the potential harm to health that chemical residues may cause. Chitosan functions by inhibiting the growth of fungi that cause degradation as well as by causing host tissues to develop resistance. Because of its ability to suppress disease through both physical and biological mechanisms, it is considered the perfect preservative covering Biology, chemistry,
engineering, and medicine are all combined in the interdisciplinary field of nanotechnology, according to [2]. It has enormous potential for the accurate diagnosis, timely identification, and tailored therapy of cancer. N-acetyl-D-glucosamine and B-(1-4)-linked D-glucosamine are randomly distributed components of chitosan (CS), a linear polysaccharide. [3] state that it is one of the primary cationic polymers and the second most prevalent polysaccharide in nature. Due to its unique qualities provided by the -NH2 and -OH groups, CS can be applied in a multitude of contexts and is easily available for chemical reactions. CS can safely and non-toxically interact with polyanions to form complexes and gels [4] and [5]. The impact of applying chitosan and nano chitosan after harvest on the storability and quality characteristics of fig fruits was evaluated in this study.

2.1. **Materials and Methods.**
Acros Organic Company (B-2440 Geel, Belgium) provided the chitosan (CS), and the average molecular weight of the CS was 170 kDa. The current study was carried out over two consecutive seasons (2021 and 2022) on Fig fruits (Ficus carica L.). Trees were grown on sandy soil in a private orchard in Abu Qurqas City, El-Minya Governorate, Egypt. Fruits were harvested at the maturity stage and transported to the laboratory and prepared for treatments.

2.1.1 **Nano Preparation of chitosan**
After dissolving CS 0.5 percent (w/v) in 1 percent (v/v) glacial acetic acid, 10N sodium hydroxide (NaOH) was added to bring the pH to 4.6–4.8. Under magnetic stirring, 1 milliliter of an aqueous tripolyphosphate solution 0.25 percent (w/v) was added to 3 milliliters of CS solution, causing chitosan nanoparticles (CSN) to form spontaneously. Centrifugation was used for 30 minutes at 9000×g to purify the nanoparticles. After discarding the supernatants, the CSN underwent a thorough rinsing with distilled water. and then freeze-dried before further use or analysis [6].
Certain weights of chitosan (chitosan from shrimp shells provided by the manufacturing engineering department, Egyptian Japanese University) were dissolved in an aqueous

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solution with 1% ascorbic acid (w/v) under continuous stirring to obtain the proposed concentrations of 0.5 %**.**

2.1.2 post-treatment and experimental design

In a completely randomized design Mature fig fruits that were undamaged, uniform in shape, weight, and color were chosen for the experiment. Fruits were then divided into three groups and treated as follows: The first group was sprayed by chitosan the second group was sprayed with Nano chitosan at 0.5% concentrations to obtain the proposed concentrations of 0.5% for each, and the third group (untreated fruits) served as control, then treated fruits were left for air-drying at laboratory temperature (25 °C). Each treatment was tripled before being stored at 0 ºC while assessments were conducted at five-day intervals during the storage period.

2.1.3 Fruit quality evaluations based on physical properties

2.1.3.1 Weight losses

Five-day intervals were used to record the initial weight of the fig fruits in each treatment. The fruit weight loss percentage was then computed by weighing the same fruits at each interval and at the conclusion of the cold storage period, using the following formula:

Weight losses%= (Initial weight-weight specific interval)/ (Initial weight) ×100

2.1.3.2 Decay

Fruit surface decay was categorized on a 5-point scale: 1 represented normalcy (none), 2 represented slightness (up to 5 percent of the fruit surface), 3 : moderateness (5-20 percent of the fruit surface), 4 moderately severe (20-50 percent of the fruit surface), and 5 : severe (>50 percent of the fruit surface). as described by [7].

2.1.3.3 Firmness

A penetrometer (AFG205N, EU) with an 8 mm diameter plunger was used to measure the firmness of the figs. After removing the epidermis at two equatorial sites, the fruits' firmness was measured with a 5 mm plunger tip. The measurements were given in kilograms per square meter.

2.1.3.4 Color assessment

lightness (L*), hue angle (hº), Chroma (C*) values of fruits were measured with a Minolta colorimeter CR-40 (Konica Minolta Sensing Inc, Sakai, Japan).

2.1.4 Fruit quality evaluations based on chemical properties

2.1.4.1 Total soluble solids in fruit

A digital pocket refractometer (model PAL 1, ATAGOTM, Tokyo Tech.) was used to calculate the total soluble solids (TSS) as a percentage.

2.1.4.2 Acidity titratable in fruits

Titratable acidity (TA) was determined in each replicate by titration against a diluted calibrated NaOH solution 40 of known normality (0.1), using phenolphthalein as a marker. Acidity was determined as a percentage of malic acid, per [7].

2.1.4.3 Total phenols

Spectrophotometric measurements of total phenolics were made using the [8]. Gallic acid (mg/100g) FW was used to express the results.

2.1.4.4 Total flavonoid

Using the aluminum chloride colorimetric method, total flavonoids were measured spectrophotometrically [9]. The results were expressed in terms of mg quercetin QE/100g FW.

2.1.4.5 Total ascorbic acid

Vitamin C was determined using [10] methodology. The direct titration technique measures the amount to which ascorbic acid in standard ascorbic acid solutions and sample extracts by decolorizes a 2,8-dichlorophenol-indophenol standard solution.

2.1.5 Analytical statistics

The storage experiments were conducted using a completely randomized design with three triplicates. ANOVA was used to analyses the data from the analytical determinations. Duncan's Multiple Range Test was used to compare means at a 5% significance level [11].

3. RESULTS AND DISCUSSION

3.1 Weight loss (%)

The water loss caused by transpiration and respiration processes is the primary cause of weight loss in fruits and vegetables [12]. Throughout all storage periods, the percentage of weight loss increased (Table 1). Untreated (control) fruits had the highest significant weight loss percentage at the end of the storage period (20 days) in both seasons, while treatments with chitosan and its nano particles had the lowest significant weight loss. Regarding the way the two variables under study treatments and storage periods interacted, fruits treated with 0.5 percent nano chitosan after 20 days of cold storage had the lowest fruit weight loss. At 20 days of storage, 0.5 percent chitosan maintained the moderate weight loss (percent), while the control fruits recorded the greatest weight loss. This holds true for the two investigated seasons.

These findings concur with those that were mentioned by [13], on longan fruit [14], on banana and mango they showed that Chitosan and nano chitosan was found to be an effective weight loss coating. According to [15], chitosan coatings function as barriers that stop the transfer of water, shield fruit skin from mechanical damage.

3.2 Decay (score)

Over the extended storage periods in both seasons, degradation percentages increased gradually (Table 2). decay incidence gradually rose from day 15 of storage till day 20. The post-harvest treatments containing 0.5 percent Nano chitosan and 0.5 percent chitosan, respectively, had the lowest significant decay percentages.

The acquired results align with the findings of [16], who said that the formation of a film coating on the fruit's surface by chitosan affects both the fruit's internal gas composition and its gas exchange with the atmosphere. One possible explanation for chitosan's anti-decay properties is that it slows down the senescence process. Through direct antifungal action, chitosan, a naturally occurring polycation molecule, may prevent fruit fungus deterioration.

3.3 Fruit firmness (kg cm ^{2})

Fruit firmness reached its lowest values near the conclusion of the storage period, based on data in Table 3 showing a significant decline in fruit firmness over time. The hardness of the figs was significantly higher in all treatments compared to control fruits; in both seasons, the maximum values were found in 0.5 percent nano chitosan. Since the untreated fruits had the lowest firmness value at the conclusion of the 20-day storage period, it should be noted that both of the treatments had an impact on the retention of fruit firmness. The outcomes are in line with the findings of [17], who Said that one of the key elements influencing fruit quality and physiology after harvesting is fruit firmness. According to [18], fruit softening can result from either the hydrolysis of starch or the degradation of insoluble proto-pectins into soluble pectins, or from enhanced membrane permeability brought on by cellular disintegration. Perhaps the most significant stage in the ripening process that results in the loss of cell integrity or firmness is the loss of pectic compounds in the middle lamellae of the cell wall [19] .

Table 1: post-harvest chitosan treatments' affecting weight loss (%) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	Season 1					**Mean**	Season 2					**Mean**
	Storage period (days)						Storage period (days)					
	0	5	10	15	20		0	5	10	15	20	
Control	0.00 j	1.23 f	3.25 c	6.29 b	9.61 a	**4.08A**	0m	5.31h	7.13d	9.14c	14.11a	**7.14A**
0.5% nano chitosan	0.00 j	0.19 ij	0.49 gh	0.73 g	1.57 e	**0.60C**	0m	0.25l	3.51j	5.79g	7.09e	**3.33C**
0.5% chitosan	0.00 j	0.35 hi	0.68 g	1.91 d	1.46 ef	**0.88B**	0m	0.42k	4.79i	6.09f	9.33b	**4.12B**
Mean	0.00E	0.59D	1.47C	2.98B	4.21A		0E	1.99D	5.14C	7.01B	10.17A	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

Table 2:. post-harvest chitosan treatments' affecting decay (score) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	Season 1					**Mean**	Season 2					**Mean**
	Storage period (days)						Storage period (days)					
	0	5	10	15	20		0	5	10	15	20	
Control	1.00c	1.00c	1.00c	3.33b	5.00a	**2.20A**	1.00c	1.00c	1.00c	3.33b	4.67 a	**2.20A**
0.5% nano chitosan	1.00c	1.00c	1.00c	1.00c	1.00c	**1.00C**	1.00c	1.00c	1.00c	1.00c	1.00 c	**1.00B**
0.5% chitosan	1.00c	1.00c	1.00c	1.00c	3.33b	**1.40B**	1.00c	1.00c	1.00c	1.00c	1.00 c	**1.00B**
Mean	1.00C	1.00C	1.00C	1.66B	3.00A		1.00C	1.00C	1.00C	1.78B	2.22A	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

Table 3:. post-harvest chitosan treatments' affecting firmness (kg cm -2) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	Season 1					**Mean**	Season 2					**Mean**
	Storage period (days)						Storage period (days)					
	0	5	10	15	20		0	5	10	15	20	
Control	2.82 a	2.56 d	2.00 g	1.55 l	1.15 m	**2.01C**	2.67 a	2.14d	1.87g	1.45 l	1.00m	**1.82C**
0.5% nano chitosan	2.82 a	2.78 b	2.64 e	2.45 h	2.33 i	**2.60A**	2.67 a	2.56b	2.47e	2.23h	2.18 i	**2.42A**
0.5% chitosan	2.82 a	2.74 c	2.46 f	2.25 j	1.94 k	**2.44B**	2.67 a	2.51c	2.34 f	2.16 j	1.86 k	**2.31B**
Mean	2.82A	2.69B	2.37C	2.08D	1.81E		2.67A	2.40B	2.23C	1.95D	1.68E	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05

Table 4: post-harvest chitosan treatments' affecting general appearance (score) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	**Season 1**					**Mean**	**Season 2**					**Mean**
	Storage period (days)						**Storage period (days)**					
	0	**5**	**10**	**15**	**20**		**0**	**5**	**10**	**15**	**20**	
Control	9.00a	9.00a	7.03b	5.67c	3.00d	**6.74C**	9.00a	7.33b	7.00b	5.337c	3.33d	**6.39C**
0.5%nano chitosan	9.00a	9.00a	9.00a	9.00a	8.33a	**8.87A**	9.00a	9.00a	9.00a	9.00a	8.33a	**8.87A**
0.5% chitosan	9.00a	9.00a	9.00a	8.33a	5.67c	**8.20B**	9.00a	9.00a	9.00a	8.33a	5.00c	**8.07B**
Mean	**9.00A**	**9.00A**	**8.34B**	**7.67C**	**5.67D**		**9.00A**	**8.44B**	**8.33B**	**7.55C**	**5.55D**	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.0

3.4 General appearance (score)

Fig fruit general appearance (GA) decreased significantly with the advancement of the storage time (Table 4). Both tested post-harvest treatments were able to keep a good appearance after the prolonged cold storage. both the treatments scored above the limits of marketability and maintained a good GA after 20 days of storage. Moreover, in both seasons, no significant difference was observed in values among the various treatments along the storage period, however, 0.5% nano chitosan manifested the highest score average of GA, significantly superior to other treatments . Untreated fruits recorded the least significant score of fruit GA in both seasons. The results obtained are consistent with [20] as they reported that chitosan has a high potential for maintaining the quality of fresh fruits and vegetables.

3.5 Fruit color measurement

Lightness L* values decreased throughout the storage period in this study, regardless of post-harvest treatments (Table 5). In terms of treatments, no significant difference in the L* values (both after 20 days of storage and as mean values) was observed between treated and untreated fruits in either season. Chroma values increased over time, regardless of post-harvest treatments (Table 6), and Hue angle **(h°)** values decreased over time, regardless of post-harvest treatments

(Table 7). In terms of treatments, no significant difference in the C* and h* parameters (both after 20 days of storage and as mean values) were observed between treated and untreated fruits in both seasons. [21] reported highly significant colour differences in papaya in terms of L* of control fruits. [22] discovered that fig chitosan-coated, improved lightness and delayed its loss during cold storage. [23] demonstrated that L* values of sliced mangoes treated with 0.5, 1 or 2 h percent chitosan changed in lightness during storage. The results obtained are consistent with [24] they discovered that hue angles decrease as the fruit ripens, and that the peel colour changes from green to yellow as the mango ripens.

3.6 Total soluble solids content (TSS %)

Regardless of treatments, the TSS % showed a consistent rise in line with the lengthening of the storage duration (Table 8). Out of all the treatments, untreated fruits had the highest TSS mean % in both seasons, The hydrolysis of cell wall polysaccharides [25], the conversion of starch to sugar [26], the reduction in respiration rate and sugar conversion to CO_2 and H_2O, and the increase in dry matter due to water loss [27] could all be contributing factors to this increase. The treatment containing 0.5% nano chitosan yielded the lowest mean percentage, however. chitosan has no influence on the TSS of mango fruits, according to [28] findings. Strawberry showed a similar response [29]. [30] discovered that fig fruits deteriorated during storage under the four treatments TSS levels and TSS/TA ratios increased during cold storage in coated and control fruits.

3.6 Titratable acidity (TA) %

Data shows that the TA percentage decreased as the storage period was extended (Table 9). In terms of treatments, the highest levels of acidity were obtained in both seasons in chitosan treatment which is in line with the results of [30], they found a decrease in the level of TA. The reported results are consistent with those obtained by [31] for guava [32], and [33] for peach. Uncoated fruits may lose more acidity since the respiratory metabolism uses organic acids as substrates [34].

Table 5: post-harvest chitosan treatments' affecting Lightness (L*) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	Season 1					Mean	Season 2					Mean
	Storage period (days)						Storage period (days)					
	0	5	10	15	20		0	5	10	15	20	
Control	42.45 a	39.22 d	35.55 h	30.12 l	22.04 m	**33.87 C**	40.4a	37.25b c	32.74e	29.33 f	21.92 g	**32.33 C**
0.5%nanochitosan	42.45 a	41.37 b	38.35 e	36.76 g	33.86 j	**38.56 A**	40.4a	39.37a b	38.33a bc	36.27c d	34.45 de	**37.77 A**
0.5%chitosan	42.45 a	40.32 c	37.70 f	34.15 i	30.64 k	**37.052 B**	40.4a	38.73a bc	38.73a bc	36.62b cd	32.06 e	**37.31 B**
Mean	42.45 A	40.30 B	37.20 C	33.67 D	28.84 E		40.41 A	38.45B	36.60C	34.07D	29.48 E	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

Table 6: post-harvest chitosan treatments' affecting color change Chroma (C*) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	Season 1					Mean	Season 2					Mean
	Storage period (days)						Storage period (days)					
	0	5	10	15	20		0	5	10	15	20	
Control	14.12 i	15.39 h	20.54 f	25.31 c	32.20 a	**21.52467 A**	14.18 i	15.36 h	20.52 f	25.31 c	32.21 a	**21.51 A**
0.5% nano chitosan	14.02 i	13.93 i	17.49 g	20.77 f	22.70 e	**17.78333 C**	14.03 i	13.91 i	17.55 g	20.76 f	22.68 e	**17.78 C**
0.5% chitosan	13.92 i	14.08 i	17.79 g	23.56 d	27.38 b	**19.34867 B**	13.93 i	14.16 i	17.83 g	23.58 d	27.43 b	**19.39 B**
Mean	14.04 E	14.47 D	18.61 C	23.21 B	27.43 A		14.05 E	14.48 D	18.63 C	23.22 B	27.44 A	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

3.7 Total phenols content (%)

It is worth noting that the total phenolic content decreased as the duration of storage progressed (Table 10). This was observed in both of the studied seasons, regardless of treatment. In terms of tested treatments, untreated fruits had the lowest total phenolic content in both seasons, followed by 0.5 percent chitosan, and the treatment with 0.5 percent nano chitosan had the highest total phenolic content with significant differences among them. These findings are consistent with those of [22], They looked at the use of chitosan coating to enhance the antioxidant system and preserve qualitative traits in fresh figs (Ficus carica L).

3.8 Total flavonoid content (%):

It is worth noting that the total flavonoid content decreased as the storage period progressed (Table 11). This was observed in both of the studied seasons, regardless of treatments. In terms of tested treatments, untreated fruits had the decreased total flavonoid content in both seasons, followed by 0.5 % chitosan, and the treatment with 0.5 % nano chitosan had the highest total flavonoid content.

These findings are consistent with those of [22], they investigated chitosan coating helps protect fresh figs' quality and strengthen their antioxidant defenses (Ficus carica L).

3.9 Total ascorbic acid content (%):

In Table (12), data demonstrated that ascorbic acid content significantly decreased over time, regardless of the treatments applied. However, when compared to untreated fruits (the control), both chitosan treatments recorded the highest significant score. This was consistent with [22] finding that chitosan coating delay the ascorbic acid content decrease in fresh fig fruits during cold storage. Whereas the chitosan coating delay the ascorbic acid content decline, the ascorbic acid content of the uncoated fruit declined throughout cold storage. This pattern was found in a study by [35], who postulated that the low oxygen permeability of the chitosan coating, which decreased enzyme activity and prevented ascorbic acid oxidation, was the cause of the reduced ascorbic acid loss in coated sweet cherries [36].

Table7: post-harvest chitosan treatments' affecting color change Hue angle ((ho) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	**Season 1**					**Mean**	**Season 2**					**Mean**
	Storage period (days)						**Storage period (days)**					
	0	**5**	**10**	**15**	**20**		**0**	**5**	**10**	**15**	**20**	
Control	72.46a	69.33d	67.96f	60.46j	55.71l	**65.18C**	71.46a	69.3e	67.94h	60.44l	55.72n	**64.97C**
0.5%nano chitosan	72.46a	70.78b	68.94e	67.54g	65.72h	**69.09A**	71.43b	70.75c	68.92f	67.50667i	65.73j	**68.87A**
0.5% chitosan	72.46a	69.87c	67.96f	62.70i	59.75k	**66.55B**	71.43b	69.85d	67.95g	62.72k	59.72m	**66.33B**
Mean	**72.46A**	**69.99B**	**68.28C**	**63.56D**	**60.39E**		**71.44A**	**69.97B**	**68.27C**	**63.56D**	**60.39E**	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

Table 8: post-harvest chitosan treatments' affecting TSS (%) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	**Season 1**					**Mean**	**Season 2**					**Mean**
	Storage period (days)						**Storage period (days)**					
	0	**5**	**10**	**15**	**20**		**0**	**5**	**10**	**15**	**20**	
Control	11.67^{j}	13.34^{de}	13.59^{d}	16.00^{c}	19.00^{a}	**14.718^{A}**	10.87^{d}	12.00^{cd}	14.37^{abc}	15.27^{ab}	15.49^{a}	**13.60^{A}**
0.5%nano chitosan	11.667^{j}	12.16^{i}	12.23^{hi}	12.52^{fgi}	12.76^{fg}	**12.27^{C}**	10.87^{d}	10.94^{d}	11.00^{d}	11.13^{d}	11.24^{d}	**11.03^{C}**
0.5% chitosan	11.67^{j}	12.67^{fg}	12.84^{fg}	13.12^{ef}	16.87^{b}	**13.44^{B}**	10.87^{d}	11.24^{d}	11.79^{cd}	12.19^{cd}	12.67^{bcd}	**11.75^{B}**
Mean	**11.67D**	**12.72C**	**12.88C**	**13.88B**	**16.21A**		**10.87E**	**11.39D**	**12.39C**	**12.86B**	**13.13A**	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

Table 9: post-harvest chitosan treatments' affecting total acidity (%) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	**Season 1**					**Mean**	**Season 2**					**Mean**
	Storage period (days)						**Storage period (days)**					
	0	**5**	**10**	**15**	**20**		**0**	**5**	**10**	**15**	**20**	
Control	0.72 a	0.55 e	0.37i	0.23 k	0.12 l	**0.40C**	0.64a	0.45e	0.32 i	0.21k	0.10 l	**0.34C**
0.5%nano chitosan	0.72 a	0.66 b	0.58 c	0.50 f	0.39 h	**0.57A**	0.64a	0.58b	0.54c	0.43 f	0.36h	**0.51A**
0.5% chitosan	0.72 a	0.65 b	0.57 d	0.45 g	0.32 j	**0.54B**	0.64a	0.58b	0.52d	0.40g	0.31 j	**0.49B**
Mean	**0.72A**	**0.62B**	**0.51C**	**0.39D**	**0.28E**		**0.64A**	**0.54B**	**0.46C**	**0.35D**	**0.26E**	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

Table 10:. post-harvest chitosan treatments' affecting total phenols (mg gallic acid GAE/100g FW) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	Season 1					**Mean**	Season 2					**Mean**
	Storage period (days)						Storage period (days)					
	0	5	10	15	20		0	5	10	15	20	
Control	56.13a	48.12g	42.72j	39.73l	35.42m	**44.42C**	95.43a	85.73h	83.19i	75.67k	70.63m	**82.13C**
0.5%nano chitosan	56.13a	54.07b	53.82c	51.51e	45.27i	**52.16A**	95.43a	94.51b	93.36c	92.47e	91.73f	**93.49A**
0.5% chitosan	56.13a	52.73d	49.37f	46.77h	40.49k	**49.09B**	95.43a	92.73d	90.47g	82.47j	74.63l	**87.14B**
Mean	**56.13A**	**51.64B**	**48.63C**	**45.99D**	**40.39E**		**95.43A**	**90.99B**	**89.00C**	**83.53D**	**78.99E**	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

Table 11: post-harvest chitosan treatments' affecting flavonoid (mg quercetin QE/100g FW) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	Season 1					Mean	Season 2					Mean
	Storage period (days)						Storage period (days)					
	0	5	10	15	20		0	5	10	15	20	
Control	56.13a	48.12g	42.72j	39.73l	35.42m	**44.42C**	52.73a	42.19g	39.93j	35.13l	33.39m	**40.67C**
0.5%nano chitosan	56.13a	54.07b	53.82c	51.51e	45.27i	**52.16A**	52.73a	49.47b	48.13c	45.57e	40.92h	**47.37A**
0.5% chitosan	56.12a	52.72d	49.36f	46.74h	40.48k	**49.09067B**	52.73a	47.37d	44.93f	40.14i	38.37k	**44.70B**
Mean	**56.13A**	**51.64B**	**48.63C**	**45.99D**	**40.39E**		**52.73A**	**46.34B**	**44.33C**	**40.28D**	**37.56E**	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

Table 12:. Post-harvest chitosan treatments' affecting total ascorbic acid (mg /100g FW) of fig fruits during cold storage in 2021 and 2022 seasons.

Treat.	Season 1					Mean	Season 2					Mean
	Storage period (days)						Storage period (days)					
	0	5	10	15	20		0	5	10	15	20	
Control	17.39a	16.33f	14.00h	11.69k	9.33m	**13.75C**	19.52a	17.14e	14.82h	11.93k	9.62m	**14.61C**
0.5%nano chitosan	17.39a	17.15b	16.93c	16.47e	13.64j	**16.31A**	19.52a	19.24b	17.34d	15.89g	13.37i	**17.07A**
0.5% chitosan	17.39a	16.72d	15.12g	13.83i	11.37l	**14.88B**	19.52a	18.57c	16.36f	13.13j	11.34l	**15.78B**
Mean	**17.39A**	**16.73B**	**15.35C**	**13.99D**	**11.44E**		**19.52A**	**18.31B**	**16.17C**	**13.65D**	**11.44E**	

Note: Small letters denote values reordered in each season, while different capital letters denote mean values. ANOVA results with significantly different values are indicated by various letters, and the Duncan test is performed at P≤0.05.

4. Conclusions

In conclusion, this study highlights the potential of nano-chitosan as an effective post-harvest treatment to prolong the storability and maintain quality attributes of Ficus carica L. figs. The use of 0.5% nano-chitosan was particularly effective in maintaining fruit firmness, reducing decay incidence , and extending storage period compared to untreated fruits. Furthermore, treated figs exhibited higher levels of total phenolics, flavonoids, and ascorbic acid, along with improved control overweight loss and decay. These findings suggest that incorporating nano-chitosan into post-harvest protocols could play a crucial role in maintaining the nutritional and commercial quality of figs, contributing to reduced post-harvest losses and improved marketability. Future studies could explore the scalability of this approach and its applicability to other fruit types.

5. Conflicts of interest

The authors declare that there is no conflict of interests.

6. Formatting of funding sources

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