Journal of
Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2023-s1-075

Research Article

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Enhancing Shelf Life of Winter Guava "Allahabad Safeda" Fruits using Nanoemulsion Coatings

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Received: September 15, 2023
Accepted: November 10, 2023
Published: November 15, 2023

Citation: Kumar A, Thakur V, Singh J. 2023. Enhancing Shelf Life of Winter Guava "Allahabad Safeda" Fruits using Nanoemulsion Coatings. *J Food Chem Nanotechnol* 9(S1): S594-S601.

Published by United Scientific Group

Abstract

Guava fruit is a crop which has a high rate of post decay rate due to short shelf-life at ambient conditions. To reduce decay-rate over the span of few days guava fruits "Allahabad safeda" were coated with different nanoemulsion coatings as nano-silicon dioxide, nano-chitosan, and nano-sodium alginate at different concentrations and were studied. Different aspects such as fruit weight (FW), total soluble solids (TSS), titratable acidity (TA), ascorbic acid (AA), total antioxidant activity (TAA), fruit firmness (FF), total sugar (TS), reducing sugars (RS) and non-reducing sugars (NRS) were also examined. Coating was formulated with Nanoemulsion technology using tween 20 as surfactant. Among various concentrations T_4 (Nano chitosan 2% + nano silicon dioxide 2%) was the best treatment in terms of enhancing shelf-life, maintaining nutritional qualities, and reducing decay rate. This current novel technology demonstrates that results can be used to research more for employing nanotechnology on a commercial level and expansion in coating industry.

Keywords

Nanoemulsion, Shelf-life, Silicon-dioxide, Chitosan

Introduction

Genus Psidium comes under the family Myrtaceae consists of 152 species of small trees and shrubs. About 20 species have edible fruit. Among these, the most popularly cultivated is guava (*Psidium guajava* L.) was introduced in India in the 17th century by Portuguese from Latin America. Guava (*P. guajava* L.) is most popular subtropical and tropical climacteric fruit crops grown in India sowing to its several health-promoting properties and value-addition paths [1]. Its other name is poor man's apple because the fruits are delicious, rich in vitamin 'C', pectin, and minerals like calcium, this process can be achieved through using different postharvest chemical treatments. With an output of 4.92 million metric tons India is currently the top producer, followed by China and Thailand [2]. Guava is grown throughout the entire nation, from sea level to 1300 m in altitude. It is thought that it started in India because of the wide genetic diversity of the indo-gangetic plains.

Following citrus, guava is Punjab's second-most significant fruit crop; it has a production area of 9580 acres. It thrives practically everywhere in the state, with Patiala, Ludhiana, Sangrur, and Fatehgarh Sahib having the highest areas [3]. Owing to its physiology, disorder, postharvest infection, and ageing, the fruit has a very limited shelf life at tropical temperature range (28 - 30 °C). Multiple variables, including storage temperatures, relative humidity, packaging components, and coating types, may have an impact on the stability of guava [4]. Guava fruit growers keep their products in conventional packaging made of paper or plastic. Despite having certain advantages, such packaging might have a significant negative impact on the environment because they are made of non-recyclable and non-edible resources [5]. Post-harvest application of bio-chemicals improves shelf life and keeping quality by reducing the rate of respiration, protein breakdown, disease incidence, and ability to strengthen bonds between the polysaccharides of the cell wall, also reduces physiological weight loss, inhibits the production and action of ethylene through delay the ripening [6].

The fruit's surface is coated with edible coatings, which are made up of imperceptibly thin membranes. As they improve the protective function of the fruit epidermis in avoiding water loss, color changes, mechanical lesions, and even microbiological degradation, and usually offer surface glossy look, they can contain naturally additives and are significant in increasing the shelf life of foods [7]. Edible coatings are a great substitute for chemical preservatives since they have lower production costs and a longer shelf life when used in conjunction with refrigeration.

A Nanoemulsion is a heterogeneous system made up of at least two incompatible liquids, one of which is distributed into the other in tiny droplets with a size between 10 and 1000 nm [8]. An aqueous phase, an oil phase, and an emulsifier are the common components of a nanoemulsion. In addition to other polar substances like co-solvents (simple alcohols and polyols), carbohydrates, proteins, minerals, acids, and bases, the aqueous phase is primarily produced with water [9]. Many nonpolar ingredients, including triacylglycerols, diacylglycerols, monoacylglycerols, free fatty acids, essential oils, mineral oils, fat replacements, waxes, weighing agents, vitamins, and lipophilic chemicals, can be used to formulate the oil phase [10].

Sand contains silicon, which is naturally present in quartz. Silicon dioxide is highly stable, has a high level of food safety, and cannot be absorbed by the digestive system. This substance has a food additive and has received approval [11]. The chemical compound silica, also referred to as silicon dioxide (SiO_2), is present in nature in the forms of quartz, crystal, vapor-silica, colloidal silica, silica gels, and aerogels [12]. Nano/SiO_2 films are widely used in a variety of industries, including the antireflection coating and packaging sector to block the permeation of gases, preventing the quick rot of fruits, vegetables, and beverages, inhibiting volatile compounds, and maintaining the physiological and sensory qualities [13]. Because of their homogenous emulsion particle size distributions, anti-wear, low water absorption, chemical inertness, biocompatibility, and friction-reducing qualities, nano/SiO_2 films are regarded as having high environmental efficiency [12]. Nano/SiO_2 has been given a safety rating even though humans cannot digest it.

Chitosan is renowned for its capacity to create films and for being antibacterial, antioxidant, non-toxic, and biodegradable. These characteristics enable their widespread application in the creation of edible coatings, edible films, and nanoemulsions. The polysaccharide sodium alginate has strong colloidal characteristics and a strong reactivity to polyvalent metal cations, which causes gels or insoluble polymers to develop [14]. It has been widely utilized as an edible coating for preserving fruits and vegetables, such as apples, peaches, mushrooms, and broccoli, due to its ability to create a semi-permeable barrier when coated to products [15]. Silicon- dioxide and sodium alginate were used in this experiment with the intent to examine the combined effects of coating material on guava fruits.

Materials and Methods

The healthy uniform trees of guava cv. Allahabad safeda tagged at fruit research farm, Department of Fruit Science, Lovely Professional University. Mature fruits of uniform size and free from scars and spots were harvested from tagged trees and collected in cushioned plastic crates and sent to the P.G. Laboratory of the department. Fruits were sorted, graded, and then washed with running tap water. Then fruits were washed with chlorine (100 ppm) by dipping for 5 min in solution.

Preparation of Nanoemulsion coatings

Emulsions were prepared by separately dissolving carboxymethyl cellulose, sodium alginate and essential oil in ultrapure water (Milli-Q water purification system) at 70 °C with continuous stirring with a magnetic stirrer at 500 rpm for 2 h. Samples from each course were taken for characterization and named as nano silicon and for surfactant use tween 20 (2 g/100 ml) and or essential oil was then dissolved in each emulsion. The mixture was homogenized at 8450 rpm for several min using. To reduce droplet size, the resultant mixture was ultrasonicated (50 W) at a frequency of 40 kHz using a sonicator probe mm in diameter. The heat obtained during the emulsification process was removed by placing the emulsion container in ice.

Application of coating

In the laboratory, the guava fruits were treated with different concentrations of nano silicon dioxide coating on the quality of winter guava (1% nano chitosan + 1% nano silicon dioxide), (1.5% nano chitosan + 1.5% nano silicon dioxide, 2% nano chitosan + 2 % nano silicon dioxide), (1% SA (sodium alginate+ 1% nano silicon dioxide), (1.5% SA + 1.5% nano silicon dioxide), (2% SA + 2 % nano silicon dioxide) and control (no treatment) at room temperature for 3 min. The coatings were dried at room temperature (20 ± 1.0 °C). Fruits were evaluated for various physiological and biochemical parameters at an interval of 3 days at room temperature respectively. The quality attributes such as FF, soluble solids concentrate, TA, AA content, antioxidants and of these fruits were estimated in the laboratory.

In this experiment, the effect of various nano coatings on various physical, physiological, and biochemical characteristics of guava Allahabad safeda variety stored at room temperature.

Characterization of nanoemulsion

Droplet size and ζ-potential of the coating forming Nanoemulsion

Droplet size and ζ-potential analyzer (Litesizer 500, Anton Paar, Graz Austria) were used for measurement of droplet size and ζ-potential value of coating forming emulsions. Emulsions were diluted with ultrapure water to avoid multiple scattering effects. The measurements of average droplet diameter and ζ-potential were done in triplicates.

Weight loss

For the estimation of weight loss in 'Allahabad safeda' guavas, the fruits were weighed at regular intervals as mentioned in the experiments using an electronic balance during the intervals of storage.

TSS

The digital refractometer (ATAGO, Japan) was used to quantify TSS from juice of guava fruits. Observations were recorded in percentage after making temperature correction by using standard chart.

TA

To determine the TA, fresh fruit pulp (5.0 g) was macerated using distilled water and volume was made to 50 ml with distilled water. The aliquot was titrated against NaOH (0.1 N) using phenolphthalein as an indicator [16].

The observed titer value was used for calculating the values as percent anhydrous citric acid by using the following formula.

$$\%\ \text{of Total Acid} = \frac{0.0064 \times \text{Volume of N/10 NaOH used (ml)} \times 100}{\text{Volume of the sample taken}}$$

Decay loss (%)

The total number of guavas fruits each replication was counted, and the loss (stated as a percentage) was computed using the formula below.

$$\text{Decay loss (\%)} = \frac{\text{Number of rotten fruits} \times 100}{\text{Number of total initial fruits}}$$

FF

FF was recorded by using "penetrometer" (Model FT-327, QA supplies, Norfolk, VA, USA). The device has a probe (8 mm diameter) made of stainless steel which was used to penetrate peeled guava flesh and the force used was recorded as pound-force (lbf).

AA

The AA content in fruits was determined using the protocol given by Gill et al. [16] with minor changes. Accordingly, fresh fruit pulp (5.0 g) was macerated and added to 95 ml of 0.4% oxalic acid. 10 ml aliquot was taken from this prepared solution and titrated against 0.4% DPCIP dye till the appearance of the end point (pink color). The results were expressed in mg 100 g^{-1} pulp.

$$AA = \frac{\text{Titre value} \times \text{dye factor} \times \text{volume made} \times 100}{\text{Volume of filtrate taken} \times \text{weight of sample}}$$

TAA

TAA in the guavas was determined by using CUPRAC (cupric reducing antioxidant capacity) method [17]. The molar absorptivity of the CUPRAC method for each antioxidant was determined from the slope of the calibration line concerned and was expressed as μmol trolox g^{-1} FW.

TS

TS are quantified from juice through procedure standardized by Apak et al. [17]. Sugars are expressed in percent and measured by formula given under

$$TS\ (\%) = \frac{\text{Fehling's solution Factor} \times \text{Dilution made} \times 100 \times 100}{\text{Titre volume} \times \text{Weight of sample taken} \times 50}$$

RS

To quantify reducing sugar standard procedure recommended by Apak et al. [17] is used and calculated using this equation:

$$RS\ (\%) = \frac{\text{Dilution use} \times .05 \times \text{factor Fehling} \times 100}{\text{Volume of filter at use} \times \text{Weight of sample taken}}$$

NRS

The amount of NRS was calculated by subtracting RS from TS and multiplying the difference by factor 0.95 as suggested by Apak et al. [17] and expressed as percentage age.

Statistical analysis

The data collected for various parameters were used to calculate the mean value for each character and the mean replicated data were used for statistical analysis. The data were statistically analyzed in CRD for calculating CD using software "statistical package for agriculture scientists', OPSTAT.

Results and Discussion

Characterization of course and nanoemulsion

Droplet size and ζ-potential of course and nanocoating's. The average droplet size of the coarse emulsions was 1200, 1000 and 1100 nm for chitosan, alginate, and silicon dioxide, respectively. While droplet size of the nano coatings ranged between 220 and 335 nm, respectively. Droplet disruption caused by the ultrasonication process may explain why Nanoemulsion have lower drop sizes than their corresponding coarse coating. Nonetheless, nanoemulsion demonstrated increased negative -potential levels than coarse emulsions (Table 1). Both coarse and nano coatings had negative potential levels.

FW (mg)

It is apparent from table 2 data that the coating maintained significant weight (120.10, 119.27, 117.67, 114.97, 112.08) was recorded with the application of T_4 (Nano chitosan 2% + nano silicon dioxide 2%) on the 3rd, 6th, 9th, and 12th day of storage and C.D. values were at par with T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) (122.17, 121.16, 119.36, 116.80, 113.37). Whereas, T_1 (Control) had the least significantly (123.77, 121.86, 119.16, 115.61, 111.38), respectively. All treatments progressively lost weight as a result of respiration and moisture evaporation. Guava FW loss results from excessive respiration and transpiration owing to its climacteric character. This result was supported by Sami et al. [12] in cantaloupe and Avestan et al. [18] strawberry fruits.

Table 1: Characterization of coarse nano coatings in terms of droplet size (nm) and ζ-potential (mV).

	Formulations	Droplet size (nm)	ζ-potential (mV)
CE	CH	1200 ± 500	-10 ± 4
	SA	1000 ± 300	-14 ± 4
	$S0_2$	1100 ± 200	-16 ± 6
NE	T_2	310 ± 20	-19 ± 6
	T_3	290 ± 20	-21 ± 4
	T_4	230 ± 20	-23 ± 7
	T_5	350 ± 30	-22 ± 4
	T_6	330 ± 30	-20 ± 5
	T_7	210 ± 30	-24 ± 8

Note: Results are expressed as means ± standard deviation.

Table 2: Effect of post-harvest treatment on FW (mg) of guava cv. Allahabad Safeda during storage.

Treatments	FW (mg)				
	Storage period (day)				
	0th day	3th day	6th day	9th day	12th day
T_1 (Control)	123.77	121.9	119.16	115.61	111.38
T_2 (Nano chitosan 1% + nano silicon dioxide 1%)	121.3	119.6	117.07	113.47	109.68
T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%)	122.77	122.4	119.16	116.2	112.38
T_4 (Nano chitosan 2% + nano silicon dioxide 2%)	120.1	119.3	117.67	114.97	112.08
T_5 (Nano sodium alginate 1% + nano silicon dioxide 1%)	120.3	118.5	115.87	112.17	108.29
T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%)	123.77	122	120.16	116.87	113.37
T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%)	122.17	121.2	119.36	116.8	113.37
C.D.	1.206	1.165	1.135	1.109	1.079
SE(m)	0.387	0.374	0.364	0.356	0.346

FF

The differences in firmness ($kgcm^{-2}$) were also observed significant due to different calcium and coating on 3rd, 6th, 9th, and 12th day of storage which are presented in table 3. The maximum firmness C.D. value (3.18, 2.60, 2.32, 2.03 and 1.54 $kgcm^{-2}$) was recorded with application of T_4 (Nano chitosan 2% + nano silicon dioxide 2%) on 3rd, 6th, 9th, and 12th day of storage, respectively. The firmness (2.05 and 1.96 $kgcm^{-2}$) was registered minimum of treatment of T_1 (Control) on 9th and 12th day of storage, respectively. This might be due to coating, edible coatings preserve the quality of fruits, retard ethylene emission and enhance texture. The firmness of the fruit is among of the most important aspects that determine the nutritional value of horticulture crops after harvesting. Enzymes that play a role in pectin and certain polysaccharides, including cellulose depolymerization, are the primary factors that determine the firmness of fruit. Reduced firmness in the control fruit is possibly attributable to fruit becoming softer, that is closely related with the quantity of ethylene generated during ambient storage circumstances. These results corroborate the findings of dos Santos et al. [19] in tomato and Kassem et al. [20] in 'Tommy Atkins' mango fruits.

Fruit decay (%)

With respect to data on coating indicated in table 4, it was clear that minimum spoilage percentage (0%) was found in C.D. values of T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%), T_4 (Nano chitosan 2% + nano silicon dioxide 2%), T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%), T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%). In T_1 (Control) found maximum spoilage percentage (4.53, 6.95 and 13.40%) on 6th, 9th, and 12th day of storage, respectively. The lowest spoilage fruits in the coating might be due to reduction of metabolic reaction by decreasing of respiration rates and thus delay the senescence of fruits. Coating slowed down the respiration rate, reduced the color change of flesh and skin reported by Kingwascharapong et al. [21] in persimmon. Eating coatings may postpone deterioration by prolonging weight loss, delaying senescence, and suppressing microorganism development. Similar results were also depicted by Hu et al. [22] in sweet cherry fruits.

Table 3: Effect of post-harvest treatment on FF ($kgcm^{-2}$) of guava cv. Allahabad Safeda during storage.

Treatments	FF ($kgcm^{-2}$)				
	Storage period (day)				
	0th day	3th day	6th day	9th day	12th day
T_1 (Control)	3.07	2.51	2.24	2.05	1.96
T_2 (Nano chitosan 1% + nano silicon dioxide 1%)	3.29	2.69	2.4	2.1	2.1
T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%)	3.18	2.6	2.32	2.03	1.89
T_4 (Nano chitosan 2% + nano silicon dioxide 2%)	3.18	2.6	2.32	2.03	1.54
T_5 (Nano sodium alginate 1% + nano silicon dioxide 1%)	3.15	2.57	2.29	2.05	2
T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%)	3.33	2.72	2.42	2.17	2.12
T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%)	3.48	2.84	2.53	2.21	1.98
C.D.	0.03	0.029	0.025	0.021	0.018
SE(m)	0.01	0.009	0.008	0.007	0.006

Table 4: Effect of post-harvest treatment on FD (%) of guava cv. Allahabad Safeda during storage.

Treatments	FD rate %				
	Storage period (day)				
	0th day	3th day	6th day	9th day	12th day
T_1 (Control)	0	0	4.53	6.95	13.4
T_2 (Nano chitosan 1% + nano silicon dioxide 1%)	0	0	0	0	2.23
T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%)	0	0	0	0	0
T_4 (Nano chitosan 2% + nano silicon dioxide 2%)	0	0	0	0	0
T_5 (Nano sodium alginate 1% + nano silicon dioxide 1%)	0	0	0	0	2.5
T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%)	0	0	0	0	0
T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%)	0	0	0	0	0
C.D.	0	0	0.104	0.143	0.263
SE(m)	0	0	0.033	0.046	0.084

Overall acceptability

Data pertaining to the effect of post-harvest treatment on overall acceptability of guava fruits during the storage period is presented in table 5. The result shows that maximum organoleptic value for overall acceptability of fruits (8.25 to 5.71 out of 9) was recorded under treatment T_4 (Nano chitosan 2% + nano silicon dioxide 2%) on initial day to 12th day of storage period and C.D. values followed by treatment T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) (8.42 to 5.54 out of 9) and treatment T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%) (8.18 to 5.35 out of 9). The minimum organoleptic value for overall acceptability of fruits (8.22 to 4.46 out of 9) was recorded under treatment T_1 (control) on initial day to 12th day of storage period.

TSS (°Brix)

TSS of fruits as influenced by the different treatment was found significant. Data are tabulated in table 6. The result for effect of coating on TSS was also found significant. The TSS (8.82, 9.60, 10.88, 10.57, 10.23 °Brix) was noted maximum with the application of T_4 (Nano chitosan 2% + nano silicon dioxide 2%), also C.D. values of T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) (8.57, 9.40, 10.60, 10.29, 9.96 °Brix), T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%) (8.70, 9.58, 10.68, 10.37, 10.04 °Brix) were on par with T_4 (Nano chitosan 2% + nano silicon dioxide 2%) on 0, 3rd, 6th, 9th, and 12th of storage, respectively. Similarly, the minimum TSS (8.39, 9.03, 10.19, 9.88, 9.58 °Brix) was also noted with T_1 (control) on 0, 3rd, 6th, 9th, and 12th day of storage. Findings of Sharanaiahswamy et al. [23] that the physico-chemical parameters increase up to 8 days in guava fruits under storage. The increase in TSS up to 8 days may be attributed to the hydrolysis of acid and deposition of polysaccharides during storage. The increase in TSS due to coating was reported by Basumatary et al. [24] in pineapple fruits.

TA (%)

The data pertaining to the acidity was significantly affected by chemicals and coating on 0, 3rd, 6th, 9th, and 12th day of storage. Data are presented in table 7. The maximum acidity (0.70, 0.58, 0.58, 0.45 and 0.36%) was recorded with T_4 (Nano chitosan 2% + nano silicon dioxide 2%) on 0, 3rd, 6th, 9th, and 12th day of storage. T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%) (0.70, 0.64, 0.60, 0.51, 0.38%) and T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) (0.70, 0.64, 0.60, 0.51, 0.38%) C.D. values were on par with T_4 (Nano chitosan 2% + nano silicon dioxide 2%). On the other hand, the minimum acidity (0.64, 0.58, 0.58, 0.45, 0.38%) was observed in T_1 (Control) on 0, 3rd, 6th, 9th, and 12th day of storage, respectively. This might be due to lesser availability of oxygen of fruits in the later stage of storage. It appears that an organic acid which participates in respiratory process is not oxidized and therefore their levels is remains high by Zhang et al. [25] in canino apricot fruits. Similar results were also obtained by Eldib et al. [26] in blueberry fruits and Sami et al. [12] in cantaloupe.

TAA

With regards to TAA of guava fruit influenced by coating was also found significant on, 0, 3rd, 6th, 9th, and 12th days of storage. The data are conferred in table 8. An appraisal of data in table 8 indicated that coating exerted their significant effect on TAA. The loss of antioxidant content during storage period was more rapid and faster in control. However, the antioxidant content of guava fruits was significantly affected by various post-harvest treatments during the storage interval i.e., 0, 3rd, 6th, 9th, and 12th days respectively. The result indicates that the highest antioxidant content (41.31, 40.42, 38.44, 37.65 and 35.08) was found in treatment T_4 (Nano chitosan 2% + nano silicon dioxide 2%), respectively C.D. values followed by treatment T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%) (42.64, 40.79, 38.84, 38.09, 35.77) and treatment T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) (41.41, 39.85, 37.75, 36.86, 34.58).

However, the lowest antioxidant content (42.44, 35.87, 35.44, 33.36 and 31.12) was observed in treatment T_1 (control) on 3rd, 6th, 9th, and 12th days of storage, respectively. Fruits' antioxidant content must be preserved all over storage in order to sustain the other qualities necessary for quality. By increasing the potential for reactive oxygen species, the chitosan coating boosts the antioxidant content of different fruits. Fur-

Table 5: Effect of post-harvest treatment on OA of guava cv. Allahabad Safeda during storage.

Treatments	OA				
	Storage period (day)				
	0th day	3th day	6th day	9th day	12th day
T_1 (Control)	8.22	8.12	7.33	6.04	4.46
T_2 (Nano chitosan 1% + nano silicon dioxide 1%)	8.45	8.15	7.06	6.53	5.48
T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%)	8.18	7.99	7	5.51	5.35
T_4 (Nano chitosan 2% + nano silicon dioxide 2%)	8.25	8.15	7.36	6.17	5.71
T_5 (Nano sodium alginate 1% + nano silicon dioxide 1%)	8.61	8.32	7.23	5.35	5.51
T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%)	8.22	8.02	7.03	5.64	5.41
T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%)	8.42	8.22	7.13	5.35	5.54
C.D.	0.082	0.078	0.069	0.057	0.052
SE(m)	0.026	0.025	0.022	0.018	0.017

Table 6: Effect of post-harvest treatment on TSS (°Brix) of guava cv. Allahabad Safeda during storage.

Treatments	TSS (°Brix)				
	Storage period (day)				
	0th day	3th day	6th day	9th day	12th day
T_1 (Control)	8.39	9.03	10.19	9.88	9.58
T_2 (Nano chitosan 1% + nano silicon dioxide 1%)	8.53	9.49	10.52	10.28	9.95
T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%)	8.7	9.58	10.68	10.37	10.04
T_4 (Nano chitosan 2% + nano silicon dioxide 2%)	8.82	9.6	10.88	10.57	10.23
T_5 (Nano sodium alginate 1% + nano silicon dioxide 1%)	8.57	9.22	10.5	10.15	9.83
T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%)	8.53	9.35	10.57	10.21	9.88
T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%)	8.57	9.4	10.6	10.29	9.96
C.D.	0.087	0.094	0.099	0.096	0.094
SE(m)	0.028	0.03	0.032	0.031	0.03

Table 7: Effect of post-harvest treatment on TA (%) of guava cv. Allahabad Safeda during storage.

Treatments	TA (%)				
	Storage period (day)				
	0th day	3th day	6th day	9th day	12th day
T_1 (Control)	0.64	0.58	0.58	0.45	0.38
T_2 (Nano chitosan 1% + nano silicon dioxide 1%)	0.58	0.51	0.51	0.38	0.3
T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%)	0.7	0.64	0.6	0.51	0.38
T_4 (Nano chitosan 2% + nano silicon dioxide 2%)	0.7	0.58	0.58	0.45	0.36
T_5 (Nano sodium alginate 1% + nano silicon dioxide 1%)	0.66	0.58	0.58	0.45	0.38
T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%)	0.64	0.58	0.51	0.38	0.34
T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%)	0.7	0.64	0.6	0.51	0.38
C.D.	0.058	0.021	0.024	0.055	0.049
SE(m)	0.019	0	0.008	0.018	0.016

Table 8: Effect of post-harvest treatment on TAA of guava cv. Allahabad Safeda during storage.

Treatments	TAA				
	Storage period (day)				
	0th day	3th day	6th day	9th day	12th day
T_1 (Control)	42.44	35.87	35.44	33.36	31.12
T_2 (Nano chitosan 1% + nano silicon dioxide 1%)	40.22	39.67	38.18	37.25	33.76
T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%)	42.64	40.79	38.84	38.09	35.77
T_4 (Nano chitosan 2% + nano silicon dioxide 2%)	41.31	40.42	38.44	37.65	35.08
T_5 (Nano sodium alginate 1% + nano silicon dioxide 1%)	42.4	39.01	37.03	36.46	33.14
T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%)	42.4	39.53	37.72	37	33.36
T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%)	41.41	39.85	37.75	36.86	34.58
C.D.	0.401	0.38	0.362	0.351	0.322
SE(m)	0.129	0.122	0.116	0.113	0.103

thermore, by eliminating oxygen-free radicals and reducing respiration during storage, covering fruits may help maintain their antioxidant capacity. The present findings are in conformity with Kassem et al. [20] in 'Tommy Atkins' Mango fruits and Sayed et al. [27] in blueberry fruits.

AA (mg/100 g)

Regarding the AA content of guava fruit as influenced by coating was also found significant on, 0, 3rd, 6th, 9th, and 12th days of storage. An appraisal of data in table 9 indicated that coating exerted a significant effect on AA content. Significantly, maximum AA content (219.33, 211.78, 204.19, 194.74, 192.80 mg/100 g pulp) was registered under T_4 (Nano chitosan 2% + nano silicon dioxide 2%) and C.D. values followed by T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) (209.21, 202.33, 194.08, 183.96, 181.21) on 3rd, 6th, 9th, and 12th days of storage, respectively. While T_1 (control) recorded significantly minimum with respect to AA content of guava fruit (209.85, 199.13, 183.37, 169.46 and 168.61 mg/100 g

Table 9: Effect of post-harvest treatment on AA of guava cv. Allahabad Safeda during storage.

Treatments	AA				
	Storage period (day)				
	0th day	3th day	6th day	9th day	12th day
T_1 (Control)	209.85	199.1	183.37	169.46	168.61
T_2 (Nano chitosan 1% + nano silicon dioxide 1%)	216.17	209.3	198.54	186.49	184.63
T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%)	218.69	209.9	203.59	189.69	187.79
T_4 (Nano chitosan 2% + nano silicon dioxide 2%)	219.33	211.8	204.19	194.74	192.8
T_5 (Nano sodium alginate 1% + nano silicon dioxide 1%)	211.11	205.5	193.48	181.44	180.52
T_6 (Nano sodium alginate 1.5% + nano silicon dioxide 1.5%)	205.42	198.5	189.69	180.17	177.48
T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%)	209.21	202.3	194.08	183.96	181.21
C.D.	2.041	1.98	1.876	1.767	1.762
SE(m)	0.655	0.635	0.602	0.567	0.566

pulp) on 3rd, 6th, 9th, and 12th of storage, respectively. This might be due to the coating helping in reducing the rate of respiration and ripening, which resulted in dissipation of AA into dehydro AA during storage. The present findings are in conformity with Kamil et al. [28] in canino apricot fruits and Li et al. [29] in blueberry fruits.

TS

TS was also significantly influenced by different coating on the 3rd, 6th, 9th, and 12th days of storage. The TS is conferred in figure 1. Similarly, coating exerted a significant effect on TS on the 3rd, 6th, 9th, and 12th days of storage. The maximum TS (7.06, 7.16, 7.59, 8.21, 9.28%) was observed in T_4 (Nano chitosan 2% + nano silicon dioxide 2%) and C.D. values followed by T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) (7.16, 7.37, 7.83, 8.49, 9.11). While minimum TS (7.16, 7.26, 7.37, 8.21, 8.35%) was registered in T_1 (Control) on 3rd, 6th, 9th, and 12th days of storage, respectively. This may be due to rapid conservation of polysaccharides into sugars in the earlier stage and later to utilization of sugars in respiration. It is possible to say that the increase in total soluble sugars is due to improved hydrolysis of starch and polysaccharides into soluble sugars during storage. Fruits' increasing sugar content may be the result of the ageing process, which caused certain carbs to undergo enzymatic conversion from starch to sugar. These findings are in conformation with Soliman et al. [30] in peach and El-Gioushy et al. [31] in date palm fruits.

RS (%)

Concerning the impact of different investigated treatments on reducing sugar content, data indicated that reducing sugar was significantly responded to the studied treatments. The data are conferred in figure 2. It was quite clear that coating exerted a significant effect on reducing sugar content of fruit on 3rd, 6th, 9th, and 12th days of storage. The maximum reducing sugar (5.55, 5.36, 5.10, 4.77, 4.22%) was observed in treatment T_4 (Nano chitosan 2% + nano silicon dioxide 2%) on 3rd, 6th, 9th, and 12th days of storage, C.D. value was at par with T_3 (Nano chitosan 1.5% + nano silicon dioxide 1.5%) (5.47, 5.31, 5.13, 4.51, 4.51%) in day of storage. The minimum

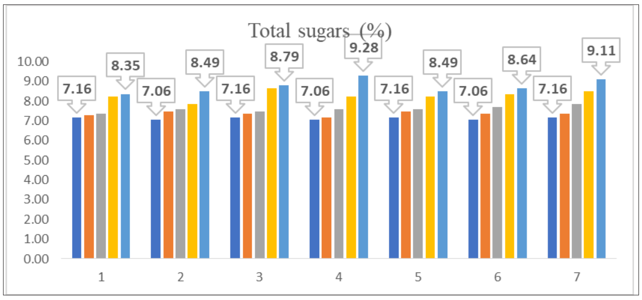

Figure 1: Effect of post-harvest treatment on TS (%) of guava cv. Allahabad Safeda during storage.

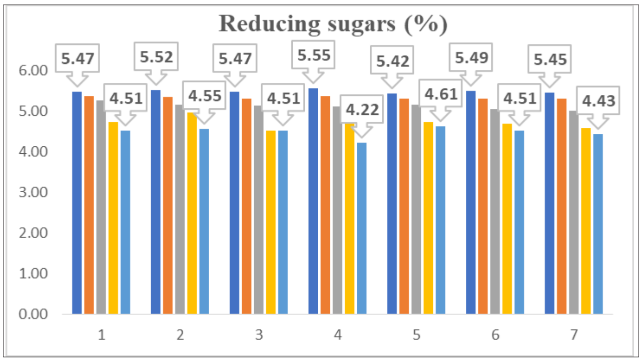

Figure 2: Effect of post-harvest treatment on RS (%) of guava cv. Allahabad Safeda during storage.

reducing sugar (5.47, 5.36, 5.26, 4.74, 4.51%) was noted in T_1 (control) on 3rd, 6th, 9th, and 12th days of storage, respectively. The quick early post-harvest maturing of control fruit may have been owing to the dry environment surrounding the fruit, which resulted in the quick transformation of starches into sugars. This accelerated the ripening process. Nonetheless, the utilization of starch as a base throughout the process of ripening might be blamed for an interruption in the sugar content's reduction. These findings are in conformation with Zhao et al. [32] in grapes and Bahmani et al. [33] in strawberry fruits.

NRS (%)

With respect to the impact of the different coating on non-reducing sugar, data (Figure 3) revealed that significant differences were found among the studied treatments in respect to non-reducing sugar on 3rd, 6th, 9th, and 12th days of storage. The result revealed that significant effect of coating was found on 3rd, 6th, 9th, and 12th days of storage. The significant value of the non-reducing sugar (1.50, 1.79, 2.49, 3.44, 5.06 %) was recorded in T_4 (Nano chitosan 2% + nano silicon dioxide 2%) and C.D value was at par with T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) (1.71, 2.07, 2.83, 3.91, 4.68) on 3rd, 6th, 9th, and 12th days of storage, respectively. However, the lowest non-reducing sugar (1.69, 1.90, 2.11, 3.48, 3.84%) was registered in T_1 (Control) on 3rd, 6th, 9th, and 12th days of storage period, respectively. Fruit with a protective coating significantly postponed an upsurge in sugars could be attributable to the reality that coating slows down post-harvest maturation, which in turn slows the ageing process and, as a result, slows the starch-to-sugar transformation. These findings are in conformation with Helal et al. [34] in cucumber and Mahmoudi et al. [35] in plum fruits.

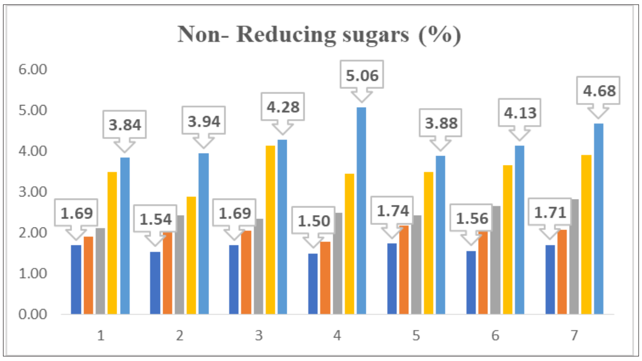

Figure 3: Effect of post-harvest treatment on NRS (%) of guava cv. Allahabad Safeda during storage.

Conclusion

T_4 (Nano chitosan 2% + nano silicon dioxide 2%) and T_7 (Nano sodium alginate 2% + nano silicon dioxide 2%) can be considered as the best treatments. Different parameters were tested, and findings showed that FW (112.08 mg), TSS (10.23 °Brix), TA (0.36%), firmness (1.54 Kgcm^{-2}), AA (192.80 mg/100 g), TAA (35.08%), TS (9.28%), RS (4.22%), NRS (5.06%) as compared with control. Moreover, the reduction of size droplet by employing nanotechnology also influenced the fruit quality. The coating also acts as a barrier against gas and moisture. Thus, nano-coatings of various formulations were successful in maintaining nutritional quality and shelf-life of guava fruits while also reducing post decay rate.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Zakaria L. 2021. Diversity of colletotrichum species associated with anthracnose disease in tropical fruit crops—a review. *Agriculture* 11(4): 297. https://doi.org/10.3390/agriculture11040297
2. Molla MM, Sabuz AA, Khan MHH, Chowdhury MGF, Miaruddin M, et al. 2022. Effect of honey and lemon juice on the physicochemical, nutritional, microbial and antioxidant properties of guava–pineapple jelly during storage periods. *Discov Food* 2: 31. https://doi.org/10.1007/s44187-022-00033-5
3. Brar JS, Arora NK, Kumar K, Boora RS, Kaur G. 2021. Effect of temperature variations on phenology and horticultural traits of guava under north-west Indian conditions. *J Agrometeorol* 23(3): 360-363. https://doi.org/10.54386/jam.v23i3.46
4. Guroo I, Gull A, Wani SM, Wani SA, Al-Huqail AA, et al. 2021. Influence of different types of polysaccharide-based coatings on the storage stability of fresh-cut kiwi fruit: assessing the physicochemical, antioxidant and phytochemical properties. *Foods* 10(11): 2806. https://doi.org/10.3390/foods10112806
5. Rosenboom JG, Langer R, Traverso G. 2022. Bioplastics for a circular economy. *Nat Rev Mater* 7(2): 117-137. https://doi.org/10.1038/s41578-021-00407-8

6. Solomon S, Swapna M. 2022. Indian sugar industry: towards self-reliance for sustainability. *Sugar Tech* 24(3): 630-650. https://doi.org/10.1007/s12355-022-01123-5
7. Munhuweyi K, Mpai S, Sivakumar D. 2020. Extension of avocado fruit postharvest quality using non-chemical treatments. *Agronomy* 10(2): 212. https://doi.org/10.3390/agronomy10020212
8. Amiri-Rigi A, Abbasi S, Emmambux MN. 2022. Background, limitations, and future perspectives in food grade microemulsions and nanoemulsions. *Food Rev Int* 39(8): 5048-5086. https://doi.org/10.1080/87559129.2022.2059808
9. Hasan SK, Ferrentino G, Scampicchio M. 2020. Nanoemulsion as advanced edible coatings to preserve the quality of fresh-cut fruits and vegetables: a review. *Int J Food Sci Technol* 55(1): 1-10. https://doi.org/10.1111/ijfs.14273
10. Soleimanian Y, Goli SAH, Shirvani A, Elmizadeh A, Marangoni AG. 2020. Wax-based delivery systems: preparation, characterization, and food applications. *Compr Rev Food Sci Food Saf* 19(6): 2994-3030. https://doi.org/10.1111/1541-4337.12614
11. Enescu D, Cerqueira MA, Fucinos P, Pastrana LM. 2019. Recent advances and challenges on applications of nanotechnology in food packaging. A literature review. *Food Chem Toxicol* 134: 110814. https://doi.org/10.1016/j.fct.2019.110814
12. Sami R, Almatrafi M, Elhakem A, Alharbi M, Benajiba N, et al. 2021. Effect of nano silicon dioxide coating films on the quality characteristics of fresh-cut cantaloupe. *Membranes* 11(2): 140. https://doi.org/10.3390/membranes11020140
13. Said NS, Howell NK, Sarbon NM. 2021. A review on potential use of gelatin-based film as active and smart biodegradable films for food packaging application. *Food Chem Toxicol* 39(2): 1063-1085. https://doi.org/10.1080/87559129.2021.1929298
14. Bi D, Yang X, Yao L, Hu Z, Li H, et al. 2022. Potential food and nutraceutical applications of alginate: a review. *Marine Drugs* 20(9): 564. https://doi.org/10.3390/md20090564
15. Nair MS, Tomar M, Punia S, Kukula-Koch W, Kumar M. 2020. Enhancing the functionality of chitosan- and alginate-based active edible coatings/films for the preservation of fruits and vegetables: a review. *Int J Biol Macromol* 164: 304-320. https://doi.org/10.1016/j.ijbiomac.2020.07.083
16. Gill KS, Dhaliwal HS, Mahajan BVC, Paliyath G, Boora RS. 2016. Enhancing postharvest shelf life and quality of guava (*Psidium guajava* L.) cv. Allahabad Safeda by pre-harvest application of hexanal containing aqueous formulation. *Postharvest Biol Technol* 112: 224-232. https://doi.org/10.1016/j.postharvbio.2015.09.010
17. Apak R, Güçlü K, Ozyürek M, Karademir SE. 2004. Novel total antioxidant capacity index for dietary polyphenols and vitamins C and E, using their cupric ion reducing capability in the presence of neocuproine: CUPRAC method. *J Agric Food Chem* 52(26): 7970-1981. https://doi.org/10.1021/jf048741x
18. Avestan S, Ghasemnezhad M, Esfahani M, Barker AV. 2021. Effects of nanosilicon dioxide on leaf anatomy, chlorophyll fluorescence, and mineral element composition of strawberry under salinity stress. *J Plant Nutr* 44(20): 3005-3019. https://doi.org/10.1080/01904167.2021.1936036
19. Santos MMM, Silva GP, Prado RDM, Pinsetta JS, Mattiuz BH, et al. 2022. Biofortification of tomato with stabilized alkaline silicate and silicic acid, nanosilica, and potassium silicate via leaf increased ascorbic acid content and fruit firmness. *J Plant Nutr* 45(6): 896-903. https://doi.org/10.1080/01904167.2021.1994599
20. Kassem HS, Tarabih ME, Ismail H, Eleryan EE. 2022. Influence of nano-silica/chitosan film coating on the quality of 'Tommy Atkins' mango. *Processes* 10(2): 279. https://doi.org/10.3390/pr10020279
21. Kingwascharapong P, Arisa K, Karnjanapratum S, Tanaka F, Tanaka F. 2020. Effect of gelatin-based coating containing frog skin oil on the quality of persimmon and its characteristics. *Sci Hortic* 260: 108864. https://doi.org/10.1016/j.scienta.2019.108864
22. Hu W, Sarengaowa, Feng K. 2022. Effect of edible coating on the quality and antioxidant enzymatic activity of postharvest sweet cherry (*Prunusavium* L.) during storage. *Coatings* 12(5): 581. https://doi.org/10.3390/coatings12050581
23. Sharanaiahswamy AM, Bhagwan A, Kumar AK, Aparna K. 2022. Study on effect of different organic based products as a post-harvest treatment on shelf life and quality of guava (*Psidium guajava* L) Cv. Lucknow-49. *Pharma Innova* 11(7): 2132-2138.
24. Basumatary IB, Mukherjee A, Katiyar V, Dutta J, Kumar S. 2022. Chitosan-based active coating for pineapple preservation: Evaluation of antimicrobial efficacy and shelf-life extension. *LWT* 168: 113940. https://doi.org/10.1016/j.lwt.2022.113940
25. Zhang X, Zhang M, Xu B, Mujumdar AS, Guo Z. 2022. Light-emitting diodes (below 700 nm): Improving the preservation of fresh foods during postharvest handling, storage, and transportation. *Compr Rev Food Sci Food Saf* 21(1): 106-126. https://doi.org/10.1111/1541-4337.12887
26. Eldib R, Khojah E, Elhakem A, Benajiba N, Helal M. 2020. Chitosan, nisin, silicon dioxide nanoparticles coating films effects on blueberry (*Vaccinium myrtillus*) quality. *Coatings* 10(10): 962. https://doi.org/10.3390/coatings10100962
27. Sayed EG, Mahmoud AWM, El-Mogy MM, Ali MAA, Fahmy MAM, et al. 2022. The effective role of nano-silicon application in improving the productivity and quality of grafted tomato grown under salinity stress. *Horticulturae* 8(4): 293. https://doi.org/10.3390/horticulturae8040293
28. Kamil OT, El-Hefnawy SM, Alashkar RA, Gad MM. 2019. The impact of nano chitosan and nano silicon coatings on the quality of canino apricot fruits during cold storage. *Agric Zagzig Uni* 46(6): 2215-2227. https://doi.org/10.21608/zjar.2019.65073
29. Li Y, Rokayya S, Jia F, Nie X, Xu J, et al. 2021. Shelf-life, quality, safety evaluations of blueberry fruits coated with chitosan nano-material films. *Sci Rep* 11(1): 55. https://doi.org/10.1038/s41598-020-80056-z
30. Soliman NG, Nomier SA, Ibrahim M, Gad MM. 2021. Effect of spraying nano-chitosan and nano-silicon on physicochemical fruit quality and leaf mineral content of Florida prince peach trees. *Agric Zagzig Univ* 48(5): 1215-1226. https://doi.org/10.21608/zjar.2021.224030
31. El-Gioushy SF, El-Masry AM, Fikry M, El-Kholy MF, Shaban AE, et al. 2022. Utilization of active edible films (chitosan, chitosan nanoparticle, and CaCl2) for enhancing the quality properties and the shelf life of date palm fruits (Barhi cultivar) during cold storage. *Coatings* 12(2): 255. https://doi.org/10.3390/coatings12020255
32. Zhao X, Tian R, Zhou J, Liu Y. 2022. Multifunctional chitosan/grape seed extract/silver nanoparticle composite for food packaging application. *Int J Biol Macromol* 207: 152-160. https://doi.org/10.1016/j.ijbiomac.2022.02.180
33. Bahmani R, Razavi F, Mortazavi SN, Gohari G, Juárez-Maldonado A. 2022. Evaluation of proline-coated chitosan nanoparticles on decay control and quality preservation of strawberry fruit (cv. Camarosa) during cold storage. *Horticulturae* 8(7): 648. https://doi.org/10.3390/horticulturae8070648
34. Helal M, Sami R, Algarni E, Alshehry G, Aljumayi H, et al. 2022. Active bionanocomposite coating quality assessments of some cucumber properties with some diverse applications during storage condition by chitosan, nano titanium oxide crystals, and sodium tripolyphosphate. *Crystals* 12(2): 131. https://doi.org/10.3390/cryst12020131
35. Mahmoudi R, Razavi F, Rabiei V, Gohari G, Palou L. 2022. Application of glycine betaine coated chitosan nanoparticles alleviate chilling injury and maintain quality of plum (*Prunus domestica* L.) fruit. *Int J Biol Macromol* 207: 965-977. https://doi.org/10.1016/j.ijbiomac.2022.03.167