ARTÍCULO CORTO

Chitosan-based edible coatings extend shelf life and preserve antioxidant properties of 'Gran Enano' banana under tropical conditions

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Abstract

The shelf life of bananas is significantly reduced under tropical conditions due to rapid ripening, weight loss, and degradation of functional compounds. This study evaluated the effect of two chitosan concentrations (1.5% and 2%) as edible coatings on the physicochemical and antioxidant properties of 'Gran Enano' bananas stored at tropical ambient temperatures (30 ± 2 °C; 70 ± 10% RH) for 12 days. Weight loss, peel color, respiration rate, total soluble solids (TSS) and total phenolic compounds, and antioxidant activity (DPPH and ABTS methods) were monitored every two days. The results showed that the chitosan coatings modified some parameters indicative of the ripening process, with lower TSS and CO2 production values, as well as higher values of the L^* and b^* indices, indicative of color, being found at the end of storage. Antioxidant activity and phenolic content peaked around day 7, decreasing thereafter, although both chitosan treatments maintained significantly higher levels than the control. The 2% chitosan treatment increased antioxidant activity on day 1 (DPPH and ABTS), but at the end of storage, the values were like the control. These results demonstrate that the chitosan concentrations evaluated in edible films do not negatively alter the characteristics of the ripening process and, on the contrary, allow for extended shelf life.

Keywords:
ABTS
DPPH
Respiration
Ripening
Shelf life

Recubrimientos de quitosán prolongan la vida de anaquel y conservan antioxidantes del banano 'Gran Enano' en condiciones ambientales

Resumen

La vida de anaquel del banano se ve significativamente reducida bajo condiciones tropicales debido al rápido proceso de maduración, pérdida de peso y degradación de compuestos funcionales. Este estudio evaluó el efecto de dos concentraciones que quitosán (1.5% y 2%) como recubrimientos comestibles sobre las propiedades fisicoquímicas y antioxidantes del banano 'Gran Enano' almacenado a temperatura tropical ambiente (30 ± 2 °C; 70 ± 10% RH) durante 12 días. Se monitorearon la pérdida de peso, el color de la cáscara, la tasa de respiración, el contenido de sólidos solubles totales (SST) y de compuestos fenólicos totales, así como la actividad antioxidante (métodos de DPPH y ABTS) cada dos días. Los resultados mostraron que los recubrimientos de quitosán modificaron algunos parámetros indicativos del proceso de maduración, encontrándose al final del almacenamiento menores valores de SST, CO2 producido, así como mayores valores de los índices L^* y b^*, indicativos de color. La actividad antioxidante y el contenido fenólico alcanzaron su punto máximo hacia el día 7, disminuyendo posteriormente, aunque ambos tratamientos con quitosano conservaron niveles significativamente superiores al control. El tratamiento con 2% de quitosán incrementó la actividad antioxidante al día 1 (métodos DPPH y ABTS), pero al final del almacenamiento los valores fueron similares al control. Estos resultan demuestran que las concentraciones de quitosán evaluadas en las películas comestibles no modifican negativamente las características del proceso de maduración y por el contrario permiten alargar la vida de anaquel.

Palabras clave:
ABTS
DPPH
Respiración
Maduración
Vida de anaquel

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1. Introduction

Chitosan is a natural biopolymer that has garnered increasing attention over recent decades due to its wide range of applications in the food, pharmaceutical, biomedical, and agricultural industries (Bhowmik et al., 2024). Derived from the deacetylation of chitin—the second most abundant natural polymer—chitosan exhibits several desirable functional properties, including film-forming ability, biodegradability, biocompatibility, and antimicrobial and antioxidant activities. These characteristics make it a promising candidate for the development of edible coatings designed to extend the postharvest shelf life of perishable commodities, particularly fruits and vegetables (Riseh et al., 2023).

The film-forming capacity of chitosan enables the elaboration of thin, transparent, and non-toxic coatings that act as semipermeable barriers, modulating gas exchange (O_2 and CO_2) and thereby delaying ripening and senescence. Moreover, chitosan coatings can inhibit the growth of various pathogenic microorganisms and reduce oxidative spoilage due to their intrinsic antimicrobial and antioxidant properties (Subramani and Manian, 2024). As such, chitosan represents a sustainable and consumer-friendly alternative to synthetic preservatives. Chitosan-based coatings have been extensively studied in both climacteric and non-climacteric fruits, including strawberries, apples, mangoes, guavas, and papayas. Several authors (Hajji et al., 208; Priyadarshi et al., 2024) demonstrated that a 1-1.5% chitosan coating significantly reduced fungal growth, weight loss, and preserved firmness in strawberries during storage. Similarly, a 2% coating extended the shelf life of papaya and reduced anthracnose symptoms (Vilaplana et al., 2020), while studies in pears reported reduced weight loss and respiration rate, along with higher retention of firmness, total soluble solids, titratable acidity, and polyphenol content (Adhikary et al., 2022).

Several studies have confirmed that the efficacy of chitosan coatings is strongly influenced by concentration of the polymer. In apricots, Algarni et al. (2022) found that 1.5% chitosan nanoparticles coating extended shelf life up to 30 days at 5 °C, compared with a 1% concentration. In cherries, Zam (2019) observed that 2% chitosan coatings enriched with olive leaf extract preserved higher levels of phenolic compounds and antioxidant activity than lower concentrations. In tomatoes, coatings of chitosan combined with grapefruit extract effectively prevented weight loss during storage (Won et al., 2018). In papaya, Escamilla-García et al. (2018) reported that a 1% chitosan coating improved firmness, reduced weight loss, and maintained antioxidant activity. Similarly, in cashews nuts, higher chitosan concentrations were more effective at reducing lipid oxidation, as evidenced by lower peroxides and TBARS levels (Azimzadeh and Jahadi, 2024). Vasile and Baican (2021) concluded that increasing chitosan concentrations enhances functional properties such as mechanical strength, selective gas permeability, and antimicrobial and antioxidant effects. However, they caution that excessively high concentrations may produce overly dense films that negatively impact fruit quality.

Banana (*Musa* spp.), a highly perishable climacteric fruit of considerable economic and nutritional importance, is particularly susceptible to rapid postharvest deterioration. Its high respiratory rate and sensitivity to ethylene accelerate ripening, leading to uneven coloration, firmness loss, and increased susceptibility to microbial decay. Several studies have demonstrated the effectiveness of chitosan coatings in mitigating these issues. Hossain and Iqbal (2016) reported that a 1% shrimp-derived chitosan coating significantly reduced weight loss and disease incidence, extending banana shelf life by 3 to 4 days. Suseno et al. (2014) found that a 2% chitosan formulation more effectively preserved vitamin C and reducing weight loss, while Sikder and Islam (2019) observed similar benefits with a 1% concentration. These findings suggest that the performance of chitosan coatings is influenced by several factors, including concentration, degree of deacetylation, molecular weight, application method (e.g., dipping, spraying, or brushing), and storage conditions. Overly concentrated solutions may lead to the formation of dense films that restrict fruit respiration and negatively affect sensory quality. Therefore, optimizing the chitosan concentration for each specific fruit cultivar is essential to ensure postharvest effectiveness and product acceptability.

Although the application of chitosan coatings in bananas has been broadly explored, limited research is available on the 'Gran Enano' (*Musa* AAA) cultivar. Furthermore, the postharvest behavior of this variety when treated with chitosan solutions at concentrations above the commonly used 1.5%—and the corresponding effects on its antioxidant properties—remains largely unknown. Because of this, the objective of this study was to evaluate the effect of edible coatings formulated with different concentrations of chitosan (1.5% and 2%) on the postharvest shelf life and antioxidant properties of 'Gran Enano' bananas.

2. Materials and Methods

2.1. Materials, reagents, and treatments

Banana fruits (*Musa* sp.) cv. 'Gran Enano' at physiological maturity were obtained from a local packing facility in Tapachula, Chiapas, Mexico. A total of 150 fruits from the same harvest lot were selected based on uniform size, absence of defects, and good sanitary condition (50 fruits per treatment). Three treatments were applied: T1 = control (no treatment), T2 = coating with 1.5% chitosan solution (Q-1.5%), and T3 = coating with 2% chitosan solution (Q-2%). Chitosan (85% deacetylated, MW = 340.33), glacial acetic acid (Meyer®), and Tween 20 (Sigma-Aldrich®) were used. All reagents were of analytical grade.

2.2. Preparation of chitosan solutions

Chitosan coating solutions were prepared by dissolving 1.5% or 2% (w/v) chitosan in distilled water previously acidified

with 1.5% (v/v) acetic acid to reach a pH of 4. The mixtures were stirred on a magnetic plate for 24 h and used immediately after preparation (Monzón-Ortega et al., 2018).

2.3. Application of coatings

Banana fruits were washed with distilled water and immersed in a 100-ppm sodium hypochlorite solution for 1 min. They were then individually separated from the cluster using a sterile scalpel and randomly assigned to one of the three treatments. The coating solutions were manually applied using a polyurethane foam brush. After application, fruits were dried at room temperature under continuous airflow. All treated fruits were stored under ambient conditions (30 ± 2 °C; 70 ± 10% relative humidity) in a closed storage room for 9 days (Cruz-Ortiz et al., 2021).

2.4. Postharvest physiology of the fruits

One day after coating application (day 1) and subsequently every 48 h, the following parameters were measured: weight loss (Adventurer™ Pro, model AV264C), external color (MiniScanEZ colorimeter), and total soluble solids (TSS) using a digital refractometer (ATAGO, model PAL-1. CO_2 production was also measured by placing individual fruits in 3 L sealed containers for 2 h. The concentration of CO_2 was then determined using an IAQ-CALC probe (TSI®) and reported as mg CO_2 kg^{-1} h^{-1} (Monzón-Ortega et al., 2018). Weight loss and external color were measured in all fruits per treatment, while the other parameters were determined using five fruits per sampling point, with three measurements per fruit (15 measurements per sampling), performed at the apical, middle, and peduncular regions (Cruz-Ortiz et al., 2021).

2.5. Antioxidant properties of the fruits

2.5.1. Total polyphenols content

A total of 100 mg of banana pulp was macerated in 1 mL of 80% (v/v) methanol (Merck, USA) and stirred at 200 rpm for 24 h at room temperature. The mixture was centrifuged at 2,626 × g for 25 min, and the supernatant was collected and stored at −25 °C. The pellet underwent a second extraction under identical conditions. Both extracts were pooled and stored at −25 °C until analysis. Total polyphenol content was determined using the colorimetric Folin–Ciocalteu method as described by Vázquez-Olivo et al. (2019). Briefly, 20 µL of extract were mixed with 80 µL of 80% (v/v) methanol, 500 µL of Folin–Ciocalteu reagent (1:10 dilution; Sigma-Aldrich, USA), and 400 µL of sodium carbonate solution (Na_2CO_3; Meyer, Mexico). After incubation in the dark for 60 min, absorbance was measured at 765 nm using a microplate reader (MR-96A, Mindray, China). A calibration curve (0–10 mg L^{-1}) was generated using gallic acid (Merck, USA), and results were expressed as mg of gallic acid equivalents per gram of fresh pulp (mg GAE g^{-1}).

2.5.2. DPPH radical scavenging activity

The free radical scavenging activity was determined using 2,2-diphenyl-1-picrylhydrazyl (DPPH), following the method described by Farzana et al. (2023), with slight modifications. In brief, 4 mL of a 0.1 mM methanolic DPPH solution were mixed with 1 mL of sample extract. The mixture was vortexed vigorously for 1 min and then incubated in the dark at room temperature for 30 min. Absorbance was measured at 517 nm using a UV-Vis spectrophotometer. Scavenging activity was calculated as follows: DPPH scavenging activity (%) = $(A_{control} - A_{sample})/A_{control} \times 100$.

2.5.3. ABTS radical scavenging activity

The ABTS [2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)] assay was conducted following the method by Nenadis et al. (2004), with adjustments for microplate absorbance measurements. The $ABTS^{\bullet+}$ radical cation was generated by mixing 5 mL of a 7 mM ABTS solution with 88 µL of 140 mM potassium persulfate ($K_2S_2O_8$; Meyer, Mexico), and incubated in the dark at 25 °C for 12 h. The mixture was diluted with 7% ethanol to obtain an absorbance of 0.80 ± 0.03 at 734 nm, measured using a microplate reader (MR-96A, Mindray, China). For calibration, 280 µL of the $ABTS^{\bullet+}$ solution were mixed with 20 µL of Trolox standard solutions (0–800 µM), and absorbance was recorded after 6 min. The same protocol was followed for banana extracts, using 20 µL of sample extract. Results were expressed as micromoles of Trolox equivalents per gram of fresh pulp (µmol TE g^{-1}).

2.6. Data analysis

All data from the physicochemical variables were subjected to analysis of variance (ANOVA), followed by mean comparison using Tukey's test ($\alpha = 0.05$). Statistical analyses were conducted using XLSTAT © v2012 software.

3. Results and Discussion

3.1. Weight loss

As expected, weight loss increased progressively in all treatments (Figure 1) over time due to transpiration and respiration processes. However, the rate and extent of weight loss were modulated by the presence and concentration of the chitosan coatings. Control fruits exhibited a final weight loss of approximately 23% by day 9, while Q-2% coated fruits showed the lowest loss (~20%). Notably, fruits treated with Q-1.5% displayed slightly higher weight loss than the control from day 3 onwards, which may be attributed to differences in coating uniformity or permeability at lower concentrations. Although these results show a trend and possible effect, no significant differences ($P>0.05$) were found between treatments.

The best performance of the 2% chitosan coating in reducing moisture loss suggests a more effective formation of a semipermeable barrier that limits water vapor diffusion. This agrees with findings in other climacteric fruits, such as tomatoes and apricots, where thicker chitosan layers provided better protection against dehydration (Algarni et al., 2022; Won et al., 2018). Moreover, the reduced water loss in Q-2% may help delay fruit softening and senescence, indirectly contributing to the overall maintenance of

postharvest quality. The results reinforce the importance of optimizing polymer concentration to balance gas and moisture permeability. Although 1.5% is frequently reported as effective, the current data suggest that under tropical storage conditions, a 2% formulation offers greater efficacy in limiting water loss in bananas. Nevertheless, further investigation into film thickness, structural integrity, and microstructural interactions would be necessary to confirm these mechanisms.

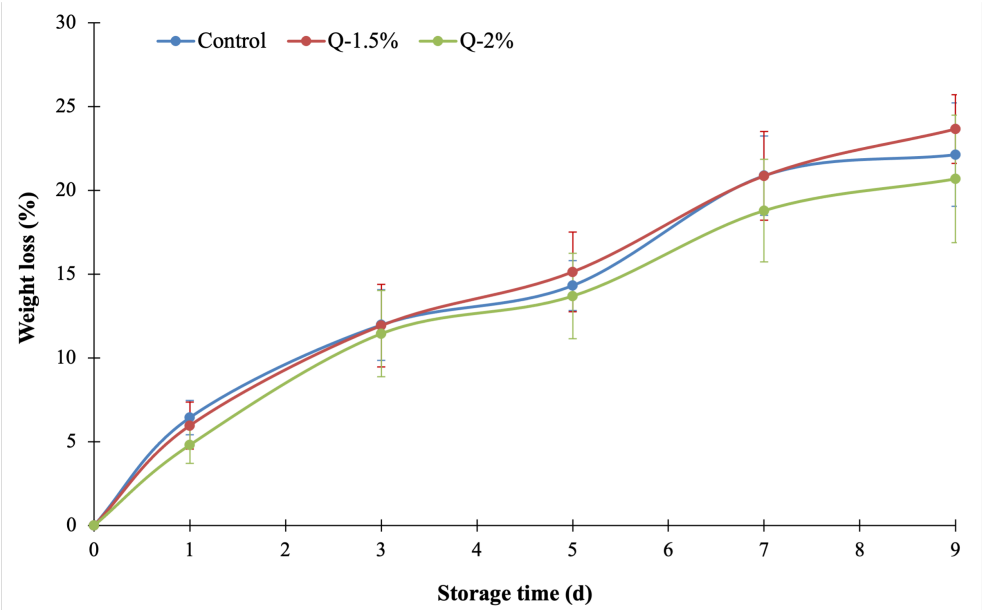

Figure 1. Weight loss of banana with and without chitosan coating during storage under tropical ambient conditions.

3.2. Peel color

*L** (lightness) values indicate the brightness of the peel, where higher values reflect a lighter color. At day 0, control bananas showed the highest *L** (55.73), while Q-1.5% and Q-2% started at lower values (46.78 and 50.49, respectively) (Figure 2). Over time, a marked decline was observed in all treatments, but the extent of the decrease varied significantly only the day 9. This day, *L** dropped sharply in the control (35.8), indicating higher browning and senescence. In contrast, Q-2% maintained a substantially higher *L** (44.67), suggesting that the coating delayed peel darkening. Q-1.5% showed the lowest *L** at day 9 (32.98), indicating less effective preservation of surface brightness. These results suggest that the 2% chitosan coating offered a more efficient barrier against oxidative and enzymatic browning, likely due to reduced oxygen penetration and water loss. Similar trends have been reported in papaya and strawberry, where chitosan-coated fruits retained better peel lightness (Priyadarshi et al., 2024; Vilaplana et al., 2020).

The *a** values reflect the transition from green (negative values) to red (positive values), closely associated with chlorophyll degradation and carotenoid accumulation during ripening. Initially, all fruits exhibited negative values (−10.21 to −8.67), typical of unripe bananas. A rapid increase in *a** values occurred in all treatments as storage progressed, with the control reaching 6.63 by day 9, indicating advanced ripening. Coated fruits followed a similar trajectory, with Q-1.5% peaking at 8.05 (day 7) and Q-2% reaching 6.73 at day 9. Interestingly, Q-2% exhibited a delayed transition to positive *a** values, remaining at −1.79 even at day 3, suggesting a slower breakdown of chlorophyll pigments. This delay in color change further supports the hypothesis that higher chitosan concentrations may reduce ethylene diffusion and respiratory activity, effectively slowing the ripening process (Sikder and Islam, 2019; Suseno et al., 2014).

The *b** component represents the intensity of yellow coloration. At the beginning, control fruits had the highest *b** value (36.79), while Q-1.5% showed the lowest (25.68), and Q-2% was intermediate (32.48). A general decrease in *b** values occurred over time, especially in the control, which reached 13.56 by day 9—a sign of senescence and pigment breakdown. Remarkably, Q-2% retained much of its yellow hue (24.48), whereas Q-1.5% declined more sharply (10.33). The preservation of *b** in Q-2% suggests a protective effect against the oxidative degradation of carotenoids. This may be attributed to both reduced oxidative stress and maintenance of membrane integrity, as suggested the results in antioxidants.

These results reinforce the idea that 2% chitosan coatings are more effective in delaying visible ripening and browning in ‘Gran Enano’ bananas under ambient tropical conditions, in agreement with previous studies in mangoes, tomatoes, and bananas (Hossain and Iqbal, 2016; Silva et al., 2020).

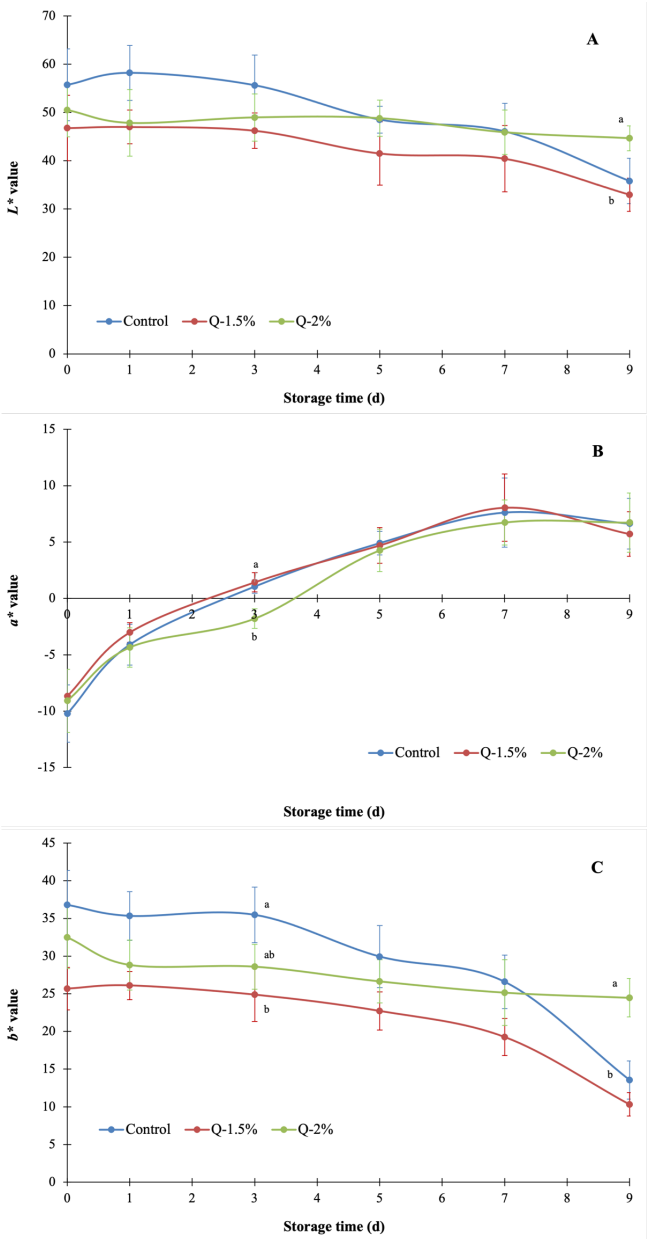

Figure 2. Color parameters of banana peel with and without chitosan coating during storage under tropical ambient conditions.

3.3. Respiration rate

The Figure 3 shows the evolution of respiration rates in 'Gran Enano' bananas. At the start of storage (day 0), all treatments displayed similar respiration rates, ranging from 23.5 to 36.3 mg CO_2 kg^{-1} h^{-1}, with Q-2% showing a slightly higher initial rate (36.3 mg CO_2 kg^{-1} h^{-1}), possibly due to temporary stress following coating application. By day 1, respiration decreased sharply in all treatments, reaching values between 6.2 and 13.0 mg CO_2 kg^{-1} h^{-1}, which may reflect transient metabolic suppression post-treatment and storage acclimatization.

A pronounced climacteric peak was observed on day 5 in the control treatment, with CO_2 production surging to 202.1 mg CO_2 kg^{-1} h^{-1}, indicating the onset of full ripening. In contrast, both chitosan treatments displayed delayed and attenuated peaks: Q-1.5% peaked later (day 9, 188.9 mg CO_2 kg^{-1} h^{-1}), while Q-2% peaked earlier but at a lower magnitude (day 7, 185.6 mg CO_2 kg^{-1} h^{-1}). Q-1.5% exhibited an early modest increase at day 5 (65.4 mg CO_2 kg^{-1} h^{-1}), followed by a sharp rise at day 9, suggesting a stronger delaying effect but less control over the eventual respiratory surge.

These trends confirm that chitosan coatings modulate respiratory activity by acting as a semipermeable barrier that restricts gas exchange and alters the internal atmosphere surrounding the fruit. This effect reduces ethylene action and oxygen availability, thereby slowing down metabolic reactions associated with ripening and senescence (Subramani and Manian, 2024). Among treatments, Q-2% demonstrated the most consistent suppression of respiration through day 9, with lower or more moderated peaks compared to the control and Q-1.5%. This finding aligns with the delay in color change and lower weight loss previously observed, reinforcing the effectiveness of the 2% chitosan concentration in extending postharvest life. The delayed climacteric peak in Q-1.5% and Q-2% also supports previous findings in bananas and papayas, where chitosan coatings postponed peak respiration and associated biochemical changes (Escamilla-García et al., 2018; Suseno et al., 2014).

3.4. Total soluble solids content

Total soluble solids (TSS) reflect the metabolic conversion of starch into simpler carbohydrates during the ripening. In untreated bananas (control), TSS levels exhibited a rapid and pronounced increase from 5.2 °Brix at day 0 to 21.7 °Brix at day 9 (Figure 4), with the most abrupt rise observed between days 3 and 5 (from 7.5 to 19.4 °Brix), corresponding to the peak of ethylene-mediated ripening and starch degradation (Zhu et al., 2021). In bananas coated with 1.5%, the TSS values increased more gradually, reaching 10.3 °Brix by day 5—nearly half of the value observed in the control at the same time point—suggesting a transient delay in starch hydrolysis. However, a substantial rise occurred between days 5 and 7 (from 10.3 to 19.5 °Brix), indicating that the delaying effect of the coating was temporary and that the fruit eventually resumed normal ripening. These results are consistent with reports in strawberries and papayas, where 1–1.5% chitosan coatings delayed—but did not fully suppress—ripening-related metabolic processes (Hajji et al., 2018; Vilaplana et al., 2020). Notably, the 2% chitosan coating demonstrated a more effective and prolonged delay in TSS accumulation. Throughout the first five days of storage, TSS values remained below 8 °Brix, reflecting a more substantial inhibition of respiratory and enzymatic activity.

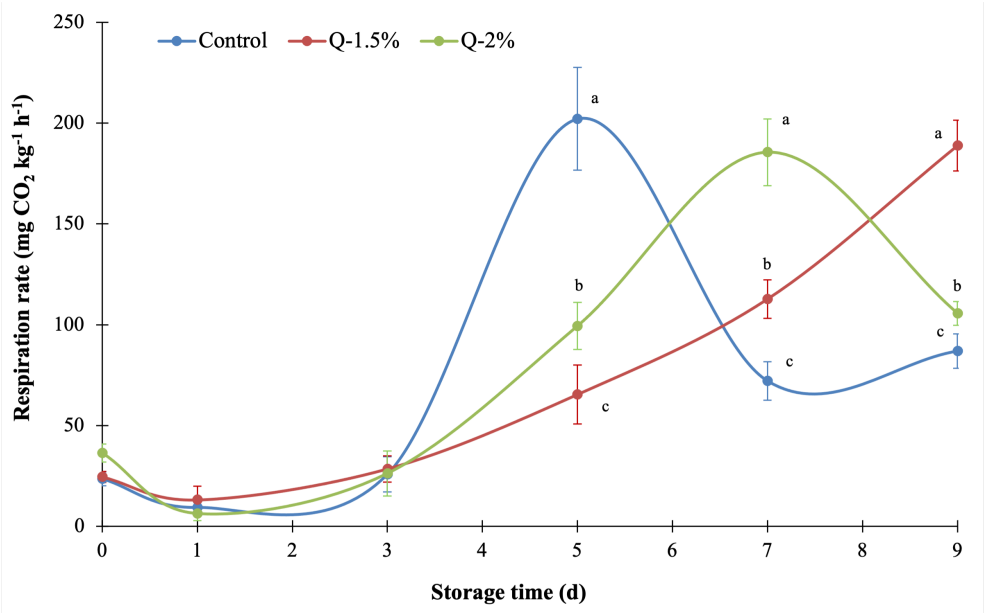

Figure 3. CO_2 production rate of banana with and without chitosan coating during storage under tropical ambient conditions.

This is likely due to the increased thickness and gas barrier properties of the higher-concentration chitosan film, which may have reduced oxygen permeability and suppressed ethylene biosynthesis, as previously documented (Algarni et al., 2022; Vasile and Baican, 2021). By day 9, however, TSS in this group increased sharply to 22.1 °Brix, surpassing the control. This sudden rise suggests that although the chitosan barrier was initially effective, ripening resumed—possibly due to saturation of the film's permeability threshold. The observed dual pattern in the 2% chitosan group (initial suppression followed by a rebound in TSS) aligns with findings in other climacteric fruits where higher chitosan concentrations extended the pre-climacteric phase, yet ultimately allowed normal ripening to resume once internal metabolic signals overcame the diffusion barrier (Subramani and Manian, 2024; Zam, 2019). Overall, these findings confirm that chitosan coatings, particularly at 2%, can effectively delay the onset of ripening in 'Gran Enano' bananas by modulating soluble solids accumulation. However, the effectiveness is time-limited, and extended storage may lead to a compensatory increase in TSS.

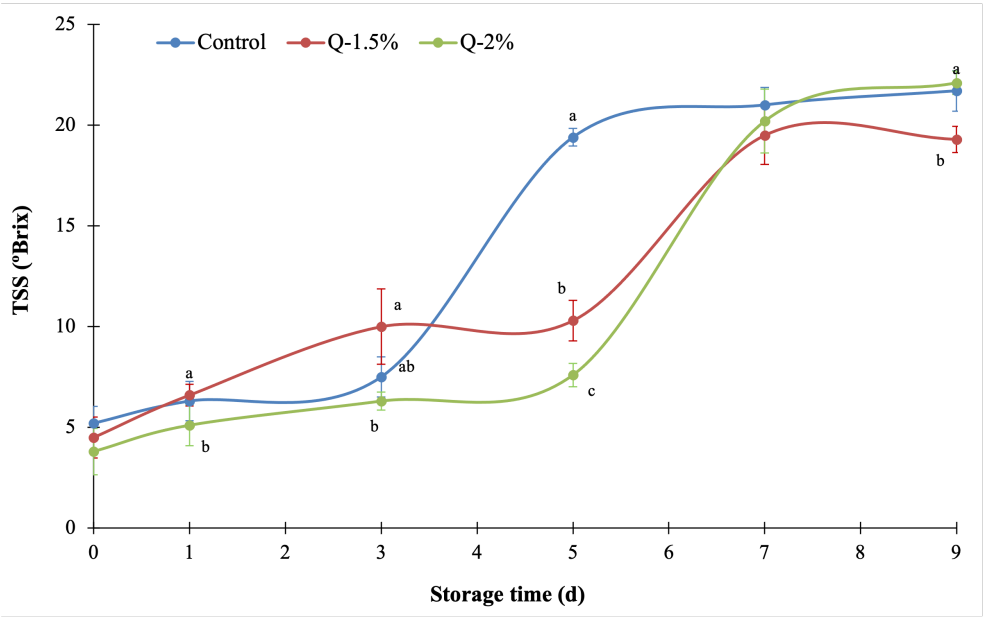

Figure 4. Total soluble solids content of banana with and without chitosan coating during storage under tropical ambient conditions.

3.5. Total phenolic content and antioxidant activity

At the beginning of storage (day 0), no significant differences (P>0.05) were observed among treatments for TPC or antioxidant capacity (Table 1), indicating that the coating process itself did not immediately alter the initial biochemical status of the fruit. However, variations became evident as storage progressed.

The TPC in control fruits showed fluctuations, peaking significantly on day 5 (5.1 ± 0.4 mg GAE 100 g^{-1}), likely due to stress-induced phenolic synthesis in response to abiotic conditions. In contrast, TPC in coated fruits (Q-1.5% and Q-2%) remained relatively stable throughout storage, ranging from 3.2 to 3.9 mg GAE 100 g^{-1}, with no significant (P>0.05) increases. This suggests that chitosan coatings may reduce oxidative or physiological stress, thereby stabilizing the phenolic profile. These findings align with previous observations in mangoes and papayas, where chitosan coatings were found to suppress stress-related phenolic accumulation (Salgado-Cruz et al., 2021; Vilvert et al., 2023).

Regarding DPPH radical scavenging activity, the control treatment showed variable values across storage, with a decline on day 1 (20.7 ± 1.8%) followed by an increased-on days 3 and 9. Interestingly, fruits coated with 2% chitosan exhibited a significantly higher DPPH activity (25.0 ± 1.9%) than the control and Q-1.5% treatments as early as day 1 (P<0.05). This trend continued throughout storage, with Q-2% consistently maintaining or improving radical scavenging capacity, suggesting that higher chitosan concentrations may enhance or preserve antioxidant systems. Similar behavior was reported in cherries and tomatoes where enriched chitosan matrices improved ROS-scavenging capacity (Zam et al., 2019; Won et al., 2018).

Table 1. Phenolic compounds content and antioxidant activity of banana fruits coated with chitosan and stored under tropical environmental conditions.

t	TPC (mg GAE 100 g^{-1})			DPPH (%)			ABTS (µmol TE g^{-1})		
	Control	Q-1.5%	Q-2%	Control	Q-1.5%	Q-2%	Control	Q-1.5%	Q-2%
0	4.0 ± 0.2	3.8 ± 0.5	3.7 ± 0.3	22.9 ± 3.4	22.6 ± 2.9	21.8 ± 3.8	65.9 ± 3.4	65.5 ± 4.2	66.6 ± 2.8
1	4.0 ± 0.2	3.4 ± 0.4	3.5 ± 0.5	20.7 ± 1.8	22.0 ± 1.0	25.0 ± 1.9*	68.5 ± 1.1	68.4 ± 0.9	66.7 ± 0.8*
3	3.4 ± 0.8	3.3 ± 0.2	3.5 ± 0.6	24.8 ± 3.8	24.1 ± 3.4	24.8 ± 4.5	67.2 ± 0.9*	65.4 ± 3.8	64.1 ± 3.5
5	5.1 ± 0.4*	3.3 ± 0.3	3.2 ± 0.2	20.1 ± 1.3*	23.0 ± 0.9	25.0 ± 1.4	64.0 ± 2.8	64.9 ± 4.2	65.6 ± 3.6
7	3.5 ± 0.7	3.9 ± 0.5	3.6 ± 0.3	23.3 ± 4.5	22.1 ± 2.8	25.3 ± 5.1	61.2 ± 5.6	60.6 ± 3.9	61.1 ± 4.5
9	3.4 ± 0.6	3.4 ± 0.4	3.6 ± 0.5	25.7 ± 2.9	27.2 ± 3.9	27.4 ± 3.6	60.9 ± 4.8	60.6 ± 4.2	60.2 ± 2.9

t = time of storage at room conditions (days); TPC = Total phenolics compounds. * Values with an asterisk are different from the other treatments (P<0.05) for the same sampling.

ABTS radical scavenging activity showed no major differences among treatments during the early storage period (days 0–5), with values ranging from 64–68 µmol TE g^{-1}. However, a significant increase was observed in Q-1.5% and Q-2% treatments on day 1 (66.7 and 66.7 µmol TE g^{-1}, respectively), compared to the control (68.5 µmol TE g^{-1}). Although the differences were minor, these findings suggest a protective effect of chitosan in maintaining redox stability during the early stages of ripening. By day 9, all treatments exhibited a decline in antioxidant parameters, with TPC and both scavenging activities decreasing slightly. However, Q-2% maintained the highest antioxidant levels, indicating a better protective effect against oxidative degradation during extended storage. This agrees with findings from Azimzadeh et al. (2018), where higher concentrations of chitosan reduced lipid peroxidation in cashew nuts.

Overall, the data indicate that chitosan coatings, particularly at 2%, can preserve antioxidant potential and phenolic stability during postharvest storage. This effect may be attributed to the semipermeable barrier formed by the coating, which reduces oxidative stress, moisture loss, and enzymatic activity, thereby delaying senescence.

4. Conclusion

Chitosan-based edible coatings proved to be an effective postharvest treatment to extend the shelf life and maintain the physicochemical and antioxidant quality of 'Gran Enano' bananas under tropical conditions. The application of 2% chitosan was particularly effective in reducing respiration rate, delaying the TSS accumulation, and preserving total phenolic and antioxidant activity throughout storage.

Conflict of interest

The authors declare that they have no conflict of interest

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