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Novel Shellac-Alginate Coating Systems: A Sustainable Approach to Strawberry Preservation

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ABSTRACT

Strawberry is a very popular fruit among the Indian population as a luxury fruit and also in fruit processing industry to prepare jam, jellies and juices but due to its very short shelf-life its post-harvest losses are very high. Natural resin like shellac (SH) which comes under GRAS along with sodium alginate was used as an edible coating material to reduce the post- harvest losses of strawberry. The coated samples were keep at refrigerated temperature (4±1°C) in different packaging conditions. Results demonstrated that shellac-alginate (SH-ALG) composite coatings significantly reduced weight loss and maintained fruit firmness compared to uncoated samples. The composite coating effectively maintained total soluble solid and titratable acidity levels, while enhancing retention of bioactive compounds including total phenolics and antioxidant capacity. The combination of SH-ALG coating with airtight polyethylene terephthalate packaging was most effective in maintaining strawberry quality and extending shelf-life. These findings suggest that shellac-alginate composite coatings represent a promising sustainable approach for strawberry preservation, offering an eco-friendly alternative to synthetic packaging materials while maintaining fruit quality and nutritional value during storage.

Key words: Natural resin, composite coating, post-harvest losses, strawberry

INTRODUCTION

Around the world, strawberries (Fragaria ananassa) are among the most popular and economical important fruits. However, this fruit species exhibits pronounced perish-ability characteristics, demonstrating limited post-harvest longevity attributed primarily to elevated metabolic activity and susceptibility to microbial deterioration. Under optimal refrigerated storage conditions (0-4°C), the commercial shelf-life of fresh strawberry fruit typically does not exceed five days. Consequently, various post-harvest preservation strategies have been investigated and implemented to extend strawberry longevity, including low-temperature storage, modified atmosphere packaging (MAP), controlled atmosphere storage (CAS) and thermal processing technologies (Guerreiro *et al.,* 2015).

The application of edible coating technologies confers multiple preservation advantages, including reduced moisture loss, retarded ripening processes, minimized chilling injury and mechanical damage, suppressed microbial decay, and enhanced surface gloss of treated fruits (Khan *et al.,* 2023; Islam *et al.,* 2024). Shellac, a complex mixture of esters and polyesters derived from lac insect (*Kerria lacca*) secretions, exhibits superior film-forming and barrier properties, making it valuable in food coating, and agricultural applications. Alginate, an anionic polysaccharide extracted from brown seaweeds (*Phaeophyceae*), demonstrates exceptional rheological behaviour, gelation capacity, and film-forming ability (Zhang *et al.,* 2022). Both biopolymers have gained prominence as biodegradable packaging materials due to their functional properties as edible coating matrices.

Various edible coating formulations have demonstrated the efficacy of edible coating applications in mitigating fruit deterioration and reducing decay in strawberry fruits (Zambrano-Zaragoza *et al.,* 2020; Khodaei *et al.,* 2021; Shafique *et al.,* 2023). Therefore, the present investigation aimed at evaluating the efficacy of shellac-alginate composite edible coatings on post-harvest shelf-life extension

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of strawberry fruit under varying storage conditions, including unpackaged storage, low-density polyethylene (LDPE) perforated packaging, and airtight polyethylene terephthalate (PET) containers at refrigerated temperatures.

MATERIALS AND METHODS

Mature strawberry (sweet Charlie variety) fruits were procured from a commercial farm located in village Saharwa (Hisar) Haryana, India. Selection criteria included uniform morphology, absence of visible pathological symptoms or mechanical damage, and consistent ripeness stage. Selected fruits were immediately transported under controlled conditions to the laboratory for experimental procedures. Shellac was bought from Tajna River Industries Pvt. Ltd., Khunti, Jharkhand and Food-grade sodium alginate, oleic acid and other reagents from Hi-Media and CDH Ltd.

Shellac-alginate (SH-ALG) composite coating was prepared by dissolving 1.0 g shellac and 0.5 g sodium alginate in 100 ml water, stirred at 70°C for 1 h. After cooling, 1 ml glycerol was added and mixed for 15 min. Shellac (SH) coating was prepared similarly, excluding alginate. Fruits were dipped in SH or SH-ALG coatings for 20 s, drained and air-dried for 15/ min. Water-dipped fruits served as control (C). All samples were stored for 20 days under three conditions: unpackaged, perforated LDPE packaging and airtight PET jars at refrigerated temperature.

Loss in weight was measured according to Chauhan *et al.* (2015) by taking difference between initial weight of the fruit and at different storage periods. For measurement, each fruit sample was taken in triplicate form (n=3). The results were expressed as percentage loss of initial weight.

$$\text{Weight loss \%} = \frac{(\text{Initial weight} - \text{Final weight})}{\text{Initial weight}} \times 100$$

Total soluble solids (TSS) in °Brix (°Bx) were determined using a digital refractometer (Rx-7000i, ATAGO Instruments Pvt. Ltd., India) at 30°C. Using a mortar and pestle, the strawberry samples were crushed. The muslin cloth was used to extract and filter the juice. The prism's surface was covered with one or two droplets of transparent and clear fruit juice, and measurements were taken (Ahamad *et al.,* 2024).

In order to calculate the titratable acidity (represented as tartaric acid percentage), 10 ml of juice were diluted with 90 ml of distilled water. Using phenolphthalein as an indicator, 10 ml of this solution were collected and titrated against 0.1N NaOH. At the termination point, the product was observed to change from colourless to bright pink (Das *et al.,* 2024).

$$\text{Tartaric acid (\%)} = \frac{0.0075 \times 0.1\ \text{N NaOH (ml)} \times \text{Final volume made}}{\text{Volume of extracted solution taken} \times \text{Volume of pulp taken}} \times 100$$

Firmness of the fruit was measured by Bitumen Penetrometer (Brand: Mac Teknik. Model Number: MTS-657B) equipped with a 5 kg load cell. The test is simple and practical, and no sample preparation is required for the experiment. The experiment can be conducted on fruit samples. The analyser was connected to a computer that recorded data via a software programme called texture expert by penetrating the fruit with a P/2 stainless steel probe at a speed of 0.2 m/s with automatic return.

The antioxidant potential of samples was assessed using the DPPH free radical assay (Dubey *et al.,* 2023). Test solutions containing 0.5 ml of 50 μM methanolic DPPH and varying concentrations of samples were prepared to a final volume of 0.6 ml, then incubated for 20 min at 37°C in darkness. Absorbance was measured at 517 nm and free radical scavenging activity was calculated as:

$$\text{Scavenging activity (\%)} = (AC–AS/AC) \times 100$$

Where, AC and AS represented absorbance of control and sample, respectively.

TPC was determined by homogenizing 0.3 g samples with 10 ml absolute ethanol, followed by ultra-sonication at 50°C for 20 min and centrifugation at 1484×g for 10 min. The supernatant was diluted to 25 ml with absolute ethanol and 0.1 ml extract was mixed with 2.0 ml diluted Folin reagent (1:10) and 2 ml of 7.5 g/l Na2CO3, with absorbance measured at 760 nm after 35 min at 25°C. Results were expressed as mg gallic acid equivalents per 100 g fresh weight (Zhang *et al.,* 2016).

RESULTS AND DISCUSSION

All fruits were started with 0% weight loss and exhibited continuous moisture loss throughout the storage period. Uncoated fruits without packaging exhibited the highest weight loss, reaching 21.45% by day20 (Table 1). Coated treatment significantly reduced weight loss. SH-ALG coated fruits stored in airtight PET jars showed the lowest weight loss of 5.98% after 20 days. These results were consistent with recent studies on coating applications for berry preservation, where composite coatings were effective in maintaining fruit weight and quality during extended storage periods (Castelo Branco Melo *et al.,* 2018; Bian *et al.,* 2022; Popescu *et al.,* 2022).

Titratable acidity showed a consistent decline during storage across all treatments, with initial values ranging from 0.87 to 0.89% (Table 2). Coating treatment significantly improved acid retention across all packaging treatments. SH-NP-ALG coating with airtight PET jar retained 0.89±0.03% acidity after 20 days, representing only a 10% decline from initial values. These results aligned with the findings of Li *et al.* (2024) and Xing *et al.* (2021), where edible coatings were effective in maintaining fruit acid levels during storage. The effectiveness of coating treatments in maintaining acidity levels followed the order: SH-ALG> SH>C.

TSS content of strawberry fruits showed a progressive increase during storage under all conditions (Table 3). Initial TSS values ranged from 8.43 to 8.47 °B across all treatments. Uncoated fruits showed maximum TSS values of 13.12 °Brix without packaging by day 8, while SH-ALG coated fruits in airtight PET jars showed highest TSS of 9.78 °Brix after 20 days of storage. The stability of TSS values in coated samples compared to uncoated controls aligned with previous studies on edible coatings. Ma *et al.* (2021) reported that shellac based coated mangoes maintained TSS values compared to uncoated samples after 17 days of storage.

Table 1. Weight loss (%) of strawberry fruits under refrigerated storage (4±1°C)

Treatment	Day 0	Day 4	Day 8	Day 12	Day 16	Day 20
Without packaging						
C	0.00±0.00^{aA}	12.34±1.08^{aB}	21.45±1.58^{aC}	-	-	-
SH	0.00±0.00^{aA}	9.67±0.95$^{b0"}$	16.89±1.45^{bC}	-	-	-
SH-ALG	0.00±0.00^{aA}	6.23±0.78$^{c0"}$	11.12±1.25^{cC}	-	-	-
LDPE perforated packaging						
C	0.00±0.00^{aA}	6.23±0.68^{aB}	9.78±0.95^{aC}	13.45±1.22^{aD}	17.23±1.48^{aE}	-
SH	0.00±0.00^{aA}	2.34±0.28^{bB}	4.89±0.58^{bC}	7.67±0.88^{bD}	10.45±1.12^{bE}	13.34±1.35^{aF}
SH-ALG	0.00±0.00^{aA}	1.56±0.22^{cB}	3.23±0.42^{cC}	5.12±0.68^{cD}	7.01±0.92^{cE}	8.89±1.15^{bF}
Air-tight PET jar						
C	0.00±0.00^{aA}	3.98±0.48^{aB}	6.23±0.78^{aC}	8.67±1.02^{aD}	11.23±1.25^{aE}	-
SH	0.00±0.00^{aA}	1.56±0.22^{bB}	3.23±0.42^{bC}	5.01±0.68^{b}0"	6.89±0.92^{bE}	8.78±1.15^{aF}
SH-ALG	0.00±0.00^{aA}	0.98±0.15^{cB}	2.12±0.32^{cC}	3.34±0.48^{cD}	4.67±0.72^{cE}	5.98±0.95^{cF}

Values are means±standard deviation. Different lowercase and uppercase letters (a-c), (A_F) in the same column and row indicate significant differences (P<0.05) among coating treatments and storage periods.

Table 2. Titratable acidity (%) of strawberry fruits under refrigerated storage (4±1°C)

Treatment	Day 0	Day 4	Day 8	Day 12	Day 16	Day 20
Without packaging						
C	0.89±0.03^{a}	0.50±0.04^{a}	0.35±0.04^{a}	-	-	-
SH	0.88±0.03^{a}	0.57±0.03^{b}	0.48±0.04^{b}	-	-	-
SH-ALG	0.89±0.03^{a}	0.65±0.03^{c}	0.±56.03^{cC}	-	-	-
LDPE perforated packaging						
C	0.89±0.03^{a}	0.83±0.03^{a}	0.74±0.04^{a}	0.68±0.05^{a}	0.54±0.06^{a}	-
SH	0.88±0.03^{a}	0.88±0.03b	0.86±0.03^{b}	0.83±0.04^{b}	0.79±0.05^{b}	0.74±0.06^{a}
SH-ALG	0.89±0.03^{a}	0.90±0.03^{c}	0.89±0.03^{c}	0.88±0.03^{c}	0.86±0.03^{c}	0.83±0.04^{b}
Air-tight PET jar						
C	0.89±0.03^{a}	0.84±0.03^{a}	0.78±0.04^{a}	0.69±0.04^{a}	0.57±0.05^{a}	-
SH	0.88±0.03^{a}	0.89±0.03^{b}	0.88±0.03^{b}	0.86±0.03^{b}	0.83±0.04^{b}	0.79±0.05^{a}
SH-ALG	0.89±0.03^{a}	0.91±0.03^{c}	0.90±0.03^{c}	0.90±0.03^{c}	0.89±0.03^{c}	0.87±0.03^{b}

Values are means±standard deviation. Different lowercase and uppercase letters (a-c), (A_F) in the same column and row indicate significant differences (P<0.05) among coating treatments and storage periods.

Table 3. Total soluble solids (TSS) (°Brix) of strawberry fruits under refrigerated storage (4±1°C).

Treatment	Day 0	Day 4	Day 8	Day 12	Day 16	Day 20
Without packaging						
C	8.45±0.23^{aA}	11.56±0.44^{aB}	13.12±0.52^{aC}	-	-	-
SH	8.47±0.21^{aA}	10.67±0.42^{bB}	11.89±0.54^{bC}	-	-	-
SH-ALG	8.46±0.20^{aA}	9.78±0.39^{cB}	10.56±0.45^{cC}	-	-	-
LDPE perforated packaging						
C	8.45±0.23^{aA}	9.23±0.31^{aB}	9.89±0.37^{aC}	10.78±0.43^{aD}	12.12±0.50^{aE}	-
SH	8.47±0.21^{aA}	8.61±0.24^{bB}	8.98±0.29^{bC}	9.56±0.35^{bD}	10.34±0.41^{bE}	11.23±0.48^{aF}
SH-ALG	8.46±0.20^{aA}	8.52±0.22^{bB}	8.69±0.27^{cC}	8.98±0.32^{cD}	9.56±0.38^{cE}	10.23±0.44^{bF}
Air-tight PET jar						
C	8.45±0.23^{aA}	8.98±0.30^{aB}	9.56±0.36^{aC}	10.34±0.42^{aD}	11.45±0.49^{aE}	-
SH	8.47±0.21^{aA}	8.56±0.23^{bB}	8.82±0.28^{bC}	9.23±0.34^{bD}	9.89±0.40^{bE}	10.67±0.46^{aF}
SH-ALG	8.46±0.20^{aA}	8.49±0.21^{cB}	8.63±0.26^{cC}	8.87±0.31^{cD}	9.23±0.37^{cE}	9.78±0.43^{bF}

Values are means ± standard deviation. Different lowercase and uppercase letters (a-c), (A_F) in the same column and row indicate significant differences (P<0.05) among coating treatments and storage periods.

Fruit firmness was significantly reduced during storage with notable differences among coating treatments and packaging systems (Table 4). ANOVA revealed highly significant effects (P<0.001) of all main factors and their interactions on the firmness of fruits with storage period. The SH-ALG coating combined with airtight PET jar packaging maintained fruit firmness at 3.31/ N after 20 days, representing only a 9.6% decline from the initial value. Airtight packaging systems provide superior protection by minimising moisture loss and maintaining optimal humidity levels while limiting oxidative processes (Zdulski *et al.,* 2024). Our findings are consistent with the study by Queiroz *et al.* (2025) where a coating developed using alginate and bees wax nanoparticles effectively reduced the respiration rate of yellow passion fruits.

The antioxidant activity (DPPH %) of strawberry fruits showed significant variations among coating treatments, storage periods, as well as packaging conditions under refrigerated storage. At day 0, all treatments showed similar DPPH values ranging from 78.45 to 78.89% (Table 5). The SH-ALG coating with airtight PET jar packaging showed DPPH scavenging activity of 80.12% after 20 days. The lowest antioxidant activity was observed in uncoated fruits (39.45%) without packaging under refrigerated conditions, followed by uncoated fruits in LDPE perforated packaging (64.56%) and uncoated fruits packaged in air-tight PET jar (69.56%). Our findings aligned with those of Vakili-Ghartavol *et al.* (2024) and Wani *et al.* (2021) who observed that applying edible coatings to strawberries led to significantly higher antioxidant activity compared to uncoated samples.

At day 0, all treatments showed similar DPPH values ranging from 245.67 to 246.45 (Table 6). Coating treatments significantly reduced the rate of phenolic degradation across all

Table 4. Firmness (N) of strawberry fruits under refrigerated storage (4±1°C)

Treatment	Day 0	Day 4	Day 8	Day 12	Day 16	Day 20
Without packaging						
C	3.84±0.12^{a}	2.84±0.19^{a}	2.13±0.25^{a}	-	-	-
SH	3.82±0.11^{a}	3.12±0.18^{b}	2.58±0.24^{b}	-	-	-
SH-ALG	3.83±0.13^{a}	3.42±0.16^{c}	3.05±0.22^{c}	-	-	-
LDPE perforated packaging						
C	3.84±0.12^{a}	3.28±0.16^{a}	2.97±0.18^{a}	2.68±0.21^{a}	2.38±0.24^{a}	
SH	3.82±0.11^{a}	3.68±0.12^{b}	3.47±0.15^{b}	3.24±0.17^{b}	3.02±0.20^{b}	2.79±0.23^{a}
SH-ALG	3.83±0.13^{a}	3.81±0.10^{c}	3.67±0.13^{c}	3.51±0.15^{c}	3.34±0.18^{c}	3.18±0.21^{b}
Air-tight PET jar						
C	3.84±0.12^{a}	3.34±0.15^{a}	3.08±0.17^{a}	2.84±0.20^{a}	2.58±0.23^{a}	-
SH	3.82±0.11^{a}	3.71±0.11^{b}	3.52±0.14^{b}	3.32±0.16^{b}	3.14±0.19^{b}	2.95±0.22^{a}
SH-ALG	3.83±0.13^{a}	3.82±0.09^{c}	3.71±0.12^{c}	3.58±0.14^{c}	3.44±0.17^{c}	3.31±0.20^{b}

Values are means±standard deviation. Different lowercase and uppercase letters (a-c), (A_F) in the same column and row indicate significant differences (P<0.05) among coating treatments and storage periods.

Table 5. Antioxidant activity (DPPH) of strawberry fruits under refrigerated storage (4±2°C)

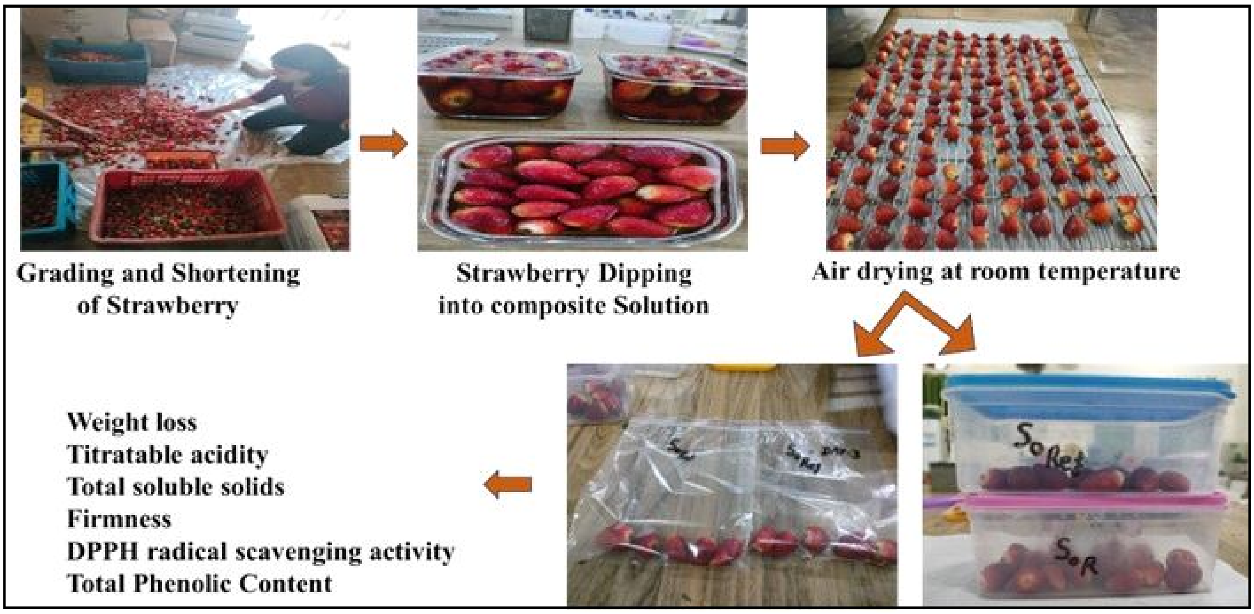
Treatment	Day 0	Day 4	Day 8	Day 12	Day 16	Day 20
Without packaging						
C	78.45±1.23[a]	44.78±1.95[a]	39.45±2.15[a]	-	-	-
SH	78.67±1.12[a]	61.23±1.88[b]	57.89±2.08[b]	-	-	-
SH-ALG	78.56±1.15[a]	66.12±1.78[c]	63.78±1.98[c]	-	-	-
LDPE perforated packaging						
C	78.45±1.23[a]	75.67±1.52[a]	72.34±1.72[a]	68.89±1.92[a]	64.56±2.12[a]	-
SH	78.67±1.12[a]	79.78±1.25[b]	78.45±1.45[b]	76.12±1.65[b]	73.78±1.85[b]	70.45±2.05[a]
SH-ALG	78.56±1.15[a]	82.45±1.12[c]	81.89±1.32[c]	80.67±1.52[c]	78.34±1.72[c]	76.89±1.92[b]
Air-tight PET jar						
C	78.45±1.23[a]	77.56±1.48[a]	75.23±1.68[a]	72.89±1.88[a]	69.56±2.08[a]	-
SH	78.67±1.12[a]	80.12±1.22[b]	79.78±1.42[b]	78.45±1.62[b]	76.12±1.82[b]	73.78±2.02[a]
SH-ALG	78.56±1.15[a]	83.56±1.08[c]	83.12±1.28[c]	82.78±1.48[c]	81.45±1.68[c]	80.12±1.88[b]

Values are means±standard deviation. Different lowercase and uppercase letters (a-c), (A_F) in the same column and row indicate significant differences (P<0.05) among coating treatments and storage periods.

Table 6. Total phenolic content of strawberry fruits under refrigerated storage (4±2°C)

Treatment	Day 0	Day 4	Day 8	Day 12	Day 16	Day 20
Without packaging						
C	245.67±3.45[a]	184.89±4.68[a]	164.56±5.12[a]	-	-	-
SH	246.23±3.32[a]	200.34±4.58[b]	173.67±5.02[b]	-	-	-
SH-ALG	246.45±3.38[a]	225.89±4.35[c]	215.67±4.78[c]	-	-	-
LDPE perforated packaging						
C	245.67±3.45[a]	232.89±3.85[a]	220.45±4.18[a]	204.78±4.58[a]	185.34±5.02[a]	-
SH	246.23±3.32[a]	245.67±3.48[b]	240.12±3.75[b]	231.78±4.08[b]	219.45±4.48[b]	203.89±4.92[a]
SH-ALG	246.45±3.38[a]	251.34±3.35[c]	249.78±3.58[c]	245.67±3.85[c]	238.12±4.25[c]	227.89±4.68[b]
Air-tight PET jar						
C	245.67±3.45[a]	238.45±3.78[a]	229.78±4.08[a]	217.34±4.48[a]	201.89±4.92[a]	-
SH	246.23±3.32[a]	247.78±3.42[b]	244.56±3.68[b]	238.12±3.95[b]	228.89±4.35[b]	216.45±4.78[a]
SH-ALG	246.45±3.38[a]	254.12±3.28[cd]	252.78±3.52[c]	249.45±3.78[c]	244.12±4.18[c]	236.78±4.58[b]

Values are means±standard deviation. Different lowercase and uppercase letters (a-c), (A_F) in the same column and row indicate significant differences (P<0.05) among coating treatments and storage periods.



Graphical Abstract

packaging treatments. Under these conditions, SH-ALG coating with airtight PET jar packaging showed TPC of 226.78 mg GAE/100 g (1.5% loss) after 20 days, while uncoated fruits without packaging showed 164.56 mg GAE/100 g (33.01% loss). This finding supported previous research of Liguori *et al.* (2021), who emphasized the importance of modified atmosphere conditions in preserving bioactive compounds in berries. The initial increase in phenolic content from day 0 to 4 and then a gradual decline on day 20 was previously reported and can be attributed to the biosynthesis of phenolic compounds as a stress response mechanism triggered by storage conditions (Mohammadi *et al.,* 2021).

CONCLUSION

The current study reveals that SH, ALG and their composite coatings significantly retained strawberry quality throughout storage. The SH-ALG composite coating combined with airtight PET container storage proved most effective for preserving strawberry quality, substantially reducing weight loss and changes in TSS and titratable acidity, while maintaining higher levels of total phenolics and antioxidant activity. Therefore, applying SH-ALG composite coatings to strawberries and storing them in LDPE or airtight PET packaging under refrigerated conditions represents a promising strategy for enhancing post-harvest quality and extending shelf-life.

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