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Composite Fabric Food Packaging with Lactic Acid and Chitosan - Shellac Coating for Preservation of Tomato and Strawberry

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Abstract

The imperative for enhanced food packaging materials that exhibit biodegradability has catalyzed significant progress in the domain of packaging material research. In this inquiry, the application of fibrous structures integrated with lactic acid and chitosan-shellac coatings for food packaging materials is being examined. This system is characterized by multifunctionality, wherein the chitosan-lactic acid layer produced provides a compensatory effect for the antimicrobial and antioxidant properties of the shellac layer, thereby contributing to the mechanical robustness of the coating. Furthermore, the effectiveness of the coated substrates in prolonging preservation was assessed utilizing tomatoes and strawberries as test subjects. Alterations in pH, concentrations of vitamin C, total soluble solids, rates of sensory acceptability, percentage weight loss, total titratable acidity, and activities of polyphenol oxidase (PPO) and peroxidase (POD) were meticulously measured after specified storage durations. The experimental results of 2, 2-diphenyl-1-picrylhydrazyl (DPPH) assay indicated that chitosan displayed the highest antioxidant potency, followed by lactic acid and the combination of chitosan with Lactic acid. This finding was further corroborated by the quality assessments of the tomatoes and strawberries, wherein preserved in chitosan-shellac-lactic acid and chitosan-shellac significantly contributed to quality preservation through the stabilization of pH, ascorbic acid content, and sensory attributes. Moreover, the coatings mitigated weight loss, preserved total titratable acidity levels, and inhibited the activities of PPO and POD during storage, thereby significantly extending the shelf life of the produce. Consequently, the outcomes of this study elucidate the potential application of lactic acid and chitosan-shellac coated composite fabrics as a sustainable and efficacious alternative for food packaging, offering numerous benefits for food preservation and protection.

KeyWords: Composite Fabric, Food Packaging, Lactic Acid, Chitosan-Shellac, Antioxidant Activity, Antimicrobial Properties

1. Introduction

Composite fabric food packaging incorporating lactic acid, chitosan, and shellac coatings presents a promising solution for enhancing food preservation and packaging sustainability. Chitosan, a natural biopolymer, offers antimicrobial properties (Dongkun *et al*., 2024) and when combined with lactic acid, can create biofilms with improved mechanical strength and barrier performance (Baoyimg *et al.,* 2024). Additionally, shellac bio-coatings have been shown to enhance the storage stability of fresh eggs, improving shell strength and reducing breakage rates (Hakan *et al.,* 2024). By incorporating these components into composite fabric packaging, it is possible to develop innovative biofilms that cater to diverse packaging requirements, offer enhanced antimicrobial properties, and contribute to reducing plastic waste in the food industry (Murtaza *et al.,* 2024). This approach holds great potential for sustainable and effective food packaging solutions.

Chitosan-based nanocomposites have emerged as promising materials for enhancing the postharvest quality of agricultural products. These nanocomposites offer unique properties such as biodegradability, antimicrobial activity, and barrier functions, making them suitable for food packaging applications. The postharvest period is critical for agricultural products, where factors like moisture loss, microbial growth, and physical damage can lead to quality deterioration and economic losses. Chitosan, derived from chitin, shows potential for improving food preservation due to its biocompatibility, biodegradability, and non-toxic nature. By incorporating chitosan into nanocomposites, researchers aim to develop innovative coatings and packaging materials that can extend the shelf life of fruits, vegetables, and other perishable goods (Saberi *et al.,* 2023). Furthermore, the fungicidal properties of clay chitosan nanocomposites were assessed both in vitro and in vivo in relation to their efficacy against *Penicillium digitatum*. (Youssef & Hashim, 2020).

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Chitosan, a natural biopolymer, possesses intrinsic antimicrobial properties (Dongkun *et al*., 2024). Chitosan is utilized in the food industry for its ability to act as a natural preservative and to improve food quality by reducing microbial contamination (Ismail *et al.,* 2023). When combined with lactic acid in composite fabric food packaging, the resulting material exhibits enhanced antibacterial effects against various pathogens like *Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, and Staphylococcus epidermidis* (Edwin *et al.,*2024). The incorporation of lactic acid not only improves the mechanical and thermal properties of the packaging films but also inhibits the growth of these harmful bacteria, contributing to food safety by preventing contamination and extending the shelf life of meat products (Edwin *et al.,* 2024). This combination of chitosan and lactic acid in composite fabric food packaging showcases promising antimicrobial capabilities that can play a crucial role in maintaining food quality and safety in the industry.

PET (Polyethylene Terephthalate) is a synthetic polymer widely used in food packaging due to its high mechanical strength, thermal stability, and excellent barrier properties for gases and moisture. Hopewell *et al.* (2009) emphasized PET's durability and versatility in packaging applications such as beverage bottles and food containers. PET is non-biodegradable and contributes significantly to global plastic pollution. Geyer *et al.* (2017) reported that most PET waste accumulates in landfills or the natural environment due to limited recycling rates. Even though PET is recyclable, its carbon footprint and the challenges of achieving high recycling efficiency remain barriers to sustainability.

PLA (Polylactic Acid) is a biodegradable polymer derived from renewable resources such as corn starch and sugarcane. Jamshidian *et al.* (2010) noted that PLA exhibits good mechanical strength and optical clarity, making it suitable for disposable packaging and compostable films. PLA has limited moisture and oxygen barrier properties compared to PET, which can restrict its use for long-term food preservation (Lim *et al.,* 2008). Effective biodegradation of PLA requires industrial composting facilities, as natural decomposition is slow under ambient conditions (Emadian *et al.,* 2017). PET and PLA dominate the food packaging industry, each with its unique strengths and limitations. Composite fabric packaging with lactic acid and chitosan-shellac coating emerges as an innovative alternative with enhanced sustainability, biodegradability, and antimicrobial properties, addressing critical gaps in food safety and environmental impact.

Additionally, advancements in nanotechnology are being leveraged to develop bio-based packaging materials with enhanced strength and flexibility, opening up new possibilities for creating eco-friendly packaging options that meet the demands of modern consumers. These cutting-edge developments are not only revolutionizing the packaging industry but also aligning with the growing consumer preference for sustainable and environmentally friendly products, driving a shift towards a more eco-conscious market (Asgher *et al.,* 2020). Moreover, collaborations between researchers and industry experts are accelerating the scale-up and commercialization of these bio-based packaging innovations, bringing us closer to a future where sustainable packaging is the norm rather than the exception (Yuvaraj *et al.,* 2021).

It is an eco-friendly and biodegradable approach where the combination of natural polymers (chitosan and shellac) with lactic acid promotes sustainability. This aligns with global trends toward reducing single-use plastics and offers a new biodegradable alternative. The increasing demand for sustainable and effective food packaging solutions necessitates innovative approaches that extend shelf life, ensure food safety, and reduce environmental impact. The use of this novel composite fabric may enable customizability in food packaging, such as applications in fresh produce, dry goods, or perishable foods, which could distinguish it from conventional films or rigid packaging.

2. Materials and Methods

2.1. Fabric collection

Two different fabrics such as thick cloth, thin cloth and paper were collected from local market, Tiruppur**,** India.

2.2. Preparation of chitosan-shellac solution

Two milliliters of acetic acid were dissolved in one hundred milliliters of distilled water to create an acetic acid solution (2% v/v).To create a 2% (w/v) chitosan solution, 2 g of chitosan (C) was dissolved in 100 mL of a 2% v/v acetic acid solution. Shellac solution (5% w/v) was prepared by dissolving 5g of shellac in 90 ml acetone and the volume is made up to 100ml using distilled water.

2.3. Coating of fabrics and paper

Different extracts (chitosan, chitosan-shellac) were coated on Thin fabric, Thick fabric and Paper**,** and they were left to dry for 2 h and a set of uncoated fabric were kept as standard.

2.4. Antioxidant activity

The radical scavenging activity by chitosan, lactic acid, chitosan + lactic acid *i.e* its antioxidant property was investigated by using 2, 2-diphenyl-1-picrylhydrazyl (DPPH) assay. Stock solution of each sample chitosan, lactic acid, chitosan + lactic acid with a concentration of 10mg/ml was prepared and from the stock solution working standard solution with the concentration of 1mg/ml was prepared. Six boiling test tubes were taken; each was added with 1 ml of distilled water. 1 ml of the working standard solution was added to the first test tube and a serial dilution was performed by taking 1 ml from each test tube and adding it to the next. Then each test tube was added with 0.25 ml of DPPH (stock solution: 0.1 mM DPPH solution was prepared by dissolving 4mg of DPPH in 100ml of methanol) stock solution. The reaction mixture was filled to a 5 ml test tube and incubated for 30 minutes at room temperature in a dark environment. Five milliliters of DPPH was used as a control when the mixture's absorbance was measured at 517 nm after 30 minutes. Butylated hydroxyl toluene (BHT) was the standard.

DPPH inhibition (%) = [Control absorbance – Test absorbance] x 100

2.5. Preparation of packaging material

Twelve 10x10-inch bags made of two distinct fabrics (thin bag = 4, thick bag = 4) and brown paper (paper bag =

4) were made in total. Two milliliters of acetic acid was dissolved in one hundred milliliters of distilled water to create an acetic acid solution (2% v/v). To create a 2% (w/v) chitosan solution, 2 g of chitosan (C) was dissolved in 100 mL of a 2% v/v acetic acid solution. Shellac solution (5% w/v) was prepared by dissolving 5g of shellac in 90 ml acetone and the volume is made up to 100ml using distilled water. A bag from each set was kept as uncoated control. The other set of bags was coated with chitosan, chitosan-shellac and chitosan-shellac-lactic acid. Tomato and strawberry were chosen as vegetable and fruit sample to be stored using the prepared packaging material. The quality characteristics of stored fruit and vegetable were analyzed by following several biochemical assays such as polyphenol oxidase (PPO) and peroxidase (POD), Total soluble solids, Titratable acids, and ascorbic acid estimation for every four days for a total period of 12 days for tomato and for 6 days for strawberry. The sensory quality evaluation, weight loss, pH were also evaluated to determine the enhanced shelf life period of stored fruits and vegetables.

2.6. Quality characteristics of stored fruits and vegetables

2.6.1. 2.6.1 Sensory quality evaluation

With a few adjustments, the sensory quality of food samples was assessed using the methodology outlined by Caleb *et al.* (2013). Scales of taste, look, and color were widely employed to evaluate the quality of strawberries and tomatoes. Thus, five laboratory staff members used hedonic scales to undertake sensory evaluations of changes in taste, appearance, and color: 5, excellent (fully characteristic tomato and strawberry, red and unwrinkled); 4, very good (pleasantly mild tomato and strawberry, red and unwrinkled). 3, good (blandly faint tomato and strawberry, but quite wrinkled; limit of marketability); 2, fair (faint off odor, change in color, wrinkled, limit of unacceptability); and 1, poor (distinct off odor, fully wrinkled and mushy).

2.6.2. Measurement of weight loss

The weight of fruit was compared every 4 days for tomatoes up to 12 days and every 6 days for strawberries in order to determine the gradual weight reduction.

2.6.3. Measurement of pH

Five grams of pulped fruit and vegetables were combined with twenty-five milliliters of distilled water, and then filtered through muslin fabric. To assess pH, a 25 ml aliquot was employed. A pH meter was used to measure the pH.

2.6.4. Measurement of total soluble solids, titratable acid, and ascorbic acid

Using a hand refractometer, the total soluble solids was measured straight from the filtered fruit and vegetable residue and expressed as brix°. 0.1 N NaOH was used to assess the titratable acidity. Using a mortar and pestle, 3g of tomato and strawberry pulp was homogenized. The mixture was then centrifuged at 3500 rpm for 10 minutes. By using the 2, 6-dichlorophenolindophenol titration method, the ascorbic acid content of the supernatant phase was measured and recorded.

2.6.5. Assays of polyphenol oxidase (PPO) and peroxidase (POD)

After homogenizing 5 g of tissue from 3 fruit pulp in 20 ml of 0.05 M phosphate buffer (pH 6.8), the homogenate was filtered through two layers of cotton cloth to eliminate cell debris. Enzyme extracts were obtained by collecting the clear supernatant following centrifugation at 10,000 rpm for 20 minutes at 4°C. PPO activity was measured by measuring the oxidation of 4-methylcatechol, in accordance with Jiang and Fu's (1999) technique. After three minutes, the rise in absorbance at 410 nm was noted. The amount of enzyme activity that changed absorbance by 0.001 per minute was considered to be one unit. POD activity was determined using the MacAdam *et al.,* (1992) method. In a final volume of 3.0 ml, the assay mixture included 0.05 M sodium phosphate buffer (pH 7.0), 0.012M H_2O_2, 0.07 M guaiacol, and 0.1 ml of enzyme solution. For three minutes, the rise in absorbance at 470 nm was noted. The amount of enzyme that changed absorbance by 0.01 per minute was considered to be one unit of enzyme activity.

2.6.6. Data and statistical analysis

All the measurements of antioxidant activity of the samples were conducted in triplicate. The results of antioxidant activity are presented as mean ± standard deviation (SD). Concentrations of each samples are presented as mean (n = 3) with the determination of the Least Significant Difference (LSD) for a p value < 0.05. Statistical analysis for stored fruit and vegetable was carried out in two replicates for the control and experimental samples. The data has been analyzed by one-way analysis of variance (ANOVA) followed by Tukey's test, Duncan's multiple range test for the average value of parameter among the treatments and used to compare the mean values between pair of treatments. Difference were calculated to compare significant effect at p<0.05 level.

3. Results

3.1. Antioxidant activity

The antioxidant activity such as standard antioxidant assay DPPH done for the samples (Chitosan, Lactic acid and Chitosan + Lactic acid) using BHT as standard. The results (Figure 1) interpreted that the samples showed increase in inhibition with increase in concentration. The standard antioxidant assay for samples chitosan, lactic acid and chitosan- lactic acid was carried out using BHT as standard among which chitosan and chitosan + lactic acid exhibited a good antioxidant activity.

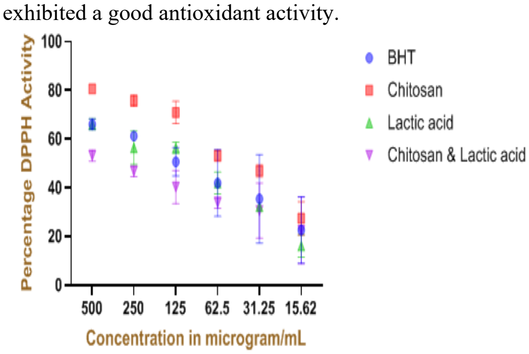

Figure 1. Antioxidant Activity of Chitosan, Lactic acid and Chitosan + Lactic acid

Table 1: EC_{50} values of antioxidant assay of chitosan, Lactic acid and Chitosan + Lactic acid

Samples	EC_{50} values µg/ml
BHT	254.64 ± 3.766[a]
Chitosan	89.61 ± 1.309[bc]
Lactic acid	95.505 ± 1.279[b]
Chitosan + Lactic acid	99.2 ± 0.7778[b]

EC_{50} values represent the concentration at which 50% of the antioxidant activity is observed, measured in mircrograms per milliliter (µg/ml). BHT- Butylated hydroxytoluene, each values in this table represented as mean± SD (n=3).Values in the same column followed by a different letter (p<0.05) are significantly different.

Chitosan, Lactic acid, and Chitosan combined with Lactic acid demonstrated EC_{50} values of 89.61 ± 1.309[bc], 95.505 ± 1.279[b], and 99.2 ± 0.7778[b], respectively (Table 1). These values indicate the concentration at which each sample exhibits 50% of the antioxidant activity compared to the BHT standard. Among the individual samples, Chitosan displayed the highest antioxidant potency, followed by Lactic acid, and the combination of Chitosan with Lactic acid.

3.2. Quality characteristics of stored Tomato

The tomatoes preserved within the coated fabric exhibited alterations in sensory evaluation (Figure 2, Figure 3, and Figure 4). The vegetable specimens that were subjected to storage within the chitosan-shellac coated fabric demonstrated significantly diminished weight loss in comparison to the other coated materials and uncoated specimens. The samples retained in chitosan-shellac-lactic acid experienced a slight reduction in weight when juxtaposed with the uncoated control and chitosan coated packaging materials (Figure 5, Figure 6 and Figure 7).

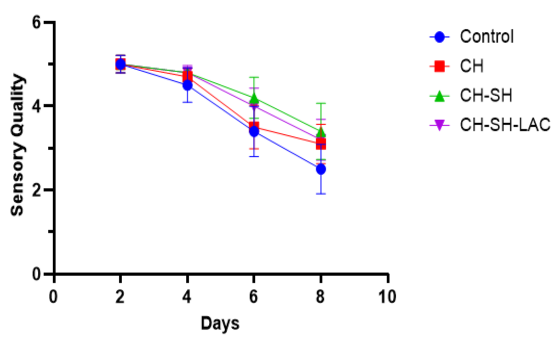

Figure 2. Sensory qualities of tomato stored in paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid. [Control - uncoated Paper, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

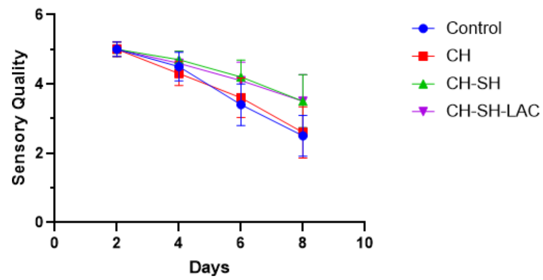

Figure 3. Sensory qualities of tomato stored in thin fabric coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid. [Control - Thin fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

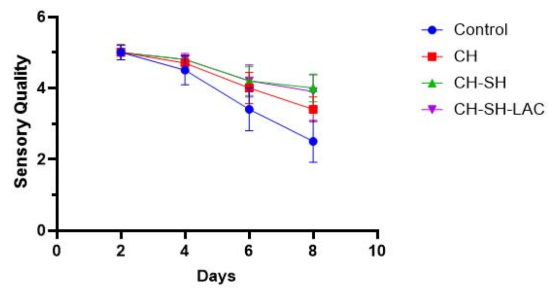

Figure 4. Sensory qualities of tomato stored in thick fabric coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid. [Control - Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

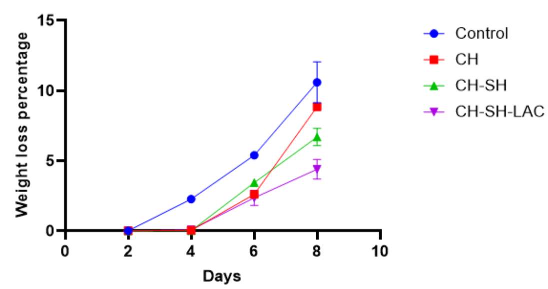

Figure 5. Weight loss % of tomato stored in paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid. [Control - uncoated Paper, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

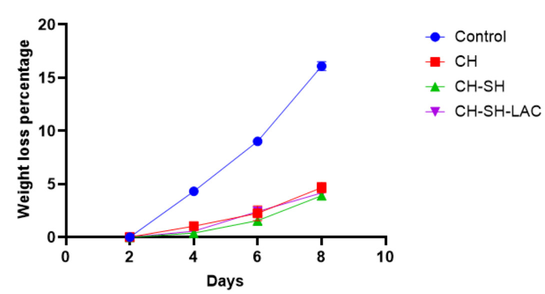

Figure 6. Weight loss % of tomato stored in thin fabric coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid.[Control - Thin fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

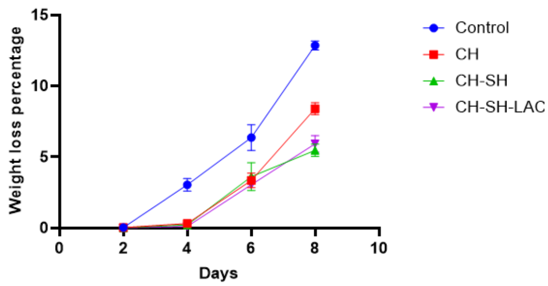

Figure 7. Weight loss % of tomato stored in thick fabric coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid. [Control - Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

The pH levels of the tomatoes fluctuated in chitosan, chitosan-shellac, and chitosan-shellac-lactic acid when compared to pre-treatment measurements on the 4th, 8th, and 12th days. However, a more pronounced difference was observed when these samples were contrasted with those from uncoated packaging materials on the same days. The specimens that were preserved in chitosan-shellac-lactic acid and chitosan-shellac exhibited minimal variations in pH (Table 2).

Following a storage period of 12 days, the total soluble solids content (Table 2), ascorbic acid levels (Table 3), and titratable acidity (Table 3) of the packed tomatoes exhibited a marked decline in comparison to pre-treatment levels. The disparity observed between the values of samples derived from coated versus uncoated packaging materials suggests that the deterioration rate of tomatoes stored in chitosan-shellac coated and chitosan-shellac-lactic acid coated packaging is relatively less severe than that of tomatoes preserved in chitosan coated and uncoated samples. Tomatoes encapsulated in coated packaging demonstrated elevated levels of total soluble solids and titratable acidity.

Throughout the storage duration, the enzymatic activities of polyphenol oxidase (PPO) and peroxidase (POD) in both packed and unpacked tomatoes exhibited an increase. After 12 days of storage, the packed tomatoes revealed enhanced reduction activities of PPO and POD. This observation implies that the coatings utilized on the paper and fabric effectively inhibited the activities of these two enzymes, as evidenced by the lower reduction activities of PPO (Table 4) and POD (Table 4) in the unwrapped and control groups.

The sensory attributes of stored tomatoes have been effectively maintained by the chitosan-shellac-lactic acid coated and chitosan-shellac coated packaging materials in comparison to the samples derived from chitosan coated and uncoated packaging materials. The color, visual appeal, and flavor of the vegetable samples preserved in the coated packaging material were significantly retained when juxtaposed with the samples from the control group.

Vegetable samples preserved in chitosan-shellac coated fabric demonstrated a markedly lower weight loss relative to those stored in alternative coated materials and uncoated samples. Furthermore, samples stored in chitosan-shellac-lactic acid exhibited a marginal reduction in weight in comparison to both the uncoated control and samples preserved in chitosan-coated packaging material. These observations underscore the effectiveness of the chitosan-shellac coating, particularly in conjunction with lactic acid, in sustaining vegetable freshness and mitigating weight loss during the storage period.

Table 2 pH and Total Soluble Solids (°Brix) of tomato stored in fabric and paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid

Sample	**pH**			Total Soluble Solids (°Brix)		
			Before treatment			
	5.8±0.12			4.4±0.17		
			After treatment			
Storage day	4	8	12	4	8	12
			Paper			
Control	5.7±0.04^a	5.4±0.04^a	5.2±0.09^a	4.7±0.09^b	4.9±0.09^b	5.1±0.04^a
CH	5.7±0.09^a	5.5±0.09^a	5.25±0.04^a	5.15±0.04^a	5.1±0.09^a	4.9±0.04^b
CH- SH	5.6±0.09^b	5.1±0.09^b	5.05±0.04^a	5.05±0.14^a	5.1±0.09^a	4.7±0.04^c
CH-SH-LAC	5.4±0.04^c	4.9±0.04^c	4.7±0.09^b	4.65±0.14^b	4.75±0.04^b	4.9±0.04^b
			Thin fabric			
Control	5.55±0.04^b	5.3±0.14^a	4.8±0.04^b	4.45±0.04^a	4.6±0.09^a	5.1±0.09^a
CH	5.75±0.04^a	5.5±0.19^a	4.8±0.04^b	4.4±0.09^b	4.6±0.09^a	4.6±0.09^b
CH-SH	5.65±0.14^a	5.1±0.04^b	5.5±0.09^a	4.15±0.04^b	4.4±0.09^b	4.5±0.04^b
CH-SH-LAC	5.55±0.04^b	5.3±0.09^a	4.8±0.04^b	4.45±0.04^a	4.65±0.04^a	4.0±0.14^c
			Thick fabric			
Control	5.45±0.14^a	5.25±0.04^b	4.9±0.09^b	4.6±0.09^a	4.85±0.04^a	5.15±0.14^a
CH	5.65±0.04^a	6.3±0.09^a	4.85±0.04^c	4.75±0.04^a	4.8±0.09^a	5.1±0.09^a
CH-SH	5.5±0.12^a	5.25±0.04^b	5.5±0.09^a	4.35±0.14^b	4.4±0.09^c	4.65±0.14^b
CH-SH-LAC	5.4±0.1^b	4.9±0.09^c	4.85±0.04^c	4.55±0.04^a	4.65±0.14^b	4.75±0.047^b

Control - uncoated Paper, thin fabric and Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values in this table represented as 'mean ± SD (n=2).Values in the same column followed by a different letter (P<0.05) are significantly different'.

The pH levels of tomatoes subjected to treatment with chitosan, chitosan-shellac, and chitosan-shellac-lactic acid were noted to diminish in comparison to their baseline levels over a duration of 12 days. Nevertheless, when juxtaposed with tomatoes maintained in uncoated packaging materials over the same timeframe, the fluctuations in pH were markedly more pronounced. Specifically, tomatoes preserved in chitosan-shellac-lactic acid and chitosan-shellac displayed relatively minimal alterations in pH, indicating the efficacy of these coating combinations in sustaining pH stability throughout the storage period.

The findings suggest that the total soluble solids content demonstrated a significant reduction in packed tomatoes following a 12-day storage period relative to pre-treatment levels. Conversely, tomatoes stored in coated packaging exhibited a lower total soluble solids content than those maintained in uncoated packaging. This observation implies that the implementation of chitosan-shellac and chitosan-shellac-lactic acid coatings effectively alleviated the decline in TSS content during storage, underscoring their potential role in preserving the quality of tomatoes.

Table 3 Total Titratable Acid (%) and Ascorbic acid (mg/ml) of tomato stored in fabric and paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid

Sample	**Total Titratable Acid (TA) (%)**			**Ascorbic acid (mg/ml)**		
			Before treatment			
	57.12±3.5			34.87±2.06		
			After treatment			
Storage day	4	8	12	4	8	12
				Paper		
Control	49.1±1.20^c	45.36±2.4^b	39.06±1.78^b	33.9±1.38^a	31.4±0.93^a	17.6±1.10^c
CH	52.9±2.41^b	44.1±1.2^b	39.07±1.76^b	31.5±0.95^b	31.5±0.95^a	22.07±0.40^a
CH- SH	51.6±1.20^b	44.1±1.2^b	46.62±1.78^a	27±1.43^d	22.8±0.60^c	17.8±0.90^c
CH-SH-LAC	59.2±1.20^a	51.66±1.2^a	39.3±4.94^b	29.5±0.95^c	25.1±0.59^b	19.6±1.14^b
				Thin fabric		
Control	51.6±1.20^c	46.6±1.78^b	39.0±1.20^c	29.5±1.14^b	24.6±0.94^c	19.9±0.31^b
CH	51.6±1.78^c	50.4±7.12^a	41.5±1.20^b	27.3±1.14^c	24.8±4.33^c	21.3±1.07^a
CH-SH	61.7±1.78^a	51.6±1.78^a	49.1±1.20^a	33.6±1.14^a	31.9±3.33^a	21.6±0.81^a
CH-SH-LAC	56.7±1.78^b	50.4±3.56^a	44.08±1.22^b	29.4±1.14^b	26.6±0.87^b	19.6±1.10^b
				Thick fabric		
Control	56.7±1.78^a	49.1±1.20^b	39.0±1.20^b	29.5±0.95^a	24.6±1.07^b	19.1±0.40^c
CH	54.1±1.78^b	51.6±3.61^a	46.5±1.16^a	31.3±1.07^a	26.6±0.83^a	19.8±0.38^c
CH-SH	55.4±3.56^a	49.1±1.20^b	44.0±1.22^a	27.8±0.62^c	24.5±0.95^b	21.6±0.81^a
CH-SH-LAC	49.1±1.78^c	45.3±2.4^c	38.0±2.16^b	28.8±1.57^b	26.4±0.98^a	20.8±1.33^b

Control - uncoated Paper, thin fabric and Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values in this table represented as 'mean ± SD (n=2).Values in the same column followed by a different letter (P<0.05) are significantly different'.

The results indicate a significant reduction in titratable acidity (TA) of packaged tomatoes after a 12-day storage period when compared to the initial measurements. Nonetheless, tomatoes preserved in coated packaging demonstrated elevated TA levels in contrast to those in uncoated packaging. This highlights the efficacy of chitosan-shellac and chitosan-shellac-lactic acid coatings in alleviating the reduction of TA during the storage process, suggesting their potential role in sustaining the acidity and overall quality of tomatoes over time.

The content of ascorbic acid in packaged tomatoes, as illustrated in Table 3, significantly diminished following a 12-day storage interval relative to pre-treatment levels. Conversely, tomatoes housed in coated packaging exhibited diminished levels of total ascorbic acid. The variation in these measurements between samples derived from coated and uncoated packaging materials implies that the degradation rate in tomatoes stored in chitosan-shellac coated and chitosan-shellac-lactic acid coated packaging is relatively lower than that observed in tomatoes stored in chitosan-coated and uncoated samples.

Table 4 PPO Activity ($\times 10^2$ units/g) and POD Activity ($\times 10^2$ units/g) of tomato stored in fabric and paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid

Sample	PPO Activity ($\times 10^2$ units/g)			POD Activity ($\times 10^2$ units/g)		
	Before treatment					
	14.77±0.72			1.83±0.26		
	After treatment					
Storage day	4	8	12	4	8	12
				Paper		
Control	12 ± 1.91^{c}	11 ± 0.95^{c}	12 ± 1.9^{c}	2 ± 0.3^{a}	2.8 ± 0.7^{a}	3.3 ± 0.3^{a}
CH	12 ± 1.91^{c}	13.6 ± 0.32^{a}	14.7 ± 0.6^{a}	2.17 ± 0.1^{a}	2.67 ± 0.3^{b}	2.8 ± 0.1^{c}
CH- SH	14.7 ± 0.69^{a}	13.6 ± 0.32^{a}	13.6 ± 03^{b}	1.8 ± 0.1^{b}	2.8 ± 0.1^{a}	3.6 ± 0.03^{a}
CH-SH-LAC	13.6 ± 0.32^{b}	12 ± 1.91^{b}	10.6 ± 1.5^{d}	1.8 ± 0.1^{b}	2.1 ± 0.1^{c}	3 ± 0.6^{b}
				Thin fabric		
Control	12 ± 1.91^{b}	11.6 ± 1.5^{c}	12 ± 1.9^{b}	2.07 ± 0.1^{b}	3.15 ± 0.4^{a}	3.3 ± 0.3^{a}
CH	14.72 ± 0.6^{a}	13.6 ± 0.3^{b}	12 ± 1.9^{b}	2 ± 0.3^{c}	2.49 ± 0.1^{b}	3.1 ± 0.4^{b}
CH-SH	14.72 ± 0.6^{a}	14.7 ± 0.6^{a}	11.6 ± 1.5^{c}	2.49 ± 0.1^{a}	3.15 ± 0.4^{a}	2.8 ± 0.1^{c}
CH-SH-LAC	14.72 ± 0.6^{a}	11.6 ± 1.5^{c}	13.6 ± 0.3^{a}	2.07 ± 0.1^{b}	2.49 ± 0.1^{b}	3.3 ± 0.3^{a}
				Thick fabric		
Control	12 ± 1.91^{c}	13.6 ± 0.3^{b}	12 ± 1.9^{b}	2.17 ± 0.1^{a}	2.9 ± 0.6^{a}	3.0 ± 0.54^{b}
CH	12 ± 1.91^{c}	13.6 ± 0.3^{b}	13.6 ± 0.3^{a}	2 ± 0.3^{b}	2.4 ± 0.1^{b}	3.0 ± 0.6^{b}
CH-SH	13.6 ± 0.32^{b}	15.2 ± 0.2^{a}	14.2 ± 0.6^{a}	1.8 ± 0.1^{c}	2.4 ± 0.1^{b}	3.1 ± 0.4^{a}
CH-SH-LAC	14.3 ± 1.01^{a}	13.6 ± 0.3^{b}	11.6 ± 1.5^{c}	2.06 ± 0.1^{a}	2 ± 0.3^{c}	3.3 ± 0.2^{a}

Control - uncoated Paper, thin fabric and Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values in this table represented as 'mean ± SD (n=2).Values in the same column followed by a different letter ($P<0.05$) are significantly different'.

The enzymatic activities of polyphenol oxidase (PPO) in both tomatoes subjected to packaging and those left unpackaged exhibited a temporal increase. Nevertheless, following a 12 day storage period, the tomatoes that were packed demonstrated a more pronounced reduction in PPO activities relative to their unpackaged counterparts. This observation implies that the coatings utilized in the fabric and paper packaging effectively mitigated the enzymatic activity, as indicated by the diminished PPO reduction activities observed in the unwrapped control samples.

Similarly, the activities of peroxidase (POD) in both packed and unpacked tomatoes manifested an increase over the duration of the study. However, after 12 days of storage, the packed tomatoes revealed a more substantial reduction in POD activities in comparison to their unpacked counterparts. This finding suggests that the coatings employed in the fabric and paper packaging served to inhibit the enzymatic activities, as evidenced by the reduced POD activities in the unwrapped control samples.

3.3. Quality characteristics of stored strawberry

The sensory attributes of preserved strawberries have been effectively maintained by the chitosan-shellac-lactic acid coated and chitosan-shellac coated packaging materials when contrasted with samples derived from chitosan coated and uncoated packaging materials (Figure 10). Following a storage duration of six days, the strawberries underwent complete deterioration.

The fruit samples that were retained within the chitosan-shellac coated material demonstrated significantly reduced weight loss in comparison to the other samples from both coated and uncoated materials. The samples preserved in chitosan shellac lactic acid exhibited a reduction in weight relative to the uncoated control and chitosan coated packaging materials (Figure 8). The pH levels of the strawberries varied among those stored in chitosan, chitosan-shellac, and chitosan-shellac-lactic acid when assessed against pre-treatment values on the sixth day. However, a more pronounced difference was observed when these were compared to samples housed in uncoated packaging material on the same days. The samples maintained in chitosan-shellac-lactic acid and chitosan-shellac exhibited minimal alteration in pH (Figure 9).

The concentration of total soluble solids, titratable acidity, and ascorbic acid in packaged strawberries exhibited a significant decline following a storage period of six days (Table 5). Strawberries encased in coated packaging demonstrated elevated levels of total soluble solids, titratable acidity, and ascorbic acid content, and the disparity between these parameters in samples derived from coated versus uncoated packaging materials suggests that the degradation rate of strawberries preserved within chitosan-shellac-coated and chitosan-shellac-lactic acid-coated packaging is relatively lower than that observed in strawberries stored in chitosan-coated and uncoated configurations.

The enzymatic activities of both polyphenol oxidase (PPO) and peroxidase (POD) in both packaged and unpackaged strawberries showed an upward trend throughout the storage duration. The strawberries that were packaged exhibited a greater reduction in the activities of PPO and POD after six days of storage, demonstrating that the coatings applied to the fabric and paper effectively inhibited the activity of these two enzymes, as evidenced by the reduced activities of PPO and POD in the unwrapped and control samples (Table 6).

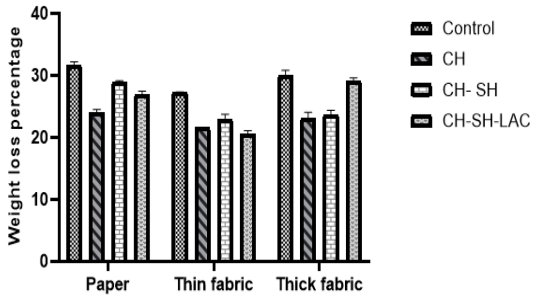

Figure 8. Weight Loss (%) of strawberry stored in fabric and paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid [Control - uncoated Paper, thin fabric and Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

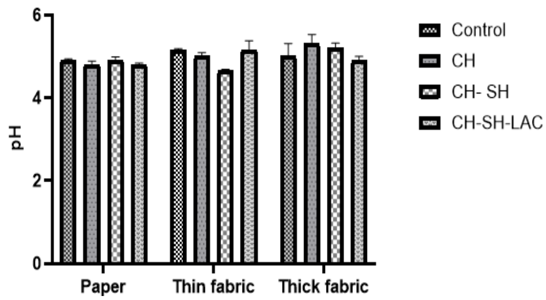

Figure 9. pH of strawberry stored in fabric and paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid [Control - uncoated Paper, thin fabric and Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC- Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

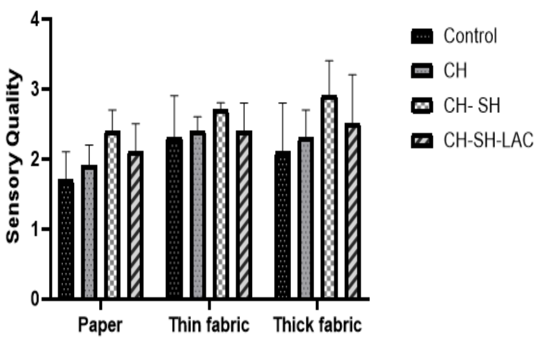

Figure 10. Sensory quality of strawberry stored in fabric and paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid [Control - uncoated Paper, thin fabric and Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values represented as 'mean ± SD (n=2)].

The sensory attributes of strawberries were significantly retained by both chitosan-shellac-lactic acid coated and chitosan-shellac coated packaging materials when juxtaposed with chitosan-coated and uncoated samples. Nonetheless, subsequent to a storage period of 6 days, all strawberries commenced to exhibit signs of deterioration. Among the coated materials, strawberries preserved within chitosan-shellac-coated fabric demonstrated a markedly reduced weight loss, whereas those encapsulated in chitosan-shellac-lactic acid experienced a reduction in weight in comparison to both the uncoated control and the chitosan-coated packaging. Fluctuations in pH levels were detected in strawberries subjected to various coatings, with chitosan-shellac-lactic acid and chitosan-shellac exhibiting minimal alteration relative to uncoated samples throughout the equivalent time frame.

Table 5 Soluble solids (°Brix), Total Titratable Acid (%) and Ascorbic acid (mg/ml) of strawberry stored in fabric and paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid

Sample	Total soluble solids (°Brix)	Total Titratable Acid (%)	Ascorbic acid (mg/ml)
Before Treatment			
	7.18±0.64	57.3±1.82	41.67±1.97
After Treatment			
Storage day	6		
Paper			
Control	7.65±0.14^{b}	50.9±2.97^{a}	34.07±1.3^{c}
CH	7.1±0.09^{c}	44.5±0.75^{c}	35.95±0.4^{b}
CH- SH	8.3±0.09^{a}	47.09±3.16^{b}	35.95±0.4^{b}
CH-SH-LAC	6.1±0.09^{d}	48.4±5.38^{b}	39.95±0.5^{a}
Thin Fabric			
Control	7.65±0.14^{b}	57.45±0.75^{a}	37.5±1.07^{b}
CH	8.45±0.04^{a}	47.65±1.23^{c}	33.4±1.0^{c}
CH-SH	7.55±0.04^{b}	50.96±0.53^{b}	41±0.47^{a}
CH-SH-LAC	6.25±0.23^{c}	57.31±0.61^{a}	38.02±1.31^{a}
Thick Fabric			
Control	6.9±0.09^{b}	50.9±0.53^{b}	37.9±1.41^{b}
CH	6.45±0.04^{b}	53.5±0.54^{b}	35.4±0.90^{c}
CH-SH	8.1±0.09^{a}	57.3±1.81^{a}	34.05±1.3^{c}
CH-SH-LAC	5.2±0.19^{c}	47.0±3.16^{c}	39.95±0.52^{a}

Control - uncoated Paper, thin fabric and Thick fabric, CH- Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values in this table represented as 'mean ± SD (n=2).Values in the same column followed by a different letter ($P<0.05$) are significantly different'.

The findings obtained indicate a notable reduction in total soluble solids, titratable acidity, and ascorbic acid concentration in packed strawberries subsequent to merely six days of storage. Conversely, strawberries encased in coated packaging exhibited diminished levels of these parameters when juxtaposed with those housed in uncoated packaging. This disparity highlights the potential efficacy of chitosan-shellac and chitosan-shellac-lactic acid coatings in alleviating the deterioration of strawberries throughout the storage period, thereby suggesting their effectiveness in maintaining the quality of the fruit over an extended duration.

Table 6 Polyphenol oxidase (PPO) and peroxidase (POD) activity of strawberry stored in fabric and paper coated with Chitosan, Chitosan and Shellac, and Chitosan and shellac with lactic acid

Sample	PPO Activity (×10^2 units/g)	POD Activity (×10^2 units/g)
	Before Treatment	
	15.67.±0.25	1.45±0.18
	After Treatment	
Storage day	6	6
	Paper	
Control	13.6±0.32^a	1.9±0.6^c
CH	8.33±1.59^c	2.5±0.1^b
CH- SH	11.6±1.59^b	2.8±0.1^a
CH-SH-LAC	8.33±1.59^c	2.0±0.3^c
	Thin Fabric	
Control	8.33±1.5^c	2.5±0.1^b
CH	8.33±1.5^c	2.8±0.1^a
CH-SH	11.6±1.5^a	2.1±0.4^c
CH-SH-LAC	9.33±1.5^b	2.0±0.6^c
	Thick Fabric	
Control	8.33±1.5^c	2.3±0.6^b
CH	11.6±1.5^b	2.5±0.1^a
CH-SH	13.6±03^a	2.1±0.4^c
CH-SH-LAC	8.33±1.5^c	2.1±0.4^c

Control - uncoated Paper, thin fabric and Thick fabric, CH-Chitosan CH+SH – Chitosan with Shellac, CH+SH+LAC - Chitosan with shellac and lactic acid. Each values in this table represented as 'mean ± SD (n=2).Values in the same column followed by a different letter (P<0.05) are significantly different'.

During the process of storage, the enzymatic activities of both polyphenol oxidase (PPO) and peroxidase (POD) in strawberries, irrespective of packaging conditions, exhibited a progressive increase over time. On the sixth day of storage, strawberries housed within coated packaging materials demonstrated a more pronounced reduction in the activities of PPO and POD in contrast to those that remained unpackaged. This observation implies that the coatings utilized in the fabric and paper packaging effectively mitigated the enzymatic activity of these biocatalysts, as corroborated by the diminished reduction activities of PPO and POD observed in the unwrapped control samples.

4. Discussion

The research on composite fabric food packaging with lactic acid and chitosan-shellac coating demonstrates the effectiveness of these coatings in preserving the quality and extending the shelf life of both tomatoes and strawberries.

The antioxidant activity assays revealed that both chitosan and chitosan-lactic acid exhibited strong antioxidant properties, with chitosan showing the highest antioxidant potency. This suggests that the incorporation of chitosan in food packaging can effectively enhance the oxidative stability of the packaged produce. The EC_{50} values for chitosan, lactic acid, and their combination were 89.61 ± 1.309^{bc}, 95.505 ± 1.279^{b}, and 99.2 ± 0.7778^{b}, respectively, highlighting the superior antioxidant potential of chitosan over lactic acid, either alone or in combination. These results align with other studies that have reported the strong antioxidant properties of chitosan, which contribute to its ability to protect food products from oxidative damage during storage. Relevant studies on the antioxidant properties of chitosan have demonstrated its efficacy in enhancing oxidative stability in food products. According to Sun *et al.* (2022), chitosan blended with ginseng residue polysaccharides acts as an antioxidant in food packaging, delaying deterioration in fresh-cut melon by enhancing oxidative stability through a proposed antioxidant mechanism. Similarly, Han *et al.* (2018) reported that chitosan enhances oxidative stability in food products by reducing lipid oxidation products through altering microstructure, entrapping fat droplets, and impacting water mobility in the meat-based matrix. Chitosan enhances oxidative stability in food products by incorporating natural extracts, essential oils, and plant extracts, which provide antioxidant properties, thus extending shelf-life and preserving quality (Muñoz-Tebar *et al.,* 2023).

Tomatoes stored in chitosan-shellac coated fabric experienced significantly lower weight loss compared to those stored in other coatings or uncoated materials. This reduction in weight loss can be attributed to the barrier properties of the chitosan-shellac coating, which effectively reduces moisture loss and delays dehydration, a common issue in the storage of fresh produce. Additionally, the chitosan-shellac-lactic acid coating further minimized weight loss, although the effect was slightly less pronounced than that of the chitosan-shellac combination. The pH stability, total soluble solids, titratable acidity, and ascorbic acid content were better preserved in tomatoes stored in chitosan-shellac and chitosan-shellac-lactic acid coated packaging, indicating the coatings' ability to maintain the quality of the tomatoes over a 12-day storage period. The inhibition of PPO and POD activities in coated tomatoes further supports the coatings' role in delaying enzymatic browning and spoilage, consistent with findings from other studies that have highlighted the effectiveness of chitosan-based coatings in reducing enzymatic activities in stored fruits. This result ties well with previous studies by Zhelyazkov *et al.* (2023), wherein Chitosan-lactic acid coatings positively impact sensory qualities by reducing water loss, enhancing taste, and increasing soluble solids and acidity, thus preserving quality and extending shelf life of food products. A similar conclusion was reached by Riseh *et al.* (2023) in the research, where Chitosan-based nanocomposites, including chitosan-lactic acid coatings, enhance postharvest quality of agricultural products without significant sensory or nutritional property alterations. Other results were broadly in line with the work carried out by Esin & Özlem (2019), and the insights are chitosan-lactic acid-based coatings inhibit *Escherichia coli* and *Salmonella enteritidis*, enhancing food safety without affecting sensory or nutritional properties of chicken and quail eggs. In addition, Pagno *et al.* (2018) reported that Chitosan-lactic acid coatings maintain firmness, reduce weight loss, lower ethylene emission, and slow down nutraceutical loss in fruits like tomatoes, preserving their sensory and nutritional qualities during storage.

In the quality characteristics of stored strawberries, similar trends were observed in strawberries, although the storage duration was shorter, with significant deterioration occurring after 6 days. The chitosan-shellac and chitosan-shellac-lactic acid coatings were effective in reducing weight loss, maintaining pH stability, and preserving total soluble solids, titratable acidity, and ascorbic acid content. The reduced PPO and POD activities in coated strawberries further demonstrate the coatings' ability to inhibit enzymatic reactions that lead to spoilage, consistent with previous research on the preservation of strawberries using chitosan-based coatings. The rapid deterioration of strawberries compared to tomatoes may be due to their higher metabolic activity and sensitivity to storage conditions, underscoring the need for effective preservation techniques in the storage of delicate fruits like strawberries. In a similar research, chitosan-based edible coatings, enriched with lactic acid bacteria, have shown significant potential in reducing strawberry spoilage during refrigerated storage. Studies have demonstrated that coatings incorporating chitosan, lactic acid bacteria, and other natural compounds like putrescine can effectively extend the shelf life of strawberries by reducing decay, weight loss, and microbial growth (Bahmani *et al*., 2024). Additionally, the application of chitosan and beeswax coatings has been found to enhance the physicochemical properties of strawberries, such as hardness, total soluble solids, and ascorbic acid content, thereby improving their overall quality and longevity at room temperature (Lalengmawii & Topno, 2024). Furthermore, the integration of phytochemical-encapsulated nanoparticles in chitosan-based coatings has been shown to inhibit microbial growth, prevent nutrient loss, and preserve the quality of strawberries during storage at both room and refrigerated temperatures (Benavides & Franco, 2023; Fan & Aimo, 2023). These findings collectively highlight the efficacy of chitosan-based edible coatings in mitigating spoilage and enhancing the storage quality of strawberries.

The integration of lactic acid and chitosan in composite fabric food packaging, particularly with shellac coating, presents a novel approach to preserving tomatoes and strawberries. This method not only enhances the shelf life of these fruits but also aligns with the growing demand for sustainable and biodegradable packaging solutions. Novel contributions to food preservation is the enhanced mechanical properties, which is evident by the incorporation of lactic acid that improves the mechanical strength of the packaging, making it more durable compared to existing chitosan-based films (He *et al.,* 2024). Studies indicate that the proposed composite can extend the shelf life of strawberries by over 15 days, surpassing many current packaging solutions (Yaowen *et al.,* 2016). This approach utilizes renewable resources, contributing to a more sustainable food packaging industry, as highlighted in recent advancements in edible coatings (Juric *et al.,* 2024).

The cost-effectiveness of composite fabric food packaging with lactic acid and chitosan, particularly when compared to traditional waxed paper, is supported by several studies. Chitosan-based coatings have demonstrated significant effectiveness in extending the shelf life of fruits like strawberries and tomatoes. For instance, coatings can reduce weight loss and inhibit microbial growth, prolonging freshness by several days (He *et al.,* 2024; Lai *et al*., 2024). Chitosan is biodegradable and non-toxic, making it a more environmentally friendly option compared to traditional waxed papers, which often contain synthetic materials (Priyadarshi *et al.,* 2024; Suresh *et al.,* 2024). The development of chitosan-based coatings aligns with the growing demand for sustainable packaging solutions, potentially reducing waste and environmental impact (Zou *et al.,* 2024). Although initial costs may be higher, the extended shelf life and reduced spoilage rates can lead to lower overall costs for producers and retailers (Suresh *et al.,* 2024). The ability to maintain product quality can enhance consumer satisfaction and reduce losses due to spoilage, ultimately benefiting the supply chain economically (Lai *et al.,* 2024).

This approach leverages the biodegradable properties of chitosan and lactic acid, enhancing food preservation while addressing environmental concerns associated with synthetic coatings. Chitosan exhibits excellent film-forming, mechanical strength, and antimicrobial properties, making it effective for extending the shelf life of strawberries (Priyadarshi *et al.,* 2024). Polylactic acid (PLA) reinforced with antibacterial fillers shows improved barrier properties and moisture resistance, effectively preserving fruits (Pradhan *et al.,* 2024). Chitosan-essential oil films enhance antimicrobial activity and antioxidant effects, providing a natural preservation method (Liu *et al.,* 2024). While synthetic coatings like polyethylene offer superior barrier properties, they are non-biodegradable and contribute to environmental pollution (Cheng *et al*., 2024). The migration of microplastics from synthetic films into food raises health concerns, prompting a shift towards biodegradable alternatives (Liu *et al*., 2024). In contrast, while biodegradable coatings like chitosan and PLA composites offer environmental benefits, they may face challenges such as inferior mechanical strength and higher costs compared to synthetic options (Cheng *et al.,* 2024). The use of composite fabric food packaging incorporating lactic acid and chitosan with shellac coating presents a promising alternative for preserving fruits like tomatoes and strawberries.

5. Conclusion

In conclusion, the application of chitosan, shellac, and lactic acid coatings on composite fabric food packaging materials demonstrated significant potential in enhancing the preservation of both tomatoes and strawberries during storage. The antioxidant activity, particularly in chitosan and the chitosan-lactic acid combination, was effective, as evidenced by their superior EC_{50} values, indicating strong antioxidant potency. The quality characteristics of the stored tomatoes and strawberries, including weight loss, pH stability, total soluble solids, titratable acidity, and ascorbic acid content were better preserved in the chitosan-shellac and chitosan-shellac-lactic acid coated packaging compared to uncoated or solely chitosan-coated samples.

Furthermore, the inhibition of polyphenol oxidase (PPO) and peroxidase (POD) activities in both tomatoes and strawberries suggests that these coatings effectively slow down enzymatic reactions that contribute to the deterioration of the fruits. The coatings also maintained the sensory qualities, such as color, appearance, and taste, of the fruits more effectively than the other tested materials.

Overall, the findings highlight the efficacy of chitosan-shellac and chitosan-shellac-lactic acid coatings in extending the shelf life and preserving the quality of fruits during storage. These results suggest that such coatings have significant potential for use in food packaging applications, offering a promising approach to reducing food spoilage and waste.

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Disclosure

The authors report no conflicts of interest in this work.

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