

Eco-Shield: Natural Edible Coatings to Reduce Fruit Waste and Environmental Impact

Soyee Lee

Chadwick International School
Incheon, Korea
soyeelee1225@gmail.com

Soyeon Shin

Chadwick International School
Incheon, Korea
izzysin3596@gmail.com

Michael Lee

Crean Lutheran High School
Irvine, CA
michael.lee.28@stu.creanlutheran.org

Abstract

Food waste is a major environmental issue, with approximately 1.3 billion tonnes of food lost or wasted globally each year. This STEM project examined whether natural edible coatings could slow fruit spoilage at the consumer stage. Three coatings were tested: chitosan (CH), chitosan combined with tea polyphenols (CT), and aloe vera gel (A). Strawberries, cherry tomatoes, and apples were treated and stored under room temperature (23°C) and refrigerated (4°C) conditions for seven days. Five indicators were recorded daily: mass loss, color change, mold growth, firmness, and odour. CT showed the most promising performance in this preliminary trial. At room temperature, on average, CT reduced strawberry weight loss from 10.6% in the control group to 7.60% – a reduction of about 3%, or roughly 28% relative to the control. Under refrigeration, CT produced the lowest strawberry weight loss at 1.42%, compared with 4.10% in the control group. CT also maintained mold and color scores of 0 for cherry tomatoes through Day 7 without cold storage. These findings suggest that chitosan combined with tea polyphenols may serve as a low-cost, biodegradable coating option for reducing fruit spoilage. Future work should use objective measurement tools to increase accuracy and credibility of the results.

Keywords

Sustainability, Environmental Waste Management, Food Waste Prevention, Business Model, Environmental Sustainability

1. Introduction

1.1 Food Loss and Food Waste

Food loss and food waste together account for a significant share of global resource waste each year. This study focuses specifically on the consumer stage — where fruit spoils before it is used — and investigates whether natural edible coatings may extend shelf life and reduce this form of waste.

1.2 Global Scale of the Problem

According to the Food and Agriculture Organization of the United Nations (FAO), approximately 1.3 billion tonnes of food are lost or wasted every year worldwide, representing nearly one-third of global food production. In South Korea alone, approximately 5 million tonnes of food waste are generated annually, adding pressure on waste management systems and the environment (Lee et al. 2024). Food waste contributes significantly to environmental damage and economic loss.

1.3 Environmental Impact of Food Loss and Waste

When food is discarded and sent to landfill, it can release methane, a major greenhouse gas associated with solid waste disposal (IPCC 2006). Beyond emissions, food waste also means wasting the water, land, and energy already spent producing it. Reducing food waste is therefore not merely an economic concern but an environmental one.

1.4 Problem Statement and Research Purpose

Fruits spoil quickly because of microbial growth, browning, and moisture loss. Common solutions include plastic wrapping, chemical preservatives, and refrigeration. However, these methods can raise cost or environmental concerns, and are not always accessible at home.

Natural edible coatings may offer a low-cost and biodegradable alternative. Chitosan, a biopolymer derived from chitin, is widely used for its film-forming and antimicrobial properties in postharvest fruit preservation (Wang et al. 2024). Tea polyphenols can improve the antioxidant function of chitosan coatings (Dai et al. 2022). Aloe vera gel has also been studied as an edible coating agent due to its antimicrobial and moisture-retaining properties (Serrano et al. 2006; Sogvar et al. 2016). This study tests whether these coatings can slow fruit spoilage and help reduce food waste.

2. Literature Review

2.1 Edible Coatings for Postharvest Preservation

Edible coatings have been studied as an alternative to synthetic packaging for extending the shelf life of fresh produce. By forming a semi-permeable barrier on the fruit surface, these coatings can show respiration, reduce moisture loss, and limit microbial growth. Natural polymer-based coatings are of particular interest because they are biodegradable and generally regarded as safe for consumption.

2.2 Chitosan in Postharvest Preservation

Chitosan is a polysaccharide derived from chitin, most commonly obtained from crustacean shells. It forms a semi-permeable film on the fruit surface that slows moisture loss and gas exchange, and has been widely studied for its antimicrobial properties in postharvest fruit preservation research (Wang et al., 2024).

2.3 Tea Polyphenols and Aloe Vera as Coating Additives

The addition of bioactive compounds to chitosan films has been explored to improve their functional performance. Tea polyphenols have antioxidant and antimicrobial properties that may complement the barrier function of chitosan. They can inhibit oxidative browning by scavenging reactive oxygen species, and their incorporation into chitosan films has been shown to improve both preservation efficacy and film mechanical properties (Dai et al., 2022).

Aloe vera gel forms a polysaccharide-based film that reduces water vapor loss and has been reported to inhibit common postharvest pathogens, including *Penicillium digitatum* and *Aspergillus niger* (BioResources, 2024). Its bioactive compounds, including acemannan and phenolic constituents, contribute mild antimicrobial and antioxidant effects (Serrano et al., 2006; Sogvar et al., 2016).

2.4 Research Gap

Most previous studies evaluated coating materials under controlled laboratory conditions and on a single fruit type. Few studies have compared multiple biodegradable coatings across fruits with different moisture contents under both refrigerated and ambient household storage conditions. This study tests whether such combinations can slow spoilage in strawberries, cherry tomatoes, and apples under both room temperature and refrigerated conditions, contributing to a practical understanding of their comparative effectiveness.

3. Methods

3.1 Materials

The following reagents and materials were used in this experiment:

Reagents: chitosan powder, tea polyphenol (or green tea extract), acetic acid, glycerol, aloe vera gel, distilled water.

Equipment: digital scale, beakers (4–5), glass rod or magnetic stirrer, measuring cylinder or pipette, strainer, labels, gloves, mask, drying tray, sealed storage containers, paper towels, camera or smartphone, ruler or caliper, data recording sheets.

Experimental fruits: three fruit types were selected to represent a range of spoilage rates: strawberries (very perishable), cherry tomatoes (moderate shelf life), and apples (longer shelf life). Strawberries were included because their high moisture content and rapid spoilage make coating effects easier to observe. Fruits of similar size, color, and ripeness were selected, and any fruits showing visible damage or softening prior to treatment were excluded.

3.2 Experimental Design

The treatment groups are described in Table 1. One fruit per treatment group was assigned to each storage condition, and each treatment-storage condition was replicated three times, resulting in 24 samples per fruit type (four coating treatments $\times$ two storage conditions $\times$ three replicates). Values reported represent the average across the three replicates.

Table 1. Treatment groups used in the Experiment

Group	Treatment	Description
Control	No coating	Uncoated; dipped in distilled water only
Treatment A	Chitosan only	Coated with 1.0% w/v chitosan solution
Treatment B	Chitosan + Tea Polyphenol	Coated with 1.0% w/v chitosan + 0.50% w/v tea polyphenol solution
Treatment C	Aloe Vera	Coated with 70% w/v aloe vera gel solution

Each fruit type was tested under two storage conditions: room temperature (23°C) and refrigerated (4°C), away from direct sunlight. Quantitative data were recorded daily over seven days (Day 0–7). The experiment was terminated on Day 7, when the room-temperature control strawberry reached a mold score of 4 — the maximum on the scale — indicating complete spoilage.

3.3 Coating Solution Preparation

Solution A — Chitosan only (100 mL): 1.0 g chitosan powder, 1.0 mL acetic acid, 0.5 mL glycerol, distilled water to 100 mL.

80 mL of distilled water was placed in a beaker. Acetic acid (1.0 mL) was added and mixed. Chitosan (1.0 g) was added gradually with continuous stirring until fully dissolved. Glycerol (0.5 mL) was added and mixed thoroughly. Distilled water was added to bring the total volume to 100 mL. The solution was allowed to stand for 20–30 minutes to allow air bubbles to dissipate before use.

Solution B — Chitosan + Tea Polyphenol (100 mL): 1.0 g chitosan powder, 1.0 mL acetic acid, 0.5 mL glycerol, 0.5 g tea polyphenol, distilled water to 100 mL.

Solution A was first prepared as described above. Tea polyphenol (0.5 g) was dissolved separately in 10–20 mL of distilled water, then added slowly to the chitosan solution with stirring. The total volume was adjusted to 100 mL and allowed to stand until bubble-free before use.

Solution C — Aloe Vera (100 mL): 70 mL aloe vera gel, 29 mL distilled water, 1 mL glycerol.

Aloe vera gel (70 mL) was placed in a beaker. Distilled water (29 mL) was added and mixed thoroughly. Glycerol (1 mL) was added as a plasticizer and stirred until homogeneous.

3.4 Fruit Preparation and Coating Application

Fruits were gently rinsed with distilled water and dried thoroughly using paper towels. Each fruit was assigned a unique identification label according to treatment group and storage condition (e.g., C-RT for control at room temperature, CT-RF for chitosan-tea polyphenol under refrigeration). Initial photographs and weight measurements were recorded prior to coating application.

Dip coating was used as the application method, consistent with standard practice in edible coating research. Fruits were fully submerged in their respective coating solutions for 30–60 seconds, removed, and excess solution was allowed to drain. Fruits were air-dried at room temperature for 30–60 minutes. Control group fruits were dipped briefly in distilled water under equivalent handling conditions.

3.5 Experimental Setup

Figure 1 shows the experimental arrangement of all fruit samples across the four treatment groups at Day 0.



Figure 1. Experimental arrangement of fruit samples (apples, cherry tomatoes, and strawberries) across four treatment groups (C = Control, CH = Chitosan, CT = Chitosan + Tea Polyphenol, A = Aloe Vera) at Day 0. Upper tray: room temperature group; lower tray: refrigerated group.

3.6 Measurement Variables

Mass loss (%): daily weight recorded using a digital scale.

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

Visual appearance score: 0 = very fresh; 1 = slight change; 2 = slight wrinkling or browning; 3 = noticeable softening or browning; 4 = partial decay; 5 = severe decay.

Mold growth: assessed on a 5-point scale, where 0 = no visible mold, 1 = slight mold, 2 = moderate mold, 3 = severe mold, and 4 = complete visible spoilage. The first date of mold appearance was also recorded.

Odor: assessed on a 4-point scale: 0 = no odor; 1 = slight fermentation smell; 2 = noticeable off-odor; 3 = strong spoilage odor.

Firmness: manual tactile evaluation on a 6-point scale: 0 = very firm; 5 = very soft.

3.7 Variables

Independent variable: coating treatment (Control / Chitosan / Chitosan + Tea Polyphenol / Aloe Vera).

Dependent variables: weight loss (%), color change score, mold growth incidence, firmness score, odor score.

Controlled variables: fruit type and variety, fruit size and ripeness, coating application method and duration (30–60 seconds), drying time (30–60 minutes), storage temperature, storage container type, observation time (same time daily), lighting conditions during photography, and measurement instruments.

3.8 Data Analysis

Each treatment-storage condition was replicated three times across independent experimental groups. The reported values are representations of the mean of three replicates. Results were compared descriptively against the control to identify trends and presented in graphs to show changes over the observation period.

4. Data Collection

Group labels: C = Control, CH = Chitosan, CT = Chitosan + Tea Polyphenol, A = Aloe Vera. Figure 2 shows the visual state of all samples at Day 7, illustrating the clear difference in spoilage progression between storage conditions.



Figure 2. Visual state of all fruit samples at Day 7. Upper tray: room temperature (23°C); lower tray: refrigerated (4°C). Strawberries in the room temperature group show extensive mold and browning across all treatment groups, while refrigerated samples—particularly CT and A—remained in better condition.

4.1 Mass Loss

Mass loss was recorded across all three fruit types under both storage conditions (Figure 3). Day 0 measurements were taken immediately after coating application and drying. Under refrigerated conditions, some groups recorded a slight weight gain at Day 1, likely due to residual moisture from the coating solution being absorbed into the fruit surface during the initial drying period. Values stabilised from Day 2 onward. For strawberries at room temperature, Day 7 values were: C = 10.61%, CH = 8.09%, CT = 7.60%, A = 10.13%. CH and CT reduced moisture loss noticeably; A did not. Under refrigeration, all groups lost less weight: C = 4.10%, CH = 3.10%, CT = 1.42%, A = 1.47%. CT and A had the lowest weight loss in this preliminary comparison. Cherry tomatoes showed little difference between groups at room temperature (11.19–12.08%), suggesting limited coating adhesion on smooth surfaces (see Section 5.2). Apples lost the least weight overall (1.34–1.93%), likely because their waxy cuticle already acts as a natural moisture barrier (see Section 5.2).

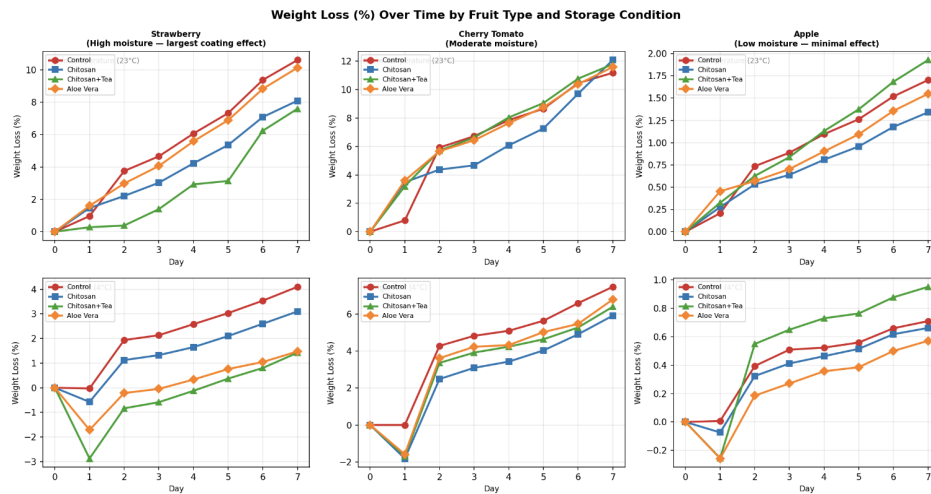


Figure 3. Weight loss (%) over time across four treatment groups (Day 0–7) for strawberries (high moisture), cherry tomatoes (moderate moisture), and apples (low moisture) under room temperature (top) and refrigerated conditions (bottom). Strawberries show the largest inter-group differences, consistent with their higher moisture content and spoilage susceptibility.

4.2 Decay Score (Mold and Color Change)

Mold growth and color change were most pronounced in strawberries stored at room temperature (Figure 4). First mold appearance in all groups occurred at Day 3 under room temperature. By Day 7, mold scores were: C = 4, CH = 4, CT = 4, A = 3, and color scores reached 4 across all groups — indicating that room temperature storage ultimately overwhelmed coating protection for strawberries regardless of treatment. Under refrigeration, however, a clear treatment effect emerged: first mold appeared at Day 5, and by Day 7 C and CH scored 1 while CT and A scored 0. Color scores followed a similar pattern, with CT and A maintaining score 0 under refrigeration at Day 7 versus score 1 for C and CH. Cherry tomatoes showed less pronounced changes compared to strawberries: by Day 7 at room temperature, CT and A scored 0 for both mold and color, while C and CH scored 1. Under refrigeration, CT, CH, and A all scored 0 while C scored 1. Apples showed no mold or color change (score 0) across all groups and conditions throughout the experiment.

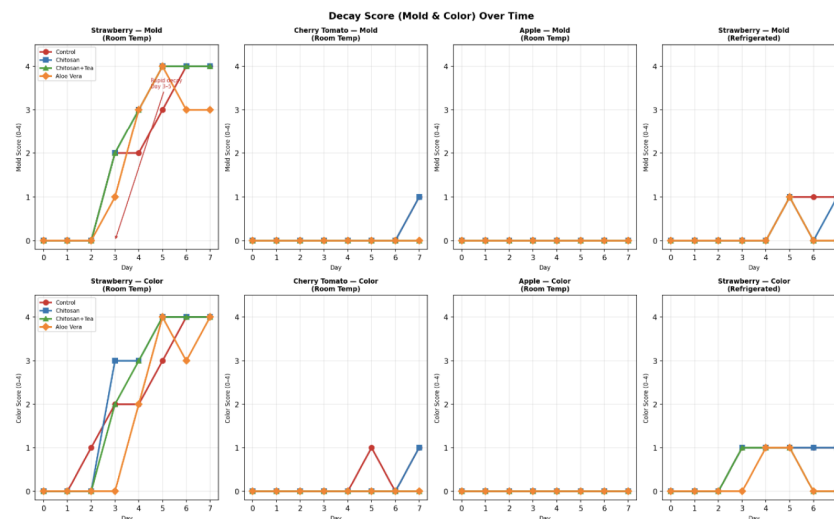


Figure 4. Mold growth score (top row) and color change score (bottom row) over time across four treatment groups (Day 0–7). Columns show strawberry room temperature, cherry tomato room temperature, apple room temperature,

and strawberry refrigerated. Strawberries show the most pronounced inter-group differences, particularly under refrigerated conditions.

4.3 Final Day Comparison

Figure 5 shows the Day 7 comparison for all four groups across strawberries. At room temperature, CT achieved the lowest weight loss (7.60%) and CH was second (8.09%); A showed no improvement over the control. Under refrigeration, CT and A both scored 0 for mold and color. CT recorded the lowest weight loss overall (1.42%).

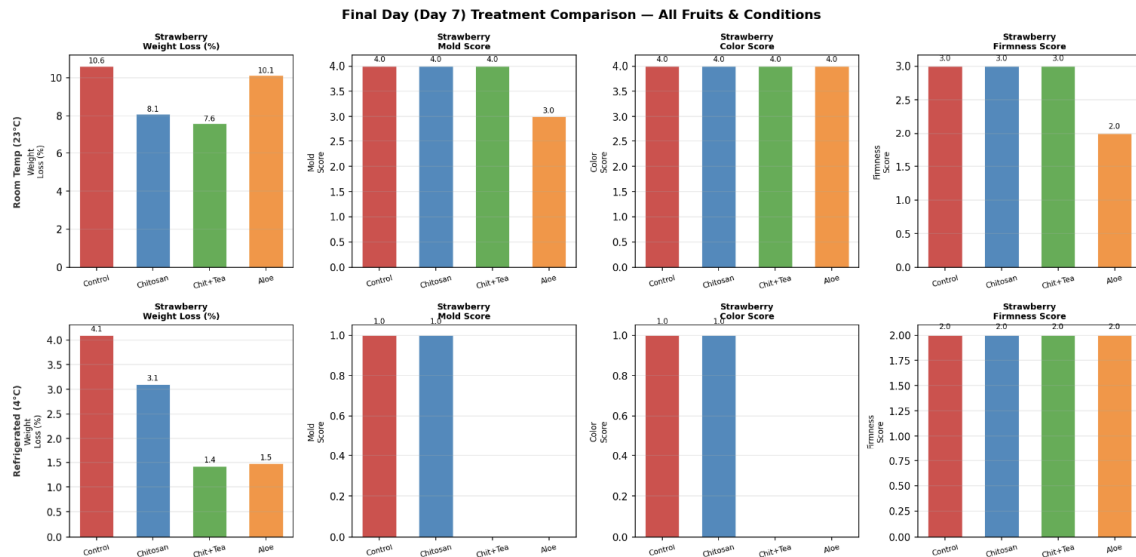


Figure 5. Final Day 7 comparison of all four treatment groups for strawberries across four variables (weight loss, mold score, color score, firmness score) under room temperature (top row) and refrigerated conditions (bottom row). CT had the most favorable Day 7 results, especially under refrigeration.

4.4 Firmness

Firmness loss was most evident in strawberries (Figure 6; scale: 0 = very firm, 5 = very soft). At room temperature by Day 7, all coating groups scored 3, identical to the control. Coating treatment made no difference to firmness under room temperature conditions for strawberries. Under refrigeration, all groups scored 2 at Day 7, suggesting refrigeration had a stronger effect on firmness than the coatings. Cherry tomatoes showed modest changes; by Day 7, CH scored 2 while C, CT, and A all scored 1. Apples remained largely firm: C scored 1 at Day 7 under room temperature while all coated groups scored 0, and all groups scored 0 under refrigeration.

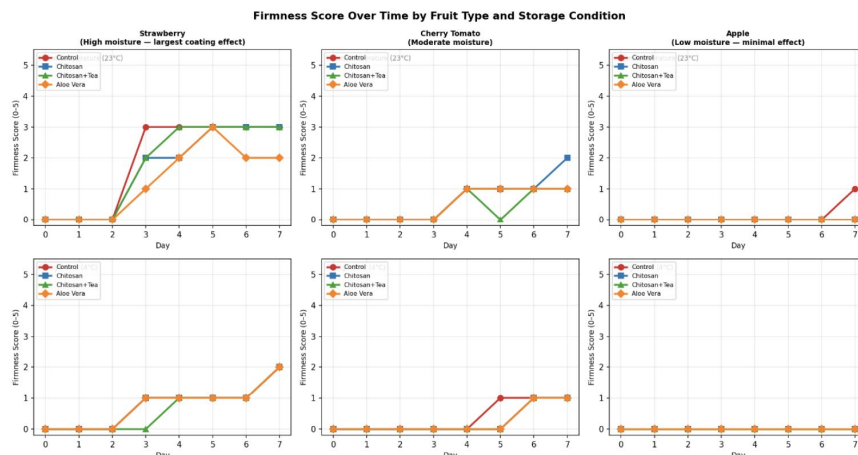


Figure 6. Firmness score over time across four treatment groups (Day 0–7) for all three fruit types under room temperature (top) and refrigerated conditions (bottom). Score range: 0 = very firm, 5 = very soft.

5. Results and Discussion

5.1 Mechanism-Based Interpretation of Results

Each coating material works through a different mechanism. Together, they may target several causes of fruit spoilage.

Chitosan (CH): Chitosan has positively charged amino groups. These can disrupt cell membranes of bacteria and fungi, causing cell death (Wang et al. 2024). It also forms a semi-permeable film on the fruit surface, slowing both respiration and moisture loss. This likely accounts for the lower weight loss in CH-coated strawberries (8.09%) versus the control (10.61%) at room temperature.

Chitosan + Tea Polyphenol (CT): CT showed the most favorable pattern, especially in strawberry samples. Tea polyphenols scavenge reactive oxygen species (ROS) and chelate metal ions involved in oxidation, thereby inhibiting browning (Dai et al. 2022). Combined with chitosan's antimicrobial barrier, CT may address both microbial growth and oxidative browning — two of the three primary spoilage drivers. This may explain why CT performed better than chitosan alone in this experiment.

Aloe Vera (A): Aloe vera forms a polysaccharide-based film that reduces water vapor loss. Its bioactive compounds — including acemannan and anthraquinones — also contribute mild antimicrobial and antioxidant effects (Serrano et al. 2006; Sogvar et al. 2016). Under refrigerated conditions, A coating achieved mold and color scores of 0 at Day 7 for both strawberries and cherry tomatoes, matching CT. At room temperature, however, moisture retention was limited in strawberries.

5.2 Effect of Fruit Moisture Content on Coating Efficacy

Coating effectiveness varied across fruit types. Strawberries — high moisture (~90%), rough surface — showed the largest differences between groups. They were the most sensitive indicator of coating performance. Cherry tomatoes showed modest benefits despite similar moisture content. Their smooth, low-porosity surface likely limited how well coatings could adhere. Apples showed almost no change across all groups. Their natural waxy cuticle already resists moisture loss and microbial growth. Based on these results, coatings appear most effective on high-moisture, highly perishable fruits, which are more likely to spoil during household storage.

5.3 Role of Storage Temperature

Refrigeration consistently outperformed room temperature as a preservation condition. Differences between coating groups were clearer under cold storage. This suggests that coatings worked best when combined with refrigeration. At room temperature, elevated microbial activity appeared to overwhelm coating protection — all strawberry groups reached the maximum mold score by Day 7 at 23°C.

5.4 Environmental Implications

Slowing fruit spoilage by even a few days could reduce the volume of fruit discarded at the household stage. To illustrate the potential scale: according to the FAO, approximately 1.3 billion tonnes of food are wasted globally each year, a significant portion of which consists of highly perishable fruits and vegetables. If edible coatings reduced spoilage of highly perishable fruits by even 10% at the household level, this could represent tens of millions of tonnes of food preserved annually. Less food waste in landfills means less methane from anaerobic decomposition (IPCC, 2006). Because the main coating materials are naturally derived and biodegradable, they may also reduce reliance on plastic-based preservation methods, offering a dual environmental benefit. However, it should be noted that this study measured preservation effects only; direct measurement of waste reduction or methane emissions was beyond the scope of this experiment. These environmental benefits therefore remain projected rather than experimentally confirmed.

5.5 Limitations

This study has two primary limitations. First, three replicates were used per treatment group per storage condition across independent experimental groups. While this provides a basis for mean comparisons, a minimum of 8–10 samples per group would be needed to enable statistically meaningful analysis in future studies. Second, visual appearance, mold, and firmness were all assessed by observation. Subjective scoring introduces inconsistency; objective instruments such as colorimeters and texture analyzers would yield more reliable data.

5. Conclusion

The most notable finding was that CT showed a measurable reduction in weight loss at room temperature across replicated experimental groups. Without cold storage, CT reduced strawberry weight loss by 28% relative to the control, and maintained mold and color scores of 0 for cherry tomatoes through Day 7. These trends suggest that chitosan combined with tea polyphenols may offer some preservation benefit under ambient conditions, which are common during transport, display, and short-term household handling. However, these findings should be interpreted as preliminary evidence rather than definitive proof of coating efficacy. Given the preliminary nature of this study, further replication and statistical analysis are needed before broader claims about coating effectiveness can be made.

References

- Food and Agriculture Organization of the United Nations, Global food losses and food waste: Extent, causes and prevention, FAO, 2011.
- Intergovernmental Panel on Climate Change, 2006 IPCC guidelines for national greenhouse gas inventories: Volume 5, waste, IPCC, 2006.
- Lee, E., et al. The management of food waste recycling for a sustainable future: A case study on South Korea, Sustainability, vol. 16, no. 2, p. 854, 2024.
- Ma, M., et al. Effect of tea polyphenols on chitosan packaging for food preservation: Physicochemical properties, bioactivity, and nutrition, International Journal of Biological Macromolecules, vol. 259, no. 2, article 129267, 2024.
- Meher, J., et al. Extending tomato freshness: The role of aloe vera gel in reducing post-harvest losses, BioResources, vol. 20, no. 3, pp. 6633–6647, 2025.
- Wang, J., et al. Application of chitosan in fruit preservation: A review, Food Chemistry: X, vol. 23, article 101589, 2024.
- Serrano, M., et al. Use of Aloe vera gel coating preserves the functional properties of table grapes, Journal of Agricultural and Food Chemistry, vol. 54, no. 11, pp. 3882–3886, 2006.
- Sogvar, O. B., et al. A., Aloe vera and ascorbic acid coatings maintain postharvest quality and reduce microbial load of strawberry fruit, Postharvest Biology and Technology, vol. 114, pp. 29–35, 2016.
- Dai, J., et al. An overview of tea polyphenols as bioactive agents for food packaging applications, LWT – Food Science and Technology, vol. 167, article 113845, 2022.

Biographies

Soyee Lee is an IB Diploma candidate at Chadwick International School. Her research interests focus on sustainable biochemical solutions and food science to address environmental challenges. Also, her interest in food sustainability emerged from observing the large amount of edible produce discarded in households despite remaining nutritionally usable. She has developed several innovative projects, including an edible okra-based microplastic filtration system for the Blue Ocean competition and "SipShield," a temperature-sensitive sensor for the Diamond Challenge. Additionally, she engineered "Eco-Shield," a biochemical edible coating designed to reduce household food waste. Beyond her research, she serves as a youth ambassador for the International Vaccine Institute (IVI). She intends to pursue further studies in Nutritional Science to develop practical, science-based sustainability practices.

Michael Lee is a student at Crean Lutheran High School with a research focus on environmental sustainability and food science. As a member of the Science National Honor Society and Mu Alpha Theta, he demonstrates strong logical reasoning and problem-solving skills in biochemistry and cellular metabolism. Beyond his academic pursuits, Michael is an accomplished violinist in the CLHS Orchestra, having performed at Carnegie Hall. He aspires to pursue a career in biological sciences and environmental studies, specifically exploring biochemical mechanisms to address global sustainability challenges.

Soyeon Shin is an IB Diploma candidate at Chadwick International School in Incheon, South Korea. Her academic interests focus on food science, sustainability, and biochemical solutions to address environmental challenges. She has conducted research on zero-sugar beverage consumption, analyzing athletes' health perceptions and evaluating the effectiveness of sugar substitutes through literature-based study. She is currently developing "Eco-Shield," a biodegradable edible coating designed to reduce household food waste by extending fruit shelf life. Beyond research, she serves as Head of the Senior Community Kitchen, preparing and delivering meals for elderly communities. She has also worked as a volunteer interpreter, supporting international visitors at Korean cultural heritage sites. Her experience includes a clinical operations internship at a hospital, where she assisted elderly patients in navigating

healthcare systems, strengthening her interest in public health and nutrition accessibility. Soyeon is also a national-level athlete, representing South Korea as a member of the National Youth Squash Team. She plans to pursue Nutritional Science to develop scalable, science-based solutions for sustainable food systems.