ViTAE

ORIGINAL ARTICLE
Published 15 December 2025
DOI: https://doi.org/10.17533/udea.vitae.v32n3a361330

Effect of Zein edible coatings on the postharvest quality of minimally processed papaya fruits fortified with ascorbic acid

Efecto De Los Recubrimientos Comestibles De Zein Sobre La Calidad Poscosecha De Frutos De Papaya Mínimamente Procesados Fortificados Con Ácido Ascórbico

A.M. Beulah[1] and K.V. Sucharitha*[2]

ABSTRACT

Background: Fresh and minimally processed fruits and vegetables are one of the major growth segments in the food retail industry. Fresh-cut fruits are physically altered from their original state (trimmed, peeled, washed, and/or cut), but remain in a fresh state, and maintaining fresh like keeping quality is a tough task. Edible coatings are a new promising technology that helps in maintaining the quality and extending the shelf-life of minimally processed fresh-cut fruits. **Objectives** In the Present study various physicochemical and nutritional, sensory characteristics, microbial quality analysis, and micro-structural studies were tested on fresh-cut papaya fruits to evaluate the impact of coatings on freshness and their shelf-life progress during storage. **Methods:** Fresh-cut papaya cubes were coated by brushing with different concentrations of zein protein biopolymer (5% and 10%) along with ascorbic acid as a fortifying agent. Ascorbic acid (10%) was added as a fortifying external agent into the zein coating solution to improve the nutritional importance of vitamin C. All the experimental and control sample analyses were carried out in triplicates and stored at refrigerated conditions (5±1°C). The experimental data output was subjected to a one-way analysis of variance (ANOVA) followed by Duncan's multiple range test and Tukey's test for comparing the mean values between pair of samples. Differences were calculated to compare significant effects at $p \leq 0.05$ level with the use of IBM SPSS statistic version 22 software. **Results:** The findings of the study revealed that the results showed significant differences ($P<0.05$) in the overall acceptability of the zein-coated samples compared with the control sample and delayed the decline in sensory quality and extended the shelf life. The addition of ascorbic acid to the coatings helped to preserve the natural ascorbic acid content in fresh-cut papaya fruits and found retention in fruits. **Conclusions**: Zein coatings delayed the color change, lower weight loss, and firmness retention, maintained the carotenoids content, and inhibited the growth of microorganisms as well as showed a potential impact as commercial coatings in preserving and extending the shelf-life of minimally processed fresh-cut papaya fruits for 12 days of storage period.

Keywords: Fresh cuts, Edible coatings, Papaya, Ascorbic acid, and Shelf life.

Palabras clave: Cortes frescos, Recubrimientos comestibles, Papaya, Ácido ascórbico y Vida útil.

JOURNAL VITAE
School of Pharmaceutical and Food Sciences
ISSN 0121-4004 | ISSNe 2145-2660
University of Antioquia
Medellin, Colombia

Afilliations

[a] Food technology, Department of Home Science, Sri Padmavati Mahila Visvavidyalayam, Tirupati, Andhra Pradesh-517502, India. 0000-0002-6905-4459

[b] Professor, Food technology division, Department of Home Science, Sri Venkateswara University, Tirupati, Andhra Pradesh-517502, India.

****Corresponding***
Dr. K.V. Sucharitha
suchivenkata@gmail.com

Received: 29 June 2025
Accepted: 05 December 2025
Published: 15 December 2025

How to cite: Beulah, A M., & Sucharitha, K V. (2025). Effect of Zein edible coatings on the postharvest quality of minimally processed papaya fruits fortified with ascorbic acid. Vitae, 32(3). https://doi.org/10.17533/udea.vitae.v32n3a361330

1. INTRODUCTION

Papaya (Carica papaya L.) is the most widely consumed tropical fruit in India and all over the world. The fruit was recognized well for its flavor, taste, and nutritional importance. According to the USDA and FDA, fresh-cut fruits are freshly cut, washed, packed, and stored under refrigerated conditions (1). Minimally processed fresh-cut fruits are gaining a reputation due to their convenience and handling, domestic vending outlets were also used for selling the minimally processed foods that involve various processes like coring, washing, slicing, and packing (2,3). These postharvest processing activities can enhance respiration rate, biochemical changes, and microbial invasion that results in rapid changes in the quality of fresh fruit cuts. Different conventional methods and techniques were considered for preserving minimally processed fresh-cut fruits but they were mediated with certain limitations and also ineffective in extending shelf-life (4). Fresh-cut processed foods can be preserved by using cost-effective and easy technologies that result in more profit along with convenient handling operations. The edible coating is such type of novel technique shaped and used to extend the shelf life and keep the quality of fresh-cut fruits. The layers of edible coatings can act as barriers to the external environment that minimize the stress factors involved in the preservation of fresh-cut fruits without affecting/interfering with the quality(5,6).

Several types of biopolymers that are produced from renewable resources have been utilized for coating and their formulation technology was focused on thoroughly being edible. Few biopolymers from food sources identified as potential coat-forming agents with unique gel-forming properties. Among them, zein is such type of peptide polymer mostly produced from corn (Zea mays) which is soluble in aqueous alcohol, glycols, and glycol esters (7). When coming to zein coatings, principally delay weight loss, and softening of tissues in fruits and vegetables along with a very decent biodegradable nature as being a renewable organic material, and these characteristics were predominantly considered for the coating and packaging of food materials (8, 9). Besides, coating materials can serve as carriers for several additives in a customized manner to achieve targeted objectives in the edible coating technology of fruits and vegetables. Zein coatings were supplemented with citric and ascorbic acid to inhibit moisture percentage in fruits (10) Andres, (1984). Zeins with oleic acid coating was used on broccoli to retain firmness (11) and delayed weight loss in both apples and pears during storage and preserve the overall quality (12, 13). The same, to make fortified fresh-cut papaya with adequate vitamin C levels, ascorbic acid is incorporated into the coating matrix as a fortification agent which is an important vitamin that is essential to the human body and decomposes easily with time during environmental stress (14).

Different edible coating effects have been tested on papaya fruits like bacteriocin-incorporated alginate coating (15), chitosan edible coatings to prevent texture loss and microbiological shelf life of fresh-cut papaya (16, 17), Carrageenan, gum arabic, gum ghatti and aloe vera gel were used as an alternative coating agent along with the other essential acids and additives to preserve the fresh cut papaya (18, 19, 20). Other side, the use of alginate and gellan-based coatings (21), and gum arabic with ginger oil was effective in maintaining the keeping quality of papaya fruits (22). The all above studies given experimental ideology and significant outcomes in edible coatings of fruits have been driven to undertake zein as an edible coating agent to improve and preserve the overall keeping quality of fresh-cut papaya. At present, our exertion towards research work was aimed to evaluate the effect of zein edible coatings along with the ascorbic acid on postharvest quality of minimally processed fresh-cut papaya under refrigerated storage conditions (5±1°C). Various quality parameters were assessed periodically to understand the qualitative and quantitative changes in fresh-cut papaya fruits during storage.

2. MATERIALS AND METHODS

2.1 Raw materials and chemicals

Matured fresh yellow-colored papaya (Carica papaya L) fruits have been procured from a local fruit vendor. Zein was purchased from HiMedia Laboratories Pvt. Ltd, Chennai, and citric acid; ascorbic acid, and glycerol (Analytical grade) were purchased from Merck Specialties Pvt. Ltd. Tirupati, India.

2.2 Minimal processing of papaya

Papaya fruits were carefully washed under running tap water and immediately immersed in 5 ppm chlorine water for a few minutes followed by proper rinsing with distilled water, and the process potentially minimizes the foreign bodies and microorganisms on the fruit surfaces. Later the fruit skin was peeled off carefully and all the seeds were removed. The peeled and deseeded fruit was then cut into 10mm thick rectangular-shaped pieces to represent equal proportions for all the experimental samples.

2.3 Edible coating

Two different concentrations of zein solution were prepared to coat the sliced papaya fruits along with and without ascorbic acid as a fortification agent. A total of four variations in edible coatings 5% and 10% zein coatings with and without the addition of 10% ascorbic acid were used to treat the experimental samples. Besides, papaya fruits without zein coating are kept as the control sample to compare the experimental results.5% and 10% zein coating solutions were prepared by dissolving 5g and 10g of zein along with the 10g of citric acid and 10 ml of glycerol (as plasticizer) in 90 ml of ethanol followed by 10ml of distilled water and mixed well until to get a complete solubilized solution. In addition, to prepare the fortification coating solution, 10g (10%) of ascorbic acid was added to the zein coating solution during the magnetic stirring. The cut fruit pieces were coated with different concentrations of zein solutions by the brushing method and allowed to stand for 45 min at room temperature to allow drain of extra solution and air dry to form a layer of zein coating on the cut fruit surface.50g of fruits were used for each experimental sample, the coated fresh-cut fruits were packed in thermoplastic bowls that properly wrapped with PVC plastic film and stored at refrigerated temperature (5±1°C) for 12 days. For better experimental execution, all the experimental samples were coded and marked concerning the storage period with an interval of 3 days for 12 days i.e., 0, 3, 6, 9, and 12 to study further quality parameters during the storage period. All samples were used in triplicates to get experimental analysis data during the storage period (Figure 1).

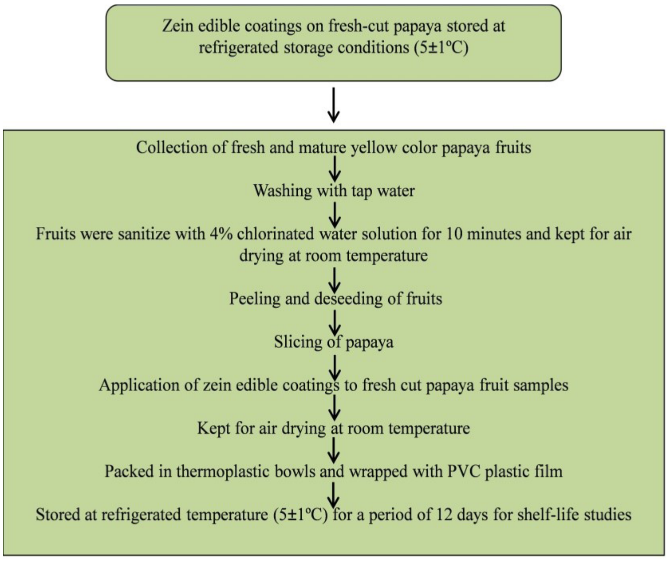


Figure 1 Schematic illustration of zein edible coating on fresh-cut papaya

2.4 Physicochemical analysis

2.4.1 Physiological loss of Weight (PLW)

Physiological loss of weight of fresh cut papaya fruit samples was recorded in an electronic weighing balance (Shimadzu- ELB300 NO: D515711067, Japan) at an interval of 3 days during the 12 days of storage period. The total weight loss was calculated by taking the difference between the initial and final weight of papaya fruit samples individually. The percent weight loss of every experimental sample was expressed by the following formula (23).

$$\text{Weight loss (\%)} = [(A-B)/A] \times 100$$

Where, A- of the sample; B -Final weight of the sample.

2.4.2 Firmness

The firmness of fresh-cut papaya fruit tissue was measured with a 5-mm diameter cylindrical probe (Digital fruit firmness tester penetrometer, T.R.Turonisrl, Italy). The mean values for maximum force were reported in Newton's (N). The averages of three replicates were taken to express a single value.

2.4.3 Overall Visual quality

Overall visual quality was evaluated with the use of a subjective method based on a 5-point rating scale (14). The parameters considered for the quality evaluation of fresh-cut papaya are mentioned below:

a) Visual appearance (5- Very good, 4- Good, 3- Fair, 2- Poor, 1- very poor)

b) Defects* (1 >50%, 2- 25-50%, 3- 10-25%, 4- 10%, 5-None)

c) Shrinkage (1 >50%, 2-50%, 3-25%, 4- 10%, 5-None)

* Defects include, discoloration, pitting and softening, and microbial spoilage

2.4.4 pH, Titratable acidity and total soluble solids

The pH, Titratable acidity (TA), and total soluble solids (TSS) were evaluated based on the method followed by (24) with slight modifications. 5g of fruit pulp was weighed accurately and homogenized with 25 ml of distilled water. The mixture was thoroughly mixed and then filtered properly to get filtrate. The filtered liquid was used for further analysis of different quality parameters. The pH of fresh-cut papaya was measured by using a pH meter (Eutech Instruments, prod-ECPH70042SEU, Singapore).The TSS was measured with a hand refractometer (Erma Inc. Tokyo, Japan) and expressed as brix^0. The TA was determined by titrating mixed fruit pulp against 0.1N sodium hydroxide (NaOH) with phenolphthalein as an indicator and the value was expressed in mg/g.

2.4.5 Ascorbic acid

Ascorbic acid/vitamin 'C' content was determined by '2, 6-dichlorophenolindophenol titration method' (25). 3g of fruit pulp is macerated in a mortar and pestle and centrifuged (Remi centrifuge, CE model, India) at 3500 rpm for 10 minutes. The collected supernatant liquid was used to estimate the content of ascorbic acid through the titration method. The formula used for the calculation of ascorbic acid content is expressed below.

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Titre} \times \text{dye factor} \times \text{Volume made up}}{\text{Aliquot of extract} \times \text{Wt/Vol.of the sample takenfor estimation}} \times 100$$

2.4.6 Total carotenoid content

Total carotenoid content was measured according to the method tailed by (26). 1g of fruit is taken and made into homogenous liquid pulp followed by the addition of 20 ml of 80 % acetone. The fine pulp mixture was further used to read under a spectrophotometer. The absorbance values of the pulp samples were read at 480 nm in a UV-Spectrophotometer against a blank reagent and expressed as mg/g fresh weight.

2.4.7 Sensory Evaluation

All the coated and uncoated fresh-cut papaya fruit samples were subjected to sensory evaluation using the 5-point hedonic rating scale method. The test was carried out by 15 members as panelists and asked to perform sensory analysis individually for different sensory attributes like appearance, texture, color, taste, odor, and overall acceptance. (5-Excellent, 4-Very good, 3-Good, 2-Fair, 1-Poor).

2.4.8 Microbial quality

The fresh-cut fruits were subjected to the evaluation of microbial count analysis up to the end of the storage period with an interval of 3 days.10g of sample was homogenized with 90ml of ringer's solution, serial dilutions were prepared and inoculum was spread on nutrient agar medium (Pour plate method) (HiMedia, M001, India) for total plate count and potato dextrose agar for yeast and molds (HiMedia, M403 India). Prepared culture plates were incubated at 35°C for 48h and 30°C±2°C for 72h (3-5 days) in a BOD incubator and upon completion of incubation, microbial colonies were counted accordingly. Microbial counts for experimental samples were analyzed in triplicate from 0 to 12th day at an interval of 3 days and results were expressed as a log of colony forming units per gram of fresh weight(log CFU/g) (27).

2.4.9 SEM Analysis

The dry sample with 3×3 mm was fixed and mounted on aluminum stubs and coated with gold at 5 mA and 1.5 kV using a sputter coater. The microstructures of coated and control samples were imagined under a Hi-Res scanning electron microscope (Carl Zeiss EVO MA15).

2.5 Statistical analysis

All the experiments were carried out in triplicates for the control and experimental samples. The experimental data output was subjected to a one-way analysis of variance (ANOVA) followed by Duncan's multiple range test for the average value of parameters among the five treatments along with Tukey's test for comparing the mean values between pair of samples. Differences were calculated to compare significant effect at p≤0.05 level with the use of IBM SPSS statistic version 22 software.

3. RESULTS

3.1 Physicochemical analysis

3.1.1 Physiological loss of Weight (PLW)

The percent PLW of zein coated without fortification samples S1, S2, and with fortification samples S3, and S4 on the 3rd day were 0.97, 0.7 and 0.91, 0.96 g, and on the 12th day were 3.34, 3.83 and 3.58 and 3.80% respectively, while the percent PLW for the control sample (uncoated) were 1.19 % on 3rd day (Figure 2).

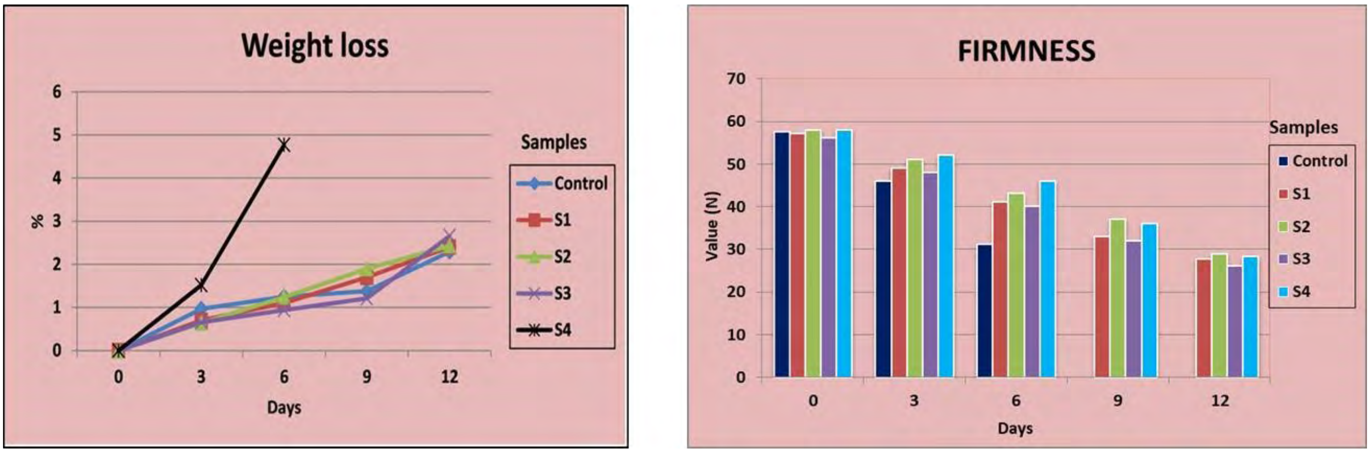


Figure 2. Weight loss and firmness of zein coated fresh cut papaya fruits on storage at 5±1^{0}C.

3.1.2 Firmness

Pectic acid hydrolysis takes place in the cell wall that accelerated the softening of fruit tissues which led to the degradation of the structural integrity of the fruit texture (21).The mean values of fruit firmness for the zein coated samples S1, S2, S3 and S4 on the initial (0) day were 57.14, 58.12, 56.11 and 58.12 N, on 12th day were 27.81, 29.05, 26.16 and 28.42 N respectively (Figure 2). Whereas, uncoated sample resulted 57.69 on initial day and 31.15 on the end of the storage (6th day).

3.1.3 Overall Visual quality

Appearance

Appearance is an important visual quality factor for fresh cut fruits and products. So, fresh-cut papaya fruits were evaluated for their keeping quality by the physical appearance. Figure 3 shown that the mean score for appearance determines that no significant difference was observed from the 0 day to 3rd day of storage among the all coated and control samples.

Defects

Defects including microbial spoilage, discoloration, pitting, and softening of the fruits were evaluated and depicted in figure.3. According to the pictorial data, the higher the mean score the lesser the defects, and the same was used to determine the degree of defects.

Shrinkage

Mean values for the shrinkage of fresh cut papaya fruits that were treated with different concentrations of zein with and without fortification of ascorbic acid were presented in figure.3 which shows the mean score for shrinkage determines no significant difference was noted from 0 to 3thday of storage among the all coated and in between control sample.

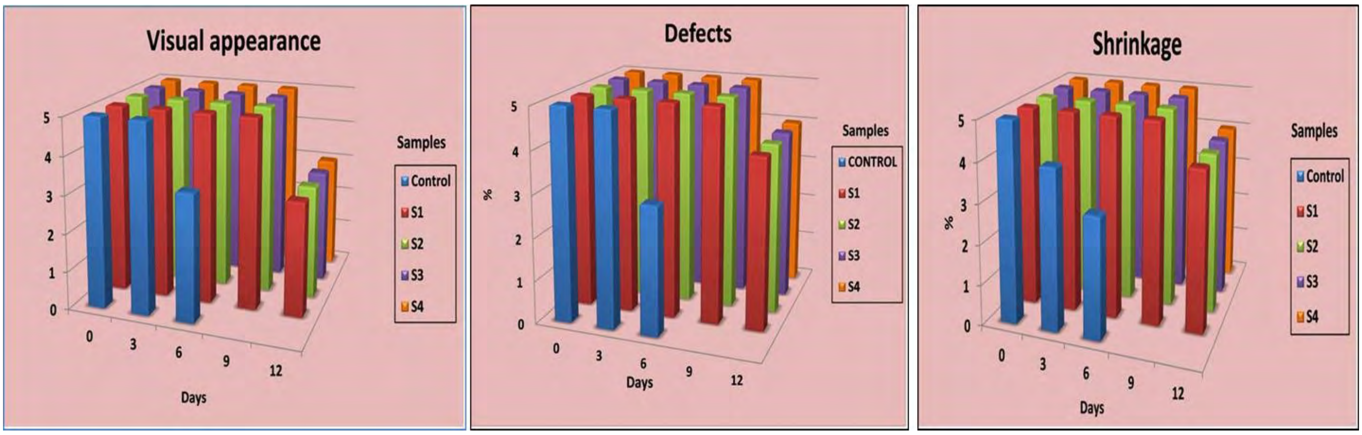


Figure 3. Overall visual quality (appearance, defects and shrinkage) of zein coated fresh cut papaya fruits on storage at 5±1⁰C.

3.1.4 pH, Titratable acidity and total soluble solids

pH

A logarithmic measure for determining whether food is basic or acidic is hydrogen ion concentration (pH). Mean values for the pH of zein-coated samples on the initial day were 4.92 (S1) and 5.20 (S2) for those without ascorbic acid and 4.90 (S3) and 5.01 (S4) for ascorbic acid-fortified coatings respectively. Whereas, the mean value for uncoated papaya (Control) was noted as 5.12. Besides, upon storage, a gradual increase in pH was observed from 0 to 15 days in all experimental samples.

Titratable Acidity

The difference in acid content is a chief indicator for tracking the different stages of the ripening process. Generally, the acid content will decrease during the ripening of fruit and it provides the appropriate markers to define the ripening process. The higher the metabolic respiration rate in the fruits, the more decline in the acidity takes place due to the formation of free acids (28).

Total Soluble Solids (TSS)

Total soluble solids of coated and uncoated fresh-cut papaya samples stored under low temperatures showed an increase in TSS at the end of the storage period. The Mean values for the TSS of zein-coated fruit samples with and without fortification i.e., S1, S2, S3, and S4 on the initial day were 12.50, 12.6, 12.50, and 12.60, while the uncoated papaya (Control) recorded 12.50 °Brix (Table no 1) on the same day.

3.1.5 Ascorbic acid

Vitamin C/Ascorbic acid levels have been estimated to understand the overall content preserved in the coated and control fruit samples. Mean values for vitamin C in zein-coated samples on the initial (0) day of S1, S2, S3, and S4 were 50.34, 52.54, 54.36, and 55.14mg/100g while the uncoated papaya (Control) was 50.25 mg/100g.Whereas on 12thday, the values for the samples of S1, S2, S3 and S4 were 46.76, 49.40, 52.06 and 53.60 g/100g.

3.1.6 Total carotenoid content

Carotenoids are colored pigments that give unique and signature color to the papaya fruits which plays a key role in attracting consumers and circulation in the retail market (29).Here, Table 1 expresses the values of carotenoid content for fresh-cut papaya fruits coated with different concentrations of zein. Carotenoids of zein coated with and without fortification on the initial (0) day expressed 1.96 mg/g for all experimental and control samples.

3.1.7 Sensory Evaluation

Table 2 represents the mean sensory evaluation scores for the appearance, color, taste, texture, flavor and overall acceptability of coated and uncoated fresh-cut papaya fruits stored at 5±1°C.

3.1.8 Microbial quality

Figure 5 shows the total plate count for fresh-cut papaya fruits coated with zein at different concentrations and kept for 12 day storage period. The mean values for the total plate count of control, zein coated without and with fortification samples on the initial day were 1.50 log CFU/g, similarly the yeast and mold count were nil on the initial day. However, at the end of the storage period, a huge difference was noted between the control and coated samples. However, the coated samples were limited to around 5 log cfu/g till the end of the storage period.

3.1.9 SEM Analysis

Microstructure and morphology

In the case of fresh-cut produce, ripening is the major factor that determines the shelf life of the particular product. Protein-based edible coatings have ideal O_2, CO_2, and water vapor permeability that can be applied on the surface of fresh-cut produce to extend the shelf life of a few folds by delaying the ripening process, inhibiting the enzymatic browning, reducing water loss and minimizing the loss of aroma (30).The formation of rod-like meshwork might be the key factor in developing good mechanical and gas barrier properties for the zein coatings (31). These complex networks on the fruit surfaces were analyzed under the electron microscope for their characteristic nature. So, SEM images of zein coatings applied on fresh-cut papaya have given informative inputs related to the complex structure.

4. DISCUSSION

4.1 Physicochemical analysis

4.1.1 Physiological loss of Weight (PLW)

The percent PLW of zein coated without fortification samples S1, S2, and with fortification samples S3, and S4 on the 3rd day were 0.97, 0.7 and 0.91, 0.96 g, and on the 12th day were 3.34, 3.83 and 3.58 and 3.80% respectively, while the percent PLW for the control sample (uncoated) were 1.19 % on 3rd day.

The PLW was found lowest in S1 followed by S3, S4, and S2 samples, which are zein-coated coated shown good control on weight loss compared to the uncoated control sample. Coated papaya fruits showed lower weight loss during the storage period when compared with the uncoated sample. Coated cut fruits (with and without fortification) showed a significant difference ($p<0.05$) in weight loss compared with the uncoated (control) sample on the 6th day of storage. The control sample was discarded on the 8th day of storage due to more juice leakage; softening and complete deterioration. The reason for a significant reduction in weight loss might be a layer of coating created a semi-permeable barrier to oxygen and water vapor thereby helping in reducing water loss and respiration. The reason for a significant reduction in weight loss might be a layer of coating creates a semi-permeable barrier to oxygen and water vapor thereby helps in reducing water loss and respiration (32). Also, the present experimental results were similar to the findings reported by (33) for gala apples coated with zein protein coating. However, another study found similar results when papaya-cut fruits were coated with chitosan and stored at cold storage conditions (34). According to Cipolatti (35) reported that protein-based edible coatings were efficient in reducing weight loss and helped in preventing cell wall degradation and tissue wilting. Therefore, the results of the present study assume that the overall quality of papaya fresh-cut fruits was significantly conserved during storage.

4.1.2 Firmness

In general, the firmness of fresh-cut papaya fruits decreased with the ripening process during the storage (Figure 2) and this was observed in the control sample. Besides, zein-coated samples maintained stability in firmness throughout the storage while rapid loss was noted in the uncoated control sample. Up on the storage, a significant difference ($P<0.05$) between the control and coated samples was observed. The firmness of the control sample started to decrease from the 3rd day onwards and on the 8th day onwards where more softening and oozing out of liquids was observed. The reason behind the oozing might be the breakdown of complex carbohydrates resulting in the loosening of cell walls and complex structure of tissue. In literature, the decrease in firmness during the storage was observed in different fresh-cut products like nectarines and peaches; pineapples, bell peppers, and mangoes (36, 37).

However, 10% zein coating (S2) was identified as the most effective coating to retain a higher value of firmness among all concentrations and it was assumed that increased concentration of zein was well organized the fruit firmness.

The potential factor may be a delay in the ripening process that induced by the external coating reduced the respiration rate which shows an impact on firmness retention during the storage. During the shelf-life, coated fresh-cut papaya showed overall good firmness values than uncoated control samples. Ascorbic acid used as a fortification agent in the coatings helped to maintain/enrich an adequate amount of antioxidant levels in the fresh-cut fruits.

4.1.3 Overall Visual quality

Appearance

During the 6th day, the uncoated samples scored significantly lower ($p < 0.05$) than the zein-coated samples and this reduction in the control sample was continued up to the end of the storage period. During the shelf-life period, it was significantly observed that the S1, S2, S3, and S4 coated samples progressively continued optimum scores until the end of the storage period. The experimental evidence for the appearance showed that the zein coatings were more active in maintaining freshness and keeping the quality of the fresh-cut papaya on storage.

Defects

No significant difference was observed from 0 to 3rd day among all the coated and control samples. However, a significant change ($p<0.05$) was detected in all coated samples in comparison with the control from the 6th day of storage. Therefore, during the entire storage period, it was notably found that the S1, S2, S3, and S4 coatings continued better scores and also, there were no traces of microbial spoilage till the end of the storage period. The decaying process reached a maximum in the control sample. After 12 days the coated fruits showed the symptoms of tissue softening, water accumulation, and liquid oozing from the papaya fruits was observed and indicates that spoilage occurred. So, the edible coating applied on fruit surfaces helped to reduce the decay percentage and shield the fruit from transpiration, and the same pattern was described by Chien (38) also our study was similar to the study conducted on gala apples(13).

Shrinkage

However, during the 6th day, the uncoated control sample gained a significantly higher ($p<0.05$) shrinkage score than the four zein-coated samples and this was continued up to the end of the storage. During the entire storage period, it was meaningfully found that the S1, S2, S3, and S4 coatings exhibited good and optimal scores for shrinkage. The rapid shrinking was observed in control samples during the storage, while zein-coated samples exhibited good control over shrinkage during the first half of the storage period. Here, it is apparent that zein coatings on the surface of the fruit cuts effectively controlled the shrinking process by creating high relative humidity and preventing moisture and gaseous escape from the fruit tissues during storage. Visual quality assessments of fresh cut papaya will determine the overall quality index on storage. Storage of fresh-cut papaya under (5±1°C) represents good visual quality standing without defects, shrinkage of all zein-coated papaya fruits up to 12 days of storage. Besides, we noted in the literature that a study (39) reported a shelf life of fresh-cut papaya for only 7 days even if they were stored at 3°C, 6°C, or 9°C. Therefore, our study strongly suggested that the low temperatures along with the edible zein coatings can increase the shelf life of papaya bifolds than uncoated ones. This type of coating will be more suitable for marketing retail fresh cut fruits which are eaten whole.

pH

While comparing all coated experiments, 5% zein coating samples S1 (5.94) & S3(5.91) recorded high pH values among the other coated samples and 10% coatings fell below the 5% zein indicating its control on maintaining pH until at the end of storage period till the values were ranges below the control readings(Table 1). At last, storage studies assumed that the zein coatings were effective in controlling the pH range in both fortified and unfortified conditions and it was observed that fortification with ascorbic acid does not influence the pH values significantly. However, control over the pH in coated samples was due to the regulatory effect of zein on the gaseous and vapor exchange by the fruit tissues that are needed for the several metabolic processes. Here, experimental results were well supported by the study (40). According to the study, lower pH values were found in coated samples when compared with the control because of the modified atmosphere created inside the coating applied on the fruit surfaces.

Titratable Acidity

According to the experimental data, on the initial day of the storage, the TA values were high in the S4 and S2 coated samples compared to S3, S1, and control samples. The reason might be the action of ascorbic acid that was added to the zein coatings. Besides that, the mean values for the titratable acidity of zein coated with and without fortification fruit samples i.e., S1, S2, S3, and S4 on the 12th day were 1.62, 1.69, 1.81, and 1.96 mg (Table 1). The mean titratable acidity was statistically ($p<0.05$) significant between control and experimental samples from the 3rd day onwards and continued up to the 6th day of the storage period. The control sample was discarded on the 8th day of storage due to complete deterioration. In the present study, the control papaya fruit samples have the lowest TA value and the highest values were observed in the coated samples S3 and S4 followed by S2 and S1. This concludes that the zein edible coatings lower the respiration rate by delaying acidity levels in fresh-cut papaya fruits. In the literature, identical results were observed in a study (34). The trends of change and decline in TA were in agreement with results in other reports found on alginate-coated plums, alginate-coated gala apples, and aloe vera-coated peaches (28, 41, 42).

Total Soluble Solids (TSS)

No significant difference was observed between the control and coated samples until day 3 of storage (Table 1). But from day 6 onwards, a significant difference was noted between control and zein-coated samples. The highest °brix was noted in control followed by in order S4 (zein 10%, fortified), S3 (zein 5%, fortified), S2 (zein 10%, unfortified), and S1 (zein 5%, unfortified). Zein edible coatings are successful in lowering TSS in papaya fruit cuts. Comparable results were reported in a study (43) where edible pectin-coated ataulfo mangoes resulted in lower TSS values than control mango fruits. Another study reported that the edible coatings as barriers to O2 and CO2 which modify/control the internal atmosphere and slow down the fruit respiration rate (44).

Table 1. Effect of zein coatings and control samples in storage period on p^H, Total soluble solids (TSS), titratable acidity (TA), Vitamin C (Ascorbic acid) and Total Carotenoids of fresh cut papaya fruits

Parameters	Storage periods (days)	Samples				
		Control	S1	S2	S3	S4
p^H	0	5.12±0.34	4.92±0.46	5.20±0.34	4.90±0.34	5.01±0.46
	3	5.71±0.28	5.57±0.34	5.46±0.40	5.59±0.28	5.80±0.40
	6	5.87±0.34	5.64±0.23	5.61±0.46	5.67±0.34	5.56±0.23
	9	*	5.78±0.40	5.76±0.46	5.75±0.34	5.78±0.40
	12	*	5.83±0.34	5.80±0.40	5.84±0.28	5.80±0.34
TSS (%)	0	12.50±0.40^{a}	12.50±0.46^{a}	12.6±0.82^{a}	12.50±0.28^{a}	12.60±0.34^{a}
	3	14.40±0.46^{a}	13.60±0.28^{a}	13.20±0.40^{a}	13.80±0.23^{a}	13.80±0.34^{a}
	6	17.70±0.46^{a}	14.60±0.28^{b}	14.7±0.23^{c}	14.90±0.28^{d}	14.30±0.11^{e}
	9	*	15.2±0.28^{a}	15.3±0.34^{a}	15.8±0.40^{b}	15.4±0.23^{c}
	12	*	16.7±0.34^{a}	17.2±0.34^{a}	16.9±0.23^{b}	17.4±0.28^{c}
TitratableAcidity (mg/100g)	0	2.30±0.23^{a}	2.32±0.34^{a}	2.40±0.40^{a}	2.36±0.46^{a}	2.40±0.34^{a}
	3	1.71±0.34^{a}	2.22±0.28^{b}	2.26±0.17^{c}	2.24±0.34^{d}	2.31±0.23^{e}
	6	1.40±0.40^{a}	1.71±0.23^{b}	1.82±0.34^{c}	1.98±0.28^{d}	1.93±0.23^{e}
	9	*	1.69±0.46^{a}	1.73±0.46^{a}	1.90±0.34^{a}	1.89±0.11^{a}
	12	*	1.62±0.17^{a}	1.69±0.46^{a}	1.81±0.40^{a}	1.96±0.23^{a}
Vitamin C (mg/100g)	0	50.25±0.28^{a}	50.34±0.28^{a}	52.54±0.46^{bBA}	54.36±0.46^{cCBA}	55.14±0.34^{dDCA}
	3	48.45±0.23^{a}	51.31±0.34^{bA}	51.11±0.34^{cAA}	55.16±0.28^{dBBA}	56.23±0.34^{eCCA}
	6	43.17±0.46^{a}	51.87±0.17^{bA}	51.41±0.17^{cAA}	54.36±0.23^{dBBA}	54.81±0.46^{eCCA}
	9	*	50.16±0.40^{aA}	50.86±0.34^{bAA}	54.20±0.46^{cBBA}	53.16±0.40^{dCCA}
	12	*	48.76±0.34^{aA}	49.40±0.46^{bAA}	52.06±0.40^{cBBA}	53.60±0.46^{dCAA}
Total Carotenoid (mg/g)	0	1.96±0.13^{a}	1.96±0.28^{a}	1.96±0.34^{a}	1.96±0.40^{a}	1.96±0.46^{a}
	3	2.08±0.46^{a}	2.01±0.23^{a}	2.02±0.34^{a}	2.10±0.28^{a}	2.03±0.40^{a}
	6	3.96±0.17^{a}	2.16±0.46^{b}	2.32±0.40^{c}	2.16±0.28^{d}	2.29±0.23^{e}
	9	*	2.41±0.11^{a}	2.72±0.17^{a}	2.38±0.23^{a}	2.41±0.28^{a}
	12	*	2.78±0.34^{a}	2.81±0.28^{a}	2.65±0.23^{b}	2.82±0.28^{a}

Mean values± standard deviation. Means with the same letters within a period of storage (row) are not significant ($p>0.05$), *sample deteriorated

Note:- S1 (Zein 5%) , S2 (Zein 10%) , S3 (Zein-5% fortified with ASA) and S4 (Zein-10% fortified with ASA) samples

4.1.5 Ascorbic acid

In general, the vitamin C content will increase with the ripening gradually however; it declines in the fully ripened state of the fruits (45). The ascorbic acid values were decreased during the storage period in all coated and control samples (Table 1). A significant difference (p<0.05) in vitamin C between experimental and control samples was observed on 3rd and 6th day of the storage period. The decreasing trend was little accelerated in control compared to the coated samples and the difference was significant at p<0.05. The reduction rate of ascorbic acid was noted maximum in the control sample (43.17mg/100g) on the 6th day consequently; more retention was noticed in zein coatings that fortified with ascorbic acid. However, all the coated samples with and without fortification well maintained the ascorbic acid levels in the fruits. The reason might be reduced oxygen permeability in the fruits which delays the oxidation and thereby prevents the degradation of ascorbic acid (46).

4.1.6 Total carotenoid content

The mean total carotenoid content was statistically significant (P<0.05) between control and experimental samples on the 6th day of the storage period. The control sample was discarded on the 8th day of storage due to complete deterioration. Here, the development of carotenoids was well controlled in coated samples when compared with the control. The S4 sample which was 10% zein along with ascorbic acid resulted in the maximum carotenoids among the coated samples i.e., 2.82 mg/g, whereas the control sample noted 5.23 mg/g at the end of the storage (Table 1). The difference between the control and experimental samples was assumed that edible coatings have significant control over the development of carotenoids in fresh-cut fruits. In general, the carotenoids were increased along with the ripening of the fruits. So, in the present study, it was clear that zein coatings showed a gradual decrease in total carotenoid content from 1.96 mg/g to 2.82 mg/g whereas control showed more increase from 1.96 to 3.96 mg/g at the end of the storage. So, it was concluded that coating with zein successfully delayed the ripening process and thereby increased the shelf life of papaya fresh-cut fruits by up to 12 days without any quality issues.

4.1.7 Sensory Evaluation

Appearance

The results showed a significant (P<0.05) difference in the appearance of the zein-coated samples compared to the control. The fruits coated with zein scored maximum by means of appearance with the panelists. The mean scores recorded for all zein coatings and control samples were 5.00 at the initial (0) day and it was 3.00 for all zein-coated samples at the end of the storage (Table 2), however, the control sample deteriorated on 8th day of the storage period. The above overall scores for the appearance indicated the effect of zein coatings on the preservation of fresh-cut papaya.

Color

The results showed a significant (P<0.05) difference in the color of zein-coated samples when compared with the control sample on the 12th day of storage. The mean scores recorded for the zein-coated, fortified, and control samples are 5.00 on initial day and 3.00 for the zein-coated samples on the 12th day storage period (Table 2). However, the control sample deteriorated on the 8th day of the storage period thus indicates the effect of zein coatings on the fruit color. Fruits treated with zein coating exhibited maximum scores for the color and coatings can be worked to preserve the natural color of the fruits.

Taste

The results show significant (P<0.05) differences in the taste of the zein-coated samples compared with the control sample on the storage. The mean scores recorded for zein-coated samples were 5.00 on the initial day and 4.00 on the 12th day of storage (Table 2). The results showed a significant (P<0.05) difference between the taste of the zein-coated samples and control samples during the 6th day of the storage period. Hence it shows the experimental samples were good when compared with the control sample and gained maximum scores in taste by the panelists during the storage.

Texture

The results show significant differences (P<0.05) between the zein-coated and control sample at the 6th of the storage period. Mean scores recorded for zein-coated samples are 5.00 on the initial day and 4.00 on the 12th day (Table 2). The results showed a significant (P<0.05) difference between the texture of the zein-coated samples and control samples during the 6th day of the storage period. Fruit samples treated with zein coatings gained maximum scores for the textural properties by the panelists.

Flavor

The results show a significant difference (P<0.05) in the flavor of the zein-coated samples compared with the control sample on the 6th day of the storage period. The mean scores recorded for zein-coated, samples are 5.00 on the initial day and 3.00 on the 12th-day storage period (Table 2). The results showed a significant (P<0.05) difference for the flavor of the zein-coated samples and control samples during the 6th day of the storage period. It was found that the S1, S2, S3, and S4 coatings continued better scores till the end of the storage period. This shows that the zein coatings were able to preserve the flavor of the cut papaya fruits.

Overall acceptability

Irrespective of the coatings, there was a decrease in overall acceptability as the storage period was prolonged. The results showed a significant (P<0.05) difference in the overall acceptability of the zein-coated samples and control samples during 6th day of the storage period. The mean scores recorded for zein-coated samples are 5.00 on the initial day and 4.00 on the 12th day of storage (Table 2).

The fruits coated with zein scored maximum means scores by the panelists. This shows that the zein coatings can preserve the freshness of the cut papaya fruits. Hopefully, the results were similar to the experimental results reported by a study (47) stated that decline in the acceptance of papaya fruit with ripening during the storage period because of high moisture, softening of the pulp, and high total soluble solids composition. The effect of zein edible coatings on cut papaya during different storages periods was presented in figure 4.

Table 2 Effect of zein edible coatings on sensory scores for cut papaya fruits

Sensory evaluation attributes	Storage periods (days)	Samples				
		Control	S1	S2	S3	S4
Appearance	0	5 ± 0.28^a	5 ± 0.23^a	5 ± 0.34^a	5 ± 0.40^a	5 ± 0.46^a
	3	5 ± 0.28^a	5 ± 0.28^a	5 ± 0.40^a	5 ± 0.23^a	5 ± 0.17^a
	6	3.33 ± 0.40^a	5 ± 0.17^b	5 ± 0.17^c	5 ± 0.34^d	5 ± 0.28^e
	9	*	5 ± 0.34^a	5 ± 0.40^a	5 ± 0.23^a	5 ± 0.46^a
	12	*	3 ± 0.23^a	3 ± 0.23^a	3 ± 0.40^a	3 ± 0.46^a
Color	0	5 ± 0.40^a	5 ± 0.46^a	5 ± 0.28^a	5 ± 0.34^a	5 ± 0.11^a
	3	5 ± 0.28^a	5 ± 0.17^a	5 ± 0.23^a	5 ± 0.11^a	5 ± 0.34^a
	6	3 ± 0.11^a	5 ± 0.40^b	5 ± 0.23^c	5 ± 0.17^d	5 ± 0.11^e
	9	*	5 ± 0.46^a	5 ± 0.34^a	5 ± 0.17^a	5 ± 0.40^a
	12	*	3 ± 0.34^a	3 ± 0.23^a	3 ± 0.40^a	3 ± 0.28^a
Taste	0	5 ± 0.17^a	5 ± 0.11^a	5 ± 0.40^a	5 ± 0.46^a	5 ± 0.28^a
	3	4 ± 0.40^a	5 ± 0.34^a	5 ± 0.28^a	5 ± 0.40^a	5 ± 0.11^a
	6	3 ± 0.23^a	5 ± 0.46^b	5 ± 0.17^c	5 ± 0.23^d	5 ± 0.11^e
	9	*	4 ± 0.40^a	4 ± 0.46^a	4 ± 0.34^a	4 ± 0.11^a
	12	*	4 ± 0.17^a	4 ± 0.23^a	4 ± 0.23^a	4 ± 0.23^a
Texture	0	5 ± 0.28^a	5 ± 0.28^a	5 ± 0.34^a	5 ± 0.40^a	5 ± 0.23^a
	3	4 ± 0.46^a	5 ± 0.34^a	5 ± 0.28^a	5 ± 0.40^a	5 ± 0.23^a
	6	3 ± 0.40^a	5 ± 0.17^b	5 ± 0.40^c	5 ± 0.23^d	5 ± 0.46^e
	9	*	5 ± 0.23^a	5 ± 0.34^a	5 ± 0.46^a	5 ± 0.28^a
	12	*	4 ± 0.23^a	4 ± 0.17^a	4 ± 0.40^a	4 ± 0.46^a
Flavour	0	5 ± 0.28^a	5 ± 0.40^a	5 ± 0.34^a	5 ± 0.23^a	5 ± 0.34^a
	3	4 ± 0.40^a	5 ± 0.40^a	5 ± 0.34^a	5 ± 0.34^a	5 ± 0.17^a
	6	3 ± 0.23^a	5 ± 0.28^b	5 ± 0.17^c	5 ± 0.40^d	5 ± 0.34^e
	9	*	4 ± 0.40^a	4 ± 0.34^a	4 ± 0.40^a	4 ± 0.34^a
	12	*	3 ± 0.46^a	3 ± 0.34^a	3 ± 0.28^a	3 ± 0.40^a
Overall acceptability	0	5 ± 0.28^a	5 ± 0.23^a	5 ± 0.34^a	5 ± 0.40^a	5 ± 0.46^a
	3	4 ± 0.34^a	5 ± 0.17^a	5 ± 0.17^a	5 ± 0.34^a	5 ± 0.28^a
	6	3 ± 0.17^a	5 ± 0.34^b	5 ± 0.40^c	5 ± 0.23^d	5 ± 0.34^e
	9	*	4 ± 0.23^a	4 ± 0.40^a	4 ± 0.23^a	4 ± 0.23^a
	12	*	4 ± 0.23^a	4 ± 0.23^b	4 ± 0.40^c	4 ± 0.46^d

Mean values± standard deviation. Means with the same letters within a period of storage (row) are not significant (p>0.05),*sample deteriorated

Note: - S1 (zein 5%), S2 (zein 10%), S3 (zein-5% fortified with ASA) and S4 (zein-10% fortified with ASA) samples.

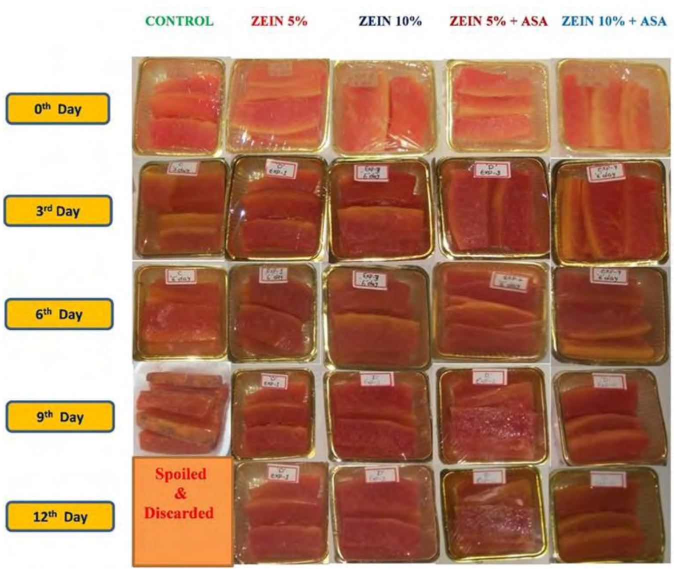


Figure 4. Effect of zein coatings on cut papaya during different storage periods

4.1.8 Microbial quality

Results of the study show that there was a significant difference (p<0.05) in the total plate counts (TPC) and yeast and mold (Y&M) during the storage period. For all coated samples of fresh-cut papaya, yeast, and mold microbial counts do not exceed the limit of 6 log CFU/g during the entire storage period (Figure 5). Finally, it is well established that zein coatings can reduce the microbial load by inhibiting/controlling their growth in the fruits. Because coatings can act as a physical barrier for the outer environment which prevents the external invasion of the microorganisms. Also, it regulates the internal atmosphere of the fruits which is not very favorable for the growth of aerobic microorganisms. In this study, zein coatings of 5% and 10% without and with fortification extended the shelf life of fresh-cut papaya samples (S1, S2, S3, S4) up to 12 days at ambient storage conditions.

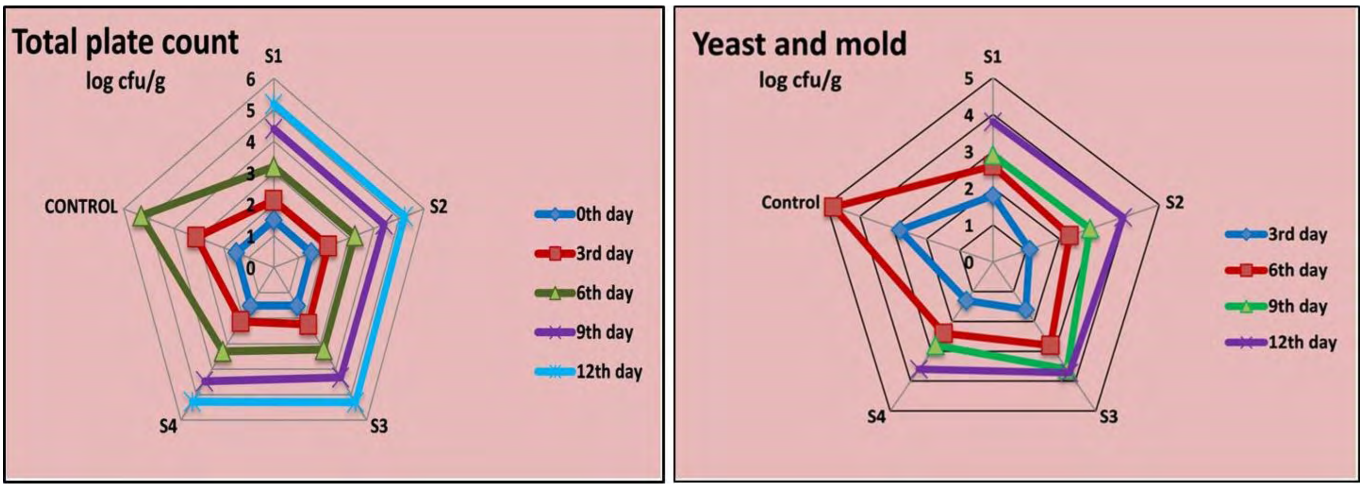


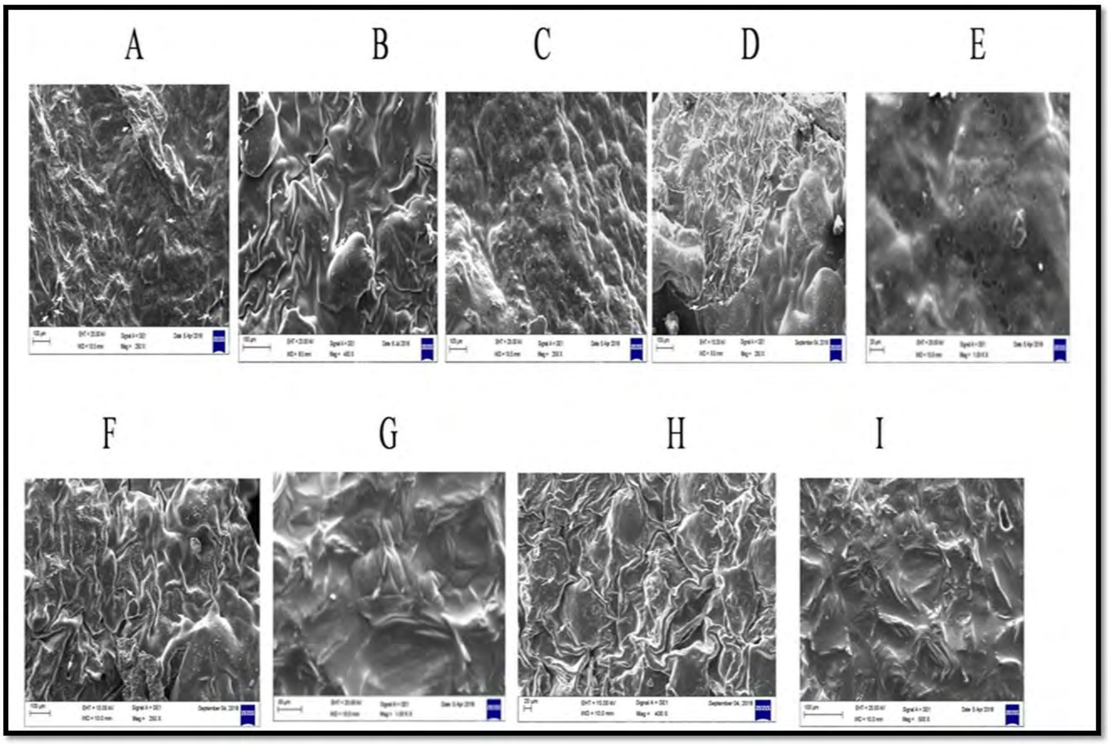
Figure 5. Effect of Zein edible coatings on total bacterial and yeast and mold count for cut papaya fruits

3.1.9 SEM Analysis

Microstructure and morphology

The arrows in Figure 6(A) indicate the micropores on the internal tissue surface of fresh-cut papaya in control, where few sacs or pores were identified in coated and fortified 5% and 10% zein-coated fruits on the initial day. The result of SEM images for control samples clearly shows several micropores, roughened and disordered surfaces with cavities. This indicates the transpiration of fresh-cut papaya. Also, coated with 5% (S1) and 10% (S2) zein (Figures B and D) revealed tightly compacted surfaces with fewer pores on the initial day. After 12 days of storage, the zein coating on the fruit surface produces a more uniform covering which appeared to be smoother, rigid, and more ordered structure without cavities (Figures C and E), it resembles the uniformity of zein coatings on papaya fruit.

The arrows in Figures F and H indicate the micropores and stomatal aperture on the papaya fruit surface coated with 5% and 10% zein fortified with ascorbic acid on the initial day. After storage for about 12 days, the zein coatings on the fruit surface produced a more uniform covering that appeared smoother without the opening of the stomatal aperture (Figures G and I). It resembles the formation of zein coatings that were homogeneously distributed on the surface of the fruits. Cutting, slicing, and peeling, etc. of fruits and vegetables will increase the water transpiration rate due to exposure of tissue following the removal of the natural epidermal layer and will also increase the surface area of exposure (48). Even fresh-cut papayas with continuous/prolonged exposure to the surface area maintained a shelf life of up to 12 days with the zein coatings distributed uniformly on the surface.



(A- control; B-5% zein initial; C-5% zein stored; D-10% zein initial; E-10% zein stored; F-5% zein fortified initial; G-5% zein fortified and stored; H- 10% zein fortified initial; I- 10% zein fortified and stored).

Figure 6. SEM micrographs of cut papaya fruits coated with zein and fortified zein at different concentrations

5. CONCLUSION

Zein-based coatings with added plasticizer (glycerol) and ascorbic acid as a fortification agent have been used to coat fresh-cut papaya fruits for their shelf-life extension. All different concentrations of zein coatings act as a good barrier for the moisture loss and gaseous exchange in the retention of fruit quality and also, help to reduce the loss of vitamin C through the fortification. Zein coatings showed good retention properties in terms of moisture, color, texture, and physical appearance which played an important role in fresh-cut fruit products. Besides, zein coatings act as a barrier to the outer environment and minimize the loss of tissue fluids, vitamins, minerals, aroma compounds, and microbial invasion from the outside environment. Zein Fortification with ascorbic acid greatly strengthens the vitamin C levels in the fresh-cut papaya which is thought to be a good move for the value addition. Concerning the overall impact, zein coatings were effectively worked to preserve the quality characteristics and extend the shelf life of minimally processed fresh-cut papaya fruits up to 12 days at low-temperature storage conditions (5±1°C). Zein coatings can be used commercially to process and preserve fresh-cut fruits and vegetables along with other natural compounds with the intention of value addition to overcome nutritional deficiencies.

Conflicts of interest: All the authors declare no potential competing interests in this work to publish it.

Authors' contributions: A.M.Beulah: Investigation; Experimentation, Writing- review & editing original draft. K.V.Sucharitha: Project administration; Resources, Supervision, Writing- review & editing

REFERENCES

[1] Mukhametzyanov RR, Ostapchuk TV, Dzhancharov TM, Ivantsova NN, Vasileva EN. Changes in global production and trade of major tropical fruits. In: Digital agriculture for food security and sustainable development of the agro-industrial complex. Cham: Springer International Publishing; 2023. p. 147–53. doi: https://doi.org/10.1007/978-3-031-27911-9_17

[2] Munira ZA, Rosnah S, Zaulia O, Russly AR. Effect of postharvest storage of whole fruit on physico-chemical and microbial changes of fresh-cut cantaloupe (*Cucumis melo* L. reticulatus cv. Glamour). Int Food Res J. 2013;20(1).

[3] Goyal MR, Mishra SK, Kumar S, editors. Nanotechnology horizons in food process engineering: Volume 3: trends, nanomaterials, and food delivery. CRC Press; 2023.

[4] Vivek K, Singh SS, RC P. A review on postharvest management and advances in the minimal processing of fresh-cut fruits and vegetables. J Microbiol Biotechnol Food Sci. 2019;8(5):1178–87. DOI: 10.15414/jmbfs.2019.8.5.1178-1187

[5] Hossain MA, Karim MM, Juthee SA. Postharvest physiological and biochemical alterations in fruits: a review. Fundam Appl Agric. 2020;5(4):453–69.

[6] Umeohia UE, Olapade AA. Physiological processes affecting postharvest quality of fresh fruits and vegetables. Asian Food Sci J. 2024;23(4):115915. DOI: 10.9734/AFSJ/2024/v23i4706

[7] De Corato U. Improving the shelf-life and quality of fresh and minimally-processed fruits and vegetables for a modern food industry: A comprehensive critical review. Crit Rev Food Sci Nutr. 2020;60(6):940–75. DOI: https://doi.org/10.1080/10408398.2018.1553025

[8] Yousuf B, Wu S, Siddiqui MW. Incorporating essential oils into edible coatings: Effect on quality and shelf life of fresh produce. Trends Food Sci Technol. 2021;108:245–57. doi: https://doi.org/10.1016/j.tifs.2021.01.016

[9] Ghidelli C, Pérez-Gago MB. Recent advances in MAP and edible coatings for fresh-cut fruits and vegetables. Crit Rev Food Sci Nutr. 2018;58(4):662–79. doi: https://doi.org/10.1080/10408398.2016.1211087

[10] Kumar L, Ramakanth D, Akhila K, Gaikwad KK. Edible films and coatings for food packaging applications: A review. Environ Chem Lett. 2022;20(1):875–900. DOI: https://doi.org/10.1007/s10311-021-01339-z

[11] Hoque M, Gupta S, Santhosh R, Syed I, Sarkar P. Biopolymer-based edible films and coatings for food applications. In: Food, medical, and environmental applications of polysaccharides. Elsevier; 2021. p. 81–107. DOI: https://doi.org/10.1016/B978-0-12-819239-9.00013-0

[12] Martin-Polo MO. Biopolymers in the fabrication of edible and biodegradable materials for food preservation. In: Food preservation moisture control fundamentals and application. 1995.

[13] Lan X, Zhang X, Wang L, Wang H, Hu Z, Ju X, et al. A review of food preservation based on zein. Food Chem. 2023;424:136403. DOI: https://doi.org/10.1016/j.foodchem.2023.136403

[14] Mesfin FM, Abera S, Neme G. Effects of calcium lactate dipping and corn zein–aloe vera gel coating on quality and storability of strawberry. Doctoral dissertation. Haramaya University; 2024. http://ir.haramaya.edu.et//hru/handle/123456789/7695

[15] Pillai AR, Eapen AS, Zhang W, Roy S. Polysaccharide-based edible biopolymer coatings for fruit preservation: A review. Foods. 2024;13(10):1529. DOI: https://doi.org/10.3390/foods13101529

[16] Armghan Khalid M, Niaz B, Saeed F, Afzaal M, Islam F, Hussain M, et al. Edible coatings for enhancing safety and quality attributes of fresh produce: A review. Int J Food Prop. 2022;25(1):1817–47. DOI: https://doi.org/10.1080/10942912.2022.2107005

[17] Park HJ, Rhim JW, Lee HY. Edible coating effects on respiration rate and storage life of Fuji apples and Shingo pears. Food Sci Biotechnol. 1996;5(1):59–63.

[18] Bai J, Alleyne V, Hagenmaier RD, Mattheis JP, Baldwin EA. Formulation of zein coatings for apples. Postharvest Biol Technol. 2003;28(2):259–68. DOI: https://doi.org/10.1016/S0925-5214(02)00182-5

[19] Beulah AM, Sucharitha KV, Dheeraj S, Prameela P. Effect of casein edible coating on postharvest quality of guava. Carpathian J Food Sci Technol. 2021;13(2). DOI: https://doi.org/10.34302/crpjfst/2021.13.2.1

[20] Narsaiah K, Jha SN, Wilson RA, Mandge HM, Manikantan MR. Optimizing microencapsulation of nisin with sodium alginate and guar gum. J Food Sci Technol. 2014;51:4054–9. doi: https://doi.org/10.1007/s13197-012-0886-6

[21] Kumari J, Nikhanj P. Evaluation of edible coatings for maintaining quality of fresh-cut papaya. J Food Process Preserv. 2022;46(10):e16790. DOI: https://doi.org/10.1111/jfpp.16790

[22] Dotto GL, Vieira ML, Pinto LA. Use of chitosan solutions for microbiological shelf life extension of papaya. LWT. 2015;64(1):126–30. DOI: https://doi.org/10.1016/j.lwt.2015.05.042

[23] Maqbool M, Ali A, Alderson PG, Mohamed MT, Siddiqui Y, Zahid N. Postharvest application of gum arabic and essential oils for banana and papaya. Postharvest Biol Technol. 2011;62(1):71–6. DOI: https://doi.org/10.1016/j.postharvbio.2011.04.002

[24] Joshi AV, Baraiya NS, Vyas PB, Rao TR. Gum ghatti edible coating with clove oil improves papaya storage. Int J Curr Microbiol Appl Sci. 2017;6(5):160–74. DOI: https://doi.org/10.20546/ijcmas.2017.605.019

[25] Pavani Y, Kumar RU, Reddy GG, Smith D. Edible film coating of fresh-cut papaya. Int J Multidiscip Adv Res Trends. 2017;4:1–4.

[26] Tapia MS, Rojas-Graü MA, Carmona A, Rodríguez FJ, Soliva-Fortuny R, Martin-Belloso O. Alginate and gellan coatings for fresh-cut papaya. Food Hydrocoll. 2008;22(8):1493–503. DOI: https://doi.org/10.1016/j.foodhyd.2007.10.004

[27] Ali A, Hei GK, Keat YW. Ginger oil + gum arabic on papaya quality. J Food Sci Technol. 2016;53:1435–44. doi: https://doi.org/10.1007/s13197-015-2124-5

[28] Ma Y, Li X, Jia P, Ma Y, Liu N, Zhang H. Zein membranes for ethanol pervaporation. Desalination. 2012;299:70–8. DOI: https://doi.org/10.1016/j.desal.2012.05.024

[29] Kim S, Xu J. Aggregate formation of zein in aqueous ethanol. J Cereal Sci. 2008;47(1):1–5. doi: https://doi.org/10.1016/j.jcs.2007.08.004

[30] Zhang L, Liu Z, Han X, Sun Y, Wang X. Ethanol influence on zein/chitosan films. Int J Biol Macromol. 2019;134:807–14. DOI: https://doi.org/10.1016/j.ijbiomac.2019.05.085

[31] Bates J. AOAC. Official Methods of Analysis. Virginia: AOAC; 1994.

[32] Tabassum N, Khan MA. Modified atmosphere packaging of fresh-cut papaya using alginate coating. Sci Hortic. 2020;259:108853. DOI: https://doi.org/10.1016/j.scienta.2019.108853

[33] Islas-Osuna MA, Stephens-Camacho NA, Contreras-Vergara CA, Rivera-Dominguez M, Sanchez-Sanchez E, Villegas-Ochoa MA, et al. Novel postharvest treatment reduces ascorbic acid losses in mango var. Kent. Am J Agric Biol Sci. 2010;342–9. DOI: 10.3844/ajabssp.2010.342.349

[34] Sucharitha KV, Beulah AM, Ravikiran K. Effect of chitosan on tomato storage. Int Food Res J. 2018;25(1):93–9.Harborne J.

Phytochemical methods. London: Chapman & Hall; 1973. p. 49–188.

[35] Harringan WF, Mccance ME. Laboratory methods in food microbiology. 1976. p. 1–115.

[36] Valero D, Díaz-Mula HM, Zapata PJ, Guillén F, Martínez-Romero D, Castillo S, Serrano M. Effects of alginate edible coating on preserving fruit quality in four plum cultivars during storage. Postharvest Biol Technol. 2013;77:1–6. DOI: https://doi.org/10.1016/j.postharvbio.2012.10.011

[37] Sancho LE, Yahia EM, González-Aguilar GA. Identification and quantification of phenols, carotenoids, and vitamin C in papaya cv. Maradol by HPLC-DAD-MS/MS-ESI. Food Res Int. 2011;44(5):1284–91. DOI: https://doi.org/10.1016/j.foodres.2010.12.001

[38] Olivas GI, Barbosa-Cánovas GV. Edible coatings for fresh-cut fruits. Crit Rev Food Sci Nutr. 2005;45(7–8):657–70. DOI: https://doi.org/10.1080/10408690490911837

[39] Guo Y, Liu Z, An H, Li M, Hu J. Nano-structure and properties of maize zein studied by AFM. J Cereal Sci. 2005;41(3):277–81. DOI: https://doi.org/10.1016/j.jcs.2004.12.005

[40] Hassani F, Garousi F, Javanmard M. Edible coating based on whey protein concentrate–rice bran oil for kiwifruit. Trakia J Sci. 2012;10(1):26–34.

[41] Bai RK, Huang MY, Jiang YY. Selective permeabilities of chitosan-acetic acid and chitosan-polymer membranes for O_2 and CO_2. Polym Bull. 1988;20:83–8. DOI: https://doi.org/10.1007/BF00262253

[42] Ali A, Muhammad MT, Sijam K, Siddiqui Y. Effect of chitosan coatings on physicochemical characteristics of Eksotika II papaya during cold storage. Food Chem. 2011;124(2):620–6. DOI: https://doi.org/10.1016/j.foodchem.2010.06.085

[43] Cipolatti EP, Kupski L, Rocha MD, Oliveira MD, Buffon JG, Furlong EB. Protein–phenolic coating on tomatoes. Food Sci Technol. 2012;32:594–8. DOI: https://doi.org/10.1590/S0101-20612012005000081

[44] Yusoff NH, Seng TC, Zainal Z. Alginate formulation enriched with essential oil for ripening delay of Sekaki papaya. 2022;12(2):1–?. ISSN 2462-1757.

[45] Allam N, Mostafa YS. Impact of edible coating on fresh-cut papaya during cold storage. Egypt J Hortic. 2025;52(1):101–12. DOI: https://dx.doi.org/10.21608/ejoh.2025.378047.1285

[46] Gorny JR, Hess-Pierce B, Kader AA. Effects of fruit ripeness and storage temperature on deterioration of fresh-cut peach and nectarine slices. 1998;110–3.

[47] González-Aguilar GA, Ayala-Zavala JF, Ruiz-Cruz S, Acedo-Félix E, Díaz-Cinco ME. Effect of temperature and MAP on quality of fresh-cut bell peppers. LWT. 2004;37(8):817–26. DOI: https://doi.org/10.1016/j.lwt.2004.03.007

[48] Singh M, Kumar N, Gupta A, Palai I, Kumari A, Arshi AM. A comprehensive review on utilization of agricultural waste for reinforced structural products: a sustainable perspective.

[49] Chien PJ, Sheu F, Yang FH. Effects of chitosan coating on quality and shelf life of sliced mango. J Food Eng. 2007;78(1):225–9. DOI: https://doi.org/10.1016/j.jfoodeng.2005.09.022

[50] Teixeira GH, Durigan JF, Mattiuz BH, Rossi Júnior OD. Processamento mínimo de mamão 'Formosa'. Food Sci Technol. 2001;21:47–50. DOI: https://doi.org/10.1590/S0101-20612001000100011

[51] Pila N, Gol NB, Rao TR. Effects of post-harvest treatments on physicochemical characteristics and shelf life of tomato. Am Eurasian J Agric Environ Sci. 2010;9(5):470–9.

[52] Jahan S, Gomasta J, Hassan J, Rahman H, Kader MA, Kayesh E. Fruit quality retention and shelf-life extension of papaya through organic coating. Heliyon. 2025;11(1).

[53] Farina V, Passafiume R, Tinebra I, Scuderi D, Saletta F, Gugliuzza G, et al. Aloe vera gel-based edible coating for fresh-cut papaya. J Food Qual. 2020;2020:8303140. DOI: https://doi.org/10.1155/2020/8303140

[54] Olivas GI, Mattinson DS, Barbosa-Cánovas GV. Alginate coatings for minimally processed Gala apples. Postharvest Biol Technol. 2007;45(1):89–96. DOI: https://doi.org/10.1016/j.postharvbio.2006.11.018

[55] Guillén F, Díaz-Mula HM, Zapata PJ, Valero D, Serrano M, Castillo S, Martínez-Romero D. Aloe gels delay postharvest ripening of peach and plum. Postharvest Biol Technol. 2013;83:54–7. DOI: https://doi.org/10.1016/j.postharvbio.2013.03.011

[56] Moalemiyan M, Ramaswamy HS, Maftoonazad N. Pectin-based coating for shelf-life extension of Ataulfo mango. J Food Process Eng. 2012;35(4):572–600. DOI: https://doi.org/10.1111/j.1745-4530.2010.00609.x

[57] Debeaufort F, Quezada-Gallo JA, Voilley A. Edible films and coatings: tomorrow's packaging. Crit Rev Food Sci Nutr. 1998;38(4):299–313. DOI: https://doi.org/10.1080/10408699891274219

[58] Raju M, Mondal R, Valliath AS, Tejaswi S, Das P. Enhancement of papaya quality and shelf-life by edible coating. 2023;9:10. DOI: https://doi.org/10.14719/pst.2024

[59] Sharma B, Nigam S, Verma A, Garg M, Mittal A, Sadhu SD. Guava-derived edible Cu/Zn oxide nanocoating for food preservation. J Polym Environ. 2024;32(1):331–44. DOI: https://doi.org/10.1007/s10924-023-02972-1

[60] Zuhair RA, Aminah A, Sahilah AM, Eqbal D. Antioxidant activity and physicochemical changes of papaya cv. Hongkong during ripening. Int Food Res J. 2013;20(4).

[61] Ribeiro TT, Barbosa AM, Nunes TP, Costa AS, Oliveira MB, Borges GR, et al. Antifungal packaging based on pectin/gelatin with *Azadirachta indica* extract for papaya coating. Appl Sci. 2025;15(8):4423. DOI: https://doi.org/10.3390/app15084423

[62] Bahmid NA, Siddiqui SA, Ariyanto HD, Sasmitaloka KS, Rathod NB, Wahono SK, et al. Cellulose-based coating for tropical fruits: method and functionality. Food Rev Int. 2023;1–24. DOI: https://doi.org/10.1080/87559129.2023.2209800

[63] Dubey N, Chitranshi S, Dwivedi SK, Sharma A. Postharvest physiology, value chain advancement, and nanotechnology in fresh-cut fruits and vegetables. In: Nanotechnology horizons in food process engineering. Apple Academic Press; 2023. p. 99–132.