Effect of mango kernel seed starch-based active edible coating functionalized with lemongrass essential oil on the shelf-life of guava fruit

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RESEARCH ARTICLE

Abstract

In the present investigation, the mango kernel seed starch-based edible coating was developed combined with different concentrations of lemongrass essential oil (EO). The effects of different edible coating formulations, such as T1 (2% mango kernel seed starch); T2 (2% mango kernel seed starch + 0.25% lemongrass essential oil); T3 (2% mango kernel seed starch + 0.5% lemongrass essential oil); and T4 (2% mango kernel seed starch + 1% lemongrass essential oil), were investigated for physiological, physiochemical, and microbiological properties of fresh guava fruit stored at 23 ± 2°C and a relative humidity of 85 ± 5% for up to 9 days. Results of the present study revealed that the mango kernel seed starch edible coating combined with lemongrass essential oil was effective in enhancing the storage life of guava fruit by maintaining their quality attributes. Treatment of mango kernel seed starch with 0.5% lemongrass essential oil (T3) was the most significant ($P < 0.05$) treatment to reduce physiological loss in weight and oxidation rate while maintaining the physiochemical characteristics, such as acidity, total soluble solids, textural property, phenolic contents, and sensory profiles of stored guava fruit samples, followed by T4 treatment. The microbial load of yeast and mold was also reduced by T3 and T4 treatments. All coating treatments were potent to enhance the storage life of guava fruit with improving post-harvest quality attributes for up to 9 days of storage. However, retention of higher quality of fruit was observed with T3 treatment.

Keywords: mango kernel seed; edible coating; essential oil; guava; shelf life; physiological disorder

Introduction

Guava (*Psidiumguajava* L.) fruit, belonging to the *Myrtaceae* family, is commercially grown in tropical regions around the world (de Aquino *et al.*, 2015; Mangaraj *et al.*, 2021). It has pleasant aroma and delicious taste, and contains rich amount of nutrients such as pectin, dietary fibers, and phytochemicals such as ascorbic acid, guaijavarin, and quercetin (Naseer *et al.*, 2018; Sharma and Saini, 2021). Guava has potential health benefits such as it helps to control cholesterol level, and has hepato-protective effects (Murmu and Mishra, 2018). It is commonly consumed as raw as well as used for producing various value-added products such as jam, jellies, and juices. Guava has a short shelf life because of higher rate of respiration and ethylene production, leading to early onset of respiratory peak (Yadav *et al.*, 2022). The early spoilage of guava fruit is mainly due to enzymatic

metabolic activity, higher respiration, and loss of moisture (Kumar *et al*., 2017; Murmu and Mishra, 2017; Teixeira, 2020). Several types of postharvest management practice and technology, including controlled atmosphere packaging (CAPs), modified atmosphere packaging (MAPs), and nontoxic formulations of edible and composite edible packaging (coating), are used for preservation of horticulture produce during storage (Manikantan *et al.*, 2022a, 2022b); this helps in increasing fruit's shelf life and improving postharvest quality attributes (Prithviraj *et al.*, 2022). In recent years, consumers' interest is visible in trends for the application of biopolymer and nontoxic edible coating for food application as well as minimizing postharvest losses in horticulture produce (Kumar *et al.*, 2021a, 2021b, 2021c; Manikantan *et al.*, 2022c; Murmu and Mishra, 2018). The edible coatings are generally recognized as safe for consumption, and are eco-friendly and effective in retarding physiological processes, such as respiration and transpiration, that delay fruit ripening, and provide microbiological safety. During the development of film and edible coating formulations, the natural biopolymers, such as polysaccharides, proteins, and lipids derived from plants and animals are generally used to developing edible and composite materials for the packaging of food materials (Madhav *et al*., 2021; Suhag *et al*., 2020). In order to overcome the postharvest losses in guava fruit, the polysaccharide matrix, that is, starches, are generally used to develop edible coatings for food applications. It has been reported that starch-based films and coatings have excellent barrier properties against permeability of O_2 and CO_2 (Neetoo *et al*., 2010). Demand for conventional food-based starches is increasing at commercial scale because of its versatility and low cost (Santana and Meireles, 2014). Recent researches are exploring the extraction of starches from unconventional sources for application in food packaging (Galus *et al*., 2020; Li *et al*., 2018; Saturos *et al*., 2021; Yadav *et al*., 2021). In this regard, mango kernel seed starch could be an alternative to food-based starches for forming edible coating and their applications on horticulture produce to improve their characteristics. Mango kernel seed starch is a natural polymer obtained from mango kernel after depulping of mangoes; it has good film-forming capabilities and is effective to preserve horticulture produce at ambient conditions by retarding water loss and gas exchange (Nawab *et al*., 2016).

The poor water barrier properties are the major drawback of polysaccharide-based edible coatings (Nesic *et al.*, 2019; Zhao *et al*., 2021). These drawbacks can be overcome by adding lipid components, such as essential oils (EOs), which help in improving the permeability of water vapor and gaseous transmissions of coating materials. Moreover, utilization of essential oils in edible coating is getting more attention because of hydrophobic nature and phytochemical profiles, as essential oils possess antibacterial, antifungal, and antioxidant properties to combat several types of food-borne pathogens and lipid oxidation. Furthermore, lemongrass essential oil possesses antimicrobial efficiency because of presence of phytochemicals and bioactive compounds, such as citral, limonene, and citronellal. The incorporation of lemongrass essential oil as an alternative to fungicide and chemical preservatives with mango kernel seed starch would improve the physiochemical and biological properties of edible coating as well as horticulture produce. The aim of the present study was to investigate the effects of mango kernel seed starch-based edible coating combined with different concentrations of lemongrass essential oil on the postharvest characteristics and shelf life of guava fruit during the storage period of up to 9 days at ambient (23 ± 2°C) storage conditions. The lemongrass essential oil could be considered as an alternative to fungicides.

Materials and Methods

Materials

Fresh guava (*Cv. Desi Kalmi*) fruit samples were procured from an orchard (Bawana, New Delhi, India). The kernels of mango (*Cv. Totapuri*) fruit were obtained from the local mango pulp industry (Rohini, New Delhi, India). The food-grade essential oil (lemongrass) was purchased from Veda Essential Oils, New Delhi, India. Plasticizer (glycerol) and emulsifier (Tween 80) were supplied by Hi-Media, New Delhi, India.

Experimental methodology

Extraction of mango kernel starch

The starch was extracted from mango seed kernel using wet grinding procedure adopted by Nawab *et al*. (2016). Initially, obtained kernels were sliced manually into 1-cm^3 pieces and immediately steeped in 0.16% sodium metabisulphite solution. The material was held at a temperature of 45°C for 16 h to avoid browning of seeds. The mixture was then ground using food-grade grinder to obtain slurry. The slurry was screened through sieves of 100 µm, followed by 300-µm mesh size. The slurry obtained after grinding of mango kernel was immersed in distilled water and centrifuged (Sigma, 3-18, KS, Germany) for 5 min at 8,000 rpm for purification of starch. The process was repeated five times to obtain white layer of starch. The white layer of starch was dried for 10 h at 45°C to obtain starch powder.

Preparation of edible coating

Mango kernel seed starch, 2% (w/v), was immersed in distilled water to prepare mango kernel seed starch-based edible coating combined with lemongrass essential

oil. The dispersions of edible coatings were heated at 95°C for 30 min using magnetic stirrer hot plate. The gelatinized starch was cooled up to 50°C. Glycerol (40% v/w), different concentrations of lemongrass essential oil (0.25%, 0.50%, and 1%), and tween 80 (0.5% v/v) as emulsifier were added to the dispersion for developing edible coatings. The prepared dispersions were subjected to homogenization at 10,000 rpm for 10 min using tissue homogenizer (Polytron, PT MR, 3100, Switzerland). Four edible coating combinations, that is, T1, T2, T3, and T4, were prepared for coating application and to investigate their effects on quality attributes and postharvest characteristics of guava fruit during storage period (Table 1). Distilled water was used as a control.

Application of edible coating on guava, and storage

Guava fruit samples weighing 60–80 g were randomly divided into five groups, each group containing 40 fruit samples. Fruit samples were gently washed in chlorinated water (200 ppm) to remove microbial contamination and other impurities and dried at 23 ± 2°C for 30 min. Thereafter, each group was dipped in different coating material for 5 min; excess of coating material was allowed to drain. The control group was immersed in distilled water. Fruit samples were air-dried at ambient conditions and stored for up to 9 days at 23 ± 2°C and relative humidity (RH) of 80 ± 5% in environmental chamber. The edible coating efficiency of guava was evaluated at intervals of 3 days for a total of 9 days.

Physiological and physiochemical characteristics of guava

Physiological loss in weight (PLW)

Effect of edible coating on the PLW of guava was determined by mass difference method using electronic balance (BSA224S-CW; Sartorius Analytical Balance, India) and the results were expressed as percentage loss calculated using following equation:

$$\mathrm{PLW}(\%) = W1 - W2 / W1 \times 100, \quad (1)$$

where

W1 is the initial mass (g) and

W2 is the final mass (g).

Table 1. Mango kernel starch-based coating formulations.

Control	Deionized water
T1	2% mango kernel starch
T2	2% mango kernel starch + 0.25% lemongrass essential oil
T3	2% mango kernel starch + 0.5% lemongrass essential oil
T4	2% mango kernel starch + 1% lemongrass essential oil

Respiration rate

The respiration rate of control and coated fruit samples was determined using gas analyzer (Dansensor®, CheckPoint 3, Ametek Mocon, USA). The samples were kept in closed air-tight jars for 2 h at 25°C for estimating O_2/CO_2 in jars' headspace. A 0.25-mm syringe was inserted in the jar through septum to transfer gases from headspace to analyzer. The percentage composition of O_2 and CO_2 was obtained digitally for calculating respiration rate, which is expressed as rate of CO_2 evolution, using the following equation:

$$\text{Respiration rate (mL } CO_2\ kg^{-1}\ h^{-1}) = CO_2\ (\%) \times \text{headspace}/100 \times \text{weight (kg)} \times \text{time (h)}. \quad (2)$$

Titratable acidity (TA)

Titratable acidity of control and treated fruit samples was calculated using titration method adopted by Kumar *et al.* (2021d). About 1 g of fruit pulp was mixed in distilled water and the total volume of the solution was made up to 100 mL by adding more of distilled water. The obtained solution was filtered and titrated against 0.1-N NaOH solution. Phenolphthalein was used as an indicator to judge the end point. The results were calculated as percentage of citric acid using the following equation:

$$\text{Titratble acidity (TA) (\%)} = \frac{\text{Vol. of NaOH} \times \text{milliequivalent weight of acid} \times \text{normality of NaOH}}{\text{Volume of sample} \times \text{weight of sample}} \times 100. \quad (3)$$

Total soluble solids (TSS)

The effect of edible coating on guava fruit samples was determined using refractometer (RX-5000α; Atago, Japan) at 20°C (Kumar *et al.*, 2021a). Results of TSS are expressed in Brix.

Ascorbic Acid

The content of ascorbic acid in uncoated and coated guava fruit samples was determined using the method adopted by Kumar *et al.* (2021d) with minor modifications. Guava fruit pulp (5 g) was macerated with 3% metaphospheric acid and made up to 100 mL using distilled water. An aliquot of 10 mL was titrated against 2,6-dicholorophenolindophenol dye to mark the end point and calculated as milligram of ascorbic acid. The average value of the result was calculated as mg/100 g of juice:

$$\text{Ascorbic acid (mg/100 g)} = \frac{(\mathrm{V\text{-}V0}) \times \mathrm{T} \times \mathrm{A}}{\mathrm{W}} \times 100, \quad (4)$$

where

V is the volume of 2,6-dichlorophenolindophenol solution used in the titration sample,

V0 is the volume of 2,6-dichlorophenolindophenol solution used for blank titration,

T is the 2,6-dichlorophenolindophenol solution titer,

A is the dilution factor, and W is the weight of sample.

Color

Color scales (CILAB) of guava during storage were evaluated by colorimetric method using hand-held colorimeter (CR-400; Konica, Japan). The surface color of guava was measured as lightness/darkness (L^*), greenish/redness (a^*), and yellowness/blueness (b^*). The total color difference (ΔE) of the samples was calculated using the following equation:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}. \quad (5)$$

where

$L^*_1 = L^*$ value of reference color;

$L^*_2 = -L^*$ value of sample color;

$a^*_1 = -a^*$ value of reference color;

$a^*_2 = -a^*$ value of sample color;

$b^*_1 = -b^*$ value of reference color;

$b^*_2 = -b^*$ value of sample color

Firmness

The firmness of guava was evaluated by texture analyzer (Stable Micro-System, TAHD Plus, UK) (Kumar *et al.*, 2021b) using 2-mm cylindrical probe at a test speed of 1 mm/s. Five readings of each sample at an equatorial diameter of fruit were taken, and firmness of the samples was expressed as force in Newton (N).

Total phenolic content (TPC)

The effects of edible coating treatment on the phenolic content of guava during storage period was measured using Folin-Ciocalteu (FC) reagent assay adopted by El-Gioushy *et al.* (2022) with some modifications. About 1 mL of fruit extract was immersed in 70 mL of distilled water along with 5 mL of 10 times diluted FC reagent and 15 mL of 20% sodium carbonate solution. The mixture volume was made up to 100 mL using distilled water, and left for incubation at room temperature for 2 h. The UV-spectrophotometer (Sican 2301; Incarp, India) was used to measure absorbance of fruit samples at 765 nm. The results of TPC were expressed as mg/100 g of gallic acid.

Total yeast and mold count

Total yeast and mold count of fruit samples was determined using standard ISO 7954 method used by Tovar *et al.* (2019). In all, 10 g of guava fruit sample was homogenised with 90 mL of peptonized water for 10 min and 10^{-1} to 10^{-6} serial dilutions were prepared from homogenate. Then 1 mL of each serial dilution was transferred to petri dishes containing potato dextrose agar (PDA) supplemented with 10% tartaric acid; the samples were allowed to incubate for 72 h at 30°C. The samples were analyzed at 3 days interval kept for 9 days, and the results were expressed as log colony-forming unit per gram (CFU/g) of total yeast and mold.

Sensory evaluation and shelf life assessment of guava fruit

The sensory characteristics of control and coated guava fruit samples were evaluated using five-point hedonic scales as proposed by Murmu and Mishra (2017). The overall acceptability (OAA) of guava was reported based on their visual and physical appearance, viz., color, aroma, percentage of decay, shrinkage, and textural quality. The hedonic score of 5 indicated maximum severity and score of 1 indicated minimum severity for each response of panellists. A total of 30 semi-trained panellists evaluated the quality of guava fruit at an interval of 3 days throughout the storage period of 9 days.

Statistical Analysis

The data were analyzed using the IBM SPSS (24.0) statistical analytical software with Duncan multiple range test at significance level of 0.05. The data results reported in the present study were average of three replications.

Results and Discussion

Effect of edible coating on physiological loss in weight

The increasing PLW of fruits and vegetables is the result of high transpiration of water and oxidation in produce during storage period (Kumar *et al.*, 2021a, 2021b). Figure 1 shows the effects of different mango kernel seed

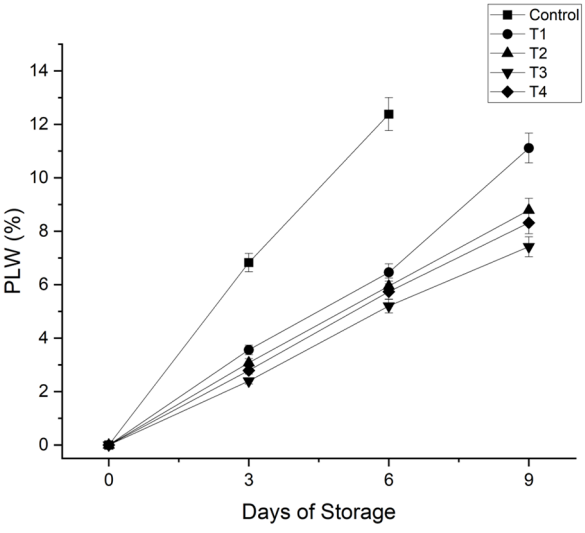

Figure 1. PLW of control and coated guava fruit. Mean ± SD, where control = water; T1 = 2% mango kernel starch; T2 = 2% mango kernel starch + 0.25% lemongrass essential oil; T3 = 2% mango kernel starch + 0.5% lemongrass essential oil; and T4 = 2% mango kernel starch + 1% lemongrass essential oil.

starch-based edible coating combined with lemongrass essential oil on guava fruit samples during storage. The PLW of all treated and untreated guava fruit samples was gradually increased, but the higher increase was recorded in control samples, followed by T1-treated samples on 3 days of storage. All treatments were found effective to control loss of PLW contrary to control samples. Control samples had more than 10% PLW (12.38 ± 0.45%) after day 6 of storage, which indicated the unmarketability of fruit. The sharp increase in PLW in control samples was attributed to higher migration of water molecules from fruit surface to the atmosphere. On day 9 of storage, guava fruit samples treated with 2% mango kernel seed starch-based edible coating (T1) showed 11.11% of PLW. The T3-treated fruit samples showed significantly ($P < 0.05$) higher PLW (7.42 ± 0.10%) as compared to other treatments and control samples. This could be possible due to minimum migration of water molecules from fruit surface to the environment because of partial covering of stomata microspores present of the surface of samples by the application of edible coating (Formiga *et al.*, 2019; Maftoonazad and Ramaswamy, 2019; Shamloo *et al.*, 2013). Hence, T2, T3, and T4 treatments were effective in reducing PLW in guava fruit samples during the storage period. Control and T1 coated samples showed statistically significant ($P > 0.05$) higher weight loss than other treatment samples. On day 6 and 9 of storage, PLW in T2- (5.95 ± 0.06%; 8.79 ± 0.27%) and T4-treated (5.74 ± 0.16%; 8.32 ± 0.10%) samples was, respectively, at par ($P = 0.05$). The results indicated that the combination of lemongrass essential oil and mango kernel seed starch effectively reduced the PLW of guava fruit samples during storage. Addition of essential oil in edible coating acted as a hydrophobic agent that helped in restricting migration of water from the outer surface of fruit. Similar results were reported by Vishwasrao and Ananthanarayan (2016), demonstrating that the edible coating of hydroxypropyl methyl cellulose (HPMC) and palm oil significantly reduced PLW in guava fruit during storage. The results of the present study were also in agreement with the results of the studies conducted by Murmu and Mishra (2017), Silva *et al.* (2021), and Sothornvit (2012).

Effect of edible coating on respiration rate

Respiration rate is one of the factors that affects the quality, including organoleptic characteristics, of fruits during storage. The process of respiration involves oxidation of sugar to produce CO_2, heat, and moisture (Tano *et al.*, 2005). Guava is a climacteric fruit with higher rate of respiratory and ethylene production (Krishna and Rao, 2017; Yadav *et al.*, 2022). Figure 2A illustrates the results of respiration rate of control and guava fruit samples coated with different formulations of mango kernel seed starch-based edible coating and lemongrass essential oil. In both control and treated samples, the respiration rate increased with storage period but higher respiration rate was recorded in control samples during the storage period of up to 6 days. The peak of respiration rate in control samples was achieved in 3 days of storage whereas all treatments demonstrated delay in the onset of peak. Control samples demonstrated the lowest respiration rate from day 3 to day 6 of storage (80.51 mL CO_2 kg^{-1} h^{-1}). This sudden decrease in respiration rate of control samples indicated their unacceptability and increasing electrolytic leakage (Kumar *et al.*, 2021a). This could be due to use of metabolites, resulting in slow down of synthesis and higher PLW (Das *et al.*, 2013; Quirós-Sauceda *et al.*, 2014). The application of edible coating effectively reduced respiration rate in fruit samples and delayed the onset of respiratory peak. This was due to creation of semi-permeable barrier on the surface of fruit samples that improved gaseous exchange with external environment, thus resulting in better retention quality of fruit (Nasrin *et al.*, 2018; Pace and Cefola, 2021). T3 treatment was found as most potential to significantly inhibit respiration rate in guava fruit samples, followed by T4 treatment, as compared to other treatments and control samples. Results of the present investigation were in line with results of the studies conducted by Chaudhary and Kumar (2019) and Martinez-Ortiz *et al.* (2019). Both studies investigated the effects of different coating materials prepared from starch, sago starch, rice starch, and wax on the quality characteristics of guava, and reported that edible coatings were effective in delaying respiratory peak in fresh produce.

Effect of edible coating on titratable acidity

Initially, the TA of control and coated guava fruit samples increased rapidly with increase in storage time to 6 days in treated and 3 days in control samples, but then came down significantly. Increased acidity on day 3 could be attributed to production of organic acid with increased ripening process (Manríquez *et al.*, 2014). On the other hand, increased acidity of fruit samples during storage indicates initiation of fermentative pathways (Kanellis *et al.*, 2009). On day 6 of storage, the acidity of control samples increased gradually from 0.61 ± 0.01% to 0.71 ± 0.01%, which demonstrated higher erosion in the value of acidity compared to coated guava fruit samples (Figure 2B). Throughout the storage period, T3 treatment was most effective for maintaining the acidity of guava compared to other treated and control samples. On day 9 of storage, the T3-treated fruit samples had significantly ($P < 0.05$) higher acidity, followed by T4- (0.78 ± 0.01%), T2- (0.77 ± 0.01), and T1-treated (0.75 ± 0.01) samples. Control samples were not available for analysis up to day 9 of storage. The higher decreasing acidity of the fruit during storage was due to utilization of organic acids in metabolic activity and invertase enzyme activity; which was responsible

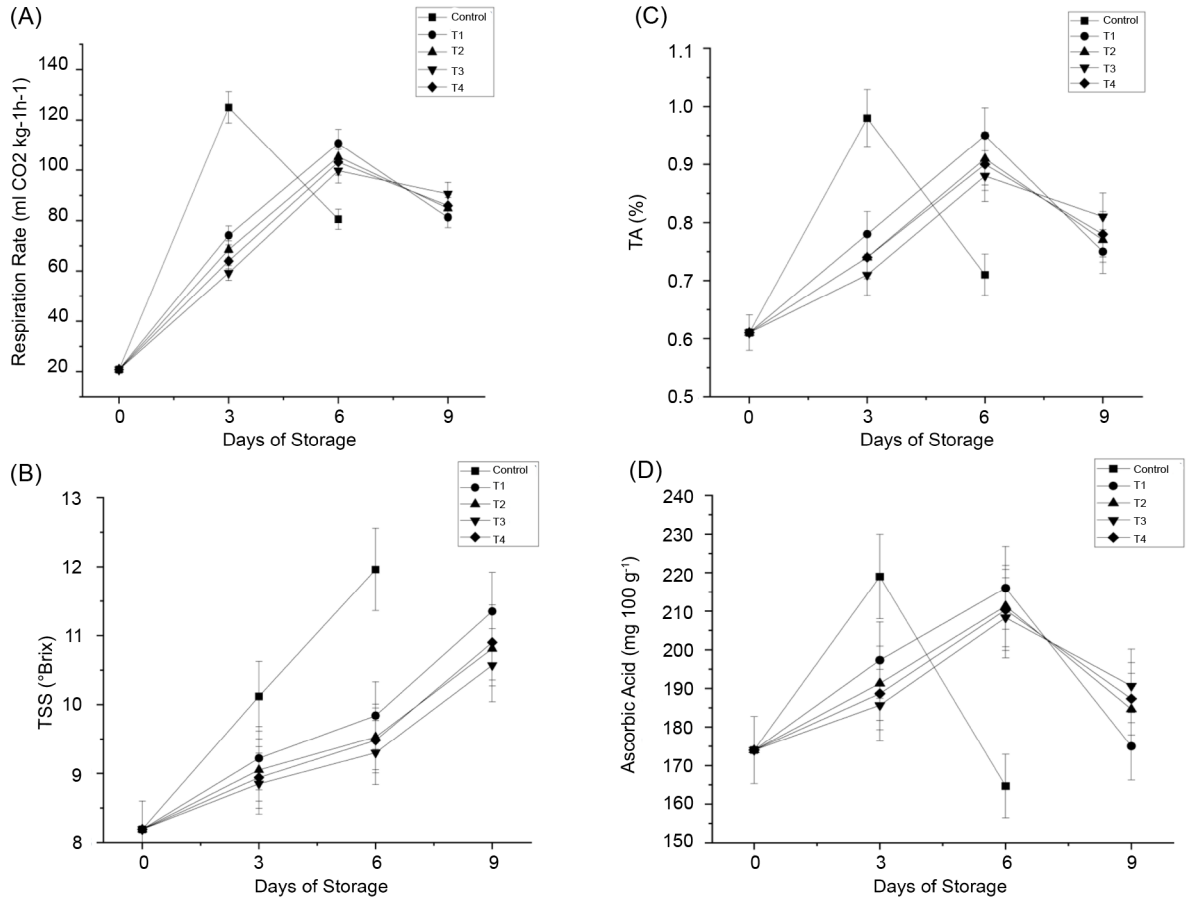

Figure 2. (A) Respiration rate, (B) TA, (C) TSS, (D) ascorbic acid of control sample and coated guava fruit. Mean ± SD, where control = water; T1 = 2% mango kernel starch; T2 = 2% mango kernel starch + 0.25% lemongrass essential oil; T3 = 2% mango kernel starch + 0.5% lemongrass essential oil; and T4 = 2% mango kernel starch + 1% lemongrass essential oil..

for transformation of acid into sugar (Pratap *et al*., 2021). The results of this study concluded that the application of mango kernel seed starch-based edible coating with 0.5% lemongrass essential oil (T3) had more potential to retain higher acidity of guava fruit during the storage period compared to other treatments and control. The results were in line with results of the study conducted by Beulah *et al*. (2021) and Kumar *et al*. (2021d); these authors investigated the effects of carboxy methyl cellulose (CMC)- and casein-based edible coating on the postharvest quality attributes of guava at ambient temperature.

Effect of edible coating on total soluble solids

Presence of TSS is the most important characteristic of fruits, indicating their sweetness (Magwaza and Opara, 2015). TSS is directly related to the maturity and ripening of fruits. Changes and increasing trend of TSS in fruits are due to the breakdown and conversion of sugar molecules from complex to simple sugar (Kumar *et al*., 2021a, 2021b). A significant increase in TSS of control and coated guava fruit samples were observed with storage period of up to 9 days. On day 6 of storage, TSS in control samples (11.96 Brix) was significantly ($P > 0.05$) higher, and unacceptable weight loss and sensorial score were observed due to higher respiration rate and electrolytic leakage (Kumar *et al*., 2021a). All coating treatments with and without lemongrass essential oil were effective to control increase in TSS of guava fruit during storage period. Significant ($P < 0.05$) changes in TSS were found in the T3-treated fruit samples during storage period as compared to other treatments and control (Figure 2C). On day 9 of storage, TSS of edible coating-treated guava samples ranged between 10.57 and 11.35 Brix. The higher TSS was exhibited by T1 treatment (11.35°Brix), followed by T4 (10.90°Brix) and T2 (10.81°Brix) treatments. The results demonstrated that the application of mango kernel seed starch-based edible coating enriched with lemongrass essential oil had potential to maintain the TSS of guava during storage period because of retardation of respiration rate and ethylene biosynthesis resulting in minimum hydrolytic changes (Ahmed *et al*., 2020). The relation and molecular interaction between essential oil

concentrations (0.5%) and mango kernel seed starch (2%) had more potential to maintain the quality attributes of guava at ambient conditions. Previous studies have reported that the edible coatings prepared with glucomannan and konjac incorporated with bee wax/guava leaf extract (Sothornvit, 2012) and cassava/rice bran starch (1%, 2%, or 3%) enriched with 1% sunflower essential oil and 1% of bee wax (Wijewardana *et al*., 2014) are effective in extending the shelf life of guava by up to 10 days at ambient storage conditions.

Effect of edible coating on ascorbic acid

The initial ascorbic acid found in guava on day 0 was 174 ± 1.73 mg 100 g^{-1} fresh weight, which increased in both control and treated samples after 3 days of storage. Ascorbic acid generally increases with ripening and decreases with over-ripening of fruit. Decrease in ascorbic acid indicates the biosynthesis of enzymes and accumulation of organic acids (Fenech *et al*., 2019). On day 6 of storage, the content of ascorbic acid (164.67 ± 2.08 mg 100 g^{-1}) decreased in control sample because of higher respiration rate, over-ripening, and higher water loss. However, the content of ascorbic acid increased gradually in all treated samples. The control sample was found unacceptable and was not available for further analysis (Figure 2D). On day 9 of storage, higher retention of ascorbic acid (190.67 ± 1.15 mg 100 g^{-1}) was found with T3 treatment, followed by T4 (187.33 ± 0.58 mg 100 g^{-1}) and other treatments. The results indicated that application of edible coating retained higher ascorbic acid level because of reduced oxidation by ascorbate oxidase (Singh and Pal, 2008). The results indicated that T3 was the most effective treatment to maintain the optimum level of ascorbic acid in guava compared to other treatments and control sample.

Effect of edible coating on color

Figure 3 shows the color properties (L^*, a^*, and b^*) of control and coated guava fruit samples during storage period. In most of the treated fruit samples, no significant difference was observed in color values, except T3 treatment. Color changes were significantly ($P < 0.05$) higher in control sample compared to treated fruit samples. On day 6 of storage, the control sample demonstrated the following color values: $L^* = 80.26 \pm 1.02$, $a^* = -3.78 \pm 0.29$, and $b^* = 53.88 \pm 0.90$. This indicated the browning of surface of guava fruit. A significantly ($P < 0.05$) higher maintenance of color values, $L^* = 73.74 \pm 0.41$, $a^* = -4.98 \pm 0.09$, and $b^* = 47.80 \pm 0.16$, were recorded with T3 treatment (2% mango kernel starch + 0.5% lemongrass essential oil) compared to other treatments, followed by T4 treatment, $L^* = 76.57 \pm 0.30$, $a^* = 4.63 \pm 0.07$, and $b^* = 49.97 \pm 0.13$. Color differences (ΔE) of the treated and control samples are shown in Figure 3D. Higher color difference was recorded in the control sample on day 6 of storage, followed by T1 treatment. These color values indicated that the increasing concentration of essential oil in mango kernel seed starch-based edible coating exhibited color retention of guava during storage period. The color parameters directly affected the appearance of fruit samples, that is, higher ripening, enzymatic browning, and metabolic activity (Murmu and Mishra, 2017).

Effect of edible coating on firmness

Firmness is a very important characteristic of fruit that influences consumers and is used to assess its quality. The firmness of guava is affected by the turgidity of cells—structure and composition of cell wall polysaccharide. Oxidation and water loss negatively affect firmness of the fruit (Cheng *et al*., 2008; Fekry, 2018). The results of control and coated fruit samples' puncture strength are shown in Figure 4. Puncture strength of the samples decreased with increasing period of storage. Lower puncture strength indicated the softness of guava, which means the fruit had less firmness. Significantly higher loss of puncture strength in control samples, from 12.12 ± 0.20 N to 5.34 ± 0.28 N, was observed between 0 and 3 days of storage. All coated fruit samples showed higher puncture strength during the storage period. However, the T3-treated sample was significantly ($P < 0.05$) least soft (4.88 ± 0.05 N), followed by T4-treated sample (4.05 ± 0.07 N) on day 9 of storage. This was due to higher rate of water transpiration, respiration, and oxidation.

The results of this study indicated that the application of mango kernel seed starch-based edible coating with lemongrass essential oil was more emphatic to delay softness of guava as compared to control and mango kernel seed starch-based edible coating without lemongrass essential oil. The addition of lemongrass essential oil influenced the antifungal and antioxidant properties of the matrix, and was effective against reactive oxygen species and minimizing of lipid oxidation (Murmu and Mishra, 2017). The results of the firmness of guava fruit were in agreement with previous studies conducted by Chawla *et al*. (2018), Fekry (2018), and Hong *et al*. (2012). The cited authors reported that the application of edible coating (combination of chitosan and calcium chloride) could maintain firmness of guava fruit.

Effect of edible coating on total phenolic content

Figure 5 shows the results of total phenolic content, which decreased gradually with increasing period of storage. The treated samples showed significantly ($P \leq 0.05$)

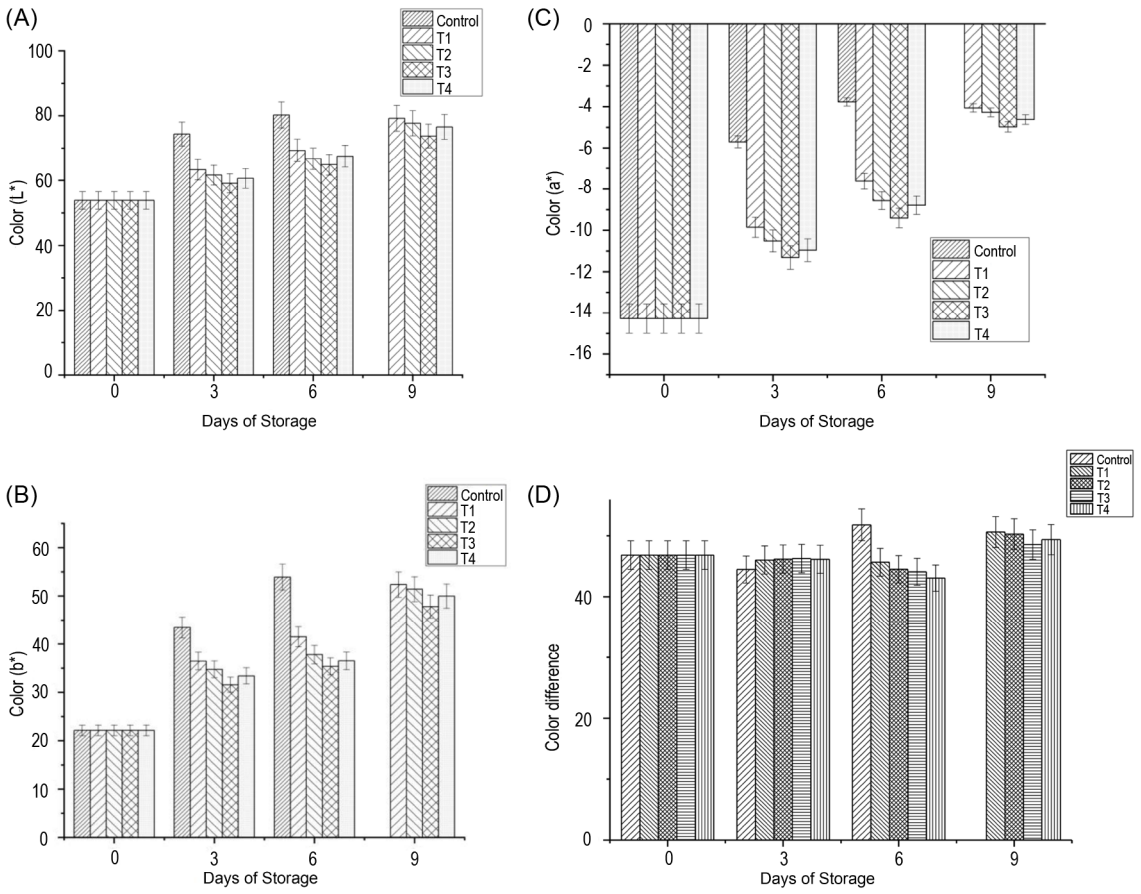

Figure 3. Color properties (A) L*, (B) a*, (C) b*, and (D) ΔE of control and coated guava fruit. Mean ± SD, where control = water; T1 = 2% mango kernel starch; T2 = 2% mango kernel starch + 0.25% lemongrass essential oil; T3 = 2% mango kernel starch + 0.5% lemongrass essential oil; T4 = 2% mango kernel starch + 1% lemongrass essential oil; and ΔE = color difference.

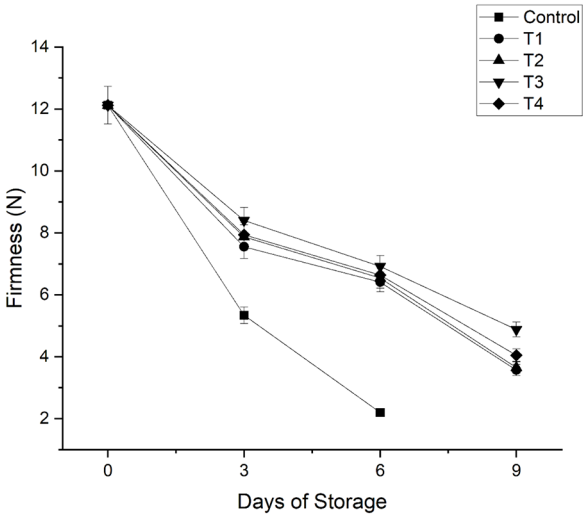

Figure 4. Firmness of control sample and coated guava fruit. Mean ± SD, where control = water; T1 = 2% mango kernel starch; T2 = 2% mango kernel starch + 0.25% lemongrass essential oil; T3 = 2% mango kernel starch + 0.5% lemongrass essential oil; and T4 = 2% mango kernel starch + 1% lemongrass essential oil.

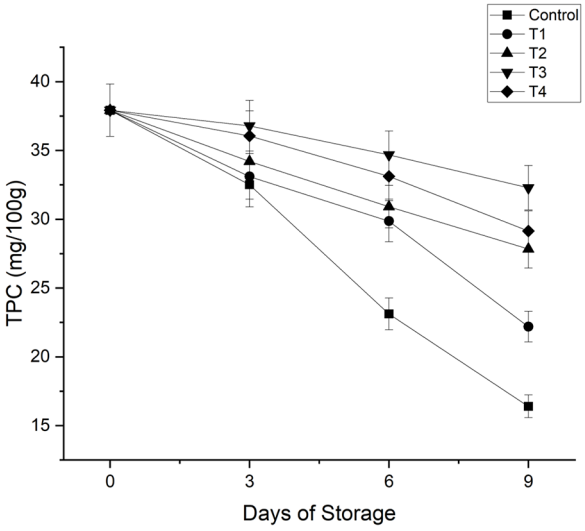

Figure 5. Total phenolic content (TPC) of control and coated guava fruit. Mean ± SD, where control = water; T1 = 2% mango kernel starch; T2 = 2% mango kernel starch + 0.25% lemongrass essential oil; T3 = 2% mango kernel starch + 0.5% lemongrass essential oil; and T4 = 2% mango kernel starch + 1% lemongrass essential oil.

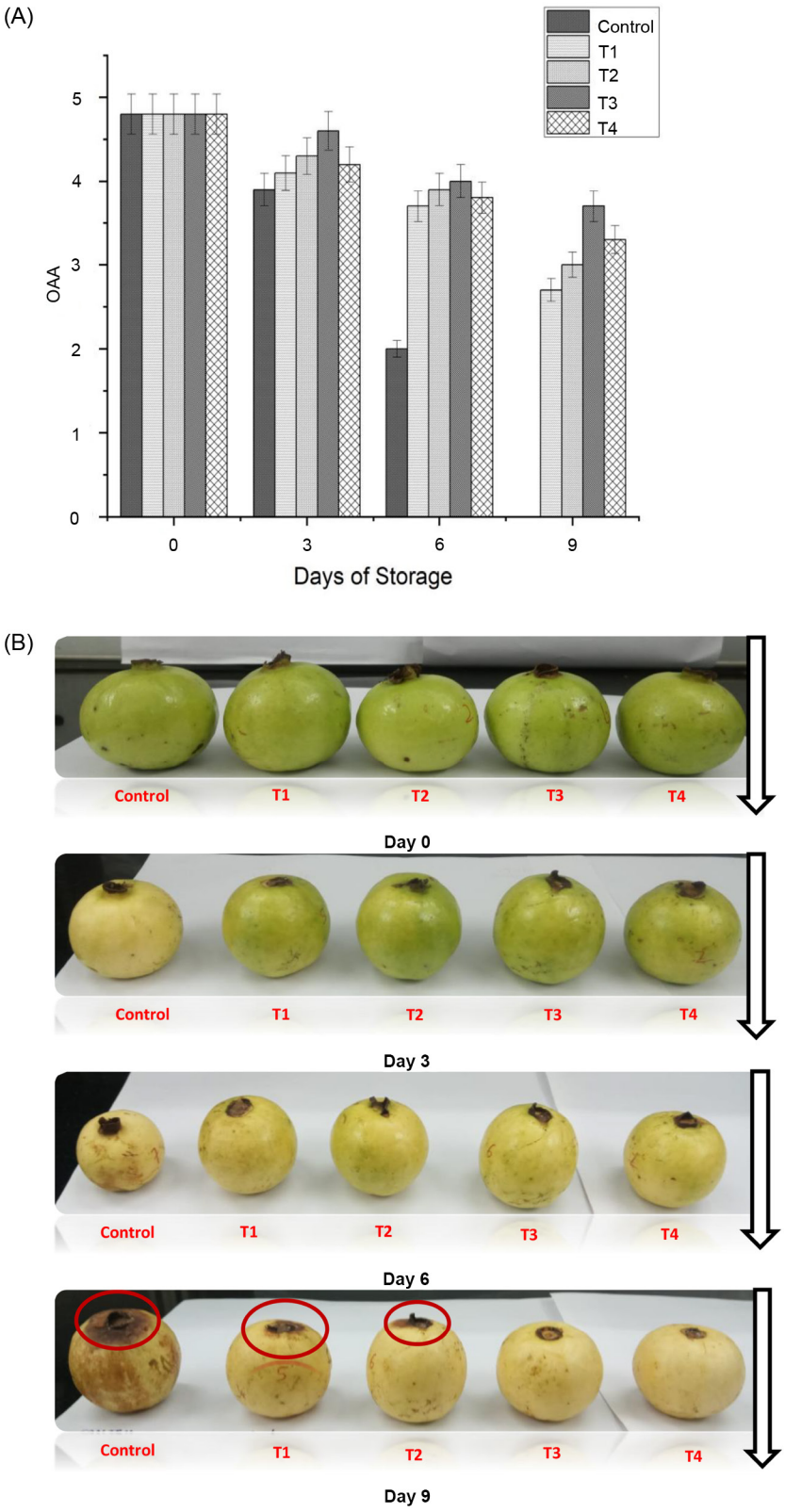

Figure 6. (A) Overall acceptability of control and coated guava fruit. (B) Visual appearance of guava fruit during storage period. Mean ± SD, where control = water; T1 = 2% mango kernel starch; T2 = 2% mango kernel starch + 0.25% lemongrass essential oil; T3 = 2% mango kernel starch + 0.5% lemongrass essential oil; and T4 = 2% mango kernel starch + 1% lemongrass essential oil.

lower reduction of phenolic content compared to control samples. Phenolic content in control samples recorded higher degradation between 3 and 6 days of storage (from 32.51 ± 0.14 mg/g to 23.12 ± 0.01 mg/g) because of higher respiration, oxidation, and enzymatic metabolic activity. On day 9 of storage, higher phenolic content was observed in the T3-treated samples (32.29 ± 0.18 mg/g), followed by other treated fruit samples, that is, T4- (29.15 ± 0.11 mg/g), T2- (27.84 ± 0.08 mg/g), and T1-treated (22.19 ± 0.21 mg/g) samples. This could be due to increasing concentration of lemongrass essential oil. The degradation of phenolic content is directly associated with reducing free radical and scavenging activity. The higher enzymatic activity of peroxidase and polyphenol oxidase is the main reason of degradation of phenolic content of samples (Augusto *et al*., 2015).

Effect of edible coating on total yeast and mold count

Table 2 shows the results of total yeast and mold count of control and coated guava samples during storage period. The coated samples with essential oil were able to inhibit yeast and mold count, and the T3- and T4-treated samples showed significant reduction ($P < 0.05$) in yeast and mold count as compared to control, T1- and T2-treated samples. Control samples showed the maximum count of 7.62 ± 0.21 log CFU/g after 6 days of storage, which indicated the unmarketability and unacceptability of guava fruit. The obtained results indicated that the increasing concentration of lemongrass essential oil in mango kernel seed starch-based edible coating had more potential to bring down the microbial load of guava fruit because of the presence of bioactive compound (citral) (Gao *et al*., 2020; Shi *et al*., 2017). A similar trend of results was reported by Murmu and Mishra (2017), who reported that the gum Arabic-based edible coating with lemongrass essential oil was effective in reducing the microbial decay of guava fruit during the storage period.

Table 2. Yeast and mold counts of control and coated guava fruits.

Treatments	Days of storage			
	0	3	6	9
Control	ND	4.11 ± 0.10	7.62 ± 0.21	N/A
T1	ND	1.75 ± 0.14	2.84 ± 0.10	5.70 ± 0.23
T2	ND	0.27 ± 0.07	1.05 ± 0.08	2.45 ± 0.06
T3	ND	ND	ND	0.81 ± 0.04
T4	ND	ND	ND	0.69 ± 0.02

Mean ± SD, where T1 = 2% mango kernel starch; T2 = 2% mango kernel starch + 0.25% lemongrass essential oil; T3 = 2% mango kernel starch + 0.5% lemongrass essential oil; and T4 = 2% mango kernel starch + 1% lemongrass essential oil. ND = Not detected.

Effect of edible coating on sensory evaluation

The overall acceptability of control and coated guava fruit was evaluated on the basis of visual and physical appearance such as color, aroma, decay percentage, shrinkage, and textural quality. The overall acceptability of all samples decreased gradually with furtherance of storage period (Figure 6A). Control samples were found unacceptable on the basis of their sensorial properties, with an overall acceptability of 2 on day 6 of storage. Furthermore, the guava samples treated with mango kernel seed starch-based edible coating enriched with 0.5% lemongrass essential oil exhibited more acceptability (3.7) on the basis of visual and physical appearance of fruit during the storage period. This was statically significant ($P < 0.05$) and high as compared to T1 (2.7), T2 (3.0), and T4 (3.3) treatments. The T4-treated sample with 2% mango kernel seed starch-based edible coating with 1% lemongrass essential oil was also found acceptable, followed by the T3-treated sample, based on the suggestions and feedback of panelists. This could be due to dark fragrance present on guava fruit because of including higher concentration (1%) of lemongrass essential oil in edible coating. The visual appearance of control and guava fruit samples is shown in Figure 6B. The figure shows changes in the visual appearance of control and coated guava fruit during 9 days of storage at ambient conditions.

Conclusions

Edible coating containing active ingredients has potential for improving the shelf life of fresh produce. The current investigation established that the mango kernel seed starch-based edible coating combined with lemongrass essential oil had a positive influence on the physiochemical and sensorial quality attributes of guava fruit at ambient storage conditions. Moreover, the retention of quality attributes was correlated with higher phenolic content and less count of yeast and mold in treated guava fruit samples. The increasing concentration of essential oil in edible coating exhibited higher quality attributes in guava fruit during storage. The application of T3 treatment, compared with other treatments and control, preserved physiochemical attributes. Further study is required to utilize mango kernel seed starch to develop active edible coating, composite, and nano-formulations for extending shelf life of fresh produce.

Author Contributions

Ajay Yadav: conceptualization, methodology, investigation, resources, formal analysis, writing—original draft and review & editing, and visualization. Nishant Kumar:

investigation, formal analysis, writing—original draft, review & editing, and visualization. Ashutosh Upadhyay: supervision, writing—review and editing. Anurag Singh: writing—review & editing; Rahul Kumar Anurag: writing—review & editing. R. Pandiselvam: resources, data analysis, formal analysis, and writing—review & editing.

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Conflicts of Interest

The authors declared no conflicts of interest.

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