Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 8, No.1, January 2026, pp. 0260105-01 ~ 0260105-010
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v8i1.2043

Pectin-based Edible Coatings with Lemongrass Essential Oils for Shelf-life Extension of Papaya

Danar Praseptiangga*, Husnawati Fatihah Habibie, Dyah Ayu Ashari, Dea Widyaastuti, Rohula Utami, Lia Umi Khasanah

Department of Food Science and Technology, Faculty of Agriculture, Universitas Sebelas Maret (UNS), Jl. Ir. Sutami No 36A Surakarta 57126, Central Java, Indonesia

*dpraseptiangga@staff.uns.ac.id

Abstract. The urgency of biodegradable packaging as an alternative for plastic-based packaging has been demanding. Accordingly, in this study, the development of pectin-based edible coating incorporated with lemongrass essential oils (LEO) has been done to sustain the physicochemical quality of papaya. The edible coating was prepared by using a simple solution method, while LEO was produced by using the water vapor distillation method. Basically, there are five applied treatments, which are uncoating (control), dip-coating (DC), spray-coating (SC), dip-coating with LEO introduction (DC/LEO1%), and spray-coating LEO incorporation (SC/LEO1%). The physicochemical characteristics of papaya were examined over 12 days of storage. Compared to the control, the application of edible coating was significantly ($p < 0.05$) enhanced weight loss, pH, ascorbic acid, and yeast and mold counts. Therefore, by mixing pectin-based coating solution with LEO can preserve the quality of papaya for almost more than 12 days at room temperature.

Keywords: biodegradable coating, lemongrass essential oils, natural preservative, papaya preservation, pectin-based edible coating

(Received 2025-05-31, Revised 2025-09-18, Accepted 2025-10-31, Available Online by 2026-01-29)

1. Introduction

Plastic packaging is the common packaging material used in the food industry, which prolongs the shelf-life of agricultural products and keeps their quality. However, we cannot rely only on this type of material anymore due to some long-term effects appearing from the use of plastic materials, though it has some benefits [1-3]. The development of sustainable and more environmentally friendly packaging becomes essential, and it leads to the development of packaging innovation, including edible packaging.

Edible packaging or coating is an edible material that can be made from polysaccharides, protein, fat, or a combination of these materials [4-5]. Various materials have been studied before, for example, the combination of chitosan and gum Arabic bilayer coatings with lemongrass essential oil, which showed a potential development, while sodium alginate-based edible coating enriched with *Siam Pontianak* tangerine peel oil also showed the same result [6-7]. To increase the functionality of the packaging, edible film is also often incorporated with active chemicals, such as essential oils (EO). EO usually provides antimicrobial activity, which helps prevent the growth of both spoilage and pathogenic microorganisms [8], so it can prolong the shelf-life of the food products. Previous studies showed that the addition of essential oils could inhibit the growth of microorganisms and enhance the shelf-life of food-based products. For example, the addition of essential oil can also maintain physical properties of food products, as shown in a previous study where essential oil from *Siam Pontianak* tangerine peel incorporated in edible coating from sodium alginate could inhibit the physical change of strawberry during storage [9].

The application of edible coating can cover various food commodities, including fruits [11-12] and one of them is papaya. However, papaya is a climacteric and perishable fruit, causing a short storage period. The application of EO-enriched edible coating is targeted to maintain the quality, reduce the number of wasted papayas, and develop the papaya market.

The combination of pectin-based edible coating with EO from fresh lemongrass has not been studied up to now, while pectin works as a physical barrier that inhibits water migration, gas exchange, and the ripening process. Thus, this research aims to evaluate two different combinations and application techniques of the combination of pectin-based edible coating with lemongrass EO on quality characteristics of papaya.

2. Methods

2.1. Materials

In the present study, fresh lemongrass (*Cymbopogon citratus*), as the base materials for preparing essential oils, were obtained from a local market (Pasar Legi), Surakarta, Indonesia. Meanwhile, the food matrix for fruit coating application, papaya, were procured from farmers' groups in Mojosongo, Boyolali (Central Java province, Indonesia), of which characteristics of them were as follows, weight range of 900-1100 g, clean, with no diseases and bruises, and the homogeneity of maturity level that were indicated by orange stripe on the surface of papaya to minimize the variability of the samples. In the preparation of the edible coating solution, pectin, as the polysaccharide biopolymer, was supplied by Cargill (Germany), and glycerol, as the plasticizer, was purchased from PT. Brataco Chemica (Indonesia). All other reagents were of analytical grade and used without further purification.

2.2. Essential Oils and Edible Coating Preparation

The lemongrass essential oils (LEO) were manufactured using the water vapor distillation method, while the edible coating was prepared using a simple solution method. Briefly, after having been sorted and cleaned, fresh lemongrass was sliced and dried under the sun until the water content reached about 14%. Subsequently, the dried sample was distilled for 4 hours, and then the extracted oils were collected and stored in dark glass vials for further use. Meanwhile, the preparation of native edible coating solution begins with diluting pectin in distilled water (5% w/v), followed by heating to 75^{o}C using a stirred hot plate to obtain complete gelatinization. Then, the edible coating solution incorporated with LEO was prepared by mixing 20 mL of glycerol in 1 L of distilled water and adding it to the pectin solution. Next, the prepared solution was heated for 30 minutes until the temperature reached 60^{o}C. Lastly, 1% (v/v) of LEO was added into the solution after allowing it to cool to room temperature to minimize denaturation.

2.3. Edible Coating Application

The application of edible coating on papaya was conducted by dipping and spraying techniques [7-8]. The first method was done by dipping papaya samples for approximately 2 minutes into the coating solution, followed by air drying. Meanwhile, the spraying method was done by spraying the solution onto the sample surface. The sprayer gun pressure was set at 3 – 4 bar. There are five treatments for edible coating application, which are uncoating (control), dipping in pectin based-edible coating solution (DC), spraying with pectin based-edible coating solution (SC), dipping in the coating solution incorporated with 1% EO (DC/LEO1%), and spraying the coating solution incorporated with 1% EO

(SC/LEO1%). All treatments were conducted with duplicate samples. After that, all samples were stored at room temperature for 12 days, and the observations were done on days 0, 3, 6, 9, and 12.

2.3.1. Determination of Physical Quality Parameters

After accurately being weighed, the weight loss of samples was determined by using equation (1) below [12], whereas firmness was measured by using a texture analyzer (Lutron FR5105, Karya Mandiri Techindo, Indonesia) and reported in Newton (N) [10].

$$\text{Weight loss (\%)} = \frac{\text{(initial weight-weight on the day of analysis)}}{\text{initial weight}} \times 100\% \quad (1)$$

2.3.2. Determination of Chemical Quality Parameters

The chemical quality parameters consist of pH, total titratable acid (TTA), total soluble solids (TSS), and ascorbic acid (vitamin C) analyses. The pH was measured in papaya pulp using a pH meter (Eutech pH testr20, Thermo Fisher Scientific, USA), while TTA was observed by titration method, where NaOH 0.1 N was used against fruit juice, and phenolphthalein as an indicator [10]. TSS was observed using a refractometer (Master Refractometer, Atago, Japan) [8]. Ascorbic acid content was assessed using the titrimetric method; 0.05% 2,6-dichlorophenol-indophenol in sodium bicarbonate was used to titrate each sample. The titration was stopped when a rosy-pink color stayed for at least 5 seconds [11].

2.3.3. Determination of Total Yeast and Mold

The total number of yeast and mold was counted by using the total plate count technique adapted from previous research with modifications [13]. The analysis was conducted by spreading diluted papaya pulp on Potato Dextrose Agar (PDA) (Merck, Germany), and then the plates were incubated at 25ºC for five days and enumerated afterward.

2.4. Sample Analysis

The experiments were conducted in a completely randomized design (CRD) with duplicate samples, and all analyses were performed in duplicate. Moreover, the obtained data were calculated as means ± standard deviation and analyzed by one-way analysis of variance (ANOVA) using SPSS software version 20 (SPSS Inc., Chicago, USA) with a significance level of 5% ($p < 0.05$), followed by the Duncan Multiple Range Test (DMRT) to analyze significant differences among the treatments.

2.5. Determination of the Best Treatment

In the present study, a compensatory model via the application of a non-dimensional scaling method was used to choose the best treatments for fruit coating application, which is described elsewhere [14] with modification [15-16]. The result of each analysis was used to determine the best treatments for the edible coating. Based on the effect of each parameter on the quality of papaya, variable weight (VW) can be varied from 0 to 1. Since all the parameters are considered equally essential to affect the quality of the sample, the decided value was 1. Subsequently, before calculating the final score, the value of normalization weight (NW) and non-dimensional value (NV) can be estimated by using equations (2) and (3), respectively. The total scores for each parameter were compared, and then the highest total score was considered to be the best treatment in the edible coating application as papaya natural preservation method.

$$\text{NW} = \frac{\text{vw}}{\sum \text{vw}} \quad (2)$$

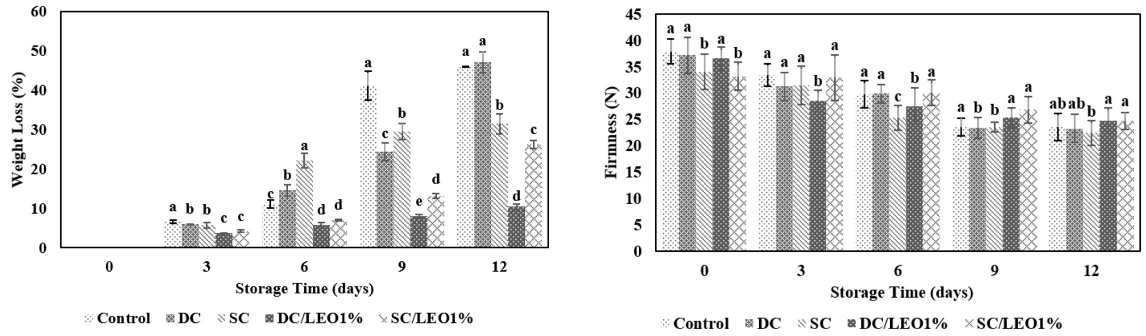
$$\text{NV} = \frac{\text{value-worst value}}{\text{best value-worst value}} \quad (3)$$

$$\text{Score} = \text{NW x NV} \quad (4)$$

3. Results and Discussion

3.1. Weight Loss

Formation of physical barriers through the application of fruit coating plays an important role in minimizing respiration activity. By coating the fruit with the polymer solution, it can prevent water loss by reducing the water vapor permeability of the fruit surface [9]. In general, all treatments, excluding the DC/LEO1% group, experienced a remarkable increase in weight loss during the observation period, as shown by Fig. 1(a). However, the weight loss of the DC/LEO1% group remained just under 15% until the end of the period, which was comparable with the application of starch/cellulose-based films for coating guavas [17].



(a) **(b)**

Figure 1. Weight Loss (a) and Firmness Analyses (b) Result of Papaya During Storage Time. Vertical bars display the standard error of means for the samples. The different lower letters above the bars on the same columns represent that they are significantly different according to DMRT ($p < 0.05$).

The result depicts the influence of the incorporation of LEO on fruit coating application as well as the coating methods. The hydrophobic nature of LEO inhibits water loss throughout papaya skin by lowering the water vapor permeability [18]. Besides that, the dipping method formed a more uniform, thicker, and well-distributed layer than the spraying method, which also notably diminished water loss [19]. A similar trend was shown by previous studies [20].

3.2. Firmness

On some fruits, including papaya, the ripening process and the quality can be indicated by firmness reduction [21]. According to Fig. 1(b), the firmness analysis result of all treatments witnessed a downward trend. After 12 days of room storage, the firmness of all treatments was gradually decreased by 37.5% approximately. Meanwhile, DC/LEO1% and SC/LEO1% maintained the hardness slightly better than other treatments, with firmness values of 24.81 N and 24.68 N, respectively. Interestingly, those groups preserved papaya texture more effectively than aloe vera-based edible coating [12].

The result also corresponded with the weight loss outcome, which was indicated by the ability of the coating formula to retard the maturation process so that they could maintain fruit rigidity. As mentioned before, the introduction of LEO into the coating formula modified the water permeability of the fruit surface, including gas permeability. In this case, gas transfer and ethylene production, which actively contributed to the ripening process, could be minimized as well as cell wall degeneration and enzymatic reactions [11,22].

3.3. pH

In general, during storage time, the pH of fruits and vegetables tends to decrease as a result of the increment of transpiration rate, acidity level, and delayed use of organic compounds [23]. As can be seen in Fig. 2(a), the result of pH analysis presented a downward trend. Moreover, the values of all treatments throughout the period ranged from 4.10 to 6.65. At the end of the period, the pH of the uncoated sample drastically decreased, whereas other treatments were quite stable.

In addition, the value of pH is attributed to the metabolism process in the fruit. The downward tendency, as presented in this study, could indicate acid production via sugar metabolism through the maturation process. On the contrary, the inclination of pH can be related to fruit senescence and enzymatic activity, which reduces acid production and increases the pH value. Interestingly, all treatments, excluding the control, could maintain the pH at the end of the storage time, which also exhibited the ability to preserve sample quality [5].

3.4. Total Titratable Acid (TTA)

Unlike pH, which represents both titratable acid and conjugated base, TTA was used to assess the total acid concentration in the sample as well as indicate the sourness of the sample. According to Fig. 2(b), from the initial day to the 9th day, the result of all treatments was not significantly different compared to the control. However, on the last day, the DC/LEO1% group displayed the lowest result, which was about 0.37%. The tendency of the result was consistent with the pH analysis result.

Moreover, compared with past studies' results, there are two trends regarding the TTA result. In this study, the increment of the result seemed to be the way of the edible coating to prevent the oxidation of organic acids, thanks to the hydrophobicity of LEO [24]. Meanwhile, other investigations exhibited the decline of TTA, which was responsible for the utilization of organic acids for metabolic process via the tricarboxylic cycle and was visually indicated by color changing along with the ageing process [25-26].

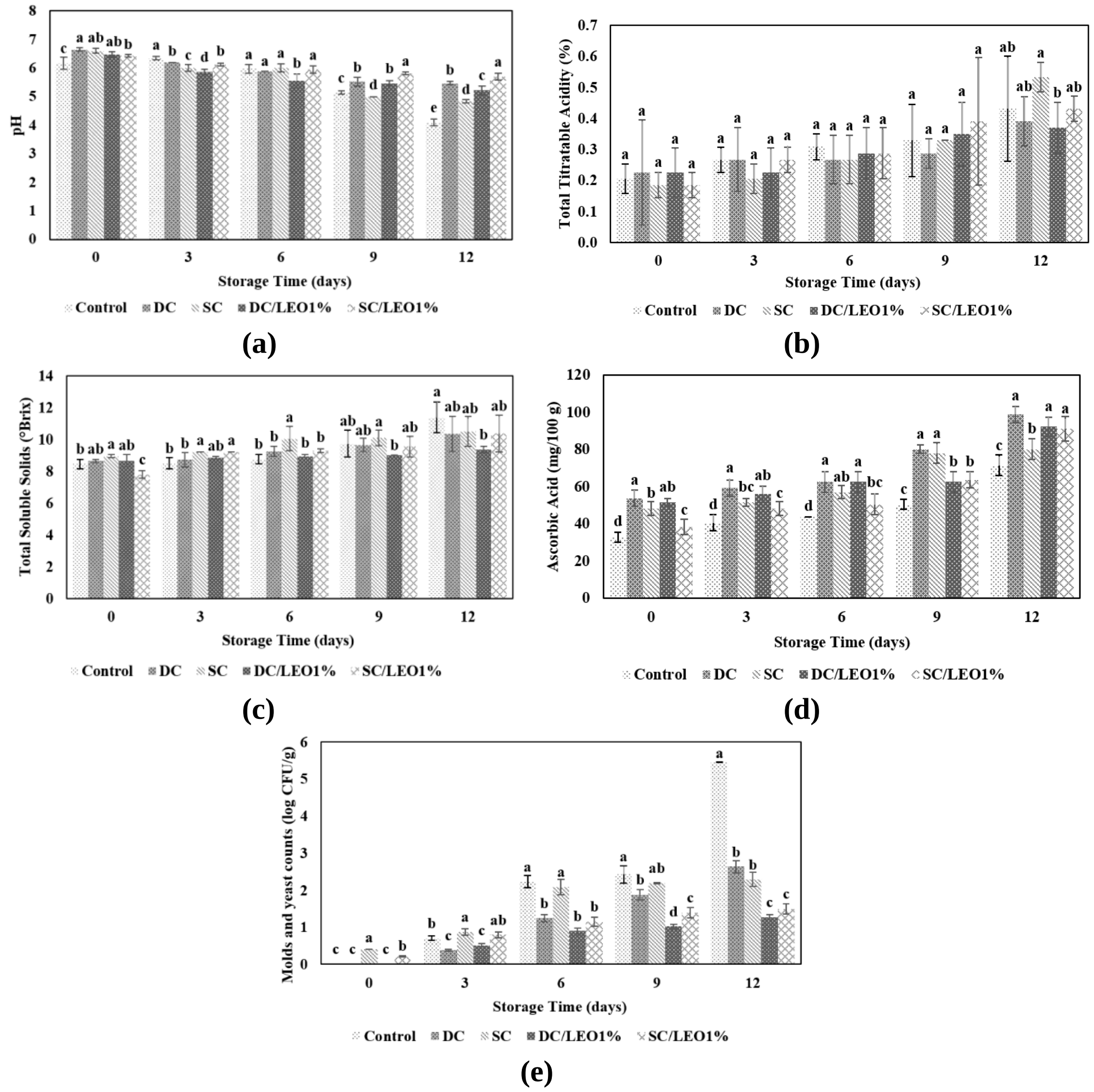


Figure 2. pH (a), Total Titratable Acidity (b), Total Soluble Solids (c), Ascorbic Acid (d), and Molds and Yeast Counts (e) Result of Papaya During Storage Time. Vertical bars display the standard error of means for the samples. The different lower letters above the bars on the same columns represent that they are significantly different according to DMRT ($p < 0.05$).

3.5. Total Soluble Solid (TSS)

The higher the TSS result, the higher the maturity level of fruits or vegetables. It is directly associated with the sweetness of fruit juice as a result of polysaccharides and starch hydrolysis over the ripening process [26]. It can be seen from Fig. 2(c) that the result remained constant from the first day to the 9th day. Although there was no significant difference among the groups, the lowest value was shown by the DC/LEO1% group, around 9.38°Brix, while the highest was depicted by the control sample, which was around 11.38°Brix.

Furthermore, the result indicated that combining the dip-coating technique with the incorporation of LEO notably lowered starch hydrolysis by minimizing transpiration rate [25]. The result was in agreement with previous studies, which showed that a chitosan/gum Arabic-based coating incorporated with lemongrass essential oils to preserve papaya quality [6]. The result was also analogous to a past study, which combined hot water and chitosan coating to prevent anthracnose in papaya [3].

3.6. Ascorbic Acid Contents

Based on the analysis result, which is illustrated by Fig. 2(d), the ascorbic acid contents of all treatments marginally increased during the period. At first glance, the control and SC groups had the lowest result, whereas the others were higher but not significantly different. However, if looking at the details, both of the groups had the lowest result from the start, and then the groups dramatically increased more than twice the initial result. On the other hand, the other treatments only increased by 65.90% - 83.67% throughout the observation.

Concerning the reduction of ascorbic acid during storage, the lower the value, the higher the senescence level [27]. In this case, DC, DC/LEO1%, and SC/LEO1% samples exhibited higher results than the control sample, which means they had better performance to suppress the alteration of ascorbic acid into dehydroascorbic acid by physically inhibiting the oxidation [28]. This result corresponded with the application of soybean starch-based coating for prolonging the storage time of sapota fruit [11].

3.7. Yeast and Mold Counts

Papaya is susceptible to mold infection, which is *C. gloeosporioides*, causing anthracnose and forming lesions that reduce consumer acceptance [5]. In accordance with Fig. 2(e), at the end of the investigation, the uncoated sample exhibited the highest yeast and mold counts (> 5 log CFU/g), followed by DC and SC groups (< 3 log CFU/g), and then DC/LEO1% and SC/LEO1%, which remained constant just under 2 log CFU/g. Thus, the control sample exceeded the acceptable limit for yeast and mold counts, which is no more than 5 log CFU/g [25].

Previous studies suggested that the inhibition mechanism of EOs or the antifungal activity is less likely to be membrane cell penetration, but seems to be enzyme-membrane cell interaction, which supports fungal cell wall integrity [29]. Past studies suggested that the bioactive compounds of EOs, such as lipophilic compounds in the LEO, were able to absorb unwanted materials and bind with proteins in the pathogen cell. Therefore, they can retard the ripening process and decay incidence [28,30].

3.8. Best Treatment

As mentioned before, the best treatment was chosen by calculating the analyses result at the end of period using non-dimensional scaling method, which is presented in Table 1. Based on the calculation, it can be seen that the highest total score was shown by the DC/LEO1% group (0.90), whereas the least score was given by the control sample (0.19). Therefore, it can be decided that the DC/LEO1% group exhibited the best performance among the treatments.

Table 1. Determination of the Best Treatment by Using the Non-Dimensional Scaling

Parameters*	Variable value				
	Control	DC	SC	DC/LEO1%	SC/LEO1%
Weight loss	0.00	0.00	0.06	0.14	0.02
Firmness	0.07	0.05	0.00	0.14	0.13
pH	0.00	0.12	0.07	0.10	0.14
TTA	0.09	0.12	0.00	0.14	0.09
TSS	0.00	0.07	0.06	0.14	0.07
AA	0.03	0.09	0.14	0.10	0.00
YM	0.00	0.08	0.10	0.14	0.13
Total score	0.19	0.53	0.43	0.90	0.58

*) TTA: titratable acidity, TSS: total soluble solids, AA: ascorbic acid, YM: yeast and mold counts.

4. Conclusion

In conclusion, the application of pectin-based edible coating has the potential to prolong the shelf-life of climacteric fruits, such as papaya. The present study revealed that the administration of lemongrass essential oils and the application methods influenced the quality of papaya throughout the storage time. The combination of those factors significantly ($p < 0.05$) improved weight loss, pH, ascorbic acid, and yeast and mold counts compared to the control sample (uncoated). Furthermore, based on the non-dimensional scaling method, the DC/LEO1% group was considered as the best treatment, which could preserve the physicochemical quality of papaya until 12 days. Thus, by applying the edible coating, it not only maintains the economic value but also prevents food waste. However, for getting a comprehensive understanding, further investigations, such as polymer characteristic analyses (particularly antioxidant and antimicrobial activities) and sensory analysis, need to be conducted.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

The authors thank Universitas Sebelas Maret, Indonesia, for supporting this research under the research grant of "PENELITIAN HIBAH GRUP RISET (PENELITIAN HGR-UNS) A" (Contract number: 194.2/UN27.22/PT.01.03/2024).

References

[1] Ammar EE, Zou X, Ghosh S, Onyeaka H, Elmasry SA, Alkeay AM, et al. Fresh Futures: Cutting-Edge Eco-Friendly Coating Techniques for Fruits. Journal of Food Processing and Preservation 2025;2025. https://doi.org/10.1155/jfpp/5201632.

[2] Barik M, BhagyaRaj GVS, Dash KK, Shams R. A thorough evaluation of chitosan-based packaging film and coating for food product shelf-life extension. Journal of Agriculture and Food Research 2024;16:101164. https://doi.org/10.1016/j.jafr.2024.101164.

[3] Vilaplana R, Chicaiza G, Vaca C, Valencia-Chamorro S. Combination of hot water treatment and chitosan coating to control anthracnose in papaya (Carica papaya L.) during the postharvest period. Crop Protection 2020;128:105007. https://doi.org/10.1016/j.cropro.2019.105007.

[4] Gan N, Li Q, Li Y, Li M, Li Y, Chen L, et al. Encapsulation of lemongrass essential oil by bilayer liposomes based on pectin, gum Arabic, and carrageenan: Characterization and application in chicken meat preservation. International Journal of Biological Macromolecules 2024;281:135706. https://doi.org/10.1016/j.ijbiomac.2024.135706.

[5] do Nascimento A, Toneto LC, Lepaus BM, Valiati BS, Faria-Silva L, de São José JFB. Effect of Edible Coatings of Cassava Starch Incorporated with Clove and Cinnamon Essential Oils on the Shelf Life of Papaya. Membranes 2023;13:772. https://doi.org/10.3390/membranes13090772.

[6] Dharini V, S PS, J J, Sadiku RE. Effect of functionalized hybrid chitosan/gum Arabic bilayer coatings with lemongrass essential oil on the postharvest disease control and the physicochemical properties of papaya (Carica papaya) fruits. South African Journal of Botany 2023;160:602–12. https://doi.org/10.1016/j.sajb.2023.07.053.

[7] Utami R, Annisa RR, Praseptiangga D, Nursiwi A, Sari AM, Ashari H, et al. Preservation effect of sodium alginate-based edible coating enriched with Siam Pontianak tangerine peel oil on chemical and microbiological properties of strawberry during refrigeration storage. IOP Conference Series: Earth and Environmental Science 2024;1377:012035. https://doi.org/10.1088/1755-1315/1377/1/012035.

[8] Utami R, Annisa RR, Praseptiangga D, Nursiwi A, Sari AM, Ashari H, et al. Effect of edible coating sodium alginate with addition of siam pontianak tangerine peel essential oil (Citrus suhuinensis cv Pontianak) on the physical quality of strawberries (Fragaria ananassa) during

refrigeration temperature storage. IOP Conference Series: Earth and Environmental Science 2023;1200:012058. https://doi.org/10.1088/1755-1315/1200/1/012058.
[9] Oliveira Filho JG de, Silva G da C, Oldoni FCA, Miranda M, Florencio C, Oliveira RMD de, et al. Edible Coating Based on Carnauba Wax Nanoemulsion and Cymbopogon martinii Essential Oil on Papaya Postharvest Preservation. Coatings 2022;12:1700. https://doi.org/10.3390/coatings12111700.
[10] Arroyo BJ, Bezerra AC, Oliveira LL, Arroyo SJ, Melo EA de, Santos AMP. Antimicrobial active edible coating of alginate and chitosan add ZnO nanoparticles applied in guavas (Psidium guajava L.). Food Chemistry 2020;309:125566. https://doi.org/10.1016/j.foodchem.2019.125566.
[11] Chettri S, Sharma N, Mohite AM. Formulation of extracted soyabean starch based edible coatings by different methods and their impact on shelf life of sapota fruit. Journal of the Saudi Society of Agricultural Sciences 2024;23:205–11. https://doi.org/10.1016/j.jssas.2023.11.003.
[12] Farina V, Passafiume R, Tinebra I, Scuderi D, Saletta F, Gugliuzza G, et al. Postharvest Application of Aloe vera Gel-Based Edible Coating to Improve the Quality and Storage Stability of Fresh-Cut Papaya. Journal of Food Quality 2020;2020:1–10. https://doi.org/10.1155/2020/8303140.
[13] Noshirvani N, Ghanbarzadeh B, Rezaei Mokarram R, Hashemi M. Novel active packaging based on carboxymethyl cellulose-chitosan-ZnO NPs nanocomposite for increasing the shelf life of bread. Food Packaging and Shelf Life 2017;11:106–14. https://doi.org/10.1016/j.fpsl.2017.01.010.
[14] Sullivan WG, Wicks EM, Koelling CP. Engineering Economy Sixteenth Edition. Upper Saddle River, New Jersey; 2015.
[15] Praseptiangga D, Afrida B, Mufida N, Widyaastuti D. Effects of Stearic Acid and Zein Incorporation on Refined Kappa Carrageenan-Based Composite Edible Film Properties. Journal of Current Science and Technology 2023;13:762–73. https://doi.org/10.59796/jcst.V13N3.2023.1324.
[16] Praseptiangga D, Wandansari, Widyaastuti D. Chemical and physical properties of canna (Canna edulis) and jack bean (Canavalia ensiformis)-based composite flours. Food Research 2022;6:354–67. https://doi.org/10.26656/fr.2017.6(2).292.
[17] Francisco CB, Pellá MG, Silva OA, Raimundo KF, Caetano J, Linde GA, et al. Shelf-life of guavas coated with biodegradable starch and cellulose-based films. International Journal of Biological Macromolecules 2020;152:272–9. https://doi.org/10.1016/j.ijbiomac.2020.02.249.
[18] Yousuf B, Wu S, Siddiqui MW. Incorporating essential oils or compounds derived thereof into edible coatings: Effect on quality and shelf life of fresh/fresh-cut produce. Trends in Food Science & Technology 2021;108:245–57. https://doi.org/10.1016/j.tifs.2021.01.016.
[19] Mannozzi C, Glicerina V, Tylewicz U, Castagnini JM, Canali G, Dalla Rosa M, et al. Influence of Two Different Coating Application Methods on the Maintenance of the Nutritional Quality of Fresh-Cut Melon during Storage. Applied Sciences 2021;11:8510. https://doi.org/10.3390/app11188510.
[20] Roshandel-hesari N, Mokaber-Esfahani M, Taleghani A, Akbari R. Investigation of physicochemical properties, antimicrobial and antioxidant activity of edible films based on chitosan/casein containing Origanum vulgare L. essential oil and its effect on quality maintenance of cherry tomato. Food Chemistry 2022;396:133650. https://doi.org/10.1016/j.foodchem.2022.133650.
[21] Liu L, Wang Y, Guo J, Han Z, Yu K, Song Y, et al. Natural variation in MdNAC5 contributes to fruit firmness and ripening divergence in apple. Horticulture Research 2025;12. https://doi.org/10.1093/hr/uhae284.
[22] Galus S, Mikus M, Ciurzyńska A, Domian E, Kowalska J, Marzec A, et al. The Effect of Whey Protein-Based Edible Coatings Incorporated with Lemon and Lemongrass Essential Oils on the

Quality Attributes of Fresh-Cut Pears during Storage. Coatings 2021;11:745. https://doi.org/10.3390/coatings11070745.

[23] Kumar N, Pratibha, Neeraj, Petkoska AT, AL-Hilifi SA, Fawole OA. Effect of Chitosan–Pullulan Composite Edible Coating Functionalized with Pomegranate Peel Extract on the Shelf Life of Mango (Mangifera indica). Coatings 2021;11:764. https://doi.org/10.3390/coatings11070764.

[24] Bajaj K, Kumar A, Gill PPS, Jawandha SK, Arora R, Singh A. Guar gum and essential oil-based composite coatings preserve antioxidant enzymes activity and postharvest quality of kinnow Mandarin. Food Bioscience 2024;61:104906. https://doi.org/10.1016/j.fbio.2024.104906.

[25] Soradech S, Nunthanid J, Limmatvapirat S, Luangtana-anan M. Utilization of shellac and gelatin composite film for coating to extend the shelf life of banana. Food Control 2017;73:1310–7. https://doi.org/10.1016/j.foodcont.2016.10.059.

[26] Lufu R, Ambaw A, Opara UL. Assessing weight loss control strategies in pomegranate (Punica granatum L.) fruit: plastic packaging and surface waxing. Sustainable Food Technology 2024;2:175–88. https://doi.org/10.1039/D3FB00089C.

[27] Kawhena TG, Opara UL, Fawole OA. Effects of Gum Arabic Coatings Enriched with Lemongrass Essential Oil and Pomegranate Peel Extract on Quality Maintenance of Pomegranate Whole Fruit and Arils. Foods 2022;11:593. https://doi.org/10.3390/foods11040593.

[28] Bajaj K, Kumar A, Gill PPS, Jawandha SK, Kaur N. Xanthan gum coatings augmented with lemongrass oil preserve postharvest quality and antioxidant defence system of Kinnow fruit under low-temperature storage. International Journal of Biological Macromolecules 2024;262:129776. https://doi.org/10.1016/j.ijbiomac.2024.129776.

[29] Andrade-Ochoa S, Chacón-Vargas KF, Sánchez-Torres LE, Rivera-Chavira BE, Nogueda-Torres B, Nevárez-Moorillón GV. Differential Antimicrobial Effect of Essential Oils and Their Main Components: Insights Based on the Cell Membrane and External Structure. Membranes 2021;11:405. https://doi.org/10.3390/membranes11060405.

[30] Ribeiro TT de B, Barbosa AM, Nunes TP, Costa ASG da, Oliveira MBPP, Borges GR, et al. Development of Antifungal Packaging Based on Pectin/Gelatin Containing Azadirachta indica Bioactive Extracts for Carica papaya L. Fruit Coating. Applied Sciences 2025;15:4423. https://doi.org/10.3390/app15084423.