ผลของสารเคลือบผิวโซเดียมอัลจิเนต โพลิไวนิลแอลกอฮอล์ และว่านหางจระเข้ต่อการเก็บรักษามะนาว
Effects of Sodium Alginate, Polyvinyl Alcohol, and *Aloe vera* Coatings on the Storage of Lime

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของสารเคลือบผิวผสมโซเดียมอัลจิเนต (SA) โพลิไวนิลแอลกอฮอล์ (PVA) และว่านหางจระเข้ (AV) ต่อคุณภาพการเก็บรักษามะนาวพันธุ์แป้นพิจิตร (*Citrus aurantifolia* Swingle cv. Pan Pichit) ผลมะนาวถูกเคลือบด้วยสูตร SA–AV และ SA–PVA–AV ที่แตกต่างกัน และเก็บรักษาที่อุณหภูมิ 9.8 ± 0.4 °ซ และความชื้นสัมพัทธ์ 48.7 ± 11.0% ประเมินคุณภาพภายนอก ได้แก่ สีเปลือก (ค่า hue angle, a*) คะแนนการเสื่อมสภาพ การสูญเสียน้ำหนัก และอายุการเก็บรักษา ผลการทดลองพบว่า ทรีทเมนต์ที่ให้ผลดีที่สุดในการชะลอการเปลี่ยนแปลงสีคือสูตร SA-AV 85:15 (v/v) และ SA-PVA = 80:20 + AV (15% v/v of SA) โดยผลมะนาวที่เคลือบทุกสูตรมีอายุการเก็บรักษานานกว่า (21 วัน) เมื่อเทียบกับกลุ่มควบคุม (16.9 วัน) ที่คะแนนเสื่อมสภาพ 3 คะแนน ในขณะที่การสูญเสียน้ำหนักเพิ่มขึ้นในทุกทรีทเมนต์ แต่ไม่มีทรีทเมนต์ไหนที่ช่วยลดการสูญเสียน้ำหนักได้เมื่อเทียบกับชุดควบคุม โดยสรุป การใช้สารเคลือบผิวที่มีส่วนผสมของโซเดียมอัลจิเนต ว่านหางจระเข้ และ โพลิไวนิลแอลกอฮอล์ เป็นแนวทางที่มีศักยภาพเพื่อประยุกต์ใช้ในการยืดอายุการเก็บรักษาและคงคุณภาพภายนอกของผลมะนาวพันธุ์แป้นพิจิตรหลังการเก็บเกี่ยวได้

คำสำคัญ: การเก็บรักษา, มะนาว, การเคลือบ, การเสื่อมสภาพ, การสูญเสียน้ำหนัก

Abstract

This study investigated the effects of composite coatings of sodium alginate (SA), polyvinyl alcohol (PVA), and *Aloe vera* extract (AV) on the storage quality of lime (*Citrus aurantifolia* Swingle cv. Pan Pichit). Fruits were coated with different SA–AV and SA–PVA–AV formulations and stored at 9.8 ± 0.4 °C and 48.7 ± 11.0% RH. External attributes, including peel color (hue angle, a* value), senescence score, weight loss, and storage life, were evaluated. The results showed that the treatments that most effectively delayed the change in peel color were SA–AV 85:15 (v/v) and SA–PVA (80:20) + AV (15% v/v of SA). All coated fruits exhibited longer storage life (21 days) than uncoated fruits (16.9 days) at a senescence score of 3. While weight loss increased across all treatments, no treatment effectively reduced weight loss compared to the control group. In conclusion, the use of coating solutions containing sodium alginate, *Aloe vera*, and polyvinyl alcohol is a promising approach for extending the storage life and maintaining the external quality of lime cv. Pan Pichit fruits after harvest.

Keywords: Storage, lime, coating, senescence, weight loss

Introduction

Lime (*Citrus aurantifolia* Swingle) is an economically important fruit widely consumed fresh and in processed products. However, its short postharvest life, characterized by rapid senescence, peel discoloration, and weight loss, restricts marketability and causes considerable economic losses. To address these problems, edible coatings based on natural polysaccharides have been investigated as postharvest treatments because they form semipermeable barriers to moisture and gases, thereby delaying quality deterioration (Nieto, 2009).

Aloe vera (AV) is being studied for extending fruit storage life because it can modify the internal atmosphere and help retain peel color (Kator *et al.*, 2018; Lerslerwong *et. al*, 2023). Its gel contains additional antioxidants, antimicrobial and natural plant hormones (auxins, gibberellic acid), and other compounds such as

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lignin, saponins, and salicylic acid (Sánchez *et al*., 2020). *Aloe vera* has been studied as a natural plant growth regulator to extend the postharvest life of lime. Buapuean and Lerslerwong (2014) reported that a 50% Aloe vera coating can prolong lime postharvest life without affecting the internal quality of lime at ambient temperature. Nevertheless, Lerslerwong *et. al* (2023) reported that a 50% *Aloe vera* coating can prolong the postharvest life of lime cv. Pan Pichit without preserving internal qualities during cold room storage. Despite this finding, the application of *Aloe vera* coating alone has a limitation. However, possessing beneficial antimicrobial and antioxidant properties, *Aloe vera* gel exhibits poor film-forming capabilities, resulting in films with potentially low barrier properties and allowing water permeability. Consequently, incorporating other film-forming agents like starch or gelatin is necessary to enhance the characteristics of *Aloe vera*-based coatings (Sarker and Grift, 2021).

Sodium alginate (SA) is a linear polysaccharide with a negative charge and is found in the form of alginate salts or alginic acid. Alginate is found in the cell walls of brown algae, which are a renewable marine biomass and have the property of being naturally biodegradable in a short time (Draget *et al*., 2002; Moore, 2015). SA has the ability to form gels when it interacts with polyvalent cations such as calcium ions (Łabowska *et al*., 2019). Owing to its ability to form a gel, alginate is commonly used as a thickening agent, gelling agent, and for film formation (Gao *et al*., 2017). Satidkoon and Lerslerwong (2016) reported that an SA–AV coating at an 85:15 ratio delayed lime peel yellowing more effectively than other formulations and the control. Satidkoon *et al*. (2022) further reported that adding AV improved transparency of alginate-aloe films but reduced tensile strength, highlighting a trade-off in film functionality. More recently, Lerslerwong *et al*. (2023) confirmed that *Aloe vera* coatings could extend lime storage life under both ambient and refrigerated conditions, particularly when combined with 1-methylcyclopropene (1-MCP). Nonetheless, problems related to application convenience and uneven coverage limited their practical effectiveness.

To overcome these limitations, polyvinyl alcohol (PVA), a synthetic polymer with strong film-forming capacity and compatibility with biopolymers, was incorporated into the SA–AV system. PVA is characterized by its low cost, safety, and rapid biodegradability, allowing it to be used to create sustainable hydrogels and films (Bercea, 2024). PVA can enhance coating homogeneity, improve mechanical strength, and reduce water vapor transmission, thereby potentially improving fruit surface coverage and barrier properties. PVA has been reported as a film-forming agent with other biopolymers to enhance the film's properties in maintaining water loss and internal qualities of mandarin oranges (Anjana Krishna *et al*., 2024). Moreover, PVA has been incorporated with SA in many applications, such as wound dressing (Bialik-Wąs *et al*., 2021), slow-release fertilizer (Meng *et al*., 2023), and fruit packaging (Younis *et al*., 2025). Nevertheless, the application of PVA as a composite coating in combination with AV in limes has not yet been studied.

Based on the aforementioned properties of SA and PVA, they were therefore used in this study to evaluate the effectiveness of composite coatings composed of SA, PVA, and AV in maintaining external quality and extending the storage life of lime under low-temperature storage conditions.

Materials and Methods

1. Plant materials and storage conditions

Uniform, mature-green lime fruits (*Citrus aurantifolia* Swingle cv. Pan Pichit) were obtained from a commercial wholesaler at Fresh Market, Hat Yai, Songkla, Thailand. Fruits of similar size, free from physical damage or visible defects, were selected, washed with distilled water, and air-dried before treatments. After coating, all fruits were stored under dark conditions in a refrigerator at 9.8 ± 0.4 °C and 48.7 ± 11.0% relative humidity (RH).

2. Coating formulations and treatments

The coating solutions were prepared by dissolving sodium alginate (SA), polyvinyl alcohol (PVA), and *Aloe vera* (AV) extract separately to create stock solutions. These solutions were then combined according to the specified treatment ratios. The experiment was arranged in a completely randomized design (CRD) with six treatments: (1) Control (uncoated), (2) SA–AV 90:10 (v/v), (3) SA–AV 85:15 (v/v), (4) SA–AV 80:20 (v/v), (5) SA–PVA 80:20 (v/v) supplemented with AV 15 (%v/v of SA volume), and (6) SA–PVA 70:30 (v/v) supplemented with AV 15 (%v/v of SA volume). Glycerol at a concentration of 15% (v/v) was added to the solution based on the alginate volume. Each treatment consisted of eight replications with one fruit per replicate (48 fruits in total). Fruits were immersed in the respective coating solution for 2 min, dipped in a 5% (w/v) calcium chloride solution for 5 min, and then air-dried before storage. The specific ratios of SA-PVA used for this study were determined based on our preliminary study (unpublished).

3. Quality evaluation

Peel color was measured at three randomly selected points per fruit using a Konica Minolta CR-400 chromameter, and results were expressed as hue angle and a* values. Senescence of lime peel was evaluated based on hue angle values according to the scale of Lerslerwong et al. (2023): Score 0: hue angle ≥ 121.00° (fully green); Score 1, hue angle 119.01–120.99°; Score 2, hue angle 116.01–118.99°; Score 3, hue angle 113.01–115.99°; Score 4, hue angle 111.01–112.99°; Score 5, hue angle < 110.99° (entirely yellow). Evaluations were conducted every 7 days, and storage life was defined as the number of days until fruits reached a senescence score of 3. Weight loss was determined as the percentage reduction in fresh weight relative to the initial weight. Peel color was measured at three randomly selected points per fruit using a Konica Minolta CR-400 chromameter, and results were expressed as hue angle and a* values.

4. Statistical analysis

Data were analyzed using R software version 4.5.1. Analysis of variance (ANOVA) was conducted, and treatment means were compared using the least significant difference (LSD) test at a 95% confidence level ($p < 0.05$).

Results

The effects of different coating formulations on the storage quality of lime are presented in Figure 1.

1. Peel color (hue angle and a* value):

Hue angle decreased across all treatments during storage (Fig. 1A). Compared to the control, the most effective treatments for delaying color change in lime are SA-AV 85:15 (v/v) and SA-PVA = 80:20 + AV (15% v/v of SA). By the end of storage, fruits coated with SA–PVA 70:30 + AV 15 (%v/v of SA volume) exhibited the lowest hue angle, whereas those coated with SA–AV 90:10 and 85:15 retained higher hue values. Regarding redness (a* value), all fruits showed a progressive increase over time; however, no significant differences were observed among treatments (Fig. 1B). After 14 days of storage, disease was observed in all treatments (data not shown).

2. Senescence score and storage life

All coating treatments maintained lower senescence scores than the uncoated control throughout storage (Fig. 1C). Coated fruits reached a senescence score of 3 after 21 days, while the control reached a score of 3 at 16.9 days. The increase in senescence score corresponded to the decrease in hue angle, as hue angle decreases during storage, which is used to determine the criteria for postharvest lime senescence (Lerslerwong *et al*., 2023).

3. Weight loss

Weight loss increased progressively with storage time (Fig. 1D). Although some formulations (SA–AV 85:15 and 90:10) exhibited significantly greater weight loss, none of the coating formulations were effective in reducing weight loss below that of the control group.

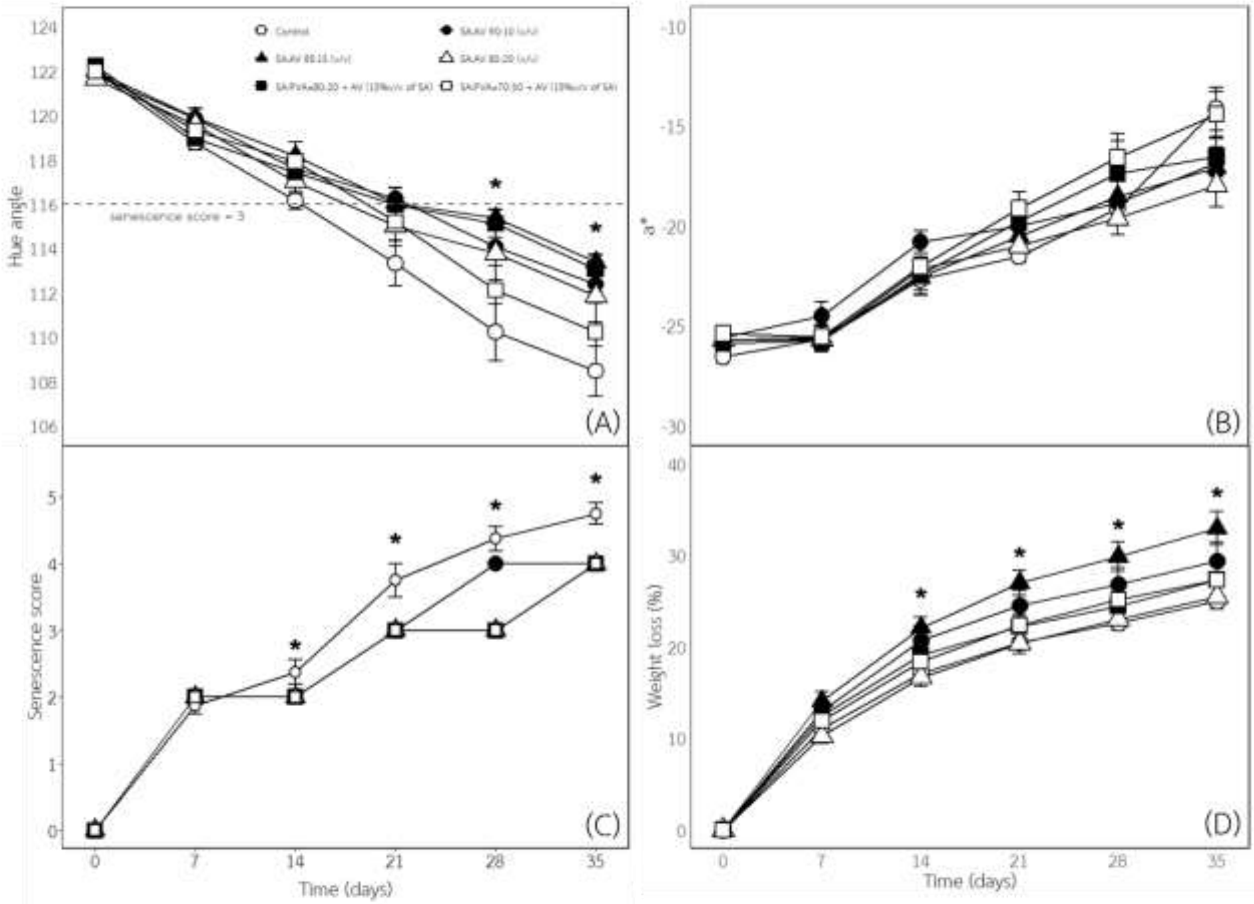

Figure 1 Changes in hue angle (A), a* value (B), senescence score (C), and weight loss (D) of lime (*Citrus aurantifolia* Swingle cv. Pan Pichit) during storage at 9.8 ± 0.4 °C and 48.7 ± 11.0% RH. The dashed line in Figure 1A represents the threshold for the end of postharvest life (senescence score = 3). Vertical bars represent the standard error (SE) of the mean.

Discussion

This study demonstrated that coatings composed of sodium alginate (SA), polyvinyl alcohol (PVA), and *Aloe vera* (AV) effectively prolonged lime storage life under refrigerated conditions (9.8 ± 0.4 °C and 48.7 ± 11.0% RH). All coated fruits maintained storage life up to 21 days compared with 16.9 days for the uncoated control (Treatment 1). These findings are consistent with previous reports showing that polysaccharide- and *Aloe*-based coatings can delay senescence and peel discoloration in lime (Lerslerwong *et al*., 2023; Satidkoon & Lerslerwong, 2016). The longer storage life observed in this study relative to earlier work under ambient conditions is likely due to the combined effects of coating application and low-temperature storage, which together slowed senescence progression.

This study exhibited that SA–AV 85:15 (v/v) and SA–PVA (80:20) + AV (15% v/v of SA) coatings are the most effective in retaining lime peel color compared to the control. As its peel color is reflected by a declining hue angle and increasing a* values, it was associated with chlorophyll degradation (Kaewsuksaeng *et al*., 2015). Since *Aloe vera* has been studied as a natural edible coating containing plant hormones such as gibberellic acid and auxins that slow down the degreening process of lime, however, *Aloe vera* coating alone has poor film-forming ability, requiring the addition of other polymers to enhance the film's properties when applying coating (Lerslerwong *et al*., 2023), such as starch (Pinzon et al., 2020), sodium alginate (Qamar *et al*., 2018; Satidkoon & Lerslerwong, 2016), chitosan (Pinzon *et al*., 2020; Qamar *et al*., 2018). Our study indicated that incorporating PVA offered no significant advantage in extending the postharvest life of lime compared to the SA-AV coating formulations. Although all coated fruits displayed slower senescence than the control, the PVA addition to the coating solution increased the coating cost without providing a significant improvement in hue angle and postharvest life. Nevertheless, low-temperature storage is the most effective method to extend the postharvest life of fresh fruits, and these conditions are also sufficient for the effective use of SA-AV coatings during cold room storage (Lerslerwong *et al*., 2023; Satidkoon & Lerslerwong, 2016).

In terms of weight loss, fruits coated with SA–AV 90:10 (Treatment 2) and 85:15 (Treatment 3) exhibited greater weight loss than the control, whereas the SA–AV formulation 80:20 (Treatment 4) recorded the lowest weight loss among the SA–AV coatings. Nevertheless, these results agree with Satidkoon et al. (2022), who reported that the addition of AV enhanced alginate film transparency but reduced tensile strength, thereby weakening its water barrier properties. Furthermore, incorporating PVA into the SA–AV system (Treatments 5 and 6) significantly reduced weight loss compared with the SA–AV 85:15 coating (Treatment 3). Ngoc *et al*. (2022) reported that combining PVA with other natural polymers, such as chitosan, can effectively reduce weight loss in orange due to its good film-forming properties, which facilitate the creation of an effective coating. Nevertheless, our results showed that none of the coating treatments reduced the weight loss of lime during storage. It was possible that the outer peel of lime (flavedo), characterized by densely packed cells and embedded oil glands (Jentzsch *et al*., 2024), may help lime reduce water loss compared to other fruits such as strawberries, which have less wax in the cuticle layer and are more prone to water loss (Hurtado *et al*., 2021). This characteristic also differentiates lime from longkong, which has a thick and leathery skin and is susceptible to moisture loss during storage (Venkatachalam, 2016). As a result, the effects of the treatments may not be effective in reducing weight loss in lime; however, this may be attributed more to the physical characteristics of the lime peel than to the treatments themselves.

Conclusion

This study demonstrated the potential of sodium alginate, polyvinyl alcohol, and *Aloe vera* as composite coatings to improve the postharvest management of lime. The finding suggested that composite coatings of SA–AV 85:15 (v/v) and SA–PVA (80:20) + AV (15% v/v of SA) were effective in extending the postharvest life of lime under cold room storage.

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Literature cited

Al-Ahbabi, H. H., Al-Ahbab, A. H., amer, M., Hasson, O., abed, S., WF., & Jassim, M. (2016). Antimicrobial activity of *aloe vera* extract on cases of keratoconjunctivitisin sheep (in vivo and invitro study) and compared with penicillin-streptomycin. Basrah Journal of Veterinary Research, 15(2), 227–245.

Anjana Krishna S V, Umadevi S, Midhun Dominic C D, Parameswaranpillai, J., Asha Bhanu A V, George, J. S., Sreedevi T, Thomas, S. and Vijayan P, P. (2024). Biomass derived cellulose nanofiber loaded PVA-nanocurcumin coating for extending the shelf life of Mandarin oranges (*Citrus reticulata*). Hybrid Advances, 5, 100162.

Bercea, M. (2024). Recent advances in poly(vinyl alcohol)-based hydrogels. Polymers, 16(14), 2021.

Bialik-Wąs, K., Pluta, K., Malina, D., Barczewski, M., Malarz, K., & Mrozek-Wilczkiewicz, A. (2021). Advanced SA/PVA-based hydrogel matrices with prolonged release of *Aloe vera* as promising wound dressings. Materials Science and Engineering C, 120, 111667.

Draget, K. I., Smidsrød, O., & Skjåk-Bræk, G. (2002). Alginates from Algae. Biopolymers Online.

Gao, C., Pollet, E., & Avérous, L. (2017). Properties of glycerol-plasticized alginate films obtained by thermo-mechanical mixing. Food Hydrocolloids, 63, 414–420.

Gol, N. B., & Chaudhari, M. L. (2015). Effect of edible coatings on quality and shelf life of fruits – A review. Agricultural Reviews, 36(3), 241–247.

Hurtado, G., Grimm, E., Bruggenwirth, M., & Knoche, M. (2021). Strawberry fruit skins are far more permeable to osmotic water uptake than to transpirational water loss. PLoS ONE, 16(5 May), 1–20.

Jentzsch, M., Albiez, V., Kardamakis, T. C., & Speck, T. (2024). Analysis of the peel structure of different Citrus spp. via light microscopy, SEM and μCT with manual and automatic segmentation. Soft Matter, 20(12), 2804–2811.

Kaewsuksaeng, S., Tatmala, N., Srilaong, V., & Pongprasert, N. (2015). Postharvest heat treatment delays chlorophyll degradation and maintains quality in Thai lime (*Citrus aurantifolia* Swingle cv. Paan) fruit. Postharvest Biology and Technology, 100, 1–7.

Kator, L., Hosea, Z., & Ene, O. (2018). The Efficacy of Aloe-vera Coating on Postharvest Shelf Life and Quality Tomato Fruits during Storage. Asian Research Journal of Agriculture, 8(4), 1–9.

Łabowska, M. B., Michalak, I., & Detyna, J. (2019). Methods of extraction, physicochemical properties of alginates and their applications in biomedical field - A review. Open Chemistry, 17(1), 738–762.

Lerslerwong, L., Buapuean, C., Rugkong, A., & Bunya-Atichart, K. (2023). Effects of 1-methylcyclopropene, gibberellic acid, and *Aloe vera* coating on lime storage life and fruit quality. Horticulture Journal, 92(2), 125–133.

Meng, W., Zhang, X., Zhang, Y., Zhang, X., Zhu, W., Huang, H., Han, X., Liu, Y., & Xu, C. (2023). Poly(vinyl alcohol)/sodium alginate polymer membranes as eco-friendly and biodegradable coatings for slow release fertilizers. Journal of the Science of Food and Agriculture, 103(7), 3592–3601.

Moore, A. (2015). Alginic Acid: Chemical Structure, Uses and Health Benefits (Chemistry Research and Applications). Nova Science Publishers.

Ngoc, L. S., Van, P. T. H., Nhi, T. T. Y., Dung, N. A., & Manh, T. D. (2022). Effects of dipping time in chitosan (CS) and polyvinyl alcohol (PVA) mixture to quality of orange fruits during storage. Food Science and Technology (Brazil), 42, 1–7.

Nieto, M. B. (2009). Structure and function of polysaccharide gum-based edible films and coatings. In Baldwin, E., Hagenmaier, R. & Bai, J. (Eds.) Edible coatings and films to improve food quality (pp. 57–112). CRC Press.

Pinzon, M. I., Sanchez, L. T., Garcia, O. R., Gutierrez, R., Luna, J. C., & Villa, C. C. (2020). Increasing shelf life of strawberries (*Fragaria ssp*) by using a banana starch-chitosan-*Aloe vera* gel composite edible coating. International Journal of Food Science and Technology, 55(1), 92–98.

Qamar, J., Ejaz, S., Anjum, M. A., Nawaz, A., Hussain, S., Ali, S., & Saleem, S. (2018). Effect of *Aloe vera* Gel, Chitosan and Sodium Alginate Based Edible Coatings on Postharvest Quality of Refrigerated Strawberry Fruits of cv. Chandler. Journal of Horticultural Science & Technology, 1(1), 8–16.

Sánchez, M., González-Burgos, E., Iglesias, I., & Gómez-Serranillos, M. P. (2020). Pharmacological update properties of *aloe vera* and its major active constituents. Molecules, 25(6).

Sarker, A., & Grift, T. E. (2021). Bioactive properties and potential applications of *Aloe vera* gel edible coating on fresh and minimally processed fruits and vegetables: a review. Journal of Food Measurement and Characterization, 15(2), 2119–2134.

Satidkoon, W., & Lerslerwong, L. (2016). Effects of coating based on alginate and *Aloe vera* extract on coloration and fruit quality of lime cv. Pan. Agricultural Science Journal, 47(3), 162–165.

Satidkoon, W., Lerslerwong, L., Rugkong, A., & Sanevas, N. (2022). Effects of *Aloe vera* gel amendment ratio in alginate on some physical properties of edible coating films. Agricultural Science Journal, 53(1), 19–28.

Venkatachalam, K. (2016). Postharvest physiology and handling of longkong fruit: A review. Fruits, 71(5), 289–298.

Younis, M., Alhamdan, A., El-Abedein, A. I. Z., Mohamed Ahmed, I. A., Kamel, R. M., Salama, M. A., Abdelkarim, D. O., & Elsayed, M. (2025). Incorporation of safflower extract into sodium alginate and polyvinyl alcohol films: Impact on physicochemical properties and food packaging applications. International Journal of Food Science and Technology, 60(1).