Effects of *Aloe vera* Gel Coating on Quality and Shelf Life of Lime (*Citrus aurantifolia*) Fruit During Ambient Storage

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Lime (*Citrus aurantifolia* var. Pan) fruits were coated with *Aloe vera* gel (AVG) at 0 (distilled water as control), 10, 20, 30, 40, and 50% concentration as a 5 min dip and stored at ambient temperature (29 ± 1°C, 74 ± 5% RH) for 16 days. AVG coating markedly slowed fruit yellowing based on color scores and CIE \( L^* \), \( a^* \), and \( b^* \) values, resulting in an increase in shelf life of about four days longer than that of the control (10 days). It did not significantly affect other fruit responses; AVG-coated and uncoated fruit had comparable weight loss, juice content, total soluble solids (TSS), titratable acidity (TA), and vitamin C content. Thus, AVG coating improved shelf life of lime primarily through delayed yellowing without adverse effects on other physicochemical attributes.

**Key Words:** *Aloe barbadensis* Miller, edible coating, fruit physicochemical characteristics, safe and environment-friendly postharvest technology.

**Introduction**

Lime (*Citrus aurantifolia*) is typically a round, green, citrus fruit that contains acidic juice vesicles. It is rich in vitamin C (35% of the daily value per 100 g serving) and contains citric acid at almost twice the level of grapefruit juice and about five times higher than that in orange juice (Penniston et al., 2008). Lime pulp and peel contain diverse phytochemicals, including polyphenols and terpenes (Loizzo et al., 2012). In Thailand, there is large demand for lime all year round as it is a major ingredient in Thai cooking and is also used in cold drinks. However, the price of lime varies widely between high and low yield-months due to large differences in supply in the market (Issarakraisila, 2018). Two leading cultivars, ‘Khai’ and ‘Pan’, are widely grown in the country.

After harvest, lime fruit turns yellow and later brown, and this is associated with loss of freshness and shelf life. This can occur within 7–10 days from harvest. Extending fruit shelf life is imperative to reduce post-harvest losses, minimize supply and price volatility, and increase profits at the farmgate and downstream markets. Several techniques are available to extend fruit shelf life, but techniques that pose no hazard to people and the environment are highly desirable and are gaining more emphasis in the global drive towards sustainable development. Among safe and environment-friendly postharvest techniques for horticultural produce is the use of edible coatings (Prasad et al., 2018).

*Aloe vera* gel (AVG) coating is an edible coating technique that has received a lot of research interest as can be seen from several reviews on its use on fruits, vegetables and fresh-cut products (Kumar and Bhatnagar, 2014; Misir et al., 2014; Prasad et al., 2018; Kahramanoglu et al., 2019; Loizzo, 2019). ‘Aloe vera’ is a perennial plant widely distributed in the tropics and subtropics. It is regarded as a ‘plant of immortality’ because of its medicinal value in treating various diseases (Dagne et al., 2000). Its leaves have two distinct layers; a green outer leaf rind and a soft, colorless, inner gel parenchyma. The mucilaginous gel is tasteless, colorless and odorless and has film-forming, antimicrobial, biodegradable and biochemical properties. *Aloe vera* contains 110 potentially active constituents from six different classes: chromone and its glycoside derivatives; anthraquinone and its glycoside derivatives; flavonoids; phenylpropanoids and coumarins;
phenylpyrone and phenol derivatives; and phytosterols (Kahramanoglu et al., 2019). As an edible coating, AVG provides a thin film on the fruit surface which acts as a barrier against atmospheric gases and moisture, thereby reducing respiration and transpiration (water loss) and delaying postharvest deterioration of produce. AVG also inhibits fruit decay due to its antimicrobial properties. Usual responses of AVG-coated fruits include reduced loss of weight, firmness, sensory and visual qualities, ascorbic acid and titratable acidity, slowed increase in total soluble solids (TSS), reduced decay and extension of shelf life. However, effective treatment and storage conditions vary: in apple, 10–20% AVG as a 5 min dip prior to cold storage (Khan et al., 2019); in grapes, 20% AVG as a 5 min dip before storage at 0°C or 30°C for the ‘Thompson Seedless’ variety (Ali et al., 2016), 67% AVG as a 5 min dip before storage at 4°C, 85±5% RH for the ‘Askari’ variety (Farahi, 2015), 5–10% AVG as a 2–3 second dip before storage at 15°C for an Indian variety (Chauhan et al., 2014), and 25% AVG spray before cold storage at 0°C±1, 90–95% RH for the ‘Flame Seedless’ red variety (Tarabih and El-Metwally, 2020); in jujube fruit, 33–50% AVG (v/v) before cold storage at 4°C (Moradinezhad et al., 2018); in mango, 100% AVG as a 3 min dip before ambient storage for the ‘Keitt’ variety (Atlaw, 2018) and 50–75% AVG as a 25 min dip before storage at ambient temperature (15–22°C) or at 13°C for the ‘Ngowe’ variety (Sophia et al., 2015); in papaya, 1.5% AVG as a 5 min dip before ambient storage for the ‘Shahi’ (BARI Papaya-1) variety (Sharmin et al., 2015) and 50% AVG as a 15 min dip before ambient storage (30±3°C, 42–55% RH) for an unspecified variety (Singh and Chauba, 2019); and in pomegranate, 100% AVG before ambient storage (Jena et al., 2019). Similar responses were obtained in vegetables: in tomato, 100% AVG for the ‘Ruchi 618’ variety at the breaker stage (Athmaselvi et al., 2013), 100% AVG as a 2 min dip for ‘Roma’ and ‘UTC’ varieties at the fully ripe stage (Kator et al., 2018), and 2% AVG as a 2 min dip in mature green fruits (unspecified variety) (Chandran and Mini, 2018); in the bell pepper var. ‘Yolo Wonder’, 4–6% AVG as a 5 min dip before cold storage at 8±1°C, 90–95% RH (Ullah et al., 2017); and in cucumber, 100% AVG (Ajiboye and Gboyinde, 2020). From these reports, there are wide differences in the effective AVG dose and treatment duration. In general, lower doses of AVG (≤ 25%) are effective preservatives for thin-skinned produce such as grapes, nectarines, raspberries, tomatoes and sweet cherries; moderate doses (25–50%) are effective for medium-skinned products such as peppers and mangoes; and high doses (≥ 50%) are required for thick-skinned fresh products such as pineapples, plums and pistachios (Kahramanoglu et al., 2019). The incorporation of ascorbic acid, glycerol or chitosan usually improves the preservative characteristics of the coatings.

In citrus, studies showed that AVG coating enhanced fruit quality and shelf life despite differences in treatment conditions. In oranges (Citrus sinensis), for example, AVG (100%) coating reduced losses in weight, firmness and total soluble solids and extended shelf life during ambient storage (27 ± 2°C, 50–60% RH) (Adetunji et al., 2012). Rasoul and Ramezanian (2019) used different treatment conditions and showed that oranges treated with 30% AVG coating had lower weight loss, higher firmness, soluble solids content, titratable acidity and vitamin C content, better sensory qualities, particularly juiciness, and longer shelf life than uncoated fruit during cold storage (4 ± 1°C, 80 ± 5% RH). In mandarin (Citrus reticulata L.), 60% AVG reduced losses in weight, titratable acidity, juice content and vitamin C content and slowed the increase in soluble solids content during storage at 5°C, 85% RH relative to that without coating (Rashid et al., 2020). To our knowledge, no study has been done on the use of AVG coating in lime fruit, particularly in Thailand. Therefore, this study explored the use of AVG coating in enhancing the quality and shelf life of lime.

**Materials and Methods**

**Lime fruit preparation**

Lime fruit ‘Pan’ were harvested at the commercial maturity stage from a commercial farm in Pathum Thani Province, Thailand. The fruit were trimmed of peduncles, sorted, and only fruit with dark green and smooth skin, of uniform size and free from defects (wounds, disease and/or insect pest damage) were used. The fruit were immersed in the AVG solution or distilled water and allowed to dry in air at ambient temperature. Ten fruits were used for each of the four replicates per treatment. Additional fruit samples were set aside for parameters requiring destructive sampling.

**Aloe vera gel (AVG) application**

Freshly harvested mature Aloe vera leaves were secured from a local farm and washed with tap water. The AVG extraction method of Navarro et al. (2011) was followed. Briefly, for each leaf, the spikes along the margins were removed before separating the rind from the inner leaf gel. The parenchymatous gel was homogenized in a blender. The homogenate was filtered through cheesecloth to separate the solid fibrous parts from the gel. The gel (100%) was diluted with distilled water to obtain the five AVG concentrations as treatments—10%, 20%, 30%, 40%, and 50% (v/v). Then, 1% glycerol was added to the AVG solution to increase the plasticizing effect. Distilled water served as a control. The fruit were immersed in the AVG solution or distilled water for 5 min. After dipping, the fruit were air-dried at ambient temperature and were then placed in foam trays for storage at ambient temperature (29 ± 1°C, 74 ± 5% RH) for 16 days.
Measurement of parameters

The different parameters were measured every two days during storage. Weight loss was taken as percentage of the initial weight. Fruit color was subjectively scored using a scale of 1–6 as follows (Fig. 1):

1 = green
2 = light green with slight yellowing of < 20% of the surface area
3 = more green than yellow (20–50% of the surface area yellow)
4 = more yellow than green (> 50–80% of the surface area yellow)
5 = yellow (> 80% of the surface area yellow)
6 = yellow with brown areas

Objective fruit color measurement used a Hunterlab Colorimeter (FRU Portable Colorimeter Model-WR10; Shenzhen Wave Optoelectronics Technology Co., Ltd., Shenzhen, China) taking the average of five readings of CIE L*, a*, and b* values from the top, middle and bottom parts of each fruit. Shelf life was taken as the number of days for the fruit to develop objectionable yellowing and/or browning (score of more than 3.0).

Fruit juice volume was measured by extracting the juice using a fruit juicer and measuring the volume as a percentage of fruit weight. Total soluble solids (TSS) content was measured using a refractometer (Model PAL-1; ATAGO Co., Ltd., Tokyo, Japan). Titratable acidity (TA) was analyzed by the titration method. Five ml juice was supplemented with one or two drops of 0.1% phenolphthalein indicator and titrated using 0.1 N NaOH to an endpoint of a faint pink color (pH 8.1). The results were expressed as percentage citric acid. Vitamin C content was determined by the 2,4-dinitrophenyl hydrazine method (Roe et al., 1948). The fruit sample (100 mg) was extracted in 5% metaphosphoric-glacial acetic acid solution. The extract was centrifuged and a clear supernatant collected. Aliquots of the supernatant were placed in a test tube and incubated for 3 h at 37°C in a water bath, after which the reaction was terminated by adding 85% sulfuric acid. The optical density of the reaction mixture was measured against a blank at 540 nm using a spectrophotometer (model DU 640B; Beckman Coulter Inc., Brea, CA, USA). Ascorbic acid content was estimated from a standard curve prepared from pure ascorbic acid.

Statistical analysis

A completely randomized design with four replicates was used. The results were analyzed by performing analysis of variance (ANOVA) and a treatment mean comparison with Tukey’s honest significance test (HSD) (P < 0.05) using Statistix 8.0 software (Analytical Software, Tallahassee, FL, USA).

Results and Discussion

Fruit yellowing and shelf life

AVG coating markedly slowed fruit yellowing during ambient storage (Fig. 2). Uncoated fruit showed lightening of the green color and slight yellowing as early as after two days of storage, manifesting as higher color scores than that of coated fruit. A sharp increase in yellowing occurred after eight days of storage with the uncoated fruit maintaining higher color scores than coated fruits. Two days later, uncoated fruit were more yellow than green (color score of 4) while coated fruits were still more green than yellow (score of 3 or lower). Uncoated fruits turned fully yellow on the 12th day of storage while most coated fruit did not turn fully yellow even at the end of the 16-day storage period. No AVG concentration effect was evident except that after 12–16 days of storage, fruit coated with a higher AVG concentration (40–50%) had a slightly lower degree of yellowing than fruits treated with 10–30% AVG.

CIE L*, a*, and b* values followed a similar trend to that of color scoring (Fig. 2). However, green color lightening and slight yellowing of uncoated fruit during the first six days of storage was indicated by higher L* values than those of coated fruits. An AVG concentration effect was apparent with the lowest AVG level of 10% showing higher L* values, followed by the 20–30% AVG coating, while that of 40–50% AVG coating was the lowest, particularly after 8–14 days of storage. It can also be seen from Figure 2 that fruits coated with 40–50% AVG had L* values during the first 12 days of storage which were almost similar to the initial values before storage, indicating that the green color intensity did not change much during storage. On the other hand, a* measures color from green (negative values) to red (positive values). All fruits had a green or tinge of green as shown by their negative a* values that decreased progressively indicated by increases in a* values from about −13 at the start of storage to −2 at the end of storage. In contrast, a* values of coated fruits were maintained at about −10 or lower throughout the storage period regardless of AVG concentration, although a* values started to increase after 10 days of storage. b* measures the color region from blue (negative values) to yellow (positive values) and values obtained were all positive regardless of treatment (Fig. 2). At the start of storage when all fruits were dark green, the b* value was about 31 and it then increased to over 40 after 14–16 days of storage, with the uncoated fruit showing the highest increase. The AVG concen-

Fig. 1. Lime fruit color scores.
The concentration effect was similar to that obtained for \( L^* \) values as the yellow color had higher \( L^* \) values than the green color.

Dark green lime fruits are the most desirable and loss of green color with yellowing and/or browning indicates loss of freshness and shelf life. Loss of green color occurred faster in uncoated fruit resulting in a shorter shelf life of 10 days compared to that of AVG-coated fruits which all lasted for 14 days at ambient temperature (Fig. 3). Peel browning was observed only in uncoated fruit as shown in Figure 4.

Fruit color is the most important visual quality trait of lime that determines marketability and shelf life. Loss of green color and the concomitant yellowing is not desirable as it is associated with a reduction in the acidic taste of the juice preferred by consumers, although yellowed limes can still be consumed. The present study showed that AVG coating retarded the loss of green color and yellowing, thus extending the

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**Fig. 2.** Color score, \( L^* \), \( a^* \), and \( b^* \) values of AVG-coated lime stored at ambient temperature. *, \( P < 0.05 \); **, \( P < 0.01 \) indicate significant differences among the AVG concentrations by Tukey’s HSD test. The values are the mean of four replicates.

**Fig. 3.** Shelf life of AVG-coated lime stored at ambient temperature. The values are the mean of four replicates.

**Fig. 4.** Appearance of AVG-coated limes before and after 14 days of storage at ambient temperature.
shelf life and marketable period of the fruit. Previous studies demonstrated retardation of fruit color change as one of the typical effects of AVG coating, such as in mango (Sophia et al., 2015), apple (Ergun and Satici, 2012; Song et al., 2013), wax apple (Supappanich et al., 2016), peach and plum (Guillen et al., 2013; Romero et al., 2017), papaya (Brishiti et al., 2013; Sharmin et al., 2015), grapes (Farahi, 2015; Ali et al., 2016), oranges (Radi et al., 2017), strawberries (Nasrin et al., 2017), kiwifruit (Benitez et al., 2015), papaya (Sharmin et al., 2015), tomato (Athmaselvi et al., 2013; Chandran and Mini, 2018), and cucumber (Ajiboye and Gboyinde, 2020). AVG and other edible coatings produce a thin film on the fruit surface that restricts gas exchange and creates an internal fruit atmosphere of low oxygen and high carbon dioxide which reduces ethylene production and delays ripening, chlorophyll breakdown, carotenoid synthesis and anthocyanin accumulation, thus delaying color change. When fruit is detached from a plant, chlorophyll starts to decline. AVG coatings reduce loss of chlorophyll, and delay ripening. This may be due to an increased CO₂ concentration and decreased O₂ levels as fruit is not directly exposed to the environment; this decreases ethylene biosynthesis and therefore delays fruit color changes (Sherani et al., 2022).

**Weight loss**

Weight loss increased with storage (Fig. 5). It was about 4–5% after two days of storage and 18–20% on the 16th and last day of storage. No distinct differences in weight loss between AVG-coated and uncoated fruits were observed. In general, uncoated fruit had only slightly higher weight loss than coated fruits regardless of AVG concentration. This can be seen also from the average weight loss, in which uncoated fruits lost about 12.8% while coated fruits lost 11.4–12.3% (Fig. 5).

The insignificant AVG effect on weight loss contrasts earlier findings on the weight loss-reducing effect of AVG coating on other citrus species (Adetunji et al., 2012; Rasouli and Ramezanian, 2019; Rashid et al., 2020). This is similar to the effect of AVG on different apple varieties in which 1–10% AVG reduced weight loss of ‘Granny Smith’ apples, but not ‘Red Chief’ apples (Ergun and Satici, 2012). These differing responses were attributed to differences in fruit surface structure and fruit size, which could be applicable to lime and other citrus species. Other factors may also be involved, such as the permeability characteristics of AVG to water transfer and coating film distribution on the fruit surface. Furthermore, the present study used freshly prepared, glycerol-added AVG without pasteurization treatment, similar to that used in some previous studies (Song et al., 2013; Sogvar et al., 2016). Pasteurization was reported to be important to stabilize the gel and to obtain good film thickness, water solubility, and swelling behavior (Kahramanoglu et al., 2019). The most preferred and successful method of AVG pasteurization is 70°C for 45 min. This could also be considered in future studies.

**Juice content**

Juice content of the fruit before storage was about 42% (Fig. 6A). During storage, the juice content either decreased or increased. Treatment effect did not show a clear trend and treatment differences in response were not statistically significant in each observation period. At the end of shelf life of uncoated fruits (10 days of storage), the juice content was about 47%, while for AVG-coated fruits (14 days of storage), the juice content ranged from 39–45%.

Juice content and juiciness are expected to decrease with storage corresponding to water loss (weight loss). This was observed in citrus mandarin and oranges and AVG coating slowed losses of juice content (Rasouli and Ramezanian, 2019; Rashid et al., 2020). One factor that possibly contributes to the erratic trend in juice content and absence of a positive response to AVG coating of lime is the physiological maturity of the fruit. Lime fruits are harvested when they reach full size with shiny dark green peel. Despite similar physical attributes, the physiological status of fruit tissues may differ. Chemical processes, including those contributing to fruit juiciness, are usually more affected than physical processes, such as weight loss. Nevertheless, the results show that AVG coating had no adverse effect on juice content.
TSS and TA contents increased while vitamin C contents decreased with storage (Fig. 6B–D). There was no consistent effect of the different AVG concentrations on these three parameters. Also, treatment differences in these three parameters were not significant in each observation period. In general, the TSS content before storage was about 8.1°Brix and increased to 9.4°Brix and 9.8–10.6°Brix after 10 and 14 days of storage, corresponding to the end of shelf life of uncoated and AVG-coated fruits, respectively (Fig. 6B). TA was about 8.6% citric acid before storage and increased to 9.7% citric acid after 10 days of storage of uncoated fruit and 9.3–10.2% citric acid after 14 days of storage of AVG-coated fruits (Fig. 6C). The increase in TSS and TA could be due to sugar and organic acid concentrations in fruit juice vesicles due to weight loss. The vitamin C content was about 48 mg/100 mL juice before storage and decreased to about 42 and 32–45 mg/100 mL juice at the end of the shelf life of uncoated and coated fruits, respectively (Fig. 6D).

TSS, TA and vitamin C

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TSS plays a crucial role in the taste of fresh produce, while TA contributes to acidity of fruit juices, which is the most desired taste trait of lime juice. On the other hand, vitamin C (ascorbic acid) is a potent antioxidant and is usually lost during postharvest storage due to the activity of phenoloxidases (Salunkhe et al., 1991). Retention of vitamin C in fruits is an important measure of the efficacy of postharvest treatments. Among the reported effects of AVG coating is a reduction in losses of TA and vitamin C content and a slowed increase in TSS during ambient or cold storage. This was observed in citrus species, including oranges treated with 100% AVG and stored at ambient temperature (Adetunji et al., 2012) or with 30% AVG and stored at 4°C (Rasouli and Ramezanian, 2019), as well as mandarin treated with 60% AVG and stored at 5°C (Rashid et al., 2020). Other fruits showed a similar response to AVG coating (Mistr et al., 2014; Kahramanoglu et al., 2019). The results of the present study seem to contradict these earlier findings, but imply that AVG coating of lime had no adverse effects on these chemical quality attributes, while retarding yellowing and extending shelf life of the fruit. Some studies support the present results, such as the comparable TSS and TA of AVG-coated and uncoated oranges stored at 12°C (Arowora et al., 2013).

Conclusion

AVG coating retarded yellowing and prolonged shelf life of lime during ambient storage without adversely affecting other physicochemical attributes. A concentration of 10% AVG as a 5-min dip appeared to be sufficient to extend shelf life. However, AVG coating had no significant effect on weight loss, juice content, TSS, TA or vitamin C relative to that of uncoated fruit. Future studies could explore further optimization of coating, including AVG preparation methods and suitable control of inherent factors (e.g. maturity) of the AVG material and lime fruit.

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