



Research article

Effect of Thai herb essential oils incorporated in hydroxypropyl methylcellulose-based nanocomposite coatings on quality of fresh mango stored at ambient temperature

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Article Info

Article history:

Received 25 August 2021

Revised 10 December 2021

Accepted 14 February 2022

Available online 30 April 2022

Keywords:

Active coating,

Ambient temperature storage,

Essential oil,

Hydroxypropyl methylcellulose,

Mango

Abstract

Importance of the work: Mango is a perishable fruit which is easily spoiled particularly by anthracnose and consequently shorten its shelf-life. To prolong the shelf-life, edible coating is a promising approach.

Objectives: To investigate the effect of Thai essential oils (EOs) in hydroxypropyl methylcellulose (HPMC)-based coatings on the quality of mango.

Materials & Methods: The EOs (ginger; G, plai; P or fingerroot; F) at a concentration of 15 g/L were incorporated in an HPMC-based nanocomposite coating to reduce the anthracnose incidence in mango. Fresh ‘Namdokmai Sithong’ mangoes were dipped in the HPMC-based nanocomposite solutions with and without each EO and compared with uncoated and water-dipped mangoes.

Results: The coating significantly reduced weight loss, delayed firmness loss and internal color changes and decreased the disease severity of fresh mangoes at ambient temperature (30°C) and 55% relative humidity. The shelf-life of the coated mangoes was extended to 15 d at 30°C, compared with uncoated samples (9 d). Furthermore, the addition of EO significantly improved the antifungal activity of the edible coating material.

Main finding: Active HPMC-EO-based nanocomposite coatings helped to inhibit the growth of *Colletotrichum gloeosporioides* and extended the shelf-life of mango. This will benefit fruit generally sold at ambient temperature and will reduce agricultural waste from fruit deterioration.

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<https://doi.org/10.34044/j.anres.2022.56.2.11>

Introduction

The development and application of edible films and coatings have received increased interest by researchers and industry as a means of maintaining and enhancing the quality of fruit (Sothornvit and Rodsamran, 2008, 2010). The gas and water vapor barrier provided by the combination of biopolymers (proteins and polysaccharides) and lipids might result in a reduction in weight loss and respiration rate by creating a modified gas composition in the fruit. This effect on fruit metabolism, with a reduction in respiration and ethylene production, can delay ripening and deterioration; subsequently this can extend the shelf-life and maintain the quality of fruit and vegetable (Guilbert, 1986). However, special attention should be paid to coating selection to provide an appropriate gas barrier for the specific product.

Mangoes (*Mangifera indica* Linn.) are climacteric fruit and ripen rapidly after harvest (Sothornvit and Rodsamran, 2008). Furthermore, anthracnose caused by *Colletotrichum gloeosporioides* is the most important disease of mango in humid production areas (Arauz, 2000). These factors limit the distribution of the fruit for long-distance commercial trading. Generally, the shelf-life of mango varies among varieties and storage conditions. For example, ‘Namdokmai Sithong’ mango is the most popular cultivar in Thailand and has a storage range of 4–8 d at room temperature and 2–3 wk in cold storage at 13°C (Abbasi et al., 2011). The application of antimicrobial edible coatings could delay the deterioration, maintain quality and extend the shelf-life of mangoes while keeping them edible without health risks. Recently, works on edible coatings have extended the quality of mangoes. For example, an edible coating based on shellac and tannic acid had an antifungal effect and improved the overall quality of mangoes stored at room temperature (25°C) with a shelf-life approximately of 10 d (Ma et al., 2021). In addition, the edible coating based on a combination of *Aloe vera* gel and chitosan decreased fruit weight loss and ascorbic acid reduction; thus, it extended the shelf-life of mangoes during storage at ambient temperature (25°C) for 21 d (Seyed et al., 2021).

Edible films and coatings based on hydroxypropyl methylcellulose (HPMC) and beeswax (BW) have shown potential to reduce weight loss, stabilize ingredients and improve the firmness properties of tomato (Fagundes et al., 2015), plum

(Navarro-Tarazaga et al., 2011) and grape (Sánchez-González et al., 2011). In addition, the antimicrobial properties of these coatings can be improved by adding food-grade additives or generally regarded as safe (GRAS) compounds such as organic acid salts and essential oils (EOs) to control decay of the fresh produces. Among natural-occurring antimicrobial agents, EOs have gained popularity and many studies show their antimicrobial activity in edible films (prepared as stand-alone film). Other work by the authors of the current study showed that HPMC-based composite films containing Thai EOs—fingerroot (*Boesenbergia pandurata*; F), ginger (*Zingiber officinale*; G) and plai (*Zingiber cassumunar*; P)—also inhibited *C. gloeosporioides* during *in vitro* testing (Klangmuang and Sothornvit, 2012). In addition, the incorporation of both BW and nanoclay improved the gas barrier and strengthened the mechanical properties of HPMC-EO-based nanocomposite film (Klangmuang and Sothornvit, 2016a). Furthermore, another study (Klangmuang and Sothornvit, 2018) showed that the active coating from HPMC-EO-based nanocomposite incorporated with EO maintained the quality of mangoes at 13°C. However, there is a need to investigate the effectiveness of active HPMC-EO-based nanocomposite coating on mangoes stored and sold at ambient temperature. Therefore, the objective of the current work was to evaluate the effect of HPMC-based nanocomposite coatings containing fingerroot, ginger and plai EOs on the postharvest microbiological and sensory qualities of mango stored at ambient temperature (30°C) in tropical zones. Furthermore, the findings should indicate the benefit of these coatings when applied on fruits that are subsequently sold at ambient temperature.

Materials and Methods

Materials

The main ingredients for the edible coatings were hydroxypropyl methylcellulose (HPMC) type K4M supplied by Dow Chemical (Midland, MI, USA) and purchased from Vicchi Enterprise Co. Ltd. (Bangkok, Thailand), an organically modified montmorillonite (Cloisite 30B) from Southern Clay Co., Ltd. (Gonzales, TX, USA), beeswax (BW) from Fluka Co. Ltd. (Buchs, Germany), stearic acid (SA) from Ajax Fine Chemicals Co. Ltd. (Sydney, NSW, Australia) and glycerol

(Gly) from Ajax Fine Chemicals Co. Ltd. (Auckland, New Zealand). The three essential oils (EOs) from plai (P), ginger (G) and fingerroot (F) prepared using the steam distillation method were obtained from Thai-China Flavors and Fragrances Industry Co. Ltd. (Ayutthaya, Thailand).

Coating preparation

The HPMC-based nanocomposite emulsions were prepared as described by Klangmuang and Sothornvit (2016a). Gly as a plasticizer and SA as an emulsifier were used at constant ratios of HPMC-to-BW (4:1), HPMC-to-Gly (3:1) and BW-to-SA (5:1). The HPMC solution was prepared by dissolving 2.0% weight per weight (w/w) in distilled water using a hot/cold technique. Clay (5% w/w of HPMC) was used to obtain the HPMC-based nanocomposite solution. From a preliminary study, the final concentration of EO (P, G or F) in the HPMC-based nanocomposite solution was 15 g/L. Then, the mixture solutions were homogenized using a homogenizer (Polytron model PT 3100; Littau, Switzerland) at 20,000 rpm for 5 min.

Sample preparation: Coating application

Unripe mangoes (*Mangifera indica* L.) cv. ‘Namdokmai Sithong’ (maturity of 110 d after fruit set) procured from a local market in Nakhon Pathom (Thailand) were weighed and samples were selected of approximately 350 g each with uniformity in size and shape and having no defects. Pedicles were trimmed to 0.5–1 cm. A solution of 0.05% (volume per volume) sodium hypochlorite was used to wash the mangoes, followed by rinsing in tap water, and air-drying at room temperature (28–30°C). Fruit samples were randomly divided in six groups, corresponding to the following treatments: uncoated (control); water-dipped; HPMC coating (HPMC); HPMC-ginger EO coating (HPMC+G); HPMC-plai EO coating (HPMC+P); and HPMC-fingerroot EO coating (HPMC+F). The mangoes were dipped in either water or the formulated coating solutions at 20°C for 2 min and dried in a hot-air oven at 40°C for 30 min. Later, the mangoes were stored at 30 ± 2°C and 55 ± 5% relative humidity, simulating local transport and trading conditions in a tropical climate. Each mango was assessed for quality at intervals of 3 d until the mango had ripened and subsequently decayed. Sampling of 15

fruits per treatment and 3 replications were performed for each property. The shelf life was determined as the period for which the mango retained a desirable sensory aspect and acceptable changes in the fruit ripening characteristics.

Weight loss

The same marked mangoes (30 mangoes per treatment) were weighed at the beginning and the end of storage. Eventually, the weight loss was recorded and calculated as a percentage of the initial weight.

Soluble solids content and pH

The mango juice was used to determine the soluble solids content using a hand refractometer (Atago model N32; Tokyo, Japan) and the pH of the juice was determined using a pH meter (Sartorius, PB-10; Goettingen, Germany).

Firmness measurements

The firmness of each fresh mango (pulp or mesocarp) was reported by measuring the force required for a probe with a diameter of 2 mm to penetrate to the center of the mango cheek, held perpendicularly to the probe using a 10 mm/min compression speed to a 5 mm depth in a Universal testing machine having a 500 N load cell (Lloyd, model LR 5K; Fareham, UK).

Color

The color of each fresh mango was determined using a spectrophotometer (Spectro-guide sphere gloss, model CD-6834; BYK; Geretsried, Germany) on peel and pulp samples, measuring the CIELAB color parameters, L*, a* and b*. A white standard plate (L* = 95.83; a* = -0.78 and b* = -0.02) was used to calibrate the instrument.

In vitro antifungal activity

The antifungal assay of each HPMC-based nanocomposite coating solution incorporated with EO was based on inhibition in radial mycelial growth of *C. gloeosporioides* on potato dextrose agar (PDA) using the poison food technique.

Each PDA dish contained a 20% coating solution. Plates with PDA without coating served as the control. The center of each plate was inoculated with a 5 mm diameter plug of 7–9 day-old cultures of *C. gloeosporioides* and incubated for 6 d at 25°C. Each treatment was applied to three replicates. Radial mycelial growth was determined for each plate after 4 d and 6 d of incubation by calculating the mean of two perpendicular diameters of the fungal colony. The results were expressed as a percentage of mycelial growth inhibition (Equation 1):

$$\text{Mycelial growth inhibition} = \frac{(dc-dt)}{dc} \times 100 \quad (1)$$

where *dc* is the average diameter of the fungal colony on control plates and *dt* is the average diameter of the fungal colony on coating-amended plates.

Disease severity index

The disease severity index caused by natural infection of the mangoes was recorded every 3 d during storage. Quantification of disease severity was performed according to the following quantitative scale from 1 to 4, where 1 = no symptoms and no disease, 2 = black spot area $\leq 40 \text{ mm}^2$, 3 = black spot area $40\text{--}60 \text{ mm}^2$ and 4 = black spot area $> 60 \text{ mm}^2$.

Sensory evaluation

Descriptive analysis was used to evaluate the sensory quality of treated samples. Ten semi-trained panelists were selected to define the mango quality attributes at 3 d intervals. Before analysis, the mangoes were kept at room temperature (30°C) until ripe. Samples were washed, peeled and cut into small cubes (2 cm \times 2 cm \times 2 cm). At least two cubes from different parts of each mango were allocated individual three-digit random codes and served at room temperature. The panelists were advised to rinse their palate with mineral spring water between the samples. Judges rated the peel color (1 = bright yellow, 4 = dark yellow and 7 = orange), texture (1 = mushy soft, 3 = quite soft and 5 = hard), flavor (1 = off-flavor and 5 = absence of off-flavor), taste (1 = bad, 4 = sweet and sour and 7 = sweet) and overall acceptance (1 = dislike, 3 = neither like nor dislike and 5 = like).

Statistical analyses

Experimental data were subjected to one-way analysis of variance. Duncan's multiple range test was used to determine significant differences between treatments at the 95% confidence level. The SPSS software for Windows (SPSS version 11; SPSS Inc.; Chicago, IL, USA) was used to analyze all data.

Results and Discussion

Weight loss

The weight loss rate of mango increased with the extension of storage time due to transpiration and water evaporation from the peel driven by a difference in vapor pressure between the mango and the surrounding atmosphere. Uncoated and water-dipped mangoes had higher weight losses than coated mango (Fig. 1A), indicating that the HPMC coatings provided a barrier to water vapor. Among the coated mango treatments, at days 6 and 9 of storage, the HPMC+P coating had a higher weight loss than the HPMC coating without EO. As previously observed, the addition of plai oil significantly increased the water vapor permeability of the HPMC-based nanocomposite film (Klangmuang and Sothornvit, 2016a). Plai oil might behave as a more effective plasticizer than the other types of EO as it reduced intermolecular interaction and loosened the compactness of the film structure (Pranoto et al., 2005). This probably enhanced moisture passing through the edible coating and thereby increased the weight loss of the coated mango. After 9 d of storage, uncoated mangoes had lost 8–9% of their original weight, whereas coated mangoes had lost only 4–5%. Furthermore, the uncoated mangoes had rapid ripening and the incidence of disease; therefore, they could not be stored beyond 9 d. However, the coated mangoes could be stored up to 15 d. In general, coatings containing hydrophobic compounds, deposited as an additional layer over the natural waxes, should improve the moisture resistance of the fruit. However, the physical properties of the coating, such as surface tension and viscosity and fruit skin morphology (presence of hairs, number of stomata, lenticels and cracks in the lenticels, thickness and type of cuticle), strongly affect mass transfer of the coated fruit (Hagenmaier and Baker, 1993). Thus, some works have

reported that the addition of lipids to polysaccharides did not reduce weight loss of coated commodities, such as plums (Navarro-Tarazaga et al., 2008) or tomatoes (Fagundes et al., 2015). However, the current results confirmed that the HPMC coating containing BW and EO formed an additional layer over the natural wax, providing an effective barrier to water vapor and extending the shelf-life. Compared with uncoated mango, the coated mango stored at ambient temperature (30°C) was extended for 6 d (from 9 d to 15 d) in the current study, while the shelf-life of coated mango stored at refrigerated temperature (13°C) in another study (Klangmuang and Sothornvit, 2018) was extended for 3 d (from 15 to 18 d). This implied that the edible coating was more effective at prolonging the shelf-life of coated mango stored at ambient temperature than for coated mango stored at a refrigerated temperature. Similarly, zein/gelatin and galactomannan coatings on mango resulted in the least weight loss (Gol and Rao, 2014).

Soluble solids content and pH

The soluble solids content (SSC) of mangoes increased with storage time in all treatments due to the change of starch to sugar by amylase (Sothornvit and Rodsamran, 2010). The results showed a significant difference in SSC values between uncoated and coated mango starting from day 6 (Fig. 1B). The SSC increased rapidly after days 3 and 6 in uncoated and coated mango, respectively. The slow change in the SSC of coated mango indicated a reduction in the metabolic activity, probably due to the gas barrier exerted by the coating, which translated into an extension of the fruit shelf-life (Sothornvit and Rodsamran, 2008). Several works have reported on the gas barrier of HPMC coatings on the fruit surface modifying the endogenous CO₂ and O₂ concentration of coated fruit and reducing fruit metabolic reactions (Navarro-Tarazaga et al., 2011; Fagundes et al., 2015). In the current work, the HPMC incorporated with EO showed a beneficial delay in the increase in SSC accumulation compared to the HPMC without EO. This might have been due to the lipophilic nature of EO providing resistance to gas diffusion and finally postponing fruit ripening. Likewise, the EOs maintained the SSC of strawberry coated with calcium chloride/thymol edible coating (Atres et al., 2010) as did thyme and lavender essential oils applied as an edible coating on the ‘Jonagold’ apple cultivar (Rabiei et al., 2011).

The pH increased significantly during storage in both coated and uncoated mangoes (Fig. 1C). As the mango fruit ripens, the organic acid content decreases and the sugar content increases, thus making the mango taste sweeter (Kittur et al., 2001). A coating application delayed acidity losses in the mangoes compared to uncoated controls, which could be related to a decrease in the weight loss and slowing down of the respiration rate and metabolic activity (Sothornvit and Rodsamran, 2008).

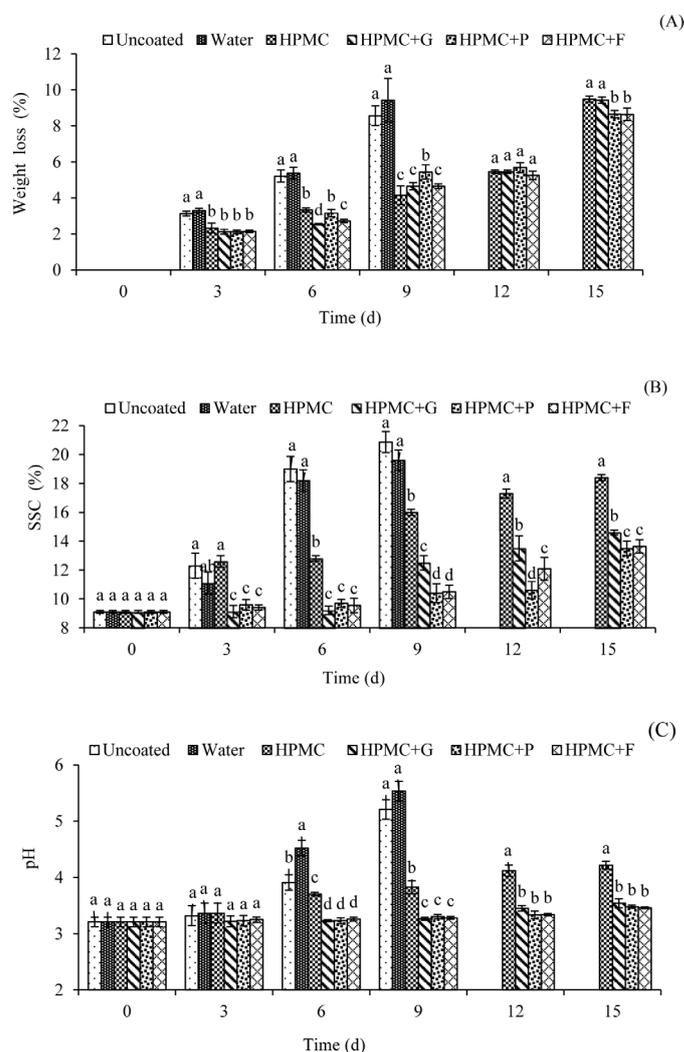


Fig. 1 Effect of hydroxypropyl methylcellulose (HPMC) coating incorporated with essential oil (plai, P; ginger, G; fingerroot, F) and storage time on fresh mango storage time: (A) weight loss; (B) soluble solids content (SSC); (C) pH, for storage at 30°C, where error bars represent SD. Different lowercase letters indicate significant ($p < 0.05$) difference among means within the same day

Firmness

Firmness is an important factor that influences the consumer acceptability of fruit and polysaccharides (pectin and cellulose) present in the cell wall are related to fruit firmness (Abbasi et al., 2011). A loss in firmness was due to the cell wall degradation by pectinesterase, polygalacturonase and other enzymes resulting in the ripening of mango (Abbasi et al., 2011). In the current study, the firmness decreased with time for both uncoated and coated mangoes (Fig. 2). However, the HPMC coating maintained firmness better than the uncoated mango during 9 d of storage at 30°C. At day 15, HPMC+G and HPMC+F coated mangoes were the firmest (Fig. 2). Therefore, edible coatings might inhibit enzyme activity involved in the cell wall degradation and maintain membrane integrity, reducing fruit softening (Gunaydin et al., 2017). The enhanced water and gas barrier of the coated mango with EO addition in the coatings could delay firmness loss during storage as was reported for chitosan coatings containing lemon and orange essential oils on mango (Rodríguez et al., 2015). In addition, the firmness decreased with the degree of fruit ripening and was related to the weight loss of mangoes, as was reported in mango (Sothornvit and Rodsamran, 2008) and guava (Sothornvit, 2013). This fact was confirmed in the current work, since mango with HPMC+G or HPMC+F coatings at day 9 had lower weight losses and these treatments also had higher firmness values.

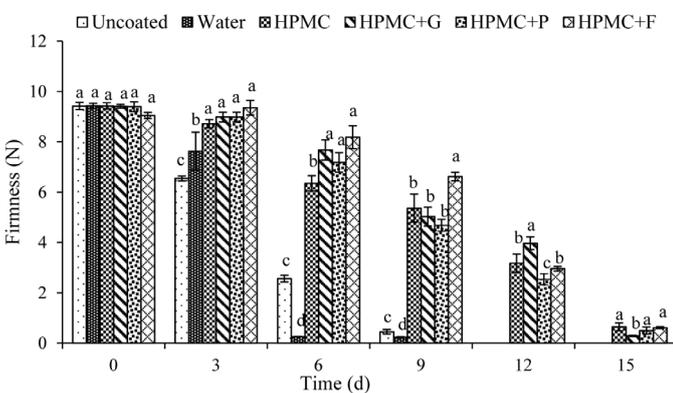


Fig. 2 Effect of hydroxypropyl methylcellulose (HPMC) coating incorporated with essential oil (plai, P; ginger, G; fingerroot, F) and storage time on the firmness of fresh mangoes during storage at 30°C, where error bars represent SD. Different lowercase letters indicate significant ($p < 0.05$) difference among means within the same day

Color

The color change in many fruits is an important quality index used by growers and consumers to judge harvest time and commercial quality (Fagundes et al., 2015). Generally, the peel color of mango fruit changes on ripening from dark green to olive-green, with sometimes reddish, orange-yellow or yellowish hues depending on the cultivar. However, ‘Namdokmai Sithong’ mangoes have a yellow peel at the harvest/unripe stage due to the high carotenoid content (Sivakumar et al., 2011) and this evolves into a golden yellow color when they ripen. Therefore, the peel color is not considered as a main component of the assessment of the maturity status in this cultivar at harvest; however, it affects consumer acceptance of the fruit. In the current study, the lightness (L^*) values of the peel and pulp mangoes decreased with storage time, whereas the a^* and b^* values increased (Fig. 3). The change in L^* and a^* values in the peel and tissue of intact fruit could be attributed to other metabolic changes, such as an increase in the carotenoids. Nevertheless, the coatings helped to maintain the color of fruits and reduced fruit darkening during storage. Notably, the addition of EO into the HPMC-based nanocomposite coating did not affect the L^* and b^* values of the peel compared to the HPMC-based nanocomposite coating without EO and uncoated mangoes. The a^* value showed a significant increase at day 9 for uncoated and water-dipped mangoes (Fig. 3B).

The pulp color of ripe mango changed from bright or light yellow to yellow or orange-yellow. The addition of EO in the HPMC coating delayed changes in the b^* values of coated mango pulp compared to a rapid change of the coating without EO. The type of EO incorporated into the HPMC coating did not affect the pulp color (Fig. 3). A delay in the color changes of coated mangoes was related to the coating being able to create a modified atmosphere surrounding the fruit. This might have inhibited the browning reaction and lowered the internal color change of the coated mangoes. Similarly, cassava starch edible coatings with citric acid better maintained the texture and color of fresh-cut mangoes with delayed carotenoid formation and browning reactions during storage (Chiumarelli et al., 2010). In addition, Rojas-Graü et al. (2007) reported lower color changes of fresh-cut apples coated with vanilla incorporated into alginate edible coatings than in those coated with oregano and lemongrass EO.

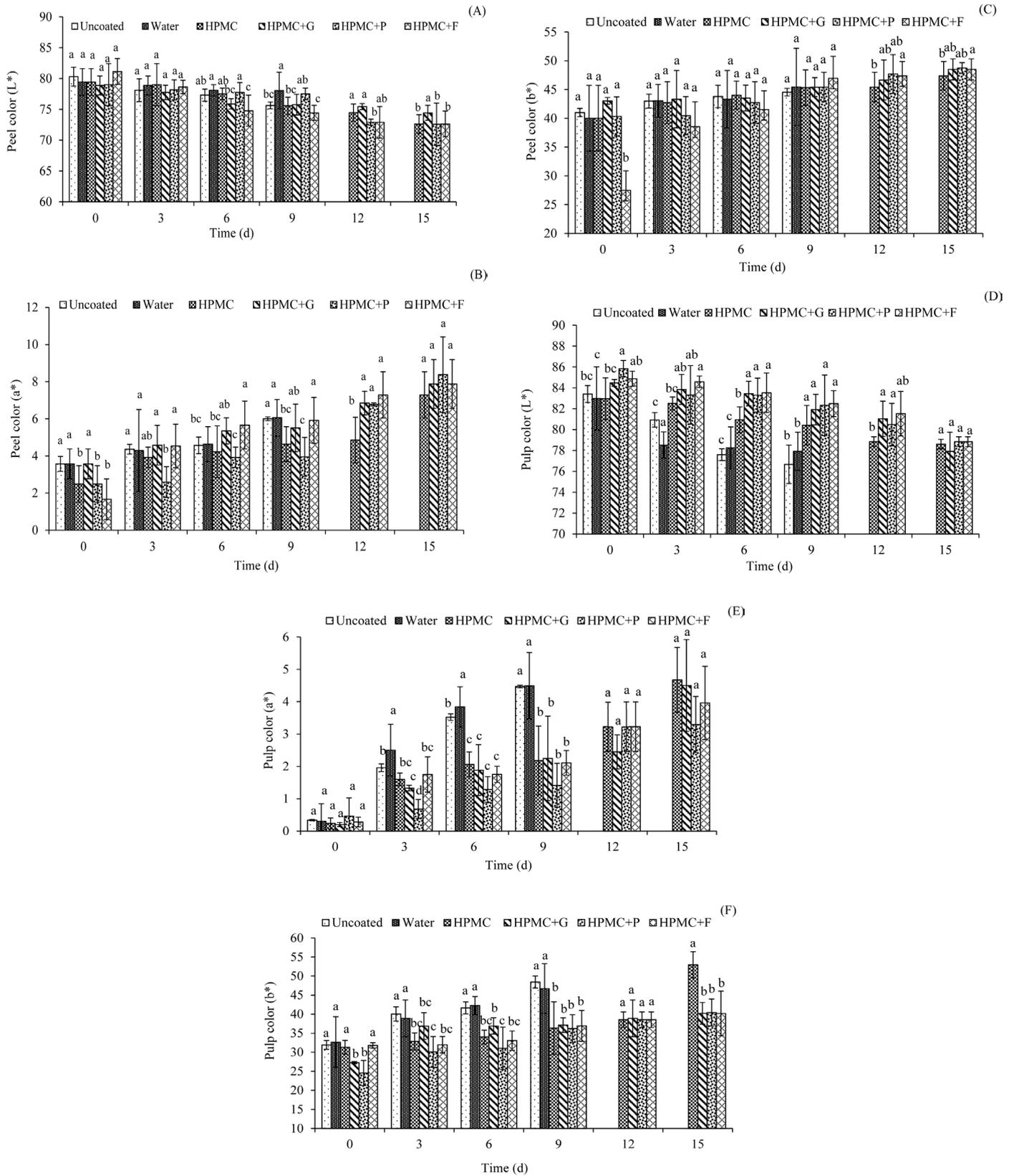


Fig. 3 Effect of hydroxypropyl methylcellulose (HPMC) coating incorporated with essential oil (plai, P; ginger, G; fingerroot, F) and storage time on stored fresh mango peel color: (A) L*; (B) a*; (C) b*; and on pulp color: (D) L*; (E) a*; (F) b*, where mangoes were stored at 30°C, error bars represent SD. Different lowercase letters indicate significant ($p < 0.05$) difference among means within the same day

Sensory evaluation

All the coatings were thin, transparent and adhered well to the ‘Namdokmai Sithong’ mango surface. These mangoes had a light yellow skin in the unripe stage, which evolved into a golden yellow when they ripened. The visual quality of the coated mangoes did not change for any treatment during the first 9 d of storage at 30°C. The disease severity of uncoated mango was evident after 3 d and increased thereafter. All HPMC coatings extended the shelf-life of the fresh mangoes to 15 d compared to uncoated and water-dipped mangoes which each had a 9 d shelf-life at 30°C.

Using EO in the HPMC coating had no significant effect on the color, texture and overall acceptance of mangoes, except for HPMC+F (Fig. 4). An HPMC coating with EO may be a good alternative, be safe for human consumption and provide natural protection without affecting the sensory characteristic of fresh mango. In many cases, EO impacts fruit flavor, but this depends on the type and concentration. For example, some authors found no significant changes in sensory attributes by adding a low concentration of lemongrass (0.3%) to alginate edible coatings in fresh-cut apples (Rojas-Graü et al., 2007) and fresh-cut pineapple (Azaraksh et al., 2014). However, in the current work, the flavor and taste characteristics were significantly affected by the incorporation of fingerroot oil in the HPMC coating compared to the other coatings. Coated mango with HPMC+F had a lower flavor score compared to the other coatings at the end of the storage period (Fig. 4B). This might have been due to several of the principal compounds of fingerroot, such as camphene, ocimen, camphor and geraniol, which adversely affected the sensory acceptability of the coated mango (Sothornvit and Rodsamran, 2010; Klangmuang and Sothornvit, 2018). Temperature affected the fresh mango flavor and the panelists detected off-flavors as the main quality attribute. Fruit storage at room temperature stimulated off-flavors more rapidly than storage at cold temperature (Sothornvit and Rodsamran, 2008). The panelists recorded similar values for good overall acceptance of all treatments during storage with no significant differences from the coated mango samples, except for the lower values of the HPMC+F coating. The HPMC+F coating negatively affected the overall acceptance of coated mango as its score was reduced by one point (score \approx 3) compared to other coated samples (score \approx 4). Furthermore, the coating itself can induce an off-flavor from

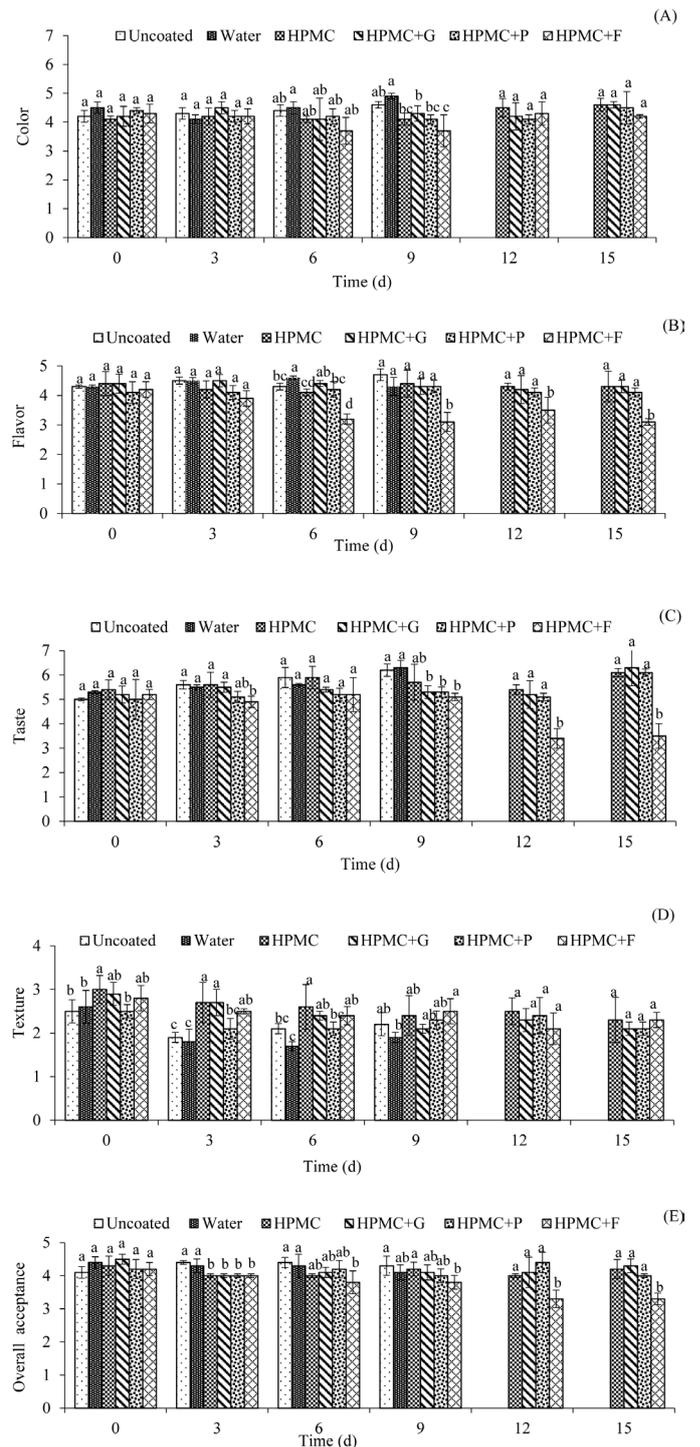


Fig. 4 Effect of hydroxypropyl methylcellulose (HPMC) coating incorporated with essential oil (plai, P; ginger, G; fingerroot, F) and storage time on sensory evaluation of fresh mangoes: (A) color; (B) flavor; (C) taste; (D) texture; (E) overall acceptance, where mangoes were stored at 30°C, error bars represent SD. Different lowercase letters indicate significant ($p < 0.05$) difference among means within the same day

anaerobic respiration which produces and releases alcohol and acetaldehyde and ultimately affects the sensory acceptability, depending on the type of fruits. For example, Ali et al. (2010) reported that tomatoes coated with 10% gum arabic had the highest scores for flavor and overall acceptability after 20 d of storage at 20°C, while tomatoes coated with 15% and 20% gum developed off-flavors and were not acceptable in the sensory evaluation. Raybaudi-Massilia et al. (2008) found that the odor, taste and firmness of fresh-cut melon were different depending on the type of essential oil added to an alginate coating. Cinnamon oil affected the odor and taste characteristics, while lemongrass oil affected the firmness of fresh-cut melon. For the sensory evaluation of texture, the mango was kept until ripe before analysis. Since the eating characteristic of ripe mango of this variety is soft, the sensory score of texture in all treatments was in the range of 2–3, considering the acceptance limit in this study.

Antifungal activity of hydroxypropyl methylcellulose coatings (in vitro study)

The antifungal activity was based on a reduction in the radial growth of fungal colonies (*C. gloeosporioides*) compared with the control. The nanoclay in all formulations was added to improve the gas barrier in the HPMC coating (Klangmuang and Sothornvit, 2016a) and to enhance the antimicrobial activity against both Gram-positive and Gram-negative bacteria (Hong and Rhim, 2008). This antimicrobial activity has been attributed to the quaternary ammonium salt in the nanoclay (Cloisite 30B) (Sothornvit et al., 2009). In the current work, all the HPMC coatings containing EO reduced the *in vitro* growth of *C. gloeosporioides* (Table 1). The EO can attack the cytoplasmic membrane of microorganisms, causing the release of their cytoplasmic constituents. These compounds caused

physical damage to the membrane or permeability barrier of microorganisms (Cowan, 1999). No significant differences in the inhibition of microbial growth on mangoes were found among EO types during the 6 d of incubation at 25°C (Table 1). Rozwarka et al. (2008) showed that ginger oil had the potential to control *in vitro* *C. gloeosporioides*. Correspondingly, the addition of fingerroot, ginger and plai oil in HPMC-based nanocomposite films also resulted in effective inhibition against *C. gloeosporioides* (Klangmuang and Sothornvit, 2012).

Disease severity caused by natural infection

Anthraxnose symptoms are expressed as dark, sunken lesions on ripe fruit with pink, slimy spore masses (Sivakumar et al., 2011). The HPMC coatings significantly reduced the severity index scores for coated mangoes compared with uncoated and water-dipped mangoes during storage. The first symptoms of decay occurred after day 3 for uncoated and water-dipped samples and after day 6 for coated mangoes. Uncoated and water-dipped mangoes were spoiled after 9 d of storage (Table 2). Using HPMC coatings helped reduce the disease severity index of coated mangoes. The decrease in decay was probably due to the effectiveness of the coating to control the pathogenic infection that in turn caused the loss of cellular or tissue integrity (Tanada-Palmu and Grosso, 2005). The results from the disease severity of mangoes (*in vivo*) were consistent with those from the antifungal activity of HPMC coatings (*in vitro*). However, the addition of EO to the HPMC coatings did not result in any significant differences in disease severity compared with the HPMC coating alone. This might have been due to the thin layer of HPMC coating solution covered on the surface of mango resulting in a small amount of EO used in the coating solution.

Table 1 Inhibition of radial growth of *Colletotrichum gloeosporioides* on potato dextrose agar amended with hydroxypropyl methylcellulose (HPMC) coatings incorporated with essential oil (plai, P; ginger, G; fingerroot, F) after 6 d of incubation at 25°C

Treatment	Inhibition in radial growth of <i>C. gloeosporioides</i> (mm)			Inhibition (%)
	Time after treatment (days)			
	0	4	6	
HPMC	0	23.5±6.37 ^b	32.30±3.33 ^b	0
HPMC+G	0	54.46±3.12 ^a	51.30±7.70 ^a	58.82
HPMC+P	0	49.17±3.26 ^a	49.83±2.25 ^a	54.27
HPMC+F	0	46.57±2.99 ^a	49.53±5.36 ^a	53.34

Mean±SD in the same column superscripted with different lowercase letters are significantly ($p<0.05$) different

Table 2 Effect of hydroxypropyl methylcellulose (HPMC) coating incorporated with essential oil (plai, P; ginger, G; fingerroot, F) and storage time on natural disease severity index of fresh mangoes during storage at 30°C

Treatment	Storage time (d)					
	0	3	6	9	12	15
Uncoated	1*	2.3	3.4	3.6		
Water	1	2.3	3.1	3.5		
HPMC	1	1	1.4	1.7	2.7	3.6
HPMC+G	1	1	1.3	1.6	2.3	3.2
HPMC+P	1	1	1.1	1.5	2.3	3.5
HPMC+F	1	1	1.2	1.5	2.5	3.6

*Disease severity index: 1 = no symptoms and no disease, 2 = black spot area < 40 mm², 3 = black spot area 40–60 mm² and 4 = black spot area > 60 mm²

Likewise, the HPMC coatings without bergamot oil on grape inhibited growth until 9 d of storage, similar to the uncoated samples at the end of storage (Sánchez-González et al., 2011). An HPMC coating containing propolis extract on grape had lower microbial growth than uncoated samples (Pastor et al., 2011). It has been reported that active ingredients, such as geraniol in fingerroot oil, gingerols in ginger oil and (E)-1-(3, 4-dimethoxyphenyl) butadiene in plai oil, are more effective at promoting antimicrobial and antifungal activity (Saad et al., 2013). Furthermore, HPMC-based nanocomposite films incorporated with fingerroot/ginger/plai oil also inhibited Gram-negative (*E. coli*), Gram-positive (*S. aureus*) bacteria (Klangmuang and Sothornvit, 2016b) and *C. gloeosporioides* fungus (Klangmuang and Sothornvit, 2012). From the results, the HPMC+G coating could be recommended as the possible best treatment for commercial application due to the fewer changes in mango quality and the desirable acceptance from the sensory evaluation.

Conclusion

The HPMC coatings incorporated with EO reduced the weight loss and delayed firmness loss, internal color changes and disease severity of fresh mango compared to uncoated and water-dipped treatments. The incorporation of ginger and plai essential oils into the coating did not affect sensory evaluation. The shelf-life of coated mangoes at 30°C was extended to 15 d. The HPMC coating incorporated with EO effectively reduced *C. gloeosporioides*. Therefore, ginger or plai oils can be utilized as safe and natural preservatives in HPMC-based edible coatings for fresh mango stored at ambient temperature. The development of such active edible coatings will benefit tropical fruit which is generally sold at ambient temperature

in the market and will reduce agricultural waste from fruit deterioration.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

Financial support was provided by the Kasetsart University Research Development Institute (KURDI), Bangkok, Thailand and the Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program jointly with Kasetsart University (Grant No. PHD/0179/2553). Miss Jitrawadee Meerasri helped with formatting this manuscript.

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