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Article

Application of Essential Oils for Maintaining Postharvest Quality of 'Rongrien' Rambutan Fruit

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Abstract: The postharvest quality of rambutan fruits (*Nephelium lappaceum* Linn.) is mainly influenced by dehydration, which causes browning of the peel and spinterns. This research investigated the effects of some essential oils—from citronella, clove, kaffir lime, and lemongrass—on 'Rongrien' rambutan fruit quality during storage at 13 °C. Screening of effective concentrations from 0.01 to 0.16% was conducted for each essential oil. The results showed that, of the essential oil treatments tested, a kaffir lime oil coating of 0.01% could best maintain the quality of fruits, reducing both weight loss and browning of the peel and spinterns. However, essential oil concentrations exceeding 0.04% severely damaged the fruit pericarp, in which scores of spintern browning were higher than those of peel browning. These results suggest that kaffir lime oil can maintain the postharvest quality of 'Rongrien' rambutan fruit as a supplement in some edible coatings.

Keywords: *Nephelium lappaceum*; pericarp browning; weight loss; kaffir lime oil; edible coating

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1. Introduction

'Rongrien' rambutan (*Nephelium lappaceum* Linn. cv. Rongrien) is very well known as an economically important fruit in Thailand. However, rambutan fruits are highly susceptible to chemical coating injuries, especially to their spinterns. Any mechanical damage could accelerate spintern browning and provide a wound allowing the postharvest entry of pathogens. Pericarp browning occurs as a result of water loss from the spinterns and the skin, and the effects on the spinterns are more pronounced than those on the skin [1]. In addition, a higher density of stomata can contribute to water loss and increase susceptibility to browning. Moreover, the higher rates of browning of the spinterns could be a result of the higher activities of polyphenol oxidase (PPO) and peroxide (POD) in the spinterns than in the peel [2]. To prolong the storage life of rambutan fruit, low temperature storage (10–13 °C) and modified atmosphere packaging (MAP) with LDPE have been recommended, as these reduce weight loss and skin browning [3]. Application of a mixture of shellac and coconut oil followed by irradiation with gamma rays was also found to be effective against fruit rot, spintern browning, and weight loss [4].

In recent years, consumers have become more health and safety conscious about foods. Therefore, research has focused on environmentally friendly agents for treating food products and postharvest treatments for disease control and shelf-life extension. Among the alternative natural plant extracts, essential oils have been widely studied because of their functional properties. Typically, volatile constituents in essential oils are a mixture of terpenes, terpenoids, and other aromatic and aliphatic compounds [5] commonly used as flavorings in the food industry. These compounds also present interesting antibacterial, antifungal, and antioxidant properties [6]. However, some studies have demonstrated that the quality of essential oils depends mainly on their constituents, which are significantly influenced by the choice of extraction method [7,8].

Several studies have addressed postharvest disease control using essential oils, such as basil oil [9], cinnamon oil [10], lemongrass oil [11], and thyme oil [12]. Positive effects of essential oils on fruit quality and disease control have been reported from many studies, such as on rambutan using cinnamaldehyde and turmeric oil [13,14], on bell pepper using lemongrass oil [15], on papaya using thyme and Mexican lime oils [16], and on avocado using thyme and cinnamon oils [17,18]. However, the great number of volatile compounds in essential oils can limit their application in postharvest treatments, mainly because they affect the sensory characteristics of the coated vegetables or fruits [19,20]. Therefore, it is necessary to optimize the effective concentration of an essential oil in its application as a postharvest treatment.

To the best of our knowledge, there is little published data on the application of essential oils in rambutan fruits [13,14]. Therefore, in this study, we investigated alternative postharvest treatments for improving the shelf life of 'Rongrien' rambutan fruit using some local essential oils in Thailand.

2. Materials and Methods

2.1. Plant Material

Fruits of rambutan (*Nephelium lappaceum* Linn. cv. Rongrien) were harvested at commercial maturity (red-orange fruit with green spintern tips) in the morning (8–11 a.m.) to minimize fruit dehydration from a local orchard in Ban Nasan district, Surat Thani province, Thailand. The rambutan fruits were immediately transported to the laboratory in an air-conditioned vehicle (25 °C). Then, the fruits were selected for uniformity of size, color, and absence of defects, damage, or bruises. Destalking of fruits was carried out with sharp scissors, leaving a 2 mm pedicel. The fruits were washed with distilled water and drained for 5 min before being subjected to a coating treatment.

2.2. Essential Oil Coating Treatment

Four types of essential oil, namely, citronella (*Cymbopogon nardus* L.), clove (*Eugenia Caryophyllata*), kaffir lime (*Citrus hystrix*), and lemongrass (*Cymbopogon citratus*) oil, were tested to find an effective treatment for improving the shelf life of rambutan. The essential oils (100%) of citronella (CT), clove (CL), kaffir lime (KF), and lemongrass (LG) were purchased from the BOTANICESSENCE company, Bangkok, Thailand. For preliminary tests, the essential oils were diluted to concentrations of 0 (control), 0.02, 0.04, 0.08, and 0.16%. Then, in the second experiment, we selected the concentrations of each essential oil to be below 0.04% based on the preliminary results, so the concentrations at this stage were 0, 0.01, 0.02, and 0.03%. All dipping solutions included added tween-80 (0.02% v/v) in order to enhance both the water vapor permeability and the mechanical properties [15]. To ensure good mixing of the plant oils in water, the blends were constantly stirred for 5 min before use, as well as during fruit dipping. Fruits in each treatment were dipped into the prepared solution for 5 min and allowed to dry on a bench covered with paper towels at ambient temperature (25 ± 3 °C) for 1 h. Then, the dry fruits were placed into clamshells (each clamshell containing eight fruits, with 65 clamshells per treatment) and stored at 13 ± 3 °C, RH 80–90%. Postharvest quality assessments were conducted with five replicates during storage for 10–12 days or up to the end of shelf life.

2.3. Fruit Quality Assessment

2.3.1. Weight Loss

The weight of fruit samples was recorded before storage (day 0) and during storage at regular intervals. Then, the percentage of weight loss was calculated as $(A - B)/A \times 100$, where A is the fruit weight (g) before storage and B is the fruit weight (g) at observation time [21].

2.3.2. Evaluation of Pericarp Browning

The browning was scored separately for peel and spintern [22]. The score of peel browning is based on a 0–4 scale as follows: 0 = no browning (excellent quality), 1 = browning < 25%, 2 = browning 25–50%, 3 = browning 51–75%, and 4 = browning 76–100% of peel surface (poor quality). For spintern browning, the score was evaluated as 0 = no browning, 1 = browning < 25%, 2 = browning 25–50%, 3 = browning 51–75%, and 4 = browning 76–100% of spintern length.

2.4. Data Analysis

All experiments applied a completely randomized design, and each treatment comprised five replicates for evaluating fruit quality (eight fruits per replicate). Data were subjected to analysis of variance (ANOVA) using SPSS software.

3. Results

3.1. Effects of Citronella Oil (CT) Coating

CT coating treatments at comparatively high concentrations (0.08 and 0.16%) tended to induce weight loss of rambutan fruit, while the 0.04% CT coating treatment did not (Table 1). The CT-treated fruit had dramatically increased peel and spintern browning compared to control fruits, and higher CT concentrations caused higher browning scores. Postharvest quality was lost in only three days for 0.08% CT-treated fruits (scores of peel browning = 1.5, scores of spintern browning = 1.1), while 0.16% CT-treated fruits showed severe browning (scores of peel and spintern browning > 2) on day 3. Rambutan treated with CT at 0.04% showed the lowest scores of browning among the tested CT concentrations and could maintain acceptable fruit quality up to day 9. However, the scores of peel and spintern browning were still slightly higher than those of the control.

Table 1. Observed weight loss, peel browning and spintern browning of citronella oil (CT)-coated rambutan fruits during storage at 13 °C.

Parameters	Treatment	Storage Time			
		Day 3	Day 6	Day 9	Day 12
Weight loss (%)	Control	1.3 ± 0.1 a	2.6 ± 0.2 a	4.4 ± 0.7 a	5.9 ± 0.6 a
	CT 0.04%	1.8 ± 0.5 a	2.4 ± 0.2 a	4.1 ± 0.4 a	5.3 ± 0.1 a
	CT 0.08%	2.0 ± 0.4 a	3.8 ± 0.6 b	N/A	N/A
	CT 0.16%	1.7 ± 0.2 a	3.1 ± 0.4 ab	N/A	N/A
Peel browning (score 0–4)	Control	0.0 ± 0.0 a	0.1 ± 0.0 a	0.7 ± 0.1 a	1.0 ± 0.0 a
	CT 0.04%	1.0 ± 0.0 b	1.3 ± 0.1 b	1.7 ± 0.1 b	1.3 ± 0.1 b
	CT 0.08%	1.5 ± 0.1 c	2.3 ± 0.1 c	N/A	N/A
	CT 0.16%	2.8 ± 0.1 d	2.9 ± 0.1 d	N/A	N/A
Spintern browning (score 0–4)	Control	0.0 ± 0.0 a	0.5 ± 0.1 a	1.3 ± 0.1 a	2.3 ± 0.2 a
	CT 0.04%	0.1 ± 0.0 a	1.7 ± 0.1 b	2.3 ± 0.1 b	2.7 ± 0.1 b
	CT 0.08%	1.1 ± 0.2 b	3.1 ± 0.1 c	N/A	N/A
	CT 0.16%	2.3 ± 0.1 c	3.8 ± 0.1 d	N/A	N/A

Data are shown as mean ± S.E. Values with different letters in the same column are significantly different ($p < 0.05$) for each parameter. N/A means no sample available at the evaluation time point.

3.2. Effect of Clove Oil (CL) Coating

There was no significant effect of CL coating on the weight loss of rambutan fruit during storage at 13 °C (Table 2). However, rambutan coated with 0.16% CL showed the highest weight loss among these treatments. Moreover, fruit browning was more pronounced with CL coating at concentrations of 0.08 and 0.16%, as peel and spintern browning could be noticed on day 3 and day 6 of storage, respectively. Rapidly increased peel and spintern browning with 0.08 and 0.16% CL treatments were found on day 9 of storage (score of peel and spintern browning > 1.5). On the other hand, acceptable postharvest quality with 0.04% CL coating and for control fruits could be observed after 12 days of storage, as the browning of peel was less than 50% of the peel surface (browning score < 2). Although peel and spintern browning of 0.04% CL-treated fruits were higher than those of controls on day 9 of storage ($p < 0.05$), no statistically significant difference ($p > 0.05$) was found on day 12.

Table 2. Summary of weight loss, peel browning, and spintern browning of clove oil (CL)-coated rambutan fruits during storage at 13 °C.

Parameters	Treatment	Storage Time			
		Day 3	Day 6	Day 9	Day 12
Weight loss (%)	Control	1.3 ± 0.1 a	2.6 ± 0.2 a	4.4 ± 0.7 a	5.9 ± 0.6 a
	CL 0.04%	1.7 ± 0.1 a	3.1 ± 0.5 a	4.6 ± 0.5 a	6.4 ± 0.4 a
	CL 0.08%	2.0 ± 0.4 a	3.0 ± 0.3 a	4.3 ± 0.3 a	6.0 ± 0.5 a
	CL 0.16%	1.4 ± 0.0 a	2.7 ± 0.1 a	4.7 ± 0.2 a	7.8 ± 0.9 a
Peel browning (score 0–4)	Control	0.0 ± 0.0 a	0.1 ± 0.0 a	0.7 ± 0.1 a	1.0 ± 0.0 a
	CL 0.04%	0.0 ± 0.0 a	0.3 ± 0.1 a	1.3 ± 0.1 b	1.1 ± 0.0 a
	CL 0.08%	0.2 ± 0.1 b	0.8 ± 0.1 b	1.5 ± 0.1 b	1.4 ± 0.1 b
	CL 0.16%	0.4 ± 0.1 c	1.4 ± 0.1 c	2.0 ± 0.1 c	1.6 ± 0.1 b
Spintern browning (score 0–4)	Control	0.0 ± 0.0 a	0.5 ± 0.1 a	1.3 ± 0.1 a	2.3 ± 0.2 a
	CL 0.04%	0.0 ± 0.0 a	0.7 ± 0.1 a	1.6 ± 0.1 b	2.1 ± 0.1 a
	CL 0.08%	0.0 ± 0.0 a	1.1 ± 0.1 b	2.0 ± 0.1 c	2.7 ± 0.1 b
	CL 0.16%	0.1 ± 0.0 a	1.8 ± 0.1 c	2.8 ± 0.1 d	2.9 ± 0.1 b

Data are shown as mean ± S.E. Values with different letters in the same column are significantly different ($p < 0.05$) for each parameter.

3.3. Effect of Kaffir Lime Oil (KF) Coating

Weight loss of rambutan fruit was not significantly affected by the KF coating treatment (Table 3), but 0.02% KF coating tended to give the lowest weight loss among these treatments. Additionally, rambutan fruit treated with a lower concentration of KF tended to have a lower score of peel and spintern browning. Slight browning of peel and spintern (score < 2), could be obtained up to day 9 of storage at 13 °C for all treatments, among which the 0.02% KF-treated fruits showed the best overall appearance. Significant differences in scores of peel and spintern browning between the 0.02% KF coating and control treatments were observed on day 9 of storage.

3.4. Effect of Lemongrass Oil (LG) Coating

Although LG coating treatments (0.02–0.16%) had no effects on weight loss of rambutan fruit during storage (Table 4), these treatments rapidly induced the browning of peel and spinterns just a few hours after treating, except at 0.02% concentration. However, degrees of peel and spintern browning for the 0.02% LG-treated fruits were noticed on day 6 of storage, and these were significantly higher than for the control fruits ($p < 0.05$). Postharvest quality of 0.02% coated fruits was maintained for up to 6 days (scores of peel and spintern browning < 2), while the control fruit remained acceptable until day 9 of storage.

Based on the results, treatment with a comparatively high 0.04% concentration of essential oils could drastically affect the weight loss and pericarp browning of rambutan. However, the essential oil of kaffir at a low 0.02% concentration showed potential for prolonging the time for which the postharvest quality of rambutan fruit is retained (Figure 1).

Table 3. Summary of weight loss, peel browning, and spintern browning of kaffir lime oil (KF)-coated rambutan fruits during storage at 13 °C.

Parameters	Treatment	Storage Time		
		Day 6	Day 9	Day 12
Weight loss (%)	Control	4.1 ± 0.6 a	5.8 ± 0.6 a	7.3 ± 0.6 a
	KF 0.02%	3.3 ± 0.5 a	5.1 ± 0.6 a	7.0 ± 0.8 a
	KF 0.04%	3.6 ± 0.3 a	5.6 ± 0.4 a	7.5 ± 0.4 a
	KF 0.08%	4.1 ± 0.5 a	5.7 ± 0.6 a	7.1 ± 0.6 a
Peel browning (score 0–4)	Control	0.1 ± 0.0 a	1.0 ± 0.1 c	0.8 ± 0.1 a
	KF 0.02%	0.2 ± 0.1 ab	0.1 ± 0.1 a	0.5 ± 0.1 a
	KF 0.04%	0.4 ± 0.1 b	0.3 ± 0.1 ab	1.1 ± 0.1 b
	KF 0.08%	0.4 ± 0.1 b	0.6 ± 0.1 b	1.1 ± 0.1 b
Spintern browning (score 0–4)	Control	0.3 ± 0.1 a	1.5 ± 0.2 b	2.6 ± 0.1 ab
	KF 0.02%	0.1 ± 0.1 a	1.0 ± 0.1 a	2.2 ± 0.1 a
	KF 0.04%	0.6 ± 0.1 b	1.3 ± 0.1 ab	2.3 ± 0.2 ab
	KF 0.08%	0.6 ± 0.1 b	1.2 ± 0.1 ab	2.7 ± 0.1 b

Data are shown as mean ± S.E. Values with different letters in the same column are significantly different ($p < 0.05$) for each parameter.

Table 4. Summary of weight loss, peel browning, and spintern browning of lemongrass oil (LG)-coated rambutan fruits during storage at 13 °C.

Parameters	Treatment	Storage Time		
		Day 6	Day 9	Day 12
Weight loss (%)	Control	4.1 ± 0.6 a	5.8 ± 0.6 a	7.3 ± 0.6 a
	LG 0.02%	3.6 ± 0.2 a	5.4 ± 0.2 a	6.5 ± 0.0 a
	LG 0.04%	N/A	N/A	N/A
	LG 0.08%	N/A	N/A	N/A
Peel browning (score 0–4)	Control	0.1 ± 0.0 a	1.0 ± 0.1 a	0.8 ± 0.1 a
	LG 0.02%	1.1 ± 0.1 b	1.3 ± 0.1 b	1.3 ± 0.1 b
	LG 0.04%	N/A	N/A	N/A
	LG 0.08%	N/A	N/A	N/A
Spintern browning (score 0–4)	Control	0.3 ± 0.1 a	1.5 ± 0.2 a	2.6 ± 0.1 a
	LG 0.02%	1.0 ± 0.1 b	2.5 ± 0.1 b	2.7 ± 0.2 a
	LG 0.04%	N/A	N/A	N/A
	LG 0.08%	N/A	N/A	N/A

Data are shown as mean ± S.E. Values with different letters in the same column are significantly different ($p < 0.05$) for each parameter. N/A means no samples available at the evaluation time point.

3.5. Comparison of Selected Essential Oil Treatments

On the basis of the previous results, only low concentrations (<0.04%) of CT, CL, KF, and LG essential oils were used in the further investigation, namely, 0.01, 0.02, and 0.03% (v/v)) in the dip coating liquid. The results showed that essential oil coatings could reduce weight loss of rambutan fruits (Figure 2). The least weight loss was found with the KF (0.02%) coating treatment, which significantly differed ($p < 0.05$) from the control treatment. Regarding fruit browning, the lowest scores of peel and spintern browning were observed with 0.01% KF treatment throughout the storage time (Figures 3 and 4). In addition, fruit browning was obvious on day 4 of storage and fruit quality became poor on day 8. However, rambutan fruit treated with 0.01% KF was of acceptable quality up to day 10 of storage (Figure 5).

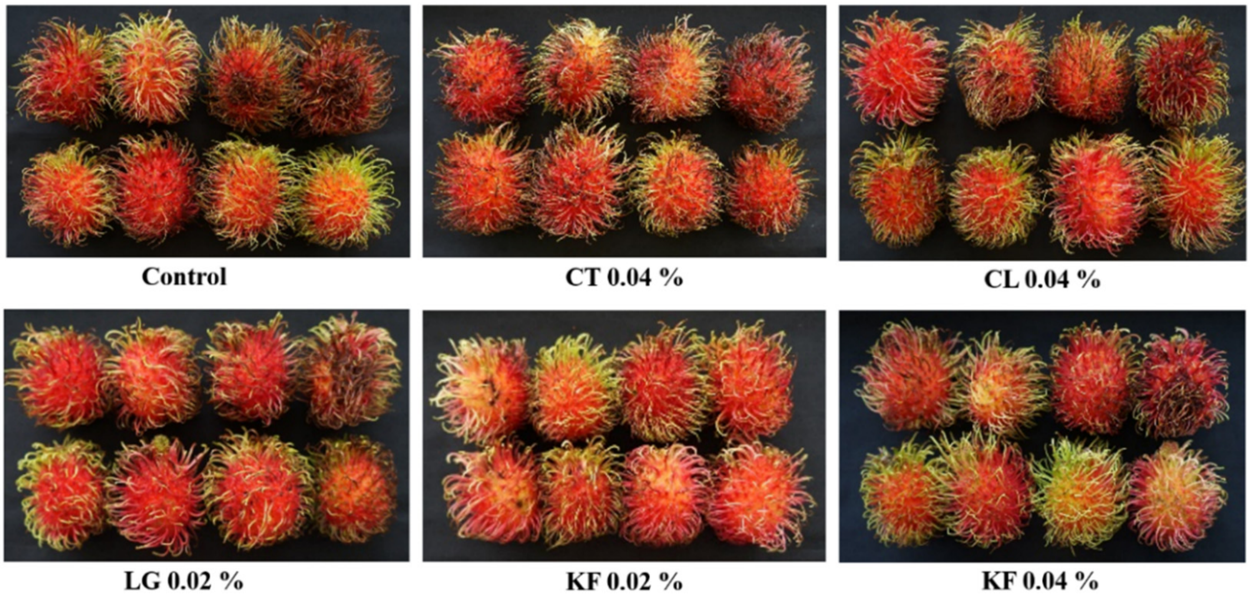

Figure 1. Overall appearance of rambutan fruits treated with various essential oils followed by storage at 13 °C for 12 days, including control fruits without actual treatment. (Control = distilled water, CT = citronella oil, CL = clove oil, LG = lemongrass oil, KF = kaffir lime oil).

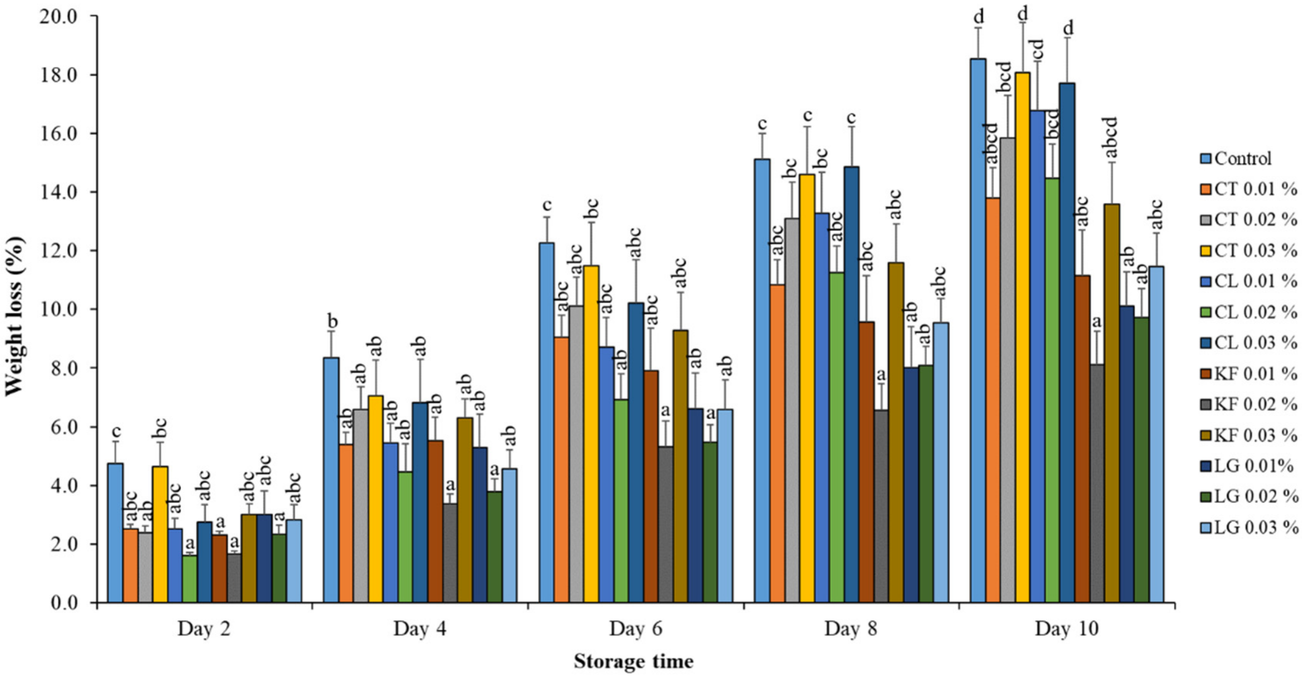

Figure 2. Weight loss of essential oil coated rambutan fruits during storage at 13 °C. Different letters indicate significant differences ($p < 0.05$) at each storage time. (Control = distilled water, CT = citronella oil, CL = clove oil, KF = kaffir lime oil, LG = lemongrass oil).

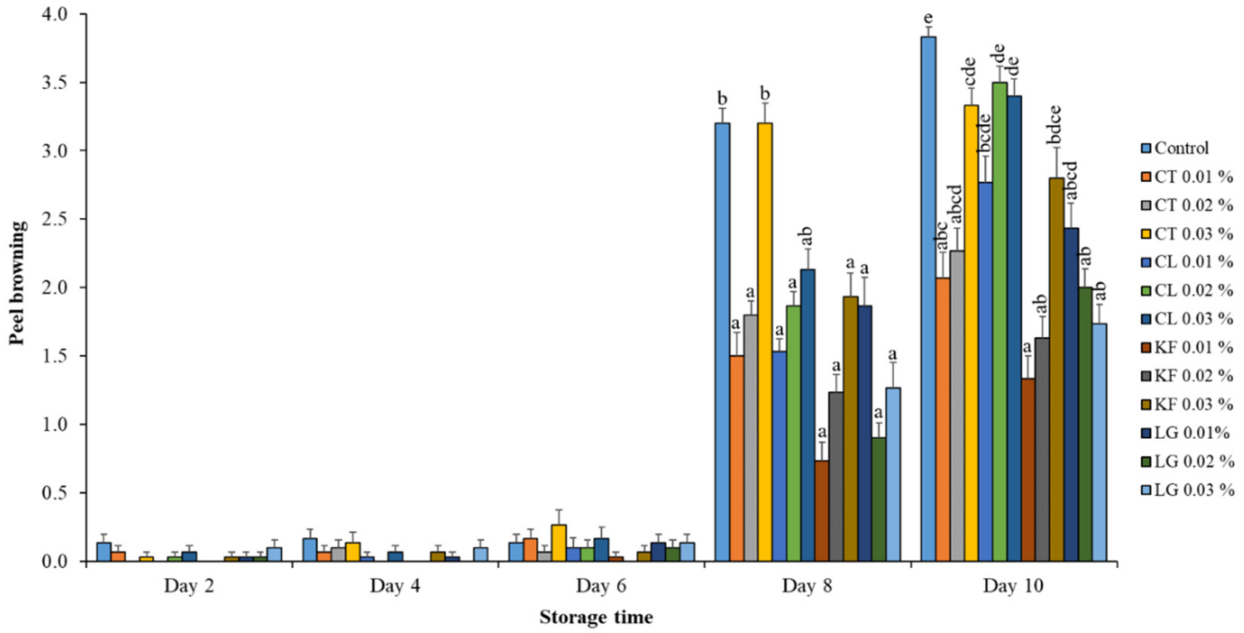

Figure 3. Score of peel browning of essential oil-coated rambutan fruits during storage at 13 °C. Different letters indicate significant differences ($p < 0.05$) at each storage time. (Control = distilled water, CT = citronella oil, CL = clove oil, KF = kaffir lime oil, LG = lemongrass oil).

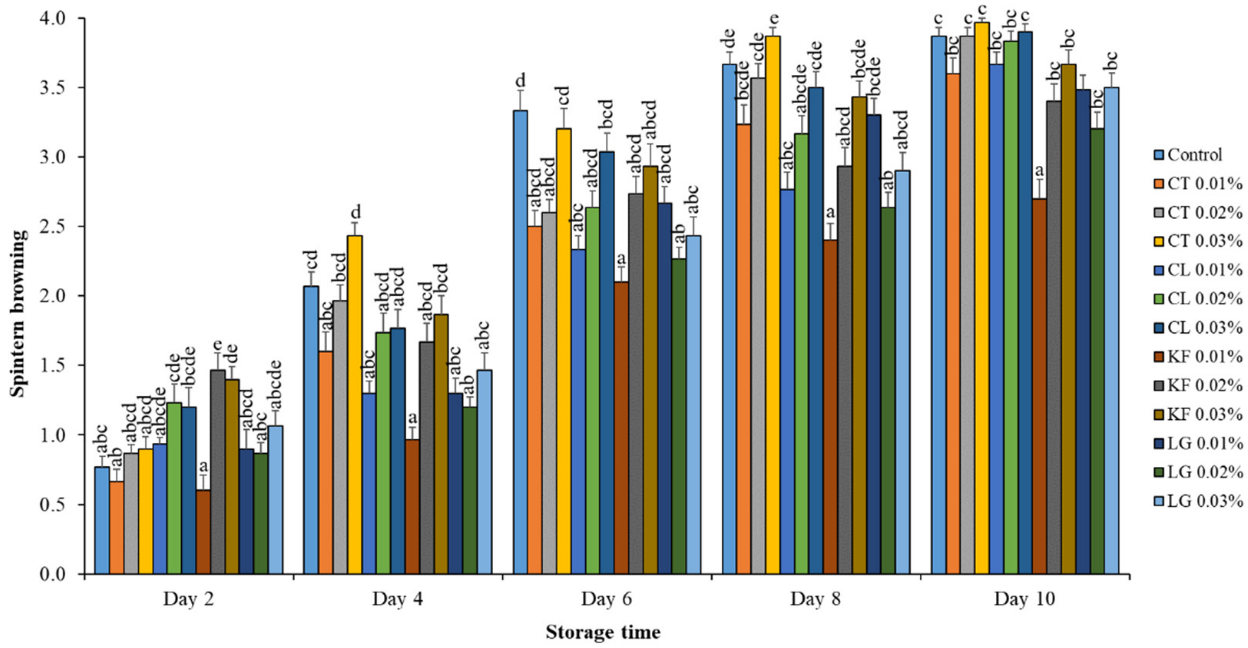

Figure 4. Score of spintern browning of essential oil-coated rambutan fruit during storage at 13 °C. Different letters indicate significant differences ($p < 0.05$) at each storage time. (Control = distilled water, CT = citronella oil, CL = clove oil, KF = kaffir lime oil, LG = lemongrass oil).

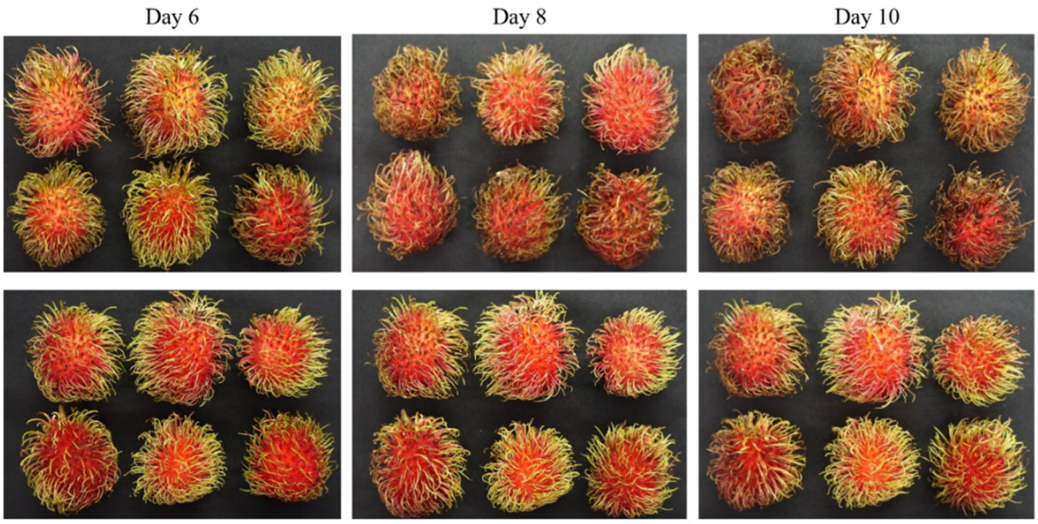

Figure 5. Overall appearance of rambutan fruits coated with kaffir lime oil (KF 0.01%) followed by storage at 13 °C for 6, 8, and 10 days compared with control fruits.

4. Discussion

According to our preliminary results, the postharvest quality of rambutan fruits was mainly dependent on pericarp browning and the degrees of peel and spintern browning. Generally, essential oils at a concentration higher than 0.04% in the dip coating liquid caused severe browning of rambutan fruit as well as higher weight loss. The phytotoxicity of high doses of essential oils affected the optical and color attributes of the product, and this has been observed in some prior studies. For example, the application of essential oils at high concentrations reduced the whiteness of fresh-cut melon after the first few hours. However, no significant differences were observed during further storage time [11].

In our study, fruit damage caused by essential oil coatings was reduced when lower concentrations were applied, and KF and LG oils showed greater potential for maintaining peel and spintern quality than the other essential oils and control. The efficiency of essential oils in preserving the postharvest quality of fruits, including the reduction of weight loss, physicochemical changes, and diseases, has been demonstrated in several studies. For instance, the application of citronella essential oil fumigation could control sprouting and improve the quality of potato tubers with respect to inhibition of weight loss, starch degradation, and reducing sugar accumulation [23]. Moreover, coating with clove oil combined with chitosan helped prolong the shelf life of minimally processed pomegranate arils by contributing to microbial inhibition, reduced weight loss, as well as the retention of physicochemical and sensory qualities. The reduction of weight loss of pomegranate arils may be due to the water vapor barrier coating reducing dehydration, this being a result of the hydrophobic essential oil in a polysaccharide-based coating [24]. The synergistic effect of essential oil-based edible coatings was also demonstrated for rambutan fruit, using a combination of chitosan and turmeric oil, and the treated fruit showed prolonged shelf life [14].

Regarding the applications of lemongrass oil, its efficiency as a coating for prolonging the shelf life of berries by inhibition of *Salmonella typhimurium* and *Escherichia coli* inoculated on the berries has been demonstrated, without adverse impacts on the flavor of the berries and their glossiness even improved. Moreover, the coatings were also effective in relation to reducing weight loss, loss of firmness, phenolic compounds, and antioxidant activity, as well as in delaying increases in total anthocyanin concentration in grape berries [25]. Furthermore, an alginate-based edible coating incorporated with 0.3% (w/v) lemongrass could extend the shelf life and maintain the quality of fresh-cut pineapple, which was related to reducing respiration rate, weight loss, total phenolic content, and yeast and mold counts. Also, this edible coating with lemongrass oil could maintain the firmness, color, sensory characteristics, and morphological properties of fresh-cut pineapple during low temperature storage [26]. In fresh-cut melon, using lemongrass with alginate in a coating resulted in reduced carbon dioxide production and oxygen consumption, which could be due to the antimicrobial effects of lemongrass and the lipophilic nature of this essential oil. As a consequence, the coating resisted gas diffusion to the fruit [11].

However, it has been reported that an edible film made of alginate–apple puree with lemongrass oil had no significant effect on the water vapor permeability of fresh-cut apple. This may be due to the main components of this essential oil, which is not lipid and mostly contains terpene-like compounds [27]. Although several studies have reported antimicrobial properties of lemongrass oil, the application of essential oils is still limited due to their high volatility, cost, and odor and flavor effects. The combination of essential oils with edible coatings may reduce their volatility and sensory impacts [19].

5. Conclusions

To conclude, our results suggest that the essential oil of kaffir lime can maintain the postharvest quality of 'Rongrien' rambutan during storage at 13 °C, mainly by reducing water loss and pericarp browning. In further investigations, we would need to improve the efficiency of this postharvest treatment by adding some edible coating materials in order to develop an effective alternative treatment for the rambutan fruit. Also, the effects of these coating solutions on fruit quality attributes, such as soluble solids content (SSC) and titratable acidity (TA), should be assessed.

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