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Research Article

Improving postharvest peel color uniformity of abiu (*Pouteria caimito*) fruit through ethephon application

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ABSTRACT

Abiu (Pouteria caimito) fruit harvested at the half-ripe stage with a predominantly green peel often exhibits delayed and non-uniform postharvest color development. Ethephon, an ethylene-releasing compound, has been widely used to promote peel color change in climacteric fruits. This study aimed to determine the most effective application method and concentration of ethephon for improving postharvest peel color uniformity in abiu fruit. The experiment was conducted from June to December 2023 using a completely randomized design with two factors: ethephon application method (dipping and soaking) and ethephon concentration (0, 100, 200, and 400 ppm). Fruits were stored at ambient temperature for 12 days. Soaking in 400 ppm ethephon was the most effective treatment, increasing the a value by 29.20% while decreasing the b* value by 4.25% and the hue angle by 3.00% compared with the control after 12 days of storage. This treatment also promoted chlorophyll degradation and increased carotenoid and anthocyanin contents. Therefore, soaking abiu fruit in 400 ppm ethephon is recommended as an effective postharvest treatment to improve peel color uniformity.*

Keywords: chromameter; degreening; ethylene; pigmentation; postharvest

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INTRODUCTION

Abiu (*Pouteria caimito*) is a tropical fruit with considerable commercial value and has long been recognized in Brazilian folk medicine for its medicinal properties (Zhao et al., 2024). Mature fruits are generally oval to round in shape, weighing approximately 175-195 g, with horizontal and vertical diameters of 10-11 cm and 8.5-9.0 cm, respectively (Thamara et al., 2024). Bioactive compounds, particularly 5-hydroxymethylfurfural, have been identified in the peel of ripe fruit, immature fruit, and ripe pulp at concentrations of 6.43%, 2.82%, and 11.81%, respectively. These compounds have been reported to possess anticancer activity (Arif et al., 2021).

Fruit color is one of the primary quality attributes influencing both consumer preference and market acceptance (Liu et al., 2021). In addition to external appearance, harvest maturity is a critical factor determining the postharvest behavior of climacteric fruits such as abiu. Fully ripe fruits harvested with completely yellow peel exhibit a sweet flavor, high total soluble solids, and low titratable acidity. However, these fruits also exhibit high respiration rates during storage, resulting in a relatively short shelf life of

approximately six days. Although the incidence of shriveling is relatively low (Arif et al., 2022), fully ripe fruit is highly susceptible to postharvest browning (Arif et al., 2023). Conversely, fruits harvested at the half-ripe stage, characterized by predominantly green peel color, possess a desirable sweet taste and a longer storage life of approximately eight days with a relatively low browning index (Habibi et al., 2025).

Ethylene is a naturally occurring plant hormone that plays an essential role throughout the fruit ripening process (Chen et al., 2022). Commercial degreening using ethylene gas is relatively expensive; therefore, synthetic plant growth regulators containing ethephon (2-chloroethylphosphonic acid; $C_2H_6ClO_3P$) are widely used as practical alternatives. Ethephon gradually releases ethylene after application and has been extensively utilized to accelerate peel color development during postharvest ripening (Wisutiamonkul et al., 2017). Degreening treatments using ethephon have been reported to be safe for citrus fruit intended for human consumption (Arzam et al., 2021). Furthermore, ethephon-induced degreening has been extensively investigated in citrus, lemon, banana, and mango. For example, Manigo and Antibo (2022) reported that dipping 'Carabao' mangoes in ethephon solution (1 mL L^{-1}, equivalent to approximately 482 ppm) for 2-3 seconds significantly accelerated peel yellowing, with visible color changes occurring after only two days of storage.

Degreening treatment markedly improves peel color uniformity, thereby increasing consumer acceptance by approximately 50-70% (Morales et al., 2019). Nevertheless, its effectiveness is strongly influenced by harvest maturity. Fruits harvested at an immature stage generally respond slowly to ethylene, whereas overripe fruits tend to soften rapidly and develop postharvest browning more readily (Arif et al., 2022). Half-ripe abiu fruit exhibits delayed peel color transition from green to yellow, and the persistence of green peel is frequently associated with increased shriveling during storage (Habibi et al., 2025). Previous studies have shown that the effectiveness of degreening is affected by both the method of ethephon application and its concentration (Arzam et al., 2021). Therefore, this study aimed to determine the most effective application method and concentration of ethephon for improving postharvest peel color uniformity in abiu fruit.

MATERIALS AND METHODS

The experiment was conducted from June to December 2023. Abiu (*Pouteria caimito*) fruits were harvested from a commercial orchard at approximately 200 m above sea level in Babakan Lebak, Balumbang Jaya Village, West Bogor District, Bogor City, Indonesia. Postharvest storage and laboratory analyses were carried out at the Postharvest and Biomass Laboratory, Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University. Fruits were harvested at the half-ripe stage (60-62 days after anthesis) during the early morning and transported to the laboratory within approximately 20 min after harvest to minimize field heat and mechanical damage.

The harvested fruits were sorted based on weight (150 ± 25 g), peel color (approximately 80% green and 20% yellow), and the absence of physical defects. Commercial ethephon 480 SL was diluted to the appropriate concentrations according to the treatments. The experiment was arranged in a completely randomized design (CRD) consisting of two factors. The first factor was the method of ethephon application, comprising dipping and soaking treatments, whereas the second factor was ethephon concentration, consisting of four levels: 0 ppm (control), 100 ppm, 200 ppm, and 400 ppm. Fruits assigned to the dipping treatment were immersed in the ethephon solution for 1 s, whereas those assigned to the soaking treatment were immersed for 60 s. All treated fruits were subsequently stored at ambient temperature (26 ± 2 °C) for 12 days. Peel color was evaluated daily throughout the storage period, whereas pigment contents were determined on Days 0, 6, and 12. The experiment consisted of three replications, resulting in 24 experimental units. Each experimental unit consisted of 15 fruits, for a total of 360.

Peel color was evaluated according to the method described by Kim et al., (2022) using a chromameter. The CIE L*, a*, and b* color coordinates were measured with a chromameter calibrated using a standard white plate (L* = 97.79, a* = -0.38, and b* =

2.05), with measurements performed on 15 fruits per treatment. The hue angle (h°) was subsequently calculated using the following equation:

$$^{o}\mathrm{H} = \arctan\left(\frac{b^*}{a^*}\right)$$

The pigment content of abiu peel was determined using a spectrophotometer. Peel samples weighing 0.1000–0.1500 g were extracted with 2 mL of acetone and centrifuged at 14,000 rpm for 10 s to obtain the supernatant. Absorbance was measured at 470, 537, 647, and 663 nm. The absorbance values were used to calculate chlorophyll a, chlorophyll b, carotenoid, and anthocyanin contents according to the equations proposed by Sims and Gamon (2002). Pigment Equation (PE):

$$\text{Chlorophyll a } (\mu\text{mol. mL}^{-1}) = 0.01373\ \text{A663} - 0.000897\ \text{A537} - 0.003046\ \text{A647}$$

$$\text{Chlorophyll b } (\mu\text{mol. mL}^{-1}) = 0.02405\ \text{A647} - 0.004305\ \text{A537} - 0.005507\ \text{A663}$$

$$\text{Anthocyanin } (\mu\text{mol. mL}^{-1}) = 0.08173\ \text{A537} - 0.00697\ \text{A647} - 0.002228\ \text{A663}$$

$$\text{Carotenoids } (\mu\text{mol. mL}^{-1}) = \frac{(\text{A470} - (17.1\ \text{x (chl a + chl b)} - 9.479\ \text{x anthocyanin}))}{119.26}$$

The calculated pigment contents were subsequently converted to mg g^{-1} using the method described by Yudiansyah et al. (2024) :

$$\text{Pigment } (\text{mg. g}^{-1}) = \frac{\text{PE } \mu\text{mol. mL}^{-1}\ \text{x MW g. mol}^{-1}\ \text{x } 0.001\ \text{mg. mol. } \mu\text{mol}^{-1}\ .\ \text{g}^{-1}}{\text{sample weight (g)}}$$

Anthocyanin content was expressed as µmol g^{-1} using the following equation :

$$\text{Anthocyanin } (\mu\text{mol. ml}^{-1}) = \frac{(\text{PE } \mu\text{mol. mL}^{-1}\ \text{x } 5\ \text{mL})}{\text{sample weight (g)}}$$

Description : The molecular weights (MW) used for unit conversion from grams to moles were 893.5 g mol^{-1} for chlorophyll a, 907.5 g mol^{-1} for chlorophyll b, and 550 g mol^{-1} for carotenoid. A conversion factor of 0.001 was applied to convert the pigment content from micromoles to milligrams per gram (mg g^{-1}).

The data were analyzed using Microsoft Excel Office 2019 and IBM SPSS Statistics version 25. Analysis of variance (ANOVA) was performed at the 5% significance level. When significant treatment effects were detected, means were compared using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

RESULTS AND DISCUSSION

Peel Color

Lightness (L*)

The L* value represents fruit peel lightness, ranging from 0 (black) to 100 (white). In the present study, the L* value of abiu peel increased progressively during storage across all treatments, indicating that the peel became brighter as ripening progressed. Similar findings were reported by Sabuz et al. (2019), who observed that ethephon-treated mangoes developed a more rapid and uniform yellow peel color than untreated fruit, which remained green or pale yellow. Ethephon stimulates pigment transformation, leading to increased peel brightness during ripening.

The soaking application resulted in higher L* values than the dipping application on Day 12 of storage, with mean values of 66.09 and 65.13, respectively (Figure 1A). These results suggest that soaking enhanced the absorption of ethephon, thereby increasing peel lightness. Likewise, fruits treated with 100, 200, and 400 ppm ethephon exhibited higher L* values than the control treatment. On Day 12, the L* values reached 66.23, 65.85, and 67.20 for the 100, 200, and 400 ppm treatments, respectively, compared with 63.17 in the untreated control (Figure 1B). Similar results were reported by Darmawati et al. (2018),

who demonstrated that ethephon accelerated peel color development, enabling fruits to reach market maturity at the scheduled harvest time.

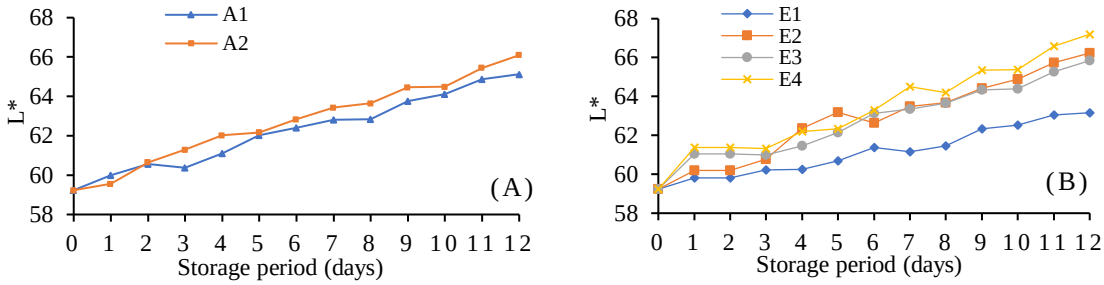


Figure 1. Changes in the L* value of abiu peel as affected by (A) the ethephon application method and (B) ethephon concentration. A1 = dipping; A2 = soaking; E1 = 0 ppm (control); E2 = 100 ppm; E3 = 200 ppm; and E4 = 400 ppm.

A significant interaction between the application method and ethephon concentration was observed for the L* value on Day 12 of storage. Fruits soaked in 100 ppm ethephon exhibited the highest L* value (68.18), whereas the control treatment produced the lowest value (63.16) (Table 1). Previous studies on mango and citrus fruits have likewise shown that ethephon application significantly enhances peel brightness during storage by accelerating chlorophyll degradation and promoting the visual dominance of lighter-colored pigments (Sabuz et al., 2019; Putranto et al., 2024).

Redness (a*) and Yellowness (b*)

The a* coordinate represents the green (negative values) to red (positive values) color axis, whereas the b* coordinate represents the blue (negative values) to yellow (positive values) color axis. On Day 12 of storage, fruits subjected to the soaking treatment exhibited higher a* values than those receiving the dipping treatment, with mean values of -13.40 and -14.54, respectively (Figure 2A). In contrast, the soaking treatment produced lower b* values than the dipping treatment, averaging 72.68 and 73.44, respectively (Figure 2C).

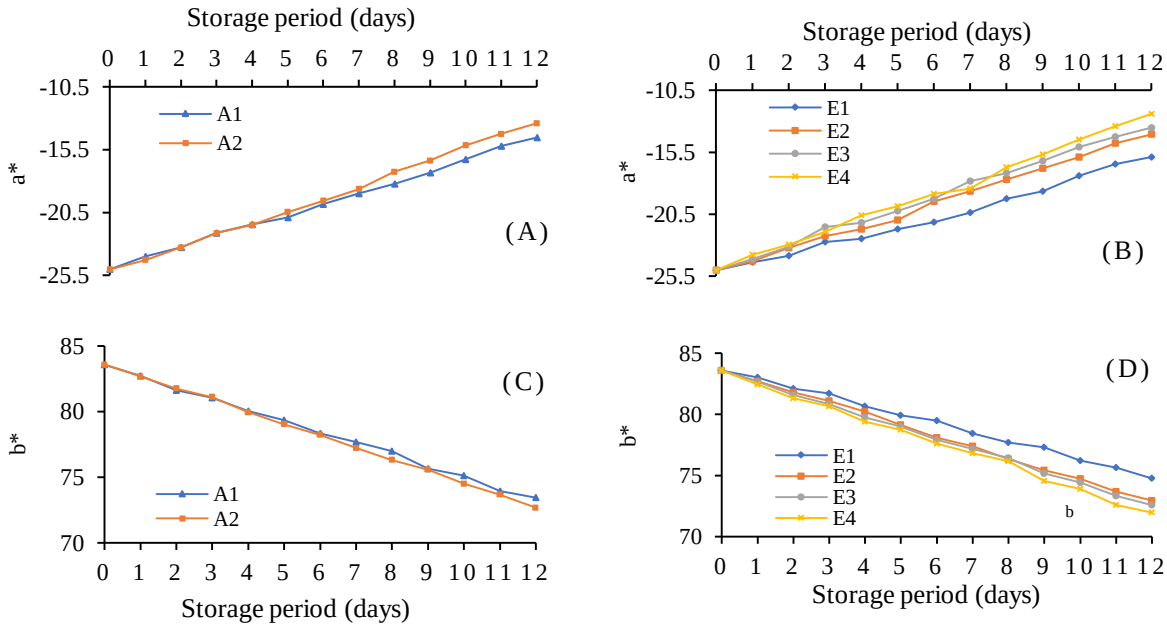


Figure 2. Changes in the a* and b* values of abiu peel as affected by (A and C) the ethephon application method and (B and D) ethephon concentration. A1 = dipping; A2 = soaking; E1 = 0 ppm (control); E2 = 100 ppm; E3 = 200 ppm; and E4 = 400 ppm.

Increasing ethephon concentration progressively increased the a* value while decreasing the b* value. On Day 12, fruits treated with 100, 200, and 400 ppm ethephon exhibited a* values of -14.07, -13.52, and -12.41, respectively, compared with -15.89 in the control treatment (Figure 2B). Likewise, the corresponding b* values decreased to 72.96, 72.58, and 71.96, whereas the untreated control remained at 74.76 (Figure 2D). A significant interaction between the application method and ethephon concentration was also detected for both a* and b* values on Day 12 of storage. Fruits soaked in 400 ppm ethephon exhibited the highest a* value (-11.25), whereas the control treatment showed the lowest value (-15.89). Conversely, the lowest b* value (71.58) was obtained from fruits soaked in 400 ppm ethephon, while the control treatment exhibited the highest value (74.76) (Table 1). Relative to the control, this treatment increased the a* value by 29.20% and reduced the b* value by 4.25%, indicating a more uniform peel color. Similar observations were reported by Putranto et al. (2024), who demonstrated that increasing ethephon concentration significantly accelerated the transition of lemon peel color from green to yellow.

Throughout storage, the a* value gradually increased, whereas the b* value declined across all treatments. The increase in a* toward zero and the concurrent reduction in b* indicate the progression of peel color from green to yellow. These changes suggest that ethephon effectively accelerated peel color development compared with the untreated control. Yellow coloration results primarily from carotenoid accumulation accompanied by chlorophyll degradation induced by ethephon (Putranto et al., 2024). In addition, ethephon has been reported to stimulate anthocyanin biosynthesis, which contributes to red pigmentation in fruit peel. Wan et al. (2025) reported that spraying grape berries with 300 mg L^{-1} ethephon significantly increased total anthocyanin accumulation in the pericarp compared with untreated fruit. In the present study, however, the increase in a* was not intended to indicate red coloration but rather to serve as a quantitative indicator of chlorophyll degradation and the transition from green to yellow, which is the commercially desirable peel color in abiu fruit.

Hue Angle (h°)

The hue angle (h°) represents the dominant color of an object within a 360° color space. A hue angle of 0° corresponds to the positive a* axis (red), 90° to the positive b* axis (yellow), 180° to the negative a* axis (green), and 270° to the negative b* axis (blue). Therefore, the hue angle is widely used to describe the dominant peel color during fruit ripening, particularly the transition from green to yellow (Ramadhani et al., 2015).

On Day 12 of storage, fruits treated by soaking exhibited a lower hue angle than those treated by dipping, with values of 100.42° and 101.19°, respectively (Figure 3A). Similarly, increasing ethephon concentration progressively reduced the hue angle. Fruits treated with 100, 200, and 400 ppm ethephon recorded hue angles of 100.91°, 100.54°, and 99.78°, respectively, whereas the control treatment remained at 102.00° (Figure 3B).

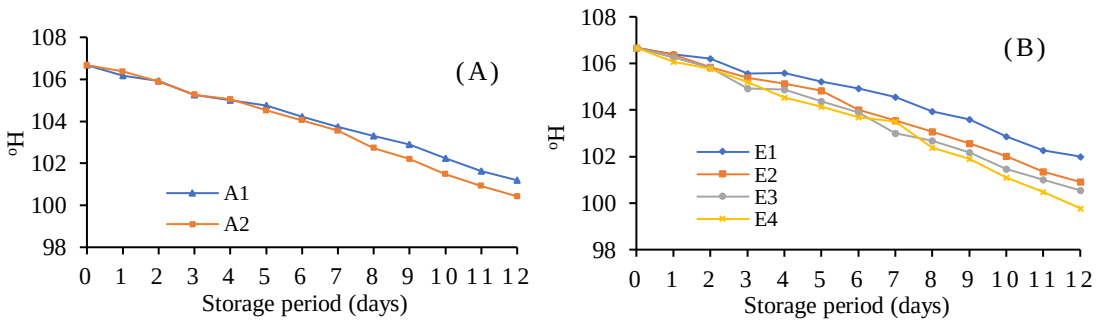


Figure 3. Changes in the hue angle (h°) of abiu peel as affected by (A) the ethephon application method and (B) ethephon concentration. A1 = dipping; A2 = soaking; E1 = 0 ppm (control); E2 = 100 ppm; E3 = 200 ppm; and E4 = 400 ppm.

The reduction in hue angle indicates the progressive transition of peel color from green to yellow. This trend is consistent with the decrease in b* values, which reflects the development of yellow pigmentation, while the a* values remained negative but gradually approached zero. These results suggest that chlorophyll degradation had not yet been completed, and that a portion of the green pigmentation remained in the peel. Approximately 10.42% of the green color remained in fruits soaked in 400 ppm ethephon, supporting the findings of Habibi et al. (2025), who reported that the persistence of green peel color in abiu fruit was associated with increased shriveling during storage. As ripening progressed, continued chlorophyll degradation resulted in a greater predominance of yellow pigmentation, indicating that the fruit had reached a more advanced stage of ripeness suitable for consumption (Mulyawanti et al., 2020).

Treatments	Storage Period (days)			Treatments	Storage Period (days)		
	0	6	12		0	6	12
A1E1				A2E1			
A1E2				A2E2			
A1E3				A2E3			
A1E4				A2E4			

Figure 4. Visual appearance of peel color changes in abiu fruit during storage. A1E1 = dipping in 0 ppm ethephon, A2E1 = soaking in 0 ppm ethephon, A1E2 = dipping in 100 ppm ethephon, A2E2 = soaking in 100 ppm ethephon, A1E3 = dipping in 200 ppm ethephon, A2E3 = soaking in 200 ppm ethephon, A1E4 = dipping in 400 ppm ethephon, and A2E4 = soaking in 400 ppm ethephon.

Table 1. Interaction between the ethephon application method and ethephon concentration on Day 12 of storage.

Treatments	L*	a*	b*	^{0}H
A1E1	63.03a	-15.89a	74.76 c	102.00e
A1E2	64.28ab	-14.56b	73.57b	101.19d
A1E3	65.25bc	-14.14b	73.11ab	100.95cd
A1E4	67.94de	-13.57bc	72.35a	100.62bc
A2E1	63.30a	-15.89a	74.76c	102.00e
A2E2	**68.18e**	-13.57bc	72.35a	100.62bc
A2E3	66.44cd	-12.89c	72.05a	100.14b
A2E4	66.46cd	**-11.25d**	**71.58a**	**98.93a**

Note: Means followed by the same letter within the same column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level. A1E1 = dipping in 0 ppm ethephon, A2E1 = soaking in 0 ppm ethephon, A1E2 = dipping in 100 ppm ethephon, A2E2 = soaking in 100 ppm ethephon, A1E3 = dipping in 200 ppm ethephon, A2E3 = soaking in 200 ppm ethephon, A1E4 = dipping in 400 ppm ethephon, and A2E4 = soaking in 400 ppm ethephon.

Application of 400 ppm ethephon accelerated the transition of abiu peel color from green to yellow, as indicated by a decrease in hue angle from 106.67° before storage to 99.78° after 12 days of storage. A comparable trend has been reported in 'Prata' banana, in which the hue angle declined from approximately 105-110° before storage to 75-85°

after 12 days as the peel changed from green to yellow (Facundo et al., 2015). The visual changes in peel color throughout storage are presented in Figure 4.

A significant interaction between the ethephon application method and concentration was observed for the hue angle on Day 12 of storage. Fruits soaked in 400 ppm ethephon exhibited the lowest hue angle (98.93°), whereas the highest value (102.00°) was recorded in the untreated control (Table 1). Compared with the control, this treatment reduced the hue angle by 3.00%, indicating a more uniform peel color. Similar findings were reported by Le and Pham (2018), who demonstrated that soaking carambola fruit in 15 mL L^{-1} ethephon accelerated and synchronized fruit ripening within five days of storage.

Peel Pigment Content

The soaking application resulted in a higher chlorophyll a content than the dipping application on Day 12 of storage, with values of 0.062 and 0.052 mg g^{-1}, respectively (Figure 5A). Among the ethephon concentrations evaluated, 400 ppm produced the lowest chlorophyll a and chlorophyll b contents. On Day 12, chlorophyll a content declined to 0.034 mg g^{-1} under the 400 ppm treatment, significantly lower than the control (0.092 mg g^{-1}). Likewise, chlorophyll b content decreased to 0.008 mg g^{-1} under the 400 ppm treatment, compared with 0.022 mg g^{-1} in the control (Figure 5B). Ethephon acts as an ethylene-releasing compound that stimulates chlorophyll-degrading enzyme activity during postharvest ripening, thereby accelerating chlorophyll degradation and producing a brighter, more uniform peel color (Zhang et al., 2019; Gautama et al., 2019). However, no significant interaction between the application method and ethephon concentration was observed for either chlorophyll a or chlorophyll b on Day 12 of storage.

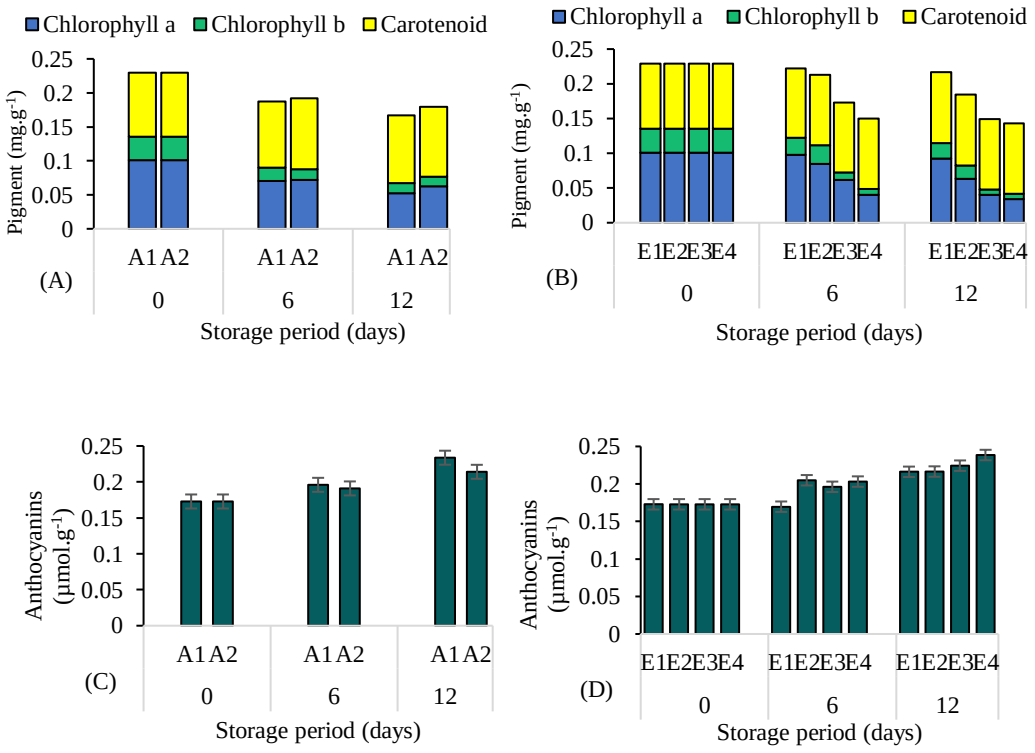


Figure 5. Pigment contents of abiu peel as affected by (A and C) the ethephon application method and (B and D) ethephon concentration. A1 = dipping; A2 = soaking; E1 = 0 ppm (control); E2 = 100 ppm; E3 = 200 ppm; and E4 = 400 ppm.

Differences in ethephon concentration did not significantly affect carotenoid content in abiu peel. Nevertheless, carotenoid content generally increased throughout storage in all treatments, whereas chlorophyll content progressively declined. The reduction in chlorophyll is attributed to the activity of chlorophyll-degrading enzymes, including chlorophyllase, chlorophyll oxidase, and peroxidase (Sumiasih et al., 2022). Similar pigment changes have been reported in Siam citrus, where peel color changes from green

to yellow or orange are associated with chlorophyll degradation accompanied by carotenoid accumulation (Hasimi et al., 2016).

The dipping application produced a higher anthocyanin content than the soaking application on Day 12, with values of 0.234 and 0.214 μmol g^{-1}, respectively (Figure 5C). The highest anthocyanin content was obtained with 400 ppm ethephon (0.24 μmol g^{-1}), which differed significantly from both the control and the 100 ppm treatment, each of which contained 0.22 μmol g^{-1} (Figure 5D). These findings are consistent with those of Chen et al. (2022), who reported that ethephon treatment significantly enhanced anthocyanin accumulation in mango fruit compared with untreated fruit. However, no significant interaction between the application method and ethephon concentration was detected for anthocyanin content.

Anthocyanins and carotenoids are the principal pigments responsible for fruit color development during ripening, producing yellow, red, or, in some cases, maintaining green coloration (Chen et al., 2022). In the present study, carotenoid content was consistently higher than anthocyanin content, explaining why yellow was the predominant peel color of abiu fruit rather than red, purple, or blue. Similar observations were reported by Ranganath et al. (2018), who found that carotenoids accumulated to a greater extent than anthocyanins during the ripening of yellow mango cultivars. In contrast, Khairi et al. (2023) reported that ethephon treatment maintained green coloration during the ripening of the NOR tomato line, indicating that the response to ethephon may vary among fruit species and genotypes.

CONCLUSIONS

Soaking abiu fruit in 400 ppm ethephon was the most effective treatment for improving postharvest peel color uniformity. Compared with the untreated control, this treatment increased the a* value by 29.20%, reduced the b* value by 4.25%, and decreased the hue angle by 3.00% after 12 days of storage. In addition, the treatment promoted chlorophyll degradation, as indicated by lower chlorophyll a and chlorophyll b contents, while enhancing carotenoid and anthocyanin accumulation. Therefore, soaking abiu fruit in 400 ppm ethephon is recommended as an effective postharvest treatment to improve peel color uniformity.

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