ADVANCES IN AGRICULTURAL AND FOOD RESEARCH JOURNAL

MALAYSIAN SOCIETY OF AGRICULTURAL AND FOOD ENGINEERS

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Original Research Article

Comparative Analysis of Ripening Behaviour in Mangoes Induced by Different Ethephon-Based Treatments

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Abstract: Ethephon, an ethylene-releasing compound, modulates the ripening process in fruits. This study aimed to analyse and compare the ripening behaviour in mangoes induced by different ethephon treatments, considering factors such as colour changes, physiological loss in mass (M_{PL}), total soluble solids (TSS), and ethylene gas release. The experimental design involved the controlled application of three different ethephon-based treatments, which consisted of control (natural ripening), ethephon dip treatment, and ethephon powder treatment at 1000 ppm on separate sets of mangoes, and the ripening process of mangoes was monitored over six days. The results indicated that mango fruits dipped in ethephon solution exhibited a rapid ripening, while those treated with ethephon powder ripened more slowly. Natural ripening mangoes experience the slowest ripening process among the treatments. Observable changes included a slight shift of colour from green to yellowish-red. Mangoes treated with ethephon solution showed the highest M_{PL} and TSS compared to other treatments. Ethylene gas measurements confirmed that ethephon treatments effectively stimulated ethylene production, with the dipping treatment demonstrating the most significant effect. These findings emphasise the potential of ethephon as a valuable asset for promoting consistent ripening in mangoes and improving fruit quality.

Keywords: Ethephon; Mango; Fruit Ripening; Ethylene Gas Release

Received: 24th April 2025

Accepted: 27th February 2026

Available Online: 5th March 2026

Published: 30th June 2026

Citation: Peh, Y-M., Lee, B-B., Ma'Radzi, A. H., *et al*. Comparative analysis of ripening behaviour in mangoes induced by different ethephon-based treatments. *Adv Agri Food Res J* 2026; 7(1): a0000600. https://doi.org/10.36877/aafrj.a0000600

1. Introduction

Ripening is a natural process in which fruits undergo changes in their physical attributes and chemical composition, rendering them appealing, palatable, and suitable for consumer consumption (Bouzayen *et al.*, 2010; Islam *et al.*, 2018). These changes involve various processes such as the breakdown of chlorophyll, synthesis of carotenoids, conversion of starch into sugars, degradation of cell walls, the transformation of organic acids into amino acids, resulting in the accumulation of soluble sugars, alteration of colour from green to yellow, softening of texture, and development of flavour and aroma (Zhang *et al.*, 2022; Abhishek *et al.*, 2016; Orisa *et al.*, 2020).

Mango (*Mangifera indica* L.), a widely consumed tropical fruit with significant nutritional value and commercial importance globally, is classified as a climacteric fruit and is typically harvested when it reaches the pre-climacteric mature green stage (Zhang *et al.*, 2017). Natural ripening poses challenges in the commercial mango trade due to its time-consuming nature and the potential for uneven ripening levels. Premature ripening before distribution can result in overripening during transit, leading to significant economic losses. Hence, induced ripening, facilitated by compounds like ethephon, ensures timely ripening and meets consumer demands in the mango trade (Maduwanthi & Marapana, 2021; Sabuz *et al.*, 2019).

Ethephon (2-chloroethyl phosphonic acid) is a commonly used chemical for commercial fruit ripening. It acts as an ethylene-releasing compound, initiating and hastening ripening in climacteric fruits like mangoes. Ethephon breaks down upon application, releasing ethylene, which triggers ripening. Its stability in aqueous solution is maintained below pH 3.5, beyond which hydrolysis occurs, releasing ethylene, chloride, and phosphate ions (Kaur, 2017; Sabuz *et al.*, 2019). Studies suggest that dipping fruits in diluted ethephon solution or treating them with ethephon at 1000 ppm concentration can achieve early, uniform ripening and desirable colour development and ensure good fruit quality (Gurjar *et al.*, 2017; Sabuz *et al.*, 2019; Doke *et al.*, 2018).

This study analyses and compares the ripening behaviour in mangoes induced by different ethephon-based treatments. Specifically, this study investigates three ways to ripen mango: a control trial representing natural ripening, an ethephon dip treatment, and an ethephon powder treatment. By systematically evaluating various ripening parameters, including colour changes, mass loss, total soluble solids, and the released ethylene gas concentration, this research aims to elucidate the effectiveness of different ethephon-based treatments for mango ripening.

2. Materials and Methods

2.1. Fruit Samples

Mangoes (Apple mango, MA 194) at the mature green stage were harvested from an orchard in Jerlun, Kedah, Malaysia. Harvested mangoes were transported to the laboratory within 2 h to minimise pre-harvest variability. Only mangoes with uniform maturity, size, and colour were selected, washed, dried at room temperature, and used for further experiments. For each treatment group, three mangoes were used as biological replicates to ensure consistency and reliability of the experimental results.

2.2. Chemicals

Ethephon 52% S.L. and ethephon powder were purchased from the local market in Malaysia, while sodium hydroxide was purchased from Merck, Germany. All chemicals and reagents used were analytical grade.

2.3. Treatments

Mangoes were divided into three groups: control (representing natural ripening), ethephon dip treatment, and ethephon powder treatment (Figure 1). Two groups of mangoes were immersed in 0 (water as control) and 1000 ppm of ethephon solution for 1 min, respectively (Lacap *et al.*, 2021; Manigo & Antibo, 2022). After that, the fruits were placed in a 7 L desiccator at 25 °C and 52.9% relative humidity for 6 days. On the other hand, 1g of ethephon powder was dissolved in 100 mL of distilled water, and the solution was placed opposite the fruits in the desiccator for the ethephon powder treatment.

Figure 1. Schematic diagram for different treatment conditions: (a) Control (Natural Ripening), (b) Ethephon Dip Treatment, and (c) Ethephon Powder Treatment.

2.4. Determination of Ripening Parameters

2.4.1. Fruit skin colour

Skin colour measurements were taken at the stem end, equatorial region, and blossom end on both sides of each fruit, and the average value was calculated (Jaman *et al.*, 2022). Each mango was labelled and photographed consistently on the same side throughout the study. Colour parameters, including L^* (lightness), a^* (green-red chromaticity), b^* (blue-yellow chromaticity), and hue angle (h^*) were quantified using image analysis software (Image J, USA) (Annisa *et al.*, 2023). Hue angle (h^*) was calculated using the Equation 1;

$$h^* = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (1)$$

where the hue angle indicates the perceived colour on a 360° colour wheel, with specific ranges representing different colours.

2.4.2. Physiological loss in mass

Changes in physiological loss in mass (M_{PL}) were recorded before and after the ripening period for both control and treated fruits. M_{PL} (%) was calculated using Equation 2:

$$M_{PL} = \frac{M_i - M_F}{M_i} \times 100\ \% \quad (2)$$

where M_i is the initial mass of the mango sample (g), and M_F is the final mass of the mango sample (g).

2.4.3. Total soluble solids

The total soluble solid (TSS) in the extracted juice of mango samples was measured by a pocket refractometer (Atago, Japan) with a range of 0 to 32 °Brix. A drop of pulp solution was placed on its prism, and a direct reading was recorded. The results were expressed as °Brix.

2.4.4. Ethylene gas release

The release of ethylene gas from the fruits was studied in desiccators at room temperature. The treated mangoes were placed in the desiccators for six days. The concentration of ethylene gas released from the fruits was measured using a portable gas detector (PG 610, Henan Inte Electrical Equipment Co., China).

2.5. Statistical Analysis

Statistical analyses were performed using Microsoft Excel (Microsoft, USA) and Minitab (Version 17; StataCorp LLC, TX, USA). One-way analysis (ANOVA) was used to determine significant differences among treatment groups, followed by a two-sample t-test to compare means between selected pairs of treatment groups. All analyses were performed with three biological replicates (n=3) per treatment group. A significant level of p<0.05 was used for all statistical tests.

3. Results and Discussions

3.1. Fruit Skin Colour

Table 1 presents the effects of different ripening treatments on the skin colour of mangoes, measured at Day 0 and Day 6, using colour parameters L^*, a^*, b^* and h^*. On Day 0, all treatments exhibited similar values across all colour parameters, indicating a uniform starting point for the fruits. The L^* values ranged narrowly from 40.33 to 41.5, while the a^* values were all negative (ranging from -4.90 to -4.37), indicating the presence of green tones. The b^* values, reflecting yellowness, were between 13.04 and 13.35, and the hue angle (h^*)

values, representing the overall colour tone, varied slightly but showed no statistically significant differences.

By Day 6, the skin colour of mangoes had transformed from green to slightly yellowish-red, with all *L**, *a** and *b** colour coordinates increasing (Figure 2). This change was attributed to the rapid degradation of chlorophyll, leading to the disappearance of the green pigment and the concurrent development of carotenoids in the skin (Nambi *et al.*, 2016; Kaur, 2017; Ho *et al.*, 2016). The most notable change was in the *h** values, which decreased significantly across treatments ($p \leq 0.05$), suggesting a consistent shift in the hue angle of mango peel colour as ripening progresses. This transition reflects the natural colour transformation in mangoes, with green hues gradually fading to yellow and orange tones (Ruslan & Roslan, 2016).

Table 1. Effect of treatment method on fruit skin colour in mangoes

Treatments	Day 0				Day 6			
	L*	a*	b*	h*	L*	a*	b*	h*
Control (Natural Ripening)	40.33 ± 3.18	-4.90 ± 0.40	13.35 ± 0.32	110.17 ± 1.86^{p}	40.74 ± 3.26	-4.49 ± 0.46	14.01 ± 0.28	107.77 ± 1.97^{p}
Ethephon Dip Treatment	41.5 ± 4.28	-4.69 ± 0.42	13.27 ± 0.55	109.54 ± 2.02^{p}	42.07 ± 4.19	-3.51 ± 0.39	14.95 ± 0.90	103.24 ± 1.91^{q}
Ethephon Powder Treatment	40.9 ± 2.5	-4.37 ± 0.14	13.04 ± 0.18	108.48 ± 0.63^{p}	41.31 ± 2.63	-3.80 ± 0.15	13.90 ± 0.24	105.28 ± 0.73^{r}

$^{p-r}$Means (±SD) with the different letters are significantly different at $p \leq 0.05$ for each column.

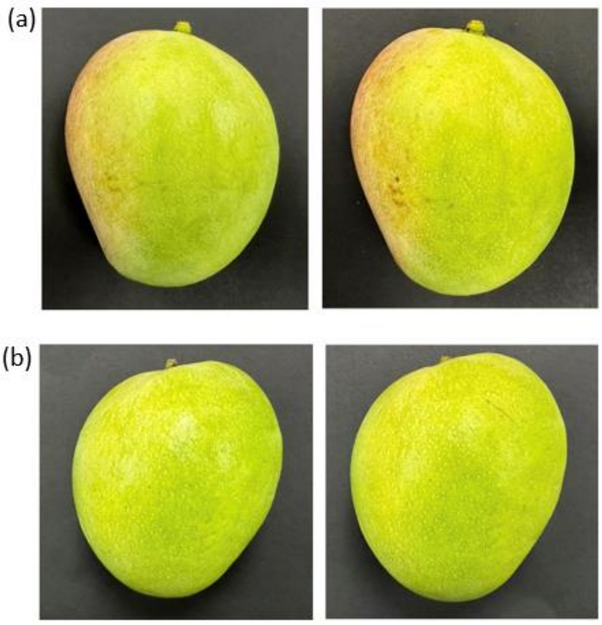

Figure 2. Visual appearance of mangoes before treatment (Day 0) (left) and after 6 days of storage (right) under different treatment conditions: (a) Control (Natural Ripening), (b) Ethephon Dip Treatment, and (c) Ethephon Powder Treatment.

3.2. Physiological Loss in Mass

The results indicate a significant effect of ethephon application on physiological loss in mass (M_{PL}) of mangoes (Figure 3) ($p \leqslant 0.05$). The highest M_{PL} was observed in mangoes treated with the ethephon dip (1000 ppm), at 1.22% after six days of treatment. This was followed by the ethephon powder treatment (1000 ppm), recording 1.12% on the Day 6 of treatment. In contrast, the control group (natural ripening) exhibited the lowest mass loss, at 0.78%.

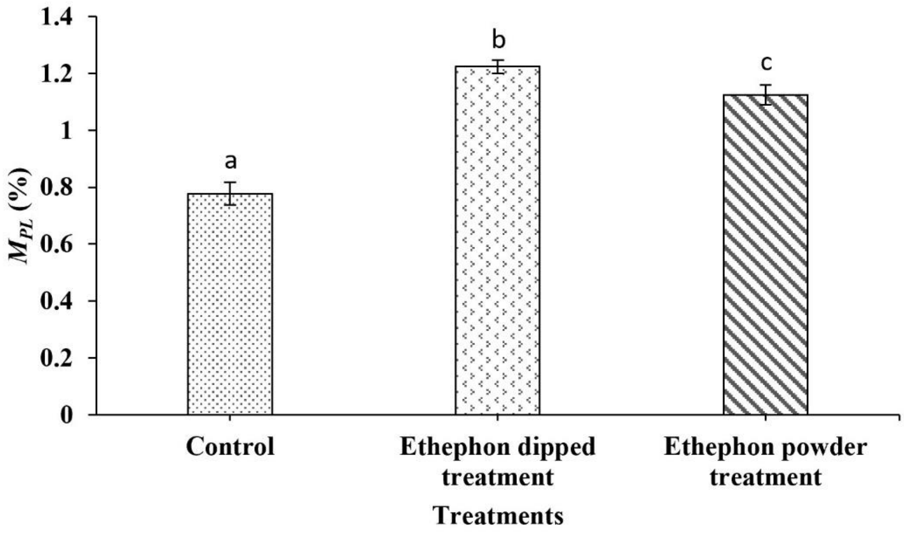

Figure 3. Effect of treatment methods on physiological loss in mass (M_{PL}). [a-c] Means with different letters on the bar are significantly different ($p \leq 0.05$).

Compared to the control, the increased mass loss in the treated fruits may be attributed to enhanced respiration, surface evaporation through the peel tissues, and other metabolic activities associated with ripening (Kaur, 2017). These findings are consistent with previous studies, which reported that higher concentrations of ethylene or ethephon accelerate ripening and led to increased moisture loss and fruit mass reduction (Dhaneshwari & Desmukh, 2023; Gurjar *et al.*, 2018; Zore *et al.*,2021; Kaur, 2017), consequently led to increased moisture loss and mass reduction in fruits. The greater mass loss observed in the dip-treated mangoes may be attributed to more rapid and uniform release of ethylene due to direct immersion of the fruit in the solution. Conversely, the ethephon powder treatment, due to its encapsulated or slower-release nature, might result in a gradual and more controlled ethylene release, leading to a less immediate change in mass loss.

3.3. Total Soluble Solids

The ethephon dip treatment fruits had the highest TSS content, 13.5 °Brix, closely followed by the ethephon powder treatment, 13.0 °Brix (Figure 4). These values significantly differed ($p \leqslant 0.05$) from those of the control fruits, which had a TSS of 9.8 ° Brix after six days of treatment. These findings are consistent with previous studies reporting increased TSS in ethephon-treated fruits (Kaur, 2017; Sabuz *et al.*, 2019).

The increase in TSS may be attributed to the breakdown of starch into simple sugars during the ripening process and the concentration of organic solutes due to water loss (Sabuz *et al.*, 2019; Zore *et al.*, 2021). Additionally, various anabolic and catabolic processes occurring during ripening may contribute to this increase, preparing the fruit for senescence (Kaur, 2017).

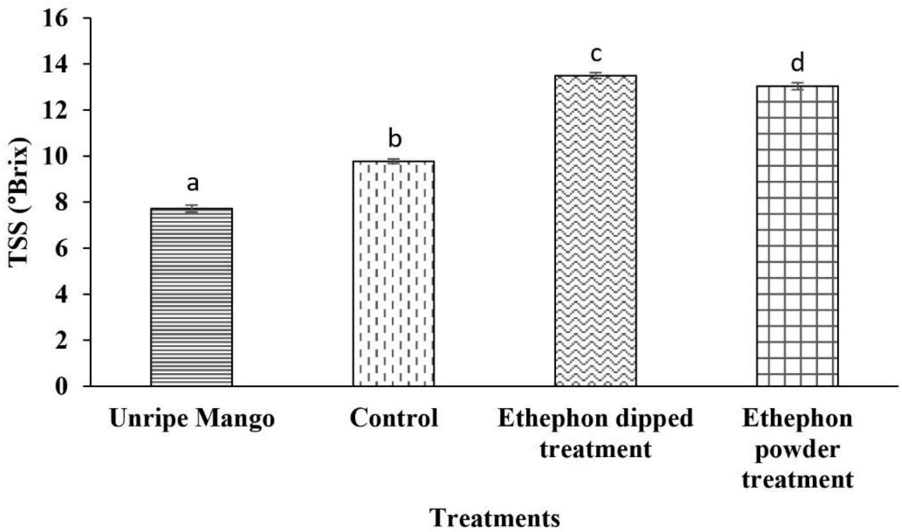

Figure 4. Effect of treatment methods on total soluble solids of mango samples measured on Day 6. [a-d] Means with different letters on the bar are significantly different ($p \leq 0.05$).

3.4. Ethylene Gas Release

As depicted in Figure 5, the results revealed ethylene gas release from control and treated fruits. Following treatment, the production of ethylene gas released from the control fruit was 149 ppm on the sixth day. Compared with the control, mangoes treated with the ethephon dip exhibited earlier and higher production of ethylene gas, measuring 253 ppm, followed by those treated with ethephon powder, which measured at 187 ppm.

The higher ethylene production in fruits subjected to the dipping treatment suggests its effectiveness in promoting ethylene synthesis within the fruit. Conversely, the application of ethephon powder resulted in a slightly slower ethylene gas release compared to the dipping treatment, though still significantly higher than the control.

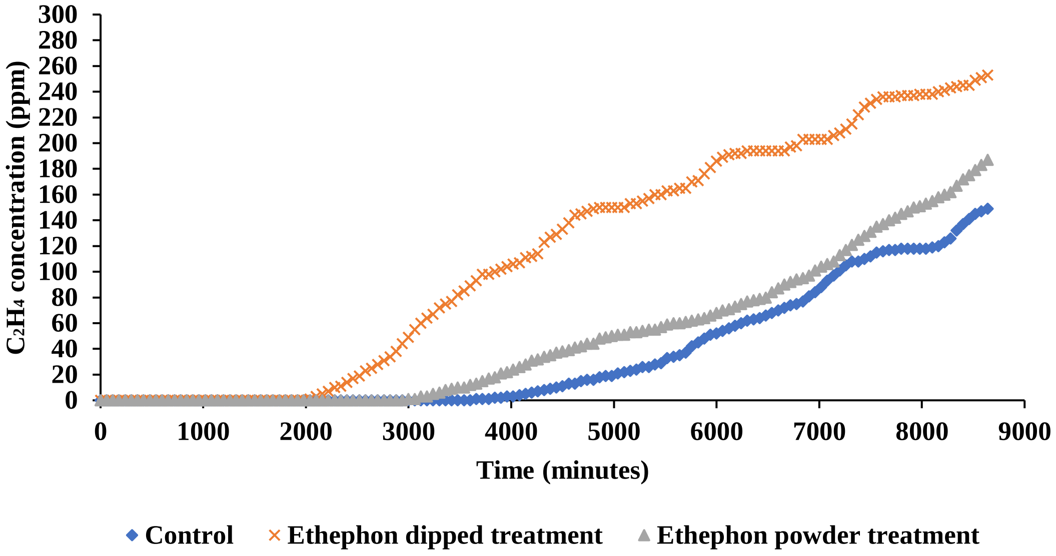

Figure 5. Effect of treatment methods on ethylene gas release concentration

4. Conclusions

In conclusion, this research compares and analyses the ripening behaviour in mangoes induced by different ethephon-based treatments. This study showed that ethephon treatments, especially the dip method at 1000 ppm, effectively accelerated mango ripening compared to natural ripening. There are significant changes in the fruit skin colour, with increased L^*, b^*, and reduced h^*, indicating a shift from green to yellow-red tones. The dip-treated fruits also showed the highest physiological loss in weight (1.22%), likely due to increased respiration and water loss during ripening. TSSs were significantly higher in treated fruits, with the dip method reaching 13.5 °Brix, suggesting enhanced sugar content. Additionally, ethylene gas release was greatest in dip-treated fruits (253 ppm), confirming its effectiveness in stimulating ethylene production. Further investigations will be conducted into different climacteric fruits to expand the understanding and applications in fruit ripening processes.

Author Contributions: Conceptualization, Yee-Ming P., Boon-Beng L., Akmal Hadi M. R., Farizul Hafiz K.; Data curation, Yee-Ming P., Boon-Beng L.; Formal analysis, Yee-Ming P., Boon-Beng L., Md Nabil A. A. S.; Investigation, Yee-Ming P.; Methodology, Yee-Ming P., Boon-Beng L., Ahmad Radi W. Y., Hafizah M. J.; Supervision, Boon-Beng L., Akmal Hadi M. R., Farizul Hafiz K.; Writing – original draft, Yee-Ming P.; writing – review and editing, Boon-Beng L., Akmal Hadi M. R., Farizul Hafiz K., Ahmad Radi W. Y., Hafizah M. J.

Funding: This research was funded by the Fundamental Research Grant Scheme (FRGS/1/2021/TK0/UNIMAP/02/70) from the Ministry of Higher Education.

Acknowledgements: The authors would like to acknowledge the financial support from the Ministry of Higher Education, Malaysia under Fundamental Research Grant Scheme (FRGS/1/2021/TK0/UNIMAP/02/70). The authors would also like to acknowledge Universiti Malaysia Perlis and Sime Darby Technology Centre Sdn Bhd for providing access to their facility and equipment.

Conflicts of Interest: The authors declare no conflict of interest.

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