*J. Trop. Agric. and Fd. Sc. 52 (2)(2024): 1 – 11*

# Postharvest behaviour of Musang King (D197) durian fruits harvested at different time intervals after anthesis

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## Abstract

One of Malaysia's leading durian varieties, D197, also known as "Musang King," is highly sought after in the export market. The postharvest behavior of Musang King durian was studied across four maturity stages: 13, 14 and 15 weeks after anthesis (WAA), and naturally abscised ripe fruit (control). Fruit characteristics were compared from harvest to ripening under ambient conditions (28 °C, 75% RH). Parameters measured included respiration and ethylene production rates, pulp firmness, husk and pulp color, quality-associated chemical composition (total soluble solids, total titratable acidity, ethanol, acetaldehyde and ethyl acetate), pulp dry matter, husk moisture content, and sensory evaluation. Consistent with literature, early-harvested fruits exhibited a typical climacteric pattern in respiration and ethylene production, with a dramatic surge in respiration up to 4-fold, while naturally abscised ripe fruits displayed a higher yet consistent respiration rate, likely due to passing the climacteric phase on the tree. Delaying the climacteric phase could be advantageous in extending the storage life of durian. Dry matter, a critical indicator of durian maturity, revealed that only fruits harvested at 15 WAA attained a similar dry matter content as the abscised fruit (60.18%). Similarly, both yellowness and pulp softening increased with maturity. Surprisingly, biochemical composition, especially parameters like total soluble solids, did not significantly differ between all early-harvested and abscised ripe fruits when fully ripe with a TSS value of 40 °Brix. Among early-harvested groups, fruits at 15 WAA exhibited similar ripening behavior and quality attributes to abscised fruits, particularly in pulp color, firmness, dry matter content, and anaerobic volatile compounds, with better sensory performance in taste and texture parameters compared to earlier maturity fruits. This suggests that harvesting at 15 WAA could be optimal for Musang King durian to achieve comparable ripening quality with abscised fruits. Further comprehensive studies, including volatile organic compounds and chemical profiling, may provide additional insights correlated with sensory evaluation and physiochemical composition.

**Keywords:** *maturity, ripening, quality, storage life, climacteric*

## Introduction

From being merely operated on a small scale decades ago, durian has now emerged as one of Malaysian new sources of wealth. In 2022, Malaysia had an acreage of 87,278 ha dedicated to durian fruit cultivation, which accounted for 43% of the total fruit cultivation in the country (Department of Agriculture 2023). From this cultivation, Malaysia produced 455,458 mt of durians, surpassing Malaysia's self-sufficiency rate by 108% (Department of Statistics Malaysia 2022). This surplus in production is sufficient to meet domestic consumption needs and has likely led to an expansion of Malaysia's export market for durians.

Six percent of the total Malaysian durian is exported mainly to traditional markets such as Singapore (49%), China (36%) and Hong Kong (12%) (Safari et al. 2018). Moreover, 227 registered durian clones have been registered in Malaysia to date (Department of Agriculture Malaysia 2023). One of the leading varieties, especially for the export market, is D197, registered as Raja Kunyit in 1993 and commercially known as "Musang King". Malaysia was granted full market access for fresh and processed durian products in Singapore and Hong Kong.

*Article history*
Received: 18.1.24
Accepted: 9.5.24

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However, only frozen whole fruit, pulp, and paste durian are allowed in China (Safari et al. 2018). The sales are projected to increase if China allows Malaysia to export durian in fresh fruit form (Malaysia Quarantine and Inspection Services 2018).

Typically, durian is harvested in Malaysia when it naturally falls off the tree upon ripening. Tree-abscised ripe Musang King durian has an inherently short shelf life; it lasts only 1 – 2 days at ambient temperature. On the other hand, its optimum storage temperature was found to be 7 °C, whereby it can be stored for only 14 days, limiting its market potential (Nur Azlin et al. 2019). While shelf life is not an issue when the tree-abscised ripe fruits are processed into frozen whole fruits, it has been a major challenge for fresh durian distribution to distant markets and long storage during fruit glut. While frozen durians have a longer shelf life, the Malaysian industry cannot solely rely on frozen forms due to the requirement of maintaining them in frozen condition, which necessitates the availability of freezing facilities along the entire supply chain**.** As durian ripens, the abscission area naturally develops at the centre of each locule, which weakens and allows the fruit to be easily opened. This may explain why Malaysian durian cannot be kept longer and transported to farther markets compared to Thailand, which has dominated the world durian market for decades. Once ripening progresses, the fruit rapidly shifts to the senescence stage and eventually decays.

On the other hand, in Thailand, durian is harvested by cutting them when fruits are physiologically mature before being abscised. The fruit of the commercial varieties in Thailand takes about 90 to 135 days from anthesis to physiological maturity, depending on varieties, fruit position on a tree, cultural techniques, and environmental conditions. Several criteria are used for judging the durian fruit maturity, such as the number of days from full bloom, the colour of the spine tip, the elasticity and disposition of the spines, the intensity of the odour emitted, the changes in the fruit stalk, the percentage of dry matter of fruit, and especially the sound of the fruit when tapped (Siriphanich 2011). In conventional practice, harvesting time is determined by calculating the number of days after anthesis (DAA), ranging from 90 to 150, depending on the cultivar. Monthong is commonly harvested in Thailand at 120 135 days, while Chanee is harvested at 100 – 115 days (Somsri 1988).

Most information available regarding the maturity, determination and optimum harvesting time has been from Thailand. For Malaysian durian, such information is still scarce. In 1992, a maturity study on Malaysian durian was carried out by Pauziah et al. found out that the D24 can be harvested at 105 – 110 days after anthesis and can be stored for up to 9 – 10 days, compared to only 3 – 4 days for fall ripe fruit (Pauziah et al. 1992). In 2021, Wan Mohd Reza Ikwan et al. reported a preliminary finding that the Musang King durian could be harvested as early as 90 days after anthesis and could undergo similar ripening process, such as pulp softening and yellowing similar to the tree-riped ones. Musang King durians harvested at the mature stage exhibit delayed husk dehiscence due to their high water content. Additionally, they produce minimal ethylene gas and delay aroma emission compared to tree-ripened ones. These preliminary findings indicate that harvesting Musang King durians before they naturally abscise could extend storage life by delaying ripening, reducing fruit cracking, and aroma emission, thereby facilitating transportation into the export market.

Limited information regarding the determination of optimum maturity for Malaysian premium durian has granted intensive research to evaluate the physicochemical characteristics of durian Musang King, highlighting the implications for fruit quality and ripening characteristics. Based on days after anthesis, there is a need to establish baseline information on the quality and ripening behaviour of durian harvested at different stages of maturity. This will determine the optimum maturity stage of the Musang King durian. Harvesting at the optimal maturity stage can extend storage life and facilitate transportation of Musang King durian to export markets. To date, no such comprehensive data has been accessible, underscoring the necessity for this research.

## Materials and method

### *Sampling preparation*

The samples for this study were sourced from a commercial farm, namely Top Fruits (M) Sdn. Bhd., located in Batu Pahat, Johor. Hand pollination was conducted to ensure a higher possibility of fruit set for the research sampling, following the method described by Muhammad Afiq et al. (2019). The flowers used in the sampling were tagged to identify and track specific fruits throughout their development and maturity stages. The harvesting time points in this study were established with a weekly interval, commencing from 13 weeks until the occurrence of natural abscission upon ripening. This timeframe was determined based on a preliminary study by Wan Mohd Reza Ikwan et al. (2021), which indicated that Musang King durians could be harvested as early as 90 days. When the designated harvesting time points were reached, the corresponding tagged fruits were meticulously harvested by cutting the peduncle 2 cm above the base, particularly for samples to assess early maturity.

The collected fruits were promptly transported to the MARDI Postharvest Complex in Serdang, Selangor, using an open-air truck, which took approximately 3 hours. This mode of transportation is commonly employed by the company for durian transport. The fruits were then immediately subjected to overnight precooling at 10 °C in a cold room upon arrival to remove both field heat and heat accumulated during transportation.

***Experimental treatment and design***

The fruits in this experiment were divided into four groups based on the number of weeks after anthesis (WAA): (1) Fruits harvested at 13 WAA; (2) Fruits harvested at 14 WAA; (3) Fruits harvested at 15 WAA; and (4) Naturally abscised ripe fruit used as the control group. These groups are denoted as 13 WAA, 14 WAA, 15 WAA, and abscised fruit in the captions of figures and tables, as well as in the paragraphs throughout this article, for the sake of simplicity.

These groups of samples were further divided into three subgroups for different purposes: 1) Fruits directly subjected to gas analysis at ambient temperature; 2) Fruits exposed to a ripening induction process using 250 ppm at 25 °C overnight for destructive physicochemical analysis; and 3) Fruits stored at ambient temperature to allow for natural ripening, which was necessary for assessing their shelf life. The experiment was laid out in a complete randomised design (CRD) with four replications. The number of fruit represented each replicate. For fruits harvested at early maturity, evaluations were carried out immediately upon reaching ripeness, which was indicated by the fruits falling off the peduncle at the abscission zone and emitting a strong aroma. Additionally, the fruits were assessed for their elastic thorn texture and the presence of a hollow sound when gently tapped.

***Determination of physical characteristics***

*Pulp colour*

The individual fruit's pulp color was determined using a reflectance colourimeter (model CR-400, Minolta, Japan). Data were presented in terms of colour, space (L*, a*, b*), hue angle (H°), and chroma (C*) values. Generally, L* indicates lightness, where values range from completely opaque (0) to completely transparent (100); a* indicates greenness, and b* indicates yellowness on the hue circle. The hue angle [H° = arctan (b*/a*)] describes the relative amounts of greenness and yellowness, in which 90° is more toward yellow and 180° is more toward green. On the other hand, Chroma [C* = (a*2 + b*2)1/2] defines saturation or intensity of the colour (McGuire 1992).

*Pulp firmness*

Pulp obtained from the fruits was determined for firmness by using a TA TX Plus Texture Analyzer (Stable Microsystems, Surrey, UK). A force of 5 kg was applied at a cross-head speed of 15 mm/min. The pre-test speed was set at 15 mm/min, while the test and post-test speeds were set at 10 and 20 mm/min, respectively. The force (N) required inserting the 6 mm diameter probe tip 0.5 cm deep into the pulp at 10 mm/min, and the result was recorded.

*Dry matter and moisture content of the pulp and husk*

The dry matter and moisture content of durian pulp and husk samples were assessed following the method outlined by Onsawai and Sirisomboon (2015). Two grams of durian pulp and husk were accurately weighed and placed in an aluminum can with an aluminum lid. The moisture content analysis was performed in triplicate using a hot air oven set at a temperature of 70 ± 2 °C until a constant weight was achieved. The percentage of moisture content was calculated using Equation 1 and the percentage of dry matter content was calculated using Equation 2:

*Equation 1: Moisture content (%) = ((W1-W2) × 100)/W1 (1), where W1 is the wet weight (g), and W2 is the oven-dried weight (g)*

*Equation 2: Dry matter content (%) = 100-MC(%)*

***Determination of respiration and ethylene production***

The fruit's respiration and ethylene production rate were measured using a gas chromatography (GC) Perkin Elmer Autosystem. The fruits were weighed and placed in an airtight jar (15L) at ambient temperature. They were capped for 1 hour to accumulate any emitted gas. Subsequently, 1 ml gas samples were withdrawn from the headspace of the jar by inserting a syringe through a fitted septum into the GC. The respiration rate was expressed as ml/kg/hr, whereas the ethylene production rate was expressed as µl/kg/hr,

***Determination of chemical content***

*Total soluble solids and total titratable acidity*

Samples for these analyses were blended using a kitchen blender. The Total Soluble Solids (TSS) of the pulp were determined directly from the puree of the fresh fruit samples using a digital refractometer (Atago Model DBX-55, Japan). The results were recorded in °Brix. For the total titratable acidity, 5 g of blended pulp samples were mixed with 20 ml distilled water and then titrated against 0.1 M Sodium Hydroxide NaOH as indicator. This was performed until the pH reading by pH meter (Microprocessor pH meter pH 2112/HANNA, USA) reached up to pH 8.1. The results were expressed as % citric acid as this acid is one of the most important organic acids in durian, along with malic, citric, tartaric and succinic acids (Voon et al. 2006).

*Ethanol, acetaldehyde and ethyl acetate content*

Ethanol, acetaldehyde, and ethyl acetate content in the pulp were measured by gas chromatography using the headspace technique according to the method by Davis and Chase (1969). An approximately 5 g of blended pulp was deposited in 25 mL glass vials and incubated in a water bath at 60 °C for 1 hour. A headspace sample was taken with a 1 ml glass syringe for the measurement of ethanol and acetaldehyde concentrations using an HP5890A gas chromatograph equipped with a flame ionization detector (at 250 °C) and a glass column (2 mm × 1.0 m) containing 5% Carbowax on 60/80 Carbopack as a stationary phase (at 85 °C).

### *Sensory evaluation*

Sensory evaluation was conducted with a trained panel of 10 members familiar with durian and had previous sensory evaluation experience. The objective of the sensory evaluation was to determine the acceptability and preference of the durian pulp. Ripe durian pulp samples were coded with 3-digit random numbers and presented at room temperature randomly for a blind taste test. The panelists rated the intensity of the chosen attributes on a 7-point category scale (1 – 7), with 7 being "Like Very Much," 6 "Like Moderately," 5 "Like Slightly," 4 "Neither Like nor Dislike," 3 "Dislike Slightly," 2 "Dislike Moderately," and 1 "Dislike Very Much." The sensory attributes tested included freshness, colour, texture, taste, aroma/smell, and overall acceptability. The results of the sensory evaluation can be correlated with the physicochemical results to determine the optimum maturity stage for harvesting Musang King durian.

### *Statistical analysis*

The data were subjected to one-way analysis of variance (ANOVA) using GLM (General Linear Models) procedures. Mean separation was done by using the Duncan Multiple Run Analysis (DMRT) for the minimum significant difference at P ≤0.05 (SAS Institute Inc. 1994).

## Results and discussion

### *Respiration and ethylene production rate*

*Figure 1* and *Figure 2* depict the rate of respiration and ethylene production, respectively, of the durian fruits harvested at various maturity stages. The initial measurement was taken one day after harvest or Day 1. On Day 1, no significant differences were observed among the fruits harvested at different maturity stages.

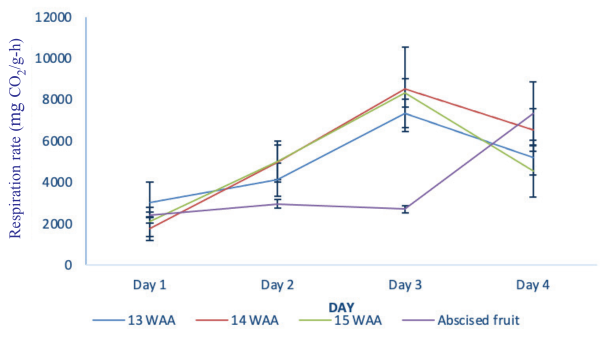


*Figure 1. Respiration rate of Musang King durian fruits harvested at different maturity stages during storage at ambient condition. Bars represent standard error*

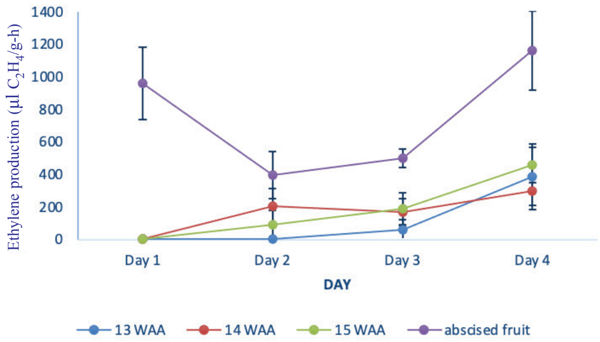


*Figure 2. Ethylene production rate of Musang King durian fruits harvested at different maturity stages during storage at ambient condition. Bars represent standard error*

However, in the subsequent days, there was an increasing trend in the respiration rate, except for the naturally abscised ripe fruit, referred to as the "abscised fruit," which exhibited relatively stable respiration rates. This is likely attributed to the abscised fruit having already passed their climacteric phase, which likely occurred while they were still attached to the tree before falling down. Climacteric fruits typically experience a notable rise in respiration during ripening, known as the climacteric rise. This finding aligns with previous research by Wan Reza et al. (2020), which reported that abscised ripe Musang King durians did not exhibit a climacteric rise upon harvesting as well or upon removal from cold storage. Similarly, other durian varieties, such as 'Chanee' and 'Kan Yao', also declined the respiratory and ethylene peaks when the fruit was overripe. In contrast, in 'Mon Tong', the peak occurs when overripe (Paull & Ketsa 2011). On the other hand, the remaining fruits harvested at earlier maturity stages demonstrated a climacteric pattern at Day 3, characterised by a substantial increase in respiration, approximately 30 – 40%.

In climacteric fruits, respiration rises concurrently or shortly after the rise in ethylene production (Wills 2007). Durian fruit produce double ethylene production peaks, where the first peak occurs before the climacteric respiratory peak when it is almost half-ripe, and the second peak is produced at the overripe stage during fruit dehusking when the pulp is very soft and releases a strong fragrance (Booncherm and Siriphanich 1991). This study did not detect ethylene on Day 1 for the early-harvested fruit. Still, a significant increase was observed on the second day for fruits harvested at 14 WAA and 15 WAA, reaching up to 200%. This can be considered the first ethylene production peak for both groups of fruits. However, the fruits harvested at 13 WAA only showed a clear peak the following day. This finding aligns with Tongdee et al.'s (1990) report that the number of days from harvest to the climacteric peak significantly decreased as the maturity stage of the fruit at harvest advanced. At this stage, the fruits might have just entered the ripening phase. Ethylene production exhibited an increasing trend until Day 4, which could be considered the onset of the second ethylene production peak for this group of early-harvested fruits, as at this point, the fruits had started to ripen and emit aroma.

On the other hand, for the naturally abscised fruit, the ethylene production rate was high starting from Day 1, which could be seen as a continuation of the second ethylene peak taking place while they are still intact on the tree. The ethylene production rate in the abscised fruit remained higher compared to the early-harvested fruits. This is in line with Tondee's report, which stated that respiration and ethylene production rates immediately after harvest were higher for fruits harvested at a more advanced maturity stage. Abscised fruit again showed a drastic increase on Day 4, which could be attributed to the condition of the fruits undergoing husk dehiscence. Typically, a Musang King abscised fruit will start to split open 1 – 2 days after being harvested.

***Colour and firmness of the pulp***

*Table 1* presents the findings regarding the pulp colour and firmness of fruits harvested at various maturity stages. The reading for the abscised fruit was conducted one day after harvest. However, a ripening induction process was implemented for the fruits at earlier maturity stages. This involved exposing the fruits to ethylene gas at a concentration of 250 ppm for 24 hours, then allowing them to ripen naturally for another 2 days. This standardized approach was employed for all destructive biochemical analyses to ensure the measurements were taken when the fruits were fully ripe. By doing so, the results obtained could effectively represent the quality of fruits intended for consumption by consumers. Data on pulp colour changes were recorded using the CIELAB method, indicating that harvesting durian fruits at early maturity stages (weeks 13, 14 and 15) does not significantly affect the overall colour of the Musang King variety when fully ripe. The hue values within the range of 88 – 90 indicate a consistent yellow colour. However, there were significant differences in the intensity of the yellow colour, as shown by the b* values. Generally, hue angle closer to 90° indicates colour range is yellow and b* values indicate a more yellowish surface colour of the pulp (Plotto et al. 2006). Abscised ripe fruits exhibited the highest b* value (52.56a), indicating a stronger yellow colour. Fruits harvested in weeks 13 and 14 did not show significant differences in yellow colour, but those harvested in week 15 showed b* values that were not significantly different from abscised ripe fruits. This indicates that durian fruits harvested in week 15, closer to their full ripeness, exhibited a similar intensity of yellow colour to abscised ripe fruits. This also suggests that the yellow color becomes more intense as the fruit is harvested later.

The dark yellow and orange colour of the durian pulp resulted from the accumulation of carotenoids, mainly in the form of β-carotene (Wisutiamonkul et al. 2017; Barreto et al. 2011). Musang King was reported to have the second highest carotenoid content after "Black Thorn", followed by "Red Prawn" and "IOI" durian (Tan et al.2020). In a mature Chanee durian, the ripening process resulted in a 30% increase in carotenoid throughout storage (Wisutiamonkul et al. 2017). However, the increase in carotenoids is not anticipated in a fully ripe Musang King durian. The pulp colour remains unchanged even after reaching the storage life limit (Wan Mohd Reza Ikwan et al. 2021). The firmness of the pulp also exhibits a similar pattern, similar to the colouring. Fruits harvested at early maturity stages, specifically in weeks 13 and 14, exhibited significantly higher firmness values than those harvested later in week 15. This indicates that the fruits harvested earlier were significantly firmer in texture. It is important to mention that the fruits at the earliest maturity stage (week 13) exhibited a softening rate 50% lower than the abscised fruit.

Table 1. Colour and firmness of ripe Musang King durian pulp harvested at different maturity stages. Means followed by different letters within respective column are significantly different ($p < 0.05$)

| Maturity stages | L* value | b* value | Hue° value | Firmness (N) |
|---|---|---|---|---|
| 13 WAA | 65.60a | 38.55b | 90.66a | 19.67a |
| 14 WAA | 69.28a | 35.28b | 88.48a | 16.15a |
| 15 WAA | 74.00a | 46.85ab | 90.03a | 12.70ab |
| Abscised fruit | 70.55a | 52.56a | 90.09a | 10.09b |

Table 2. Dry matter and moisture content of ripe Musang King durian harvested at different maturity stages. Means followed by different letters within respective column are significantly different ($p < 0.05$)

| Maturity stages | Pulp dry matter content (%) | Husk moisture content (%) |
|---|---|---|
| 13 WAA | 43.74c | 80.85a |
| 14 WAA | 45.49bc | 80.11ab |
| 15 WAA | 54.32ab | 83.68bc |
| Abscised fruit | 60.18a | 84.41c |

In contrast, fruits harvested in week 15 showed lower firmness values and did not significantly differ from abscised ripe fruits. This suggests that the fruits harvested in week 15 had further softened and reached optimal ripeness. The decrease in firmness in these fruits could be associated with the breakdown of cell wall components and the enzymatic activities involved in fruit ripening. The ripening of durian is accompanied by an increase in water-soluble pectin and a significant rise in polygalacturonase activity (Imsabai et al. 2002). The polygalacturonase activity is low in unripe durian arils but shows a marked increase during ripening. Positive correlations between polygalacturonase activity and durian softening throughout postharvest ripening were reported in Chanee durian (Imsabai et al. 2002) and Monthong (Youryon et al. 2018). However, no correlation was found between softening and pectinesterase activity in both varieties during ripening. The study conducted by (Husin et al. 2022) on the D24 durian revealed that during the developmental stage, polygalacturonase inhibitors demonstrated the highest expression, up to 8-fold, thereby inhibiting polygalacturonase (PG) enzymes throughout the young to mature durian growth stage. However, this gene is down-regulated during the ripening stage, showing a -8-fold expression, activating durian fruit pulp softening genes. The inability of the Musang King durians to be harvested at an early maturity stage in the present study to achieve a similar texture to the ripe abscised fruit could be attributed to the likelihood of still having a high expression of polygalacturonase inhibitor in the early stage of maturity.

***Dry matter and moisture content***

The results in *Table 3* showed that durians harvested at an early stage of maturity, particularly in week 13 and week 14, had significantly lower dry matter content in the pulp after ripening compared to abscised ripe durians ($p < 0.05$). On the other hand, there are no significant differences between fruits harvested at week 15 and ripe abscised fruit. As the fruit ripens, the dry matter content increases due to the breakdown of complex carbohydrates into simpler sugars, leading to a decrease in moisture content (Chaisrichonlathan & Chavapradit 2017), rendering higher dry matter content in the tree-abscised fruits. Dry matter content indicates the fruit's maturity (Pokhrel et al. 2023). Kalayanamitra et al. (2005) reported that dry matter could separate the critical stage of immature fruit of 60% from the minimum acceptable mature stage of 70% in Monthong durian. In another study, Ngoenchai et al. (2022) used dry matter content to classify each fruit into one of the four groups, with groups 1 to 4 having dry matter contents of <26.00%, 26.00 – 29.99%, 30.00 – 33.99%, and >34.00%, respectively. The dry matter contents of durians in group 1 to group 4 corresponded to 60, 70, 80, and 90% maturity levels, respectively. In the present study, the lower dry matter content observed in the pulp of early-harvested durians, especially fruits harvested at week 13, indicates that they have not reached their maximum maturity stage yet. The dry matter content was up to 28% lower in these early-harvested fruits compared to the tree-abscised ripe ones. In line with the result of this present study, Kuson & Terdwongworakul (2013) reported that in Chanee durian, there was an increase of 47.8% from young to commercial maturity. In contrast, the magnitude of the increase was significantly lower from the stage of commercial maturity to over-mature. According to the Thai Agricultural Standard (TAS 3-2013, 2014), the percentage of dry matter is commonly used as an index of maturation, and the durian pulp must constitute at least 32% dry matter content to be classified as "mature"(Ngoenchai et al. 2022).

***Quality-associated chemical attributes***

*Table 4* illustrates the differences in biochemical composition among durian fruits harvested at various maturity stages. Fruits harvested at early maturity stages (weeks 13, 14, and 15) did not exhibit significant differences compared to the abscised ripe fruits when fully ripe in terms of Total Soluble Solids (TSS), Total Titratable Acidity (TTA), and ascorbic acid content. Total Soluble Solids (TSS) is a reference index frequently used to estimate soluble sugars in fruit.

Studies conducted by Youryon et al.( 2018), Ketsa and Daengkanit (1998) and Youryon & Supapvanich (2022) have well-documented that the level of durian pulp ripeness increases significantly from the unripe stage, with the accumulation of TSS consistently correlating with total sugar content but inversely related to starch content concerning the sweetness of the ripe pulp. Consistent with TSS, the total sugar content in the tree-ripe fruits was also significantly higher than in the early-matured fruits. Durians harvested at an early maturity stage

Table 3. Quality-associated chemical attributes of ripe Musang King durian pulp harvested at different maturity stages. Means followed by different letters within respective column are significantly different ($p < 0.05$)

| Maturity stages | Total Soluble Solid (TSS) (°Brix) | Total Titratable Acidity (TTA) (%) | Ascorbic acid (mg/100g) | Acetaldehyde (mg/L) | Ethanol (mg/L) | Ethyl acetate (mg/L) |
|---|---|---|---|---|---|---|
| 13 WAA | 43.60a | 0.13a | 19.22a | 74.48a | 7447.96a | 0.23ab |
| 14 WAA | 41.83a | 0.11a | 20.05a | 75.31a | 5855.34a | 0.31a |
| 15 WAA | 39.81a | 0.12a | 22.58a | 31.46b | 2636.75b | 0.18ab |
| Abscised fruit | 40.09a | 0.10a | 19.98a | 51.95ab | 2758.63b | 0.12b |

Table 4. Sensory preference and acceptability of ripe Musang King durian pulp harvested at different maturity stages. Means followed by different letters within respective column are significantly different (p <0.05)

| Maturity stages | Freshness | Colour | Texture | Taste | Aroma/smell | Overall acceptibility |
|---|---|---|---|---|---|---|
| 13 WAA | 5.6a | 5.7a | 5.0b | 4.9b | 5.6a | 5.8a |
| 14 WAA | 6.3a | 6.3a | 5.8ab | 6.0ab | 6.0a | 6.2a |
| 15 WAA | 6.0a | 6.5a | 6.7a | 6.2a | 5.8a | 6.2a |
| Abscised fruit | 5.6a | 5.7a | 5.6ab | 5.4ab | 5.9a | 5.6a |

7-point category scale: 7 (Like very much); 6 (Like moderately); 5 (Like slightly); 4 (Neither like nor dislike); 3 (Dislike slightly); 2 (Dislike moderately) and 1 (Dislike very much)

were unable to achieve a similar TSS value as the tree-abscised ripe fruits, even after they eventually reached full ripeness postharvest, as reported by Añabesa et al. (2006) in Duyaya, Nanam and Puyat durian. The results of this present study lead to uncertainty in explaining this occurrence since the TSS of early-harvested fruits did not differ from that of the abscised ripe fruits. This finding is also inconsistent with the dry matter and firmness results presented in *Table 1* and *Table 2*, showing an increase and decrease, respectively, with advancing maturity, likely due to starch breakdown into sugar. However, the unavailability of sugar content data in this study prevented us from verifying this finding.

Regarding the Titratable Acidity (%TTA), the insignificant difference among the fruits at different maturity suggests that the acidity of durian pulp does not considerably change as it ripens, similar to what was reported by Sangpong et al. (2021). Titratable acidity refers to the total acid contents inside the food (Sadler and Murphy 2010). However, Anabesa et al. (2006) reported that durian harvested at the earliest maturity stage (105 days after anthesis) was the most acidic, with a TTA value of 0.36% at the ripe stage. The changes in TTA are related to respiratory substrate metabolism via the Tricarboxylic Acid (TCA) cycle (Wills et al. 2007). More mature fruit had lower TTA than less mature fruits since it was reported earlier that the former exhibited a higher rate of respiration (Cheyglinted 1993).

Among the three anaerobic volatile compounds measured, significant differences were observed only in ethanol and acetaldehyde, while the ethyl acetate content did not differ significantly. This indicates that the maturity at harvest had a notable effect on ethanol and acetaldehyde levels in Musang King durian. Acetaldehyde, a natural aroma component found in almost every fruit, accumulates during ripening, even under aerobic conditions (Fidler 1968). Both ethanol and acetaldehyde (AA) serve as precursors for natural aroma compounds (Knee and Hatfield 1981; Pesis 2005) Generally, fruits harvested at an early maturity stage exhibited higher levels of all three compounds, suggesting that these compounds may accumulate during the early stages of fruit development and maturation.

Conversely, fruits harvested in week 15 showed similar compositions of these three compounds compared to abscised ripe fruits. This indicates that as the fruits approached their optimal ripeness, the ethanol, acetaldehyde, and ethyl acetate levels reached a plateau or stabilized. The decreasing trend of these compounds with advancing maturity during ripening could likely be associated with a lower respiration rate, resulting in a reduced amount of pyruvate, a precursor for acetaldehyde, ethanol, and ethyl acetate production (Chairat et al. 2022). Through a study on volatile fingerprints in four commercial Thai durians, Aschariyaphotha et al. (2021) associated higher respiration during the ripening process with the husk behaving like a gas barrier, leading to low gas permeability to the pulp. This, in turn, creates a partial hypobaric condition in the aril, which eventually produces high ethanol. This finding is also likely related to the present results of this study. The results from the present study partly align with those reported by Chawengkijwanich et al. (2008) in Monthong durian, where ethyl acetate, ethyl propanoate, and ethanol were identified as the most abundant compounds emitted by mature durian pulp, while ethyl propanoate and ethyl 2-methyl butanoate were major compounds found in ripe durian pulp. Additionally, ethanol, acetaldehyde, and ethyl acetate were reported by Trainoak et al. (2007) as among the ten volatile compounds contributing to the aroma components in Monthong durian.

### *Sensory preference and acceptability*

The sensory evaluation of durian fruits is crucial for assessing overall quality and consumer acceptance, providing insights into the organoleptic characteristics that influence flavour profile and consumer preferences. *Table 4* presents the sensory evaluation of durian fruit pulp harvested at different maturity stages, focusing on colour, firmness, taste, and aroma.

Regarding pulp colour, although early-harvested fruits, especially those harvested at weeks 13 and 14, exhibited relatively paler pulp colour as indicated by the CIELAB method (*Table 1*) compared to the abscised fruit, there was no difference in the panel's perception towards the colour parameter. This suggests that the colour intensity did not significantly influence consumer perception.

In terms of firmness, it is noteworthy that there was a significant difference between the 15 WAA and 13 WAA maturity groups, paralleling the firmness result quantified by the texture analyser (*Table 1*). The 15WAA group had significantly higher scores in texture (6.70) compared to the 13WAA group (5.00).

One of the critical factors in determining the eating quality of durian is flavour. Flavour is defined as a combination of both aroma and taste, which influence each other (Xiao et al. 2022). In durian, flavour is due to fat, sugar, amino acids, volatile compounds such as esters and sulfur, and alcohol (Aziz and Jalil 2019; Pinsorn et al. 2018). According to Xiao et al. (2022), a total of 36 volatile compounds, 4 sugars, 27 organic acids and 20 free amino acids were detected in Musang King durian. In this present study, no significant difference in aroma was observed; however, there was a significant difference in taste parameters between the 15 WAA and 13 WAA maturity groups. The 15WAA group had significantly higher scores in taste (6.20) compared to the 13WAA group (4.9 respectively). This finding is not aligned with the Total Soluble Solids (TSS) analysis in *Table 3*, which showed no significant difference among all groups harvested at different maturity stages, suggesting that other components such as fat content could affect the taste perception. However, the absence of fat and volatile organic compounds cannot establish any association between aroma and taste and the eating quality of Musang King at different maturity stages in this present study. In Monthong, Ngoenchai et al. (2022) reported that the maturity stage at harvest is a critical factor in determining the eating quality of the Monthong durian, especially

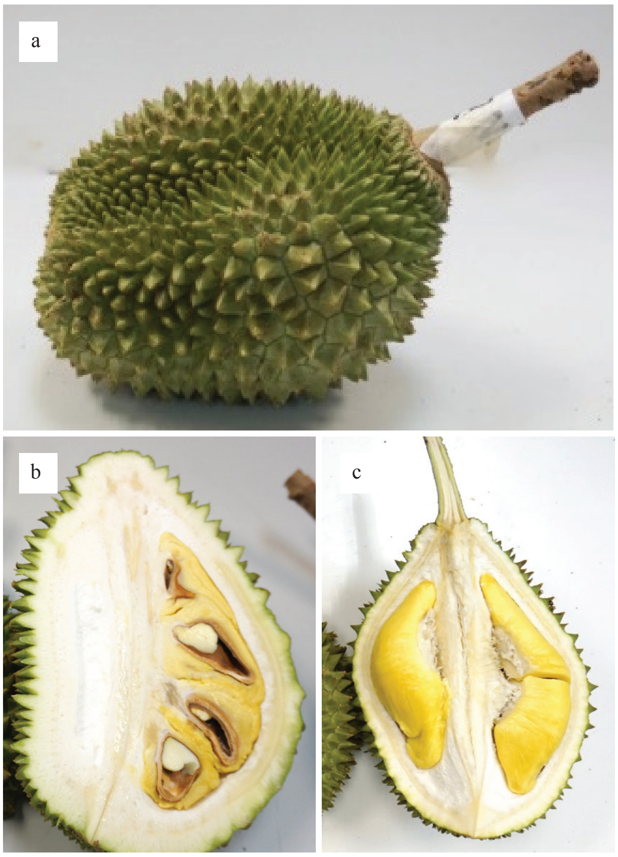


*Image 1. Physical appearance of Musang King durian (a) husk and (b) pulp upon harvest at 13 WAA, and (c) subsequently ripened*

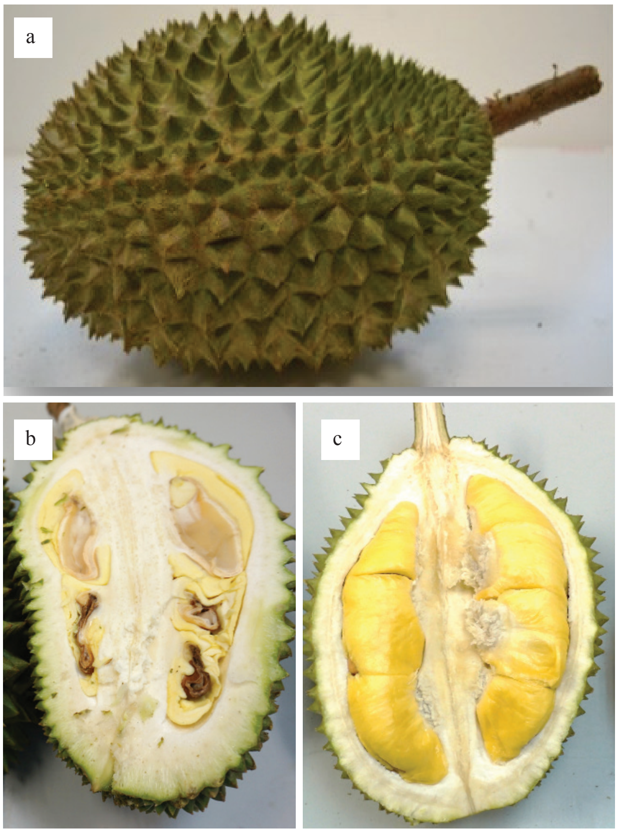


*Image 2. Physical appearance of Musang King durian (a) husk and (b) pulp upon harvest at 14 WAA, and (c) subsequently ripened*

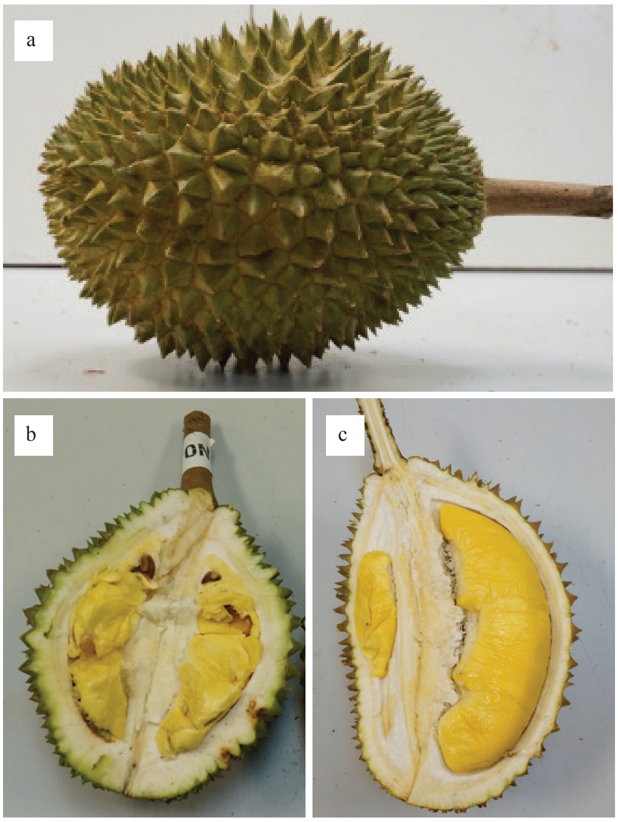


*Image 3. Physical appearance of Musang King durian (a) husk and (b) pulp upon harvest at 15 WAA, and (c) subsequently ripened*

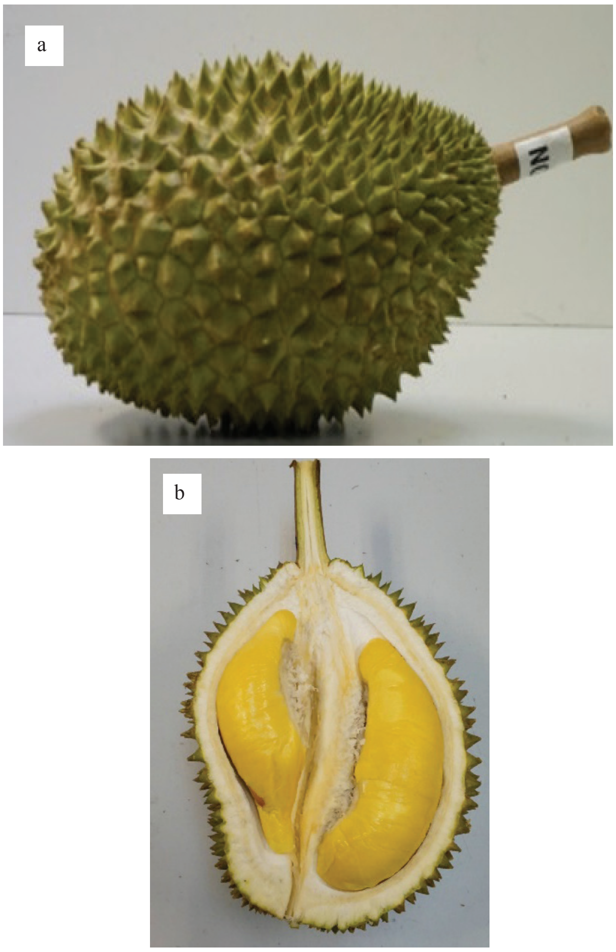


*Image 4. Physical appearance of naturally absciced ripe Musang King durian (a) husk and (b) pulp*

flavour, whereby the fruit should be harvested after reaching at least 80% maturation level to fully develop the volatile compounds during ripening.

The lack of consistency between sensory evaluation and physiochemical composition results could be attributed to subjectivity, as sensory evaluation involves human perception, which can vary based on individual preferences, experiences, and sensitivities. In spite of this, it can still be speculated that harvesting at week 15 could yield better sensory preference, especially in terms of texture and taste.

## Conclusion

In conclusion, the postharvest behaviour of Musang King durian is affected significantly by different harvesting times. The study revealed distinct differences in the respiration and ethylene production rates among fruits harvested at various maturity stages. Early-harvested fruits exhibited a climacteric pattern in respiration and ethylene production, while naturally abscised ripe fruits displayed a higher yet consistent respiration rate, likely due to having passed the climacteric phase while still on the tree. The dry matter content, yellowness, and softening of the pulp were found to increase with advancing maturity, indicating the fruit's ripening process. Interestingly, the biochemical composition of the fruits, particularly parameters associated with quality, such as total soluble solids, did not show significant differences between early-harvested and abscised ripe fruits when fully ripe. Among the three early-harvested groups, fruits harvested at 15 weeks after anthesis exhibited similar ripening behavior and quality attributes to the abscised fruits, particularly in terms of pulp colour, firmness, dry matter content, and anaerobic volatile compounds. Additionally, they showed better sensory performance in terms of taste and texture parameters compared to earlier maturity fruits. This suggests that harvesting at 15 weeks after anthesis could be the optimal time for Musang King durian to achieve comparable ripening quality with the abscised fruits. Further comprehensive studies involving parameters such as volatile organic compounds and other chemical profiling may provide additional insights to correlate with sensory evaluation and physiochemical composition. Harvesting durian before its climacteric phase offers advantages in storage and transportation. These fruits can continue ripening after harvest, allowing them to be picked when partially ripe and further ripen during transit or storage, thus extending their storage life. This warrants further study on the storability of Musang King fruit under low-temperature storage to assess its potential for export to distant markets.

## Acknowledgement

The authors express their gratitude to the management and staff of Top Fruits (M) Sdn Bhd, particularly Dr. Tan Sue Sian, En. Benson Khoo Peng Soon, Pn. Intan Nabila binti Sabri and En. Mohammed Faiz bin Roslee, for generously providing input in terms of fruit samples, valuable information, and technical assistance during our research conducted at their farm. This project is part of the collaborative research between MARDI and Top Fruits (M) Sdn Bhd titled "Studies on Self-Compatibility, Paternal Effect, Nutrient, and Postharvest Management of Durian." We also thank staffs from the Postharvest Handling Program Horticulture Research Centre MARDI, especially En. Mohd Kamal Mohd Tajuddin, En. Mohamad Abhar Akmal Hamid, Pn. Nurul Khadijah Rosly and Cik Norsyafiqah Rosali for their technical assistance at the research plot and laboratory.

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