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SOME PHYSICOCHEMICAL CHARACTERISTICS OF 'PUYAT' DURIAN FRUIT OF DIFFERENT QUALITY CLASSES AND RIPENESS STAGES

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ABSTRACT. *International demand for durian is increasing, and Philippine growers must meet both quantity and quality requirements. Accurately determining the quality and ripeness stages remains a challenge. We assessed the postharvest characteristics of ambient-stored 'Puyat' durian across three quality classes and three ripeness stages (unripe, ripe, and overripe). Fruits were graded into Class A, premium grade, suitable for the export market; Class B, with slight defects, acceptable for the local market; and Class C, slightly deformed and with some defects, for the local market and processing. Individual Class A fruit consisted of 3-4 locules, while Classes B and C had 2-3. Across classes and ripeness stages, 'Puyat' fruit showed an average of 62.97% pericarp, 26.97% pulp, and 10.05% seed. Visual quality was best in Class A. From the unripe to the overripe stage, weight loss was greater in Class C (18.47%) and overripe (21.89%) fruit. Rind color changed from green to yellowish-brown with ripening, while disease development and dehiscence were evident in overripe fruit. Pulp firmness decreased while total soluble solids (TSS) increased with ripening. Pulp color changed from creamy white in unripe fruit to yellow-orange in overripe fruit. Dry matter content was higher at the ripe stage. Observable ripening indicators included spine tip browning, hollow sound, fruit aroma, and peduncle abscission. Whole fruit aroma peaked at the overripe stage. Pulp color, spine tip browning, hollow sound, spine pliability, TSS (r = 0.85–0.97), and pulp firmness (r = –0.80) showed strong correlations with ripening,*

confirming their utility as ripening indicators. Under ambient conditions, all fruit classes reached the table-ripe stage five days after harvest and dehiscence by day eight. This quality assessment of the various quality classes and ripeness stages of 'Puyat' durian also included a rind color rating scale to support intact fruit evaluation.

KEYWORDS: *quality grades, ripening indicators, weight loss, visual quality*

INTRODUCTION

Durian (*Durio zibethinus*) is recognized as one of the high-value priority crops in the Philippines and is known as the "flagship fruit" of Mindanao (Daniel et al. 2022). There is increasing demand for durian worldwide, with exports reaching a peak of 930 thousand tons in 2021, and China was the largest importer from 2020 to 2022, accounting for 95% of total global imports (FAO 2023). China has increased its durian imports by an average of 26% per year over the past decade (Noodaeng 2017). In 2023, the Philippines struck a 2 billion USD fruit export deal with China that required 5.7 million kg of durian exports every season (Rodriguez 2023). With open trade in China's export market, there is demand for durian fruit of acceptable export quality. Among the country's popular durian varieties, 'Puyat' durian is the primary export variety due to its competitiveness in terms of disease resistance (Abad & Cruz 2013) and consumer preference regarding aroma (Tagubase et al. 2018). In 2020, the country's overall durian exports were 767 metric tons; however, by 2022, this declined to 89 metric tons (PSA 2025). In the Philippines, mature fruit is harvested using conventional methods, including tapping for a hollow sound and other maturity indices (DA-BPI 2022). The former indicator relies heavily on the harvester's expertise. When harvested at different maturities, rates of respiration and ethylene production, as well as physicochemical characteristics, vary, which influence overall fruit quality (Nordey et al. 2016) and eating quality (Walsh 2022). On the other hand, exporters face challenges such as immature fruit, improper postharvest handling, and inadequate quality control. More reliable fruit quality recognition is desirable to ensure that consumers obtain the fruit types they desire (Diana et al. 2025). Growers and exporters become familiar with the quality standards, albeit accurately assessing internal quality remains a

challenge. Quality standards ensure uniform quality and food safety, thereby establishing consumer confidence, especially when specifications are set in trade agreements. The standard can serve as a tool for gaining a competitive advantage, particularly in international markets (Walsh 2022). Meeting the demand for fruit poses challenges in both quantity and quality. This study determined and compared the physicochemical characteristics of 'Puyat' durian across various quality classes and three ripeness stages.

MATERIALS AND METHODS

Sample collection

Sixty-six 'Puyat' durian fruit of the required quality were procured from a farm in Calinan, Davao City, Philippines. The durian fruit was harvested at the commercial maturity stage by trained harvesters on the farm, with approximately 5 days remaining until ripening. Fruit were sorted and classified according to quality grades as Class A (Premium Grade), Class B (Grade I), and Class C (Grade II).

The quality grade classification was based on the Philippine National Standard (2004) for durian fruit. This study included the number of locules per fruit and the use of A, B, and C as quality classes, based on growers' and packhouses' actual grading. Classes A, B, and C correspond with Premium Grade, Grade 1, and Grade II, respectively. In premium grade, or Class A for export, durian fruit is well-formed, of superior quality, free from defects associated with insects and microorganisms, and free from external physiological disorders, except for very slight superficial defects that do not detract from the appearance of the produce, keeping quality, and presentation in the package. The quality grade I, or Class B, may allow for slight defects that do not exceed 10% of the total surface area of the fruit, provided these do not affect appearance, keeping quality, or the package's presentation. This quality grade is acceptable for the local market. The quality grade II, or Class C, consists of fruit which do not qualify in the higher classes like fruit that are deformed and other defects such as broken spines. It is often used for processing. The weight of durian for the three classes should be between 1.5 and 4 kg.

Samples were transported and stored in ambient room conditions (26.51 ± 1.14℃, 76.73 ± 7.09% RH) in the Postharvest Biology Laboratory at the University of the Philippines Mindanao for postharvest quality evaluation. These were monitored at three ripeness stages: unripe (at harvest), ripe (5 days after harvest), and overripe (8 days after harvest). Physical evaluation included the number of locules, fruit weight, weight loss, rind color, visual quality, degree of disease, degree of fruit dehiscence, days to dehiscence, ripening index, and days to the table ripe stage. Other characteristics measured were dry matter content, pulp weight, seed weight, pericarp weight, pericarp thickness, pulp color, pulp firmness, and total

soluble solids.

Parameters measured

Physical characteristics

Fruit circumference (vertical and horizontal) was initially assessed at the mid-transverse part of the fruit using a twine, which was measured with a ruler. The number of locules of each fruit was recorded upon harvest. For percentage weight loss, the initial weight of fruit at harvest, ripe, and overripe stages were recorded using a digital weight balance and Equation 1:

$$Percentage\ weight\ loss\ (\%) = \frac{initial\ weight\ loss - final\ weight\ (ripe\ and\ over\ ripe)}{initial\ weight} \times 100 \quad (1)$$

Rind color was assessed using a 1-5 scale index, where 1 - more green than brown; 2 - more brown than green; 3 - brown with traces of green; 4 - yellowish brown; and 5 - blackish brown or dark brown or full yellow (Figure 1).

Visual quality of fruit was determined using a modified scale of Alpos et al. (2023) with 8-9 as excellent, field fresh to 1 as very poor (Figure 2), while disease severity was evaluated using the rating scale: 1 (no signs of disease), 2 (1-20% disease), 3 (21-40% disease), 4 (41-60% disease), 5 (61-80% disease), and 6 (81-100% disease) (Figure 3).

The degree of fruit dehiscence was also determined using Alpos et al. (2023) scale for 'Puyat' with 1 (no dehiscence), 2 (dehiscence up to ¼ of suture length), 3 (up to ½ of suture length), 4 (up to ¾ of suture length), and 5 (along the entire suture length) (Figure 4). The number of days to dehiscence or capsule splitting was also recorded.

Figure 1. 'Puyat' durian fruit rind color rating scale

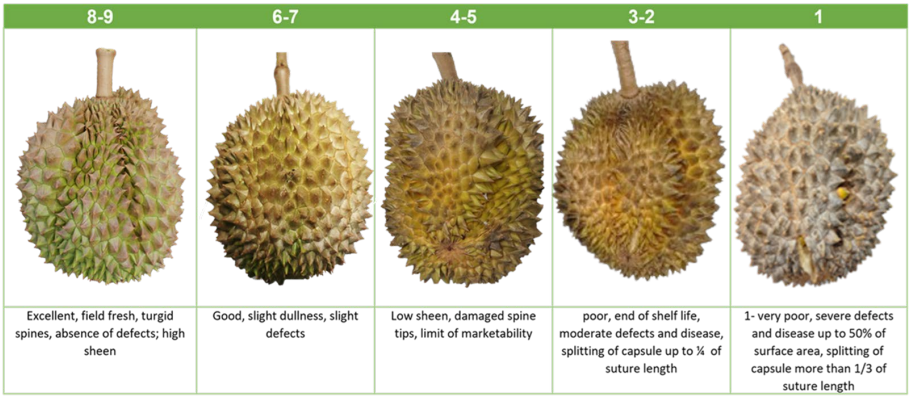

Figure 2. 'Puyat' durian fruit visual quality rating scale (modified from Alpos et al. 2023)

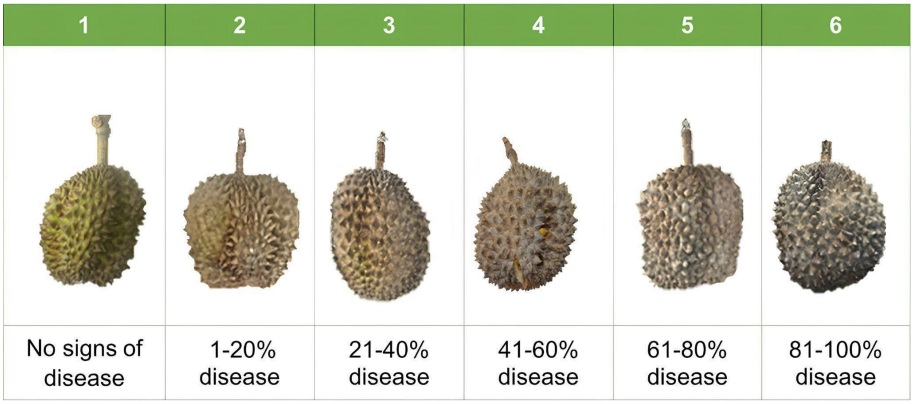

Figure 3. 'Puyat' durian fruit degree of disease rating scale (adapted from Alpos et al. 2023)

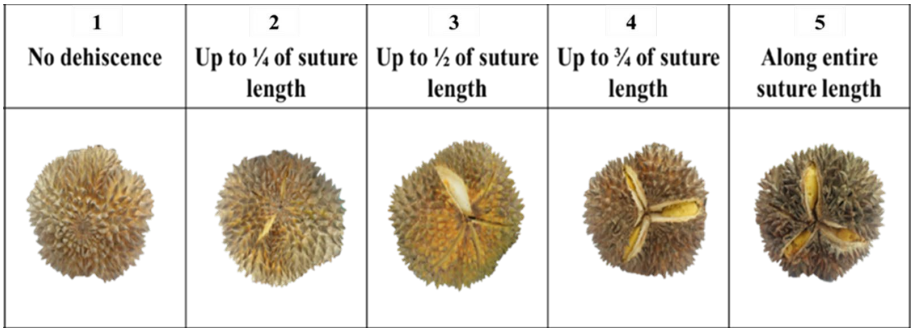

Figure 4. 'Puyat' durian degree of fruit dehiscence rating scale (adapted from Alpos et al. 2023).

Ripening characteristics

Various indicators were used to monitor durian ripening. Ripening indicators used include fruit stalk (peduncle) abscission and presence of hollow sound (Paull & Ketsa 2014) as well as change in spine tip color, degree of pliability of spines, intensity of whole fruit aroma, and pulp color (BPI-DNCRDPSC, 2019). Pliability of spine was measured using a five-point rating scale wherein 1= not pliable, 2= slightly pliable, slight 'give' with strong hand pressure; 3= moderately pliable, spine deforms with moderate hand pressure aroma; 4= pliable, spine deforms with light hand pressure; and 5= very pliable, spine easily deforms with very light hand pressure. Peduncle abscission was also determined in a 1-5 rating scale as 1= intact, 2= slight crack, 3= slight abscission, 4= more than 50% abscission, and 5= detached fruit stem. Meanwhile, the intensity of the whole fruit aroma was measured as 1= no aroma, 2= very weak aroma, 3= weak aroma, 4= strong aroma, and 5= very strong aroma. The number of days to the ripe stage (TRS) of fruit was also recorded.

Other fruit characteristics

Dry matter content was analyzed using the method of Sangwanangkul & Siriphanich (2000). A pulp sample from the middle segment of each locule was cut into pieces and thoroughly mixed. A composite sample of about 20 g of the mixed pulp was dried to constant weight in a hot air oven at 70 ℃ for 48 h. The percentage of dry matter content was calculated using Equation 2:

$$Dry\ matter\ content\ (\%) = \frac{Final\ weight}{Initial\ weight} x100 \quad (2)$$

The aril or pulp, seeds, and the pericarp or capsule were weighed separately using a digital weighing balance. Pericarp thickness was measured from the middle part of the pericarp using a digital caliper. The color of 'Puyat' durian was subjectively assessed using a six-scale index, where 1 = white, 2 = creamy white, 3 = light yellow, 4 = yellow, 5 = yellow-orange, and 6 = orange. On the other hand, pulp firmness was measured using an analog fruit firmness tester (TR 53200, Narmada Machineries and Tools, Haryana, India) equipped with a cylindrical plunger 0.5 cm in diameter. The plunger was inserted into the pulp to a depth of 1 cm, and the force exerted (kgF) was recorded. For total soluble solids (TSS), 4g of durian pulp was added with 12 mL of distilled water and was homogenized using a glass blender (Osterizer, Oster, Metro Manila, Philippines). The TSS of the sample was measured using a hand-held refractometer (PAL-1, Atago Co., Ltd., Tokyo, Japan), with % Brix readings multiplied by 3 to account for the dilution.

Statistical analysis

The experiment was laid out in a completely randomized design (CRD) using two factors, quality classes (Class A, B, and C) and ripeness stages (unripe, ripe, and

overripe). Each quality class per ripening stage consisted of 10 fruits as non-destructive samples for physical evaluation and four replicates as destructive samples for physicochemical assessment—an individual fruit served as a replicate. Data were analyzed using a Two-Way Analysis of Variance (ANOVA), and treatment means were compared using the Least Significant Difference at the 5% level of significance. Statistical analysis was performed using the R Package Statistical Tool (R Core Team 2019), a free and licensed software.

RESULTS AND DISCUSSION

Some morphological characteristics of 'Puyat' durian fruit

Vertical and horizontal circumference of the fruit samples among the three classes did not vary, while the number of locules did (Table 1). The durian fruit typically has three to seven locules, each of which develops into a fruitlet from the ovary after successful pollination (Ketsa et al. 2020). For instance, export-grade 'Musang King' durians typically exhibit five locules and an average fruit weight of about 2 kg (Nor & Ding 2023).

Table 1. Fruit circumference and locule number of different quality grades of 'Puyat' durian (n= 10)

Quality	Circumference (vertical, cm)	Circumference (horizontal, cm)	Number of locules
Class A	23.91[a]	20.96[a]	3.60[a]
Class B	22.86[a]	20.75[a]	2.80[b]
Class C	23.46[a]	21.26[a]	2.80[b]

Note: Means in a column with common letters are not significantly different using LSD at 5% level of significance.

Variation in locule number and development can be attributed to the pollination source. Lim & Luders (1998) observed that self-pollinated durian fruit produced fewer locules and were deformed. Honsho et al. (2009) made similar observations, noting that self-pollination among four durian cultivars also resulted in misshapen fruit and fewer developed seeds. In the absence of seeds, aril development in certain locules may cease, leading to poor locule formation. Inadequate locule development ultimately contributes to the

deformation of Class C fruit. This aligns with Brown's (1997) idea that the presence of seeds influences fruit shape, which Honsho et al. (2009) suggest is likely due to the uneven distribution of hormones produced by developing seeds. This may also imply that Class A durians are likely the result of cross-pollination, whereas Class C fruit may have arisen from self-pollination. Self-pollinated durian fruit has been reported to result in poor yield and quality, including misshapen, lower fresh weight, seed and aril, heavier and uneven thick rind (Lim & Luders 2009).

On the other hand, fruit weight was highest in Class A durians at the unripe stage, with lower weights noted in the lower-quality classes and at advanced ripeness (Table 2). Pericarp thickness and weight were generally similar among quality classes, except in overripe fruit, where both were reduced. On the other hand, pulp and seed weights were greater in Class A durian, while these were lower in Class C and Class B fruit, respectively.

Table 2. Parts of the fruit and characteristics of 'Puyat' durian of different quality grades and ripening stages (n= 4)

Factor	Fruit weight (G)	Pericarp thickness (cm)	Pericarp weight (g)	Pulp weight (g)	Seed Weight (g)	Pericarp (%)	Pulp (%)	Seed (%)
Quality (A)								
Class A	2572.22^{a}	8.32^{a}	1523.77^{a}	718.55^{a}	308.51^{a}	59.74^{b}	28.17^{a}	12.09^{a}
Class B	2190.99^{b}	7.87^{a}	1368.98^{a}	641.41^{a}	157.12^{c}	63.16^{ab}	29.59^{a}	7.25^{b}
Class C	2098.60^{b}	8.40^{a}	1379.91^{a}	481.56^{b}	218.19^{b}	66.35^{a}	23.16^{b}	10.49^{a}
Ripeness stage (B)								
Unripe	2512.98^{a}	8.91^{a}	1508.71^{a}	798.09^{a}	182.16^{b}	60.62^{b}	32.06^{a}	7.32^{b}
Ripe	2314.76^{ab}	9.62^{a}	1521.51^{a}	486.71^{b}	284.66^{a}	66.36^{a}	21.23^{b}	12.41^{a}
Overripe	2034.07^{b}	6.06^{b}	1242.43^{b}	556.71^{b}	216.99^{b}	61.62^{b}	27.61^{c}	10.76^{a}
Interaction (A x B)	ns	ns	ns	ns	*	ns	ns	*

Note: Data reckoning for Factor A is at harvest, Factor B is when fruit has reached the particular ripening stage. Per factor, means in a column with common letters are not significantly different using LSD at 5% level of significance.

Class A durians exhibited a lower pericarp-to-fruit weight ratio, along with higher percentages of pulp and seed. In contrast, Class B fruit had a higher

pulp percentage and a lower seed proportion, while Class C durians were characterized by higher percentages of pericarp and seed, and a lower pulp content.

Honsho et al. (2009) reported that seed weight is strongly associated with overall fruit weight, possibly due to the sink strength of developing seeds. Two types of seeds, namely normal and aborted, are typically produced in durian. According to Bhimidine et al. (2013), strong sink strength, driven by high invertase activity, sugar import, and signaling, promotes the development of normal seeds. The absence of these mechanisms results in weak sink strength, leading to the formation of aborted seeds. Normal seeds draw more assimilates from the parent plant and develop into larger, heavier, and well-formed seeds. On the other hand, aborted seeds, which function as poor sinks, pull fewer resources and often develop into thinner, compressed, and shrunk. Thus, Honsho et al. (2009) have concluded that although aborted seeds still function as sinks, they do not significantly contribute to fruit development.

This process may also be linked to the ability of normal seeds to undergo proper development and produce adequate hormones required for optimal cell growth and fruit development (Kang et al. 2013, Balaguera-Lopez et al. 2020). Thus, Class A durians, which characteristically exhibit normal fruit shape and well-developed locules, are likely to contain typically developed seeds. This is further supported by their higher seed weight, increased pulp proportion, and greater overall fruit weight.

In contrast, Class B fruit may contain aborted seeds, as indicated by their lower seed weight, reduced seed percentage, and relatively higher pulp content. These findings are further supported by Ketsa et al. (2020), who reported that locules containing aborted seeds are often associated with increased pulp thickness, sometimes reaching up to 3 cm, as also described by Siriphanich (2011).

In the case of Class C fruit, the reduced pulp percentage may be attributed to their pollen source, as self-pollination has been shown to result in misshapen fruit with fewer locules, fewer well-formed arils, and lower flesh recovery (Lim & Luders 1998). In the present study, these characteristics were also observed in Class C samples. Quyen et al. (2025) have indicated that poor nutrient availability and excessive soil moisture may contribute to reduced aril development in durians. These conditions may further intensify competition for assimilates between developing seeds and arils, potentially affecting aril formation and overall fruit quality.

Regarding ripening, Sriyook et al. (1994) reported shrinkage in both the outer green and inner white parts of the rind, resulting from water loss during capsule splitting during durian dehiscence. This shrinkage may contribute to the reduced pericarp and overall fruit weight observed at the overripe stage compared to the unripe and ripe stages. Moreover, unripe fruit displayed a higher pulp weight because the aril had not undergone extensive changes relative to the ripe and overripe aril. Ripe fruit showed a higher seed weight, possibly due to fully developed seeds. Conversely, ripe fruit displayed a higher % pericarp and % seed but low % pulp, while unripe fruit had a higher % pulp. Notably, a lower % seed was observed in unripe fruit, likely due to a higher pulp percentage.

Fruit quality and ripening characteristics

Visual quality was better in Class A fruit than in other quality grades and declined with ripening (Table 3). Towards the overripe stage, durian fruit becomes susceptible to diseases, capsule splitting, and more rapid weight loss. The different fruit classes exhibited weight losses ranging from 14% to 18.47% across the three ripeness stages. Better fruit quality in Class A fruit is due to its soundness or the absence of defects, physiological disorders, insects, and microbial damage. On the other hand, deformed or misshapen forms in Class C fruit result in reduced size.

In strawberries, Ariza et al. (2011) reported similar observations, indicating a direct correlation between greater weight loss and smaller misshapen fruit. This is due to the greater surface area-to-volume ratio in smaller fruit, which provides more sites for water loss, thereby reducing fruit weight. Moreover, Nunes & Emond (2007) found a direct effect of weight loss on lower visual quality in produce due to water loss, reduced gloss, and greater shriveling, resulting in reduced fruit quality.

Overripe fruit recorded a 21.89% weight loss. During storage, weight loss increased with ripening from the unripe to the overripe stages. This can be attributed to the storage duration of 8 d in ambient conditions (26.51 ± 1.14℃, 76.73 ± 7.09% RH). In earlier reports, Alpos et al. (2023) noted weight losses in ‘Puyat’ durian held in ambient conditions (27.24 ± 0.51℃, 86.73 ± 2.58% RH) over 12 days, ranging from 24.4 to 28.8%. These two weight losses in ‘Puyat’ varied due to the higher RH in the storage in the earlier durian study by Alpos et al. (2023). Ketsa & Pangkool (1994) reported that durian had mean daily weight losses of 3.8% and 2.7% at 75% and 83% RH, respectively. In addition, weight loss reached 21.0% when stored at 30℃ and

70% RH for more than 9 days.

Table 3. Physical quality of 'Puyat' durian of different quality grades and ripeness stages.

Factor	Visual quality	Rind color	Degree of disease	Degree of fruit dehiscence	Weight loss (%)
Quality (A)					
Class A	5.33[a]	2.53[a]	1.07[a]	1.83[a]	14.54[b]
Class B	4.87[b]	2.30[a]	1.07[a]	1.63[b]	14.00[b]
Class C	3.40[c]	2.17[a]	1.17[a]	1.47[b]	18.47[a]
Ripeness stage (B)					
Unripe	5.83[a]	1.57[c]	1.00[b]	1.00[b]	-
Ripe	5.20[b]	2.33[b]	1.00[b]	1.00[b]	9.45[b]
Overripe	2.57[c]	3.10[a]	1.30[a]	2.83[a]	21.89[a]
Interaction (A x B)	*	ns	ns	ns	ns

Note: Reckoning for Factor B is when the fruit has reached the particular ripening stage. Per factor, means in a column with common letters are not significantly different using LSD at 5% level of significance. (N=10). Visual quality rating: 8-9= excellent, field fresh, turgid; 6-7= good, slight dullness; 4-5= low sheen, damaged spine tips; 2-3= poor, end of shelf life, moderate defects. Rind color rating scale of 1 to 5: 1 = more green than brown; 2 = more brown than green; 3 = yellowish brown; 4 = brown; 5 = blackish brown or dark brown. Degree of disease rating scale: 1= no signs of disease, 2= 1-20% disease, 3= 21-40% disease, 4= 41-60% disease, 5= 61-80% disease, and 6= 81-100% disease. Degree of dehiscence: 1 = no dehiscence, 2 = up to 1/4 of the suture length, 3 = up to 1/2 of the suture length, 4 = up to 3/4 of the suture length, 5 = along the entire suture length.

Meanwhile, rind color did not vary among the three quality classes, but there was a notable color change from green to a more yellowish-brown as the fruit ripened (Figure 5). Ketsa & Pangkool (1994) observed a loss of greenish coloration in durian fruit ripened at low humidity, compared to durian fruit ripened at high humidity, in which the rind color remained green. In the present study, the fruit samples were held at 69.64-83.84% RH. The brown pigmentation observed in the rind of ripe durian may be attributed to the periderm and lenticels along the grooves and sutures, which develop a brown coloration upon fruit maturity (Siriphanich 2011).

In addition, the degreening in durian can be due to chlorophyll breakdown in the rind, possibly induced by higher ethylene production in the husk

(Tanaka & Ito 2025, Booncherm & Siriphanich 1991). Tanaka & Ito (2025) reported that ethylene induced the expression of chlorophyll-degrading enzymes during ripening. This is mediated by the binding of ethylene response factors, transcription factors that bind the promoters of chlorophyll catabolic genes, thereby activating their expression (Liu et al. 2015).

Figure 5. Physical appearance of various grade qualities and ripeness stages of 'Puyat' durian fruit held in ambient conditions (26.51 ± 1.14℃, 76.73 ± 7.09% RH)

The degree of disease did not vary among the quality classes, but disease progression was distinct at the overripe stage. Additionally, Class A fruit displayed a slightly higher level of fruit dehiscence compared to other classes, whereas dehiscence was primarily observed in overripe fruit. Dehiscence in durian fruit is known to typically occur along the sutures between locules (Sriyook et al. 1994). Higher levels of splitting might be associated with a greater number of locules among Class A durians. Similarly, Shakya & Lal (2018) reported increased respiration and ethylene production during the overripe stage in climacteric fruits such as durian. Exposure to ethylene then increases the incidence of durian dehiscence (Sriyook et al. 1994). This is possibly due to increased expression of dehiscence-related genes involved in cell wall degradation in the presence of endogenous ethylene (Ogawa et al. 2009).

Pulp characteristics

Pulp firmness and total soluble solids did not vary among the fruit quality classes (Table 4). Higher dry matter content was recorded in class B fruit and

at the ripe stage of fruit. Fruit softening was high at the overripe stage. Total soluble solids increased from unripe to overripe fruit. A notable color change in the pulp was observed, from creamy white in unripe fruit to an orange color in overripe fruit.

Table 4. Pulp characteristics of 'Puyat' durian of different quality grades and ripeness stages (n= 4)

Factor	Pulp firmness (kgF)	Pulp total soluble solids (% Brix)	Pulp color	Pulp dry matter content (%)
Quality (A)				
A	3.75[a]	15.76[a]	4.50[a]	37.38[b]
B	4.31[a]	16.63[a]	4.58[a]	40.42[a]
C	3.31[a]	16.92[a]	4.92[a]	36.73[b]
Ripening stage (B)				
Unripe	10.08[a]	9.89[c]	2.58[c]	38.71[a]
Ripe	1.07[b]	18.80[b]	5.42[b]	40.38[a]
Overripe	0.76[b]	20.63[a]	6.00[a]	35.44 [b]
Interaction (A x B)	ns	ns	ns	*

Note: Reckoning for Factor B is when the fruit has reached the particular ripening stage. * Per factor, means in a column with common letters are not significantly different using LSD at 5% level of significance. TRS-table ripe stage. Pulp color rating scale: 1 - white; 2 - creamy white; 3 - light yellow; 4 - yellow; 5 - yellow orange; 6 - orange.

Durian pulp or aril softening is attributed to endogenous ethylene production of fruit during ripening and dehiscence (Thongkum et al. 2018, Ketsa et al. 2020). The reduction in pulp firmness is associated by enzymatic conversion of water-insoluble pectin to water-soluble pectin by cell wall-degrading enzymes such as polygalacturonase (Ketsa & Daengkanit 1999, Ketsa et al. 2020). The change in durian pulp color from creamy to dark yellow or orange is likely due to the accumulation of β-carotene during ripening (Siriphanich 2011). Elevated TSS levels in ripe and overripe stages are caused by an increase in total sugars, resulting from starch degradation (Añabesa et al. 2006, Sangwanangkul & Siriphanich 2000).

Chaisrichonlathan & Chavapradit (2017) found that dry matter (DM) content in durian pulp accumulates during maturation due to moisture loss, and that late or mature harvest resulted in higher DM content at both harvest and the ripe stage (Nordey et al. 2016). This is evident in the increasing trend of DM from unripe to ripe in the present study. Sharma et al. (2022) reported a similar trend: higher DM at the unripe-to-ripe stage, followed by a decline at the overripe stage.

DM content is also known as the total solids in fruit excluding water (Scalisi & O'Connell 2021, Nordin et al. 2017). This includes carbohydrates, starch, proteins, minerals, cell walls, organic acids, and fibers (Ibrahim et al. 2021, Yongyut et al. 2025). The decline in DM in overripe fruit is possibly due to the degradation of cell wall pectin during pulp softening at the overripe stage (Ketsa & Daengkanit 1998, 1999).

Ripening characteristics

The ripening characteristics, such as the color change of spine tips from green to brown and the production of a hollow sound, were observed five days after harvesting (Table 5). The degree of fruit stem abscission was similar in all quality classes; however, this was notably faster and greater at the overripe stage. Likewise, the whole fruit aroma was not distinct and was relatively weak across classes; however, a slight increase in aroma intensity was observed at the overripe stage, with a maximum aroma score of 4.24 (data not shown).

The spine's pliability did not differ among the quality classes. However, as the fruit ripened, there was a progression in spine pliability, starting at the ripe stage and becoming increasingly pliable at the overripe stage.

The aroma of durian fruit is influenced by its level of maturity, with durian harvested at the mature stage having a weaker aroma than those that naturally drop from trees (Nanthachai 1994, Ho & Bhat 2015). This can be attributed to the reduced number of volatile compounds, particularly esters, in fruit harvested at 75–85% maturity compared to those at full maturity (100%) (Maninang et al. 2011). In addition, the stronger odor of durian at the overripe stage may be due to the aroma from the exposed durian pulp resulting from capsule splitting. Compared to the durian rind, the pulp was found to have more concentrated levels of sulfur compounds in the forms of thiols and thioesters that are responsible for the distinct pungent odor of the fruit (Sospeter et al. 2025).

Subhadrabandhu & Ketsa (2001) reported that the flexibility of spines,

when pressed against each other, is possibly due to the softening of rind tissues during fruit dehiscence (Siriphanich 2011). This softening is likely caused by the degradation of pectin and hemicellulose by cell wall–degrading enzymes (Khurnpoon et al. 2008). The hollow sound of fruit is produced when the aril separates from the rind, leaving space in between as the fruit continues to mature and ripen (Siriphanich 2011).

Table 5. Ripening characteristics of 'Puyat' durian with different quality grades and ripening stages in ambient conditions (26.51 ± 1.14℃, 76.73 ± 7.09% RH) (n = 10).

Factor	Days to brown spine tips	Days to hollow sound	Degree of fruit stalk abscission	Whole fruit aroma intensity	Degree of spine pliability	Days to TRS	Days to fruit dehiscence
Quality (A)							
Class A	5.0[a]	5.0[a]	2.1[a]	1.87[a]	2.67[a]	5.0[a]	8.0[a]
Class B	5.0[a]	5.0[a]	1.8[a]	1.33[b]	2.57[a]	5.0[a]	8.0[a]
Class C	5.0[a]	5.0[a]	1.5[a]	1.63[ab]	2.57[a]	5.0[a]	8.0[a]
Ripening stage (B)							
Unripe	-	-	1.0[b]	1.00[b]	1.0[c]	-	-
Ripe	5.0[a]	5.0[a]	2.0[a]	1.07[b]	2.0[b]	5.0[a]	-
Overripe	-	-	2.4[a]	2.77[a]	4.8[a]	-	8.0[a]
Interaction (A x B)	ns	ns	ns	ns	ns	ns	ns

Note: Reckoning for Factor B is when fruit has reached the particular ripening stage. Per factor, means in a column with common letters are not significantly different using LSD at 5% level of significance. Aroma: 1= no aroma, 2= very weak aroma, 3= weak aroma, 4= strong aroma, 5= very strong aroma. Fruit stalk abscission: 1= intact, 2= slight crack, 3= slightly open, 4= more than 50% opening, 5= detached fruit stem. Spine pliability: 1= not pliable, 2= slightly pliable, slight 'give' with strong hand pressure, 3= moderately pliable, spine deforms with moderate hand pressure aroma, 4= pliable, spine deforms with light hand pressure, 5= very pliable, spine easily deforms with very light hand pressure. - = none. TRS- table ripe stage.

Other ripening indicators include abscission of the fruit stem among overripe fruit, rind yellowing, fruit dehiscence (Amornputti et al. 2014), and the sutures becoming evident, and the tip of spines had begun to dry (Wiangsamut & Wiangsamut 2023).

Ripening indices, table ripe stage (TRS), and dehiscence

Table 6 shows the correlation between the different characteristics of ripening fruit. Among these characteristics, pulp color, spine tip browning, hollow sound, total soluble solids (TSS), and spine pliability showed strong positive correlations with ripening (r = 0.85 to 0.97). These physical characteristics change consistently as the fruit transitions from unripe to ripe to overripe, highlighting their reliability as indicators of fruit development and senescence.

Table 6. Correlation between different ripening characteristics and fruit ripeness stage

Index	Ripeness stage	Pulp color	Aroma	Brown tips	Hollow sound	TSS	Firm-ness	Spine pliability	Fruit stalk abscission
Ripeness stage	1								
Pulp color	0.85	1							
Aroma	0.48	0.62	1						
Brown tips	0.87	0.89	0.74	1					
Hollow sound	0.87	0.89	0.74	1	1				
TSS	0.87	0.89	0.66	0.92	0.92	1			
Firmness	-0.80	-0.97	-0.67	-0.91	-0.91	-0.90	1		
Spine pliability	0.97	0.86	0.57	0.91	0.91	0.89	-0.84	1	
Fruit stalk abscission	0.26	0.33	0.40	0.42	0.42	0.38	-0.37	0.26	1

Note: Hollow sound: 1= none, 2=present. Spine tip browning: 1= none, 2=present.

On the other hand, firmness showed a strong negative correlation (r = -0.80), suggesting an inverse relationship with ripening, in which fruit (pulp) becomes progressively softer as it ripens. On the other hand, aroma and fruit stalk abscission displayed weak correlations (r = 0.48 and 0.26, respectively), implying these indicators may become distinct later in the ripening of ‘Puyat’ durian. Hence, the days until the ripe stage (TRS) were

reckoned upon the presence of strongly correlated ripening indicators. All fruit classes reached TRS at 5 days after harvest and exhibited dehiscence at 8 days of storage (Table 5). This similarity can be attributed to uniform maturity among the fruit classes in the samples as determined by the experienced harvester.

CONCLUSIONS

'Puyat' durian fruit of three quality grades (Classes A, B, and C) were procured and evaluated at three ripening stages, namely, unripe, ripe, and overripe under ambient conditions (26.51 ± 1.14℃, 76.73 ± 7.09% RH). The grading practices of farmers and packhouses, including locule number, were followed in this study. The number of locules averaged 3.6 for Class A fruit and 2.8 for Classes B and C fruit, while the vertical and horizontal circumferences of fruit did not vary. Class A durian exhibited greater fruit weight than Classes B and C, with unripe fruit exhibiting a higher initial weight. 'Puyat' durian consisted of 62.97% pericarp, of which both pericarp thickness and weight were reduced at the overripe stage. The pulp and seed comprised 26.97% and 10.05% of the fruit, respectively. Class C fruit was deemed least desirable because it had lower pulp weight and a higher % pericarp relative to the whole fruit.

Class A fruit showed superior visual quality that declined with ripening. Fruit weight loss ranged from 14% to 18.47% across ripeness stages. Rind color changed consistently from green to yellowish-brown along with disease incidence, though progression of the latter was more evident in overripe fruit. Fruit dehiscence was higher in overripe fruit. During ripening, pulp firmness decreased while TSS increased to twice that of the unripe fruit, and pulp color changed from creamy white to orange. Dry matter content was higher in the unripe and ripe stages across three fruit classes. Among ripening characteristics, pulp color, spine tip browning, spine pliability, hollow sound, TSS ($r = 0.85$-0.97), and pulp firmness ($r = -0.80$) showed strong correlation with ripening, demonstrating their utility as good ripening indicators. All fruit classes reached the table ripe stage and dehiscence at 5 and 8 days after harvest, respectively. This study reports on the physicochemical characteristics of 'Puyat' durian classes and ripeness stages and estimates the natural fruit ripening duration under ambient conditions to help reduce issues with harvested fruit quality. Likewise, it has developed a rating scale

for rind color.

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