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Impact of harvesting stages on physicochemical properties, antioxidant activity and enzymatic digestibility of durian flour

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Abstract The physicochemical, antioxidant, and digestive characteristics of the durian cv. Monthong flesh flour harvested at various maturity stages (90, 95, 100, 105, 110, 115, and 120 days post-full bloom) were examined. The lightness (L*) of durian flour decreased with the harvesting stage, along with the redness (a*), while the yellowness (b*) tended to increase. In addition, the total sugar content also rose with the maturation stage. The amylose content and DPPH antioxidant inhibition levels increased with the harvesting stage but declined at 120 days. Both 110-days and 115-days durian flours were selected for further study. Rapid Visco Analysis revealed an elevation in peak viscosity, trough viscosity, final viscosity, breakdown, and setback in 115-days durian flour, whereas their pasting temperatures were indifferent for both samples. The 110-days durian flour exhibited a slower glucose release compared to the 115-days durian flour, especially during the initial 60 min of digestion. Furthermore, the granule morphology of both durian flours, as observed by Scanning Electron Microscopy, demonstrated pentagonal, angular, and irregular shapes. The 110-days durian flour had higher levels of protein, fat, crude fiber, and moisture content compared to that from 115- days. This result indicated that harvesting durians at 110 days is found to be optimal for producing durian flour with functional attributes, in terms of antioxidant inhibition and a low glucose release rate, making it suitable as a functional food component.

Keywords: Durian flour, Harvesting stages, Antioxidant, Enzyme digestion

Introduction

Durian (*Durio zibethinus* L.) is a premium fruit belonging to the Malvaceae family. It flourishes in the tropical climes of Southeast Asia, predominantly cultivated in Thailand, Malaysia, and certain regions of Indonesia. Limited cultivation also occurs in Australia and Florida. China is the leading importer of durian, succeeded by Hong Kong, Singapore, Taiwan, Macao, and Japan. Due to its distinctive flavor, fragrance, nutritional benefits, and varied

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industrial uses, durian has garnered considerable attention recently. The market was valued at $23.23 billion in 2022 and is anticipated to attain $46.35 billion by 2032. Despite the persistently rising market demand, the durian sector encounters numerous issues associated with irregular output and availability in recent years (Ali *et al*., 2024).

Khaksar *et al*. (2024) reported that durian flesh is rich in nutrients, although the amount of nutrients can change depending on the variety of durian. Durian flesh contains between 84 and 185 kcal/100g (fresh weight). The Thai Kradum variety has the highest energy content at 185 kcal, while the Indonesian Hejo variety has the lowest at 84 kcal. Moreover, it contains carbohydrate content ranges from 15.65 to 34.65 g/100g (fresh weight) across different cultivars. Protein levels are between 1.40 and 3.50 g/100g, while fat content is high, ranging from 1.59 to 5.39 g/100g. The total sugar content is between 3.10 and 19.97 g/100g, with sucrose being the most abundant sugar (5.57 to 17.89 g), followed by glucose, fructose, and maltose. In addition to its unique flavor and health benefits, durian flesh is rich in various nutrients, including vitamins B1, B2, A, C, and E and minerals such as calcium, phosphorus, potassium, and iron. Durian also exhibits high antioxidant properties from polyphenol compounds, particularly caffeic acid and quercetin, as well as sulfur-containing compounds like glutathione (GSH) and its precursor, gamma-glutamylcysteine (γ-EC). Moreover, durian is a very rich natural source of folate, with a content of 0.175-0.44 mg/100g (fresh weight). The daily recommended intake for folate is 0.3 mg, meaning durian lovers in Southeast Asia can easily exceed their daily requirement by consuming more than 200 g/day (Striegel *et al*., 2018).

The amount and type of bioactive compounds in durian flesh including phenolic compounds, flavonoids, carotenoids, and anthocyanins vary significantly depending on factors such as cultivar and ripening stage. The relationship between these compounds and ripening shows that in Monthong durian, the concentration of total phenolic compounds and flavonoids is significantly higher in ripe fruit than in the mature or overripe stages. The main antioxidants identified in the ripe stage are caffeic acid and quercetin (Arancibia-Avila *et al*., 2008). This is consistent with a study by Paśko *et al*. (2011), which found that ripe and overripe Monthong durian had the highest levels of polyphenols, flavonoids, flavanols, tannins, and vitamin C, as well as the highest antioxidant capacity. A study of various durian cultivars (Monthong, Chanee, Kanyao, Puang Manee, and Kradum) found that Monthong had the highest total phenolic and flavonoid content (361.4 mg GAE/100 g and 93.9 mg CE/100 g, respectively) (Toledo *et al*., 2012). Furthermore, it was also found that ripe durian contains the highest levels of bioactive compounds and antioxidant properties compared to other stages, with phenolic compounds being a key factor contributing to the overall antioxidant effectiveness of the pulp. Previous research also indicates that the durian's ripening stage affects its internal composition, such as starch and sugar content. Starch content significantly decreases as the fruit ripens, with unripe fruit having a higher starch content. In contrast, fully ripe fruit undergoes internal changes, such as an increase in sugar content, which is a result of the fruit's metabolic processes converting carbohydrates into more sweetness. Structural changes to the starch granules, as well as their water absorption capacity and physical state, also change with the level of fruit ripeness. Therefore, the chemical properties and structure of durian in its unripe or ripe stages are crucial for the quality of processed products and their suitability for the food industry (Bai-Ngew *et al*., 2014). However, when considering harvesting and waste, Thai farmers harvest mature durian based on criteria such as the number of days after flowering, color, and thorn firmness, which gives the fruit a long shelf life of 5-10 days. With the increase in durian cultivation in Southeast Asia, its economic potential, and the health benefits tied to its ripeness or harvest stage. The research aim was to study the physicochemical properties, antioxidant capacity, and enzymatic digestibility of flour from Monthong durian flesh harvested at 90-120 days post-full bloom.

Materials and methods

Materials

Raw material in this study was the unripe durian cv. Monthong which obtained from local durian orchard in Pong Nam Ron District, Chanthaburi Province, Thailand. Porcine pancreatic α-amylase (A-3176), pepsin (P-6887), pancreatin (P-1750), amyloglucosidase (A-7420), and 2,2-diphenyl-1-picrylhydrazyl (D9132) were purchased from Sigma-Aldrich (Sigma Chemical Co., St. Louis, Mo., USA). The other chemicals were of analytical grade.

Sample collection

Sampling was carried out from May 2024 to June 2024, the durian season. The sample collection was divided into 7 harvesting stages as follows: 90 days, 95 days, 100 days, 105 days, 110 days, 115 days, and 120 days, respectively (post-full bloom). Durian samples were separated into two sets. Sample set 1 was collected starting on May 15, 2024, from flowers that had bloomed on February 15, 2024 (90 days) whereas sample set 2 was collected starting on May 25, 2024, from flowers that had bloomed on February 25, 2024 (90 days). All samples had an average fruit weight of 2-5 kg and were harvested from the same tree within each set.

Durian flour preparation

Monthong durians harvested at various stages were processed into durian flour. The sample fruits were first peeled to separate the flesh from the seeds and husk. The flesh was then cut into small, equally-sized pieces (approximately 0.5 cm thick), arranged on trays, and dried in a hot-air oven at 60°C for 36 h, or until the moisture content was less than 12%. The dried samples were then finely ground, sieved through a 100-mesh sieve, and stored in sealed zip-lock bags at room temperature for futher analysis.

Amylose content and total sugar content analysis

The amylose content was analysed using an amperometric titration as described by Juliano (1984). Total sugar content was analyzed using the phenol-sulfuric acid method according to the method of Fox and Robyt (1991).

Antioxidant activity by DPPH radical scavenging assay

The antioxidant activity was analyzed using the DPPH (Diphenyl picrylhydrazyl) radical scavenging assay, according to the method of Zhu *et al.* (2006) with slight modification. In brief, 2.9 ml of DPPH (2,2-diphenyl-1-picrylhydrazyl) solution (0.1 mM in 95% ethanol) was mixed with the sample (0.1 ml). Then, the solution was incubated in a dark condition for 30 minutes. The absorbance was measured using a spectrophotometer at 517 nm. Ascorbic acid was used as the positive control. The percentage radical scavenging activity was calculated using the following equation:

$$\text{DPPH radical scavenging activity (\%)} = \frac{(A0 - A1)}{A0} \times 100$$

When A0 and A1 are the absorbance of control sample (containing all reagents except the sample) and the absorbance of test sample, respectively.

Physicochemical properties analysis

The dry weight percentage of durian flour was investigated according to the method of the National Bureau of Agricultural Commodity and Food Standards (2003). Color values were measured by using the CIE L* a* b* color system with a color meter (Color Flex 45/0, Hunter Lab, USA). In this system: L* represents lightness, ranging from 0 to 100 (0 indicates complete darkness and 100 indicates complete brightness). a* represents the green to red color axis (negative a* indicates green, positive a* indicates red). b* represents the blue to yellow color axis (negative b* indicates blue, positive b* indicates yellow).

Pasting properties analysis

Pasting properties of durian flour samples were determined using a Rapid Visco-Analyzer (RVA-3D, Newport Scientific, Narrabeen, Australia). Durian flour slurry (12% w/w, db) was prepared by mixing 2.5 g durian flour with 25 g distilled water. The temperature cycle started with heating to 50 °C for 1 min, then continued heating at a rate of 12 °C/min until it reached 95 °C. It stayed at 95 °C for 2.5 min, then cooled at the same rate until it reached 50 °C and stayed there for 1.5 min. The measured parameters were pasting temperature, peak viscosity (PV; the highest viscosity of the paste during the heating phase), trough viscosity (the lowest viscosity of the durian paste during the cooling phase), breakdown viscosity (PV-trough viscosity), final viscosity (FV; the viscosity at the end of the cooling phase), and setback viscosity (FV-trough viscosity).

Enzyme digestibility analysis

The enzyme digestibility of durian flour samples was expressed as the amount of glucose released, which was analyzed based on the methods of Na-Nakorn *et al*. (2019) and Sopade and Gidley (2009). A 0.25 g (dry weight) sample of durian flour was weighed and mixed with 0.5 mL of α-amylase solution (Porcine Pancreatic α-amylase, 250 U/mg, prepared in 20 mM sodium buffer at pH 6.9 with 6.7 mM sodium chloride). Then, 2.5 mL of pepsin solution (1 mg/mL in 0.02 M HCl, pH 2) was added. The mixture was incubated in a shaking water bath at 37°C and 170 rpm for 30 min. Enzyme activity was stopped by adding 2.5 mL of 0.02 M sodium hydroxide. After that, a mixed enzyme solution containing pancreatin (2 mg/mL in 0.2 M sodium acetate, pH 6) and amyloglucosidase (28 U/mL in 0.2 M sodium acetate, pH 6) was added in a volume of 15 mL. From the mixture, 100 μL aliquots were taken at the following time points: 0, 20, 30, 60, 90, 120, 150, and 180 min. The 0-minute sample was taken before the mixed enzyme solution was added. The glucose concentration at each time point was measured using a glucose meter, and the results were used to calculate the amount of glucose released during each digestion period.

Proximate compositions analysis

Proximate compositions including moisture content, protein content, ash content, crude fat, crude fiber, and calculated total carbohydrates were analyzed according to AOAC method (2000).

Morphological characteristics determination

The morphological characteristics of durian flour samples were determined using a scanning electron microscopy (SEM). carried out using a scanning electron microscope (SEM) (Carl Zeiss, AURIGA, Germany). The samples were mounted on an aluminium stub using double-sided adhesive tape and coated with a thin film of gold. Then, it was capture at a magnification of 5,000x.

Statistical analysis

A completely randomized design (CRD) was performed for the study on the impact of harvesting stages on physicochemical properties, antioxidant activity and enzymatic digestibility of durian flour. Analysis of variance (ANOVA) was analyzed using SPSS 28.0 software (SPSS Inc., IL, USA). The experiment was conducted in duplicate. The differences between mean values were compared using Duncan's Multiple Range Test (DMRT) at a 95% significant level.

Results

The color attributes and dry weight percentage of durian flour from Monthong cultivar at different harvesting stages of 90 to 120 days post-full bloom are shown in Table 1. The results indicated that the lightness value (L*) of durian flour varied with the harvesting period ($p<0.05$). The maximum L* values of 95.26 and 95.04 were at 100 and 95 days, respectively. The 115-day interval had the minimum L* (91.99), whereas the redness (a*) consistently decreased during the harvest period. The maximum value was 3.57 during the 90-day interval, thereafter declining to 2.41 in the 115 and 120-day intervals. The yellowness (b*) increased during the harvest period, with a highest value of b* (13.97) originating from the lowest value recorded in the 90-day period (11.52). For dry weight percentage, durian flour obtained from fruits harvested at 120 days exhibited the highest value (41.10%), followed by 115 days (39.55%), whereas the lowest value was observed at 90 days (26.93%). Appearance of durian flour from Monthong cultivar at different harvesting stages are shown in Figure 1.

The amylose and total sugar content of durian flour from Monthong cultivar at different harvesting stages is shown in Table 2. The highest amylose concentrations were recorded at 115 days (4.16%) and 110 days (4.07%), respectively, which were considerably higher than the lowest value of 90 days (3.00%). Total sugar content showed a definite increasing trend with durian fruit maturity. At 90 days, the total sugar content was the lowest (6.62%), while at 120 days, it reached the greatest (10.42%), indicating a significant difference from the initial stage ($p<0.05$).

Table 1. Color values and dry weight percentage of durian flour from Monthong cultivar at different harvesting stages

Harvesting Stages (Day)	Color			Dry weight percentage (%)
	L*	a*	b*	
90	94.25±0.01^{b}	3.57±0.01^{a}	11.52±0.00^{f}	26.93 ± 2.45^{c}
95	95.04±0.02^{a}	3.13±0.02^{b}	11.78±0.01^{e}	30.42 ± 3.01^{c}
100	95.26±0.01^{a}	2.84±0.03^{c}	12.17±0.05^{d}	35.53 ± 0.98^{b}
105	94.97±0.02^{b}	2.69±0.02^{d}	12.20±0.01^{d}	36.98 ± 1.66^{b}
110	93.55±0.05^{d}	2.66±0.03^{d}	12.36±0.02^{c}	36.05 ± 1.50^{b}
115	91.99±0.19^{e}	2.41±0.02^{e}	13.86±0.04^{b}	39.55 ± 0.92^{a}
120	94.32±0.13^{c}	2.41±0.01^{e}	13.97±0.03^{a}	41.10 ± 1.98^{a}

$^{a-e}$ Mean values with different letters in each column are significantly different ($p<0.05$) according to Duncan's multiple range test.

Figure 1. Appearance of durian flour from Monthong cultivar at different harvesting stages

The antioxidant activity of durian flour at various harvesting stages were ranged from 90 to 120 days post-full bloom. The results were statistically significant changed in antioxidant capacity when examined using the DPPH method (Table 3). The DPPH free radical inhibition value was highest in durian flour from the 110- and 115-day harvests (approximately 9.12% and 9.17%, respectively). These numbers are both similar to and significantly different from those of previous harvest times. The lowest IC_{50} values were observed at 120 days (7.03%) and 90 days (7.15%). The durian flour from the 115- and 110-day periods had the lowest IC_{50} values of 34.91 and 35.38, respectively. It has a low IC_{50} value (3.40) and a DPPH inhibition value of 97.72%, which was significantly lower than ascorbic acid (vitamin C), a commonly used antioxidant.

Table 2. Amylose and total sugar content of durian flour from Monthong cultivar at different harvesting stages

Harvesting Stages (Day)	Amylose content (%)	Total sugar content (%)
90	3.00±0.14^{ab}	6.62±0.42^{d}
95	3.12±0.25^{b}	6.84±0.47^{d}
100	3.04±0.28^{d}	7.41±0.48^{c}
105	3.55±0.24^{c}	7.95±0.33^{c}
110	4.07±0.58^{a}	9.66±0.46^{b}
115	4.16±0.72^{a}	10.24±0.23^{a}
120	3.80±0.04^{bc}	10.42±0.39^{a}

$^{a-d}$ Mean values with different letters in each column are significantly different ($p<0.05$) according to Duncan's multiple range test.

Table 3. Antioxidant properties of durian flour from Monthong cultivar at different harvesting stages

Harvesting Stages (Day)	IC_{50}DPPH	Antioxidant Inhibition (DPPH) (%)
Ascorbic acid	3.40±0.02	97.72±0.13
90	50.83±0.12^{a}	7.15±0.06^{d}
95	49.53±0.29^{b}	7.41±0.05^{c}
100	48.74±0.12^{c}	7.71±0.06^{b}
105	47.56±0.16^{d}	7.81±0.14^{b}
110	35.38±0.39^{e}	9.12±0.03^{a}
115	34.91±0.07^{e}	9.17±0.04^{a}
120	50.94±0.08^{a}	7.03±0.06^{d}

$^{a-e}$ Mean values with different letters in each column are significantly different ($p<0.05$) according to Duncan's multiple range test.

Rapid Visco Analyzer (RVA) was used to observe the pasting properties of durian flour harvested at 110 and 115 days post-full bloom. RVA profile of both durian flours are demonstrated in Figure 2. The viscosity parameters were significantly different ($p < 0.05$), with the exception of the peak temperature ($p < 0.05$) (Table 4). The peak viscosity of flour from durian fruits harvested at 115 days was 133.0 cP, significantly higher than at 110 days (78.0 cP). The trough and final viscosity were similarly greater at 115 days compared to 110 days. Breakdown viscosity was also significantly higher at 115 days (69.5 cP) compared to 110 days (24.5 cP). The setback viscosity was higher at 115 days (21.0 cP) than at 110 days (15.0 cP).

Table 4. Pasting properties of durian flour from the Monthong cultivar harvested at 110 and 115 days, analyzed using a Rapid Visco Analyzer (RVA)

Pasting parameter (RVU)	**Harvesting Stages (Day)**	
	110	115
Peak Viscosity (cP)	78.0 ± 0.0^{b}	133.0 ± 1.4^{a}
Trough Viscosity (cP)	53.5 ± 0.7^{b}	63.5 ± 0.7^{a}
Breakdown (cP)	24.5 ± 0.7^{b}	69.5 ± 2.1^{a}
Final Viscosity (cP)	68.5 ± 0.7^{b}	84.5 ± 0.7^{a}
Setback (cP)	15.0 ± 1.4^{b}	21.0 ± 0.0^{a}
Peak Temperature (°C)	63.5 ± 0.0^{ns}	63.9 ± 0.6^{ns}

$^{a\text{-}b}$ Mean values with different letters in each column are significantly different ($p<0.05$) according to Duncan's multiple range test.

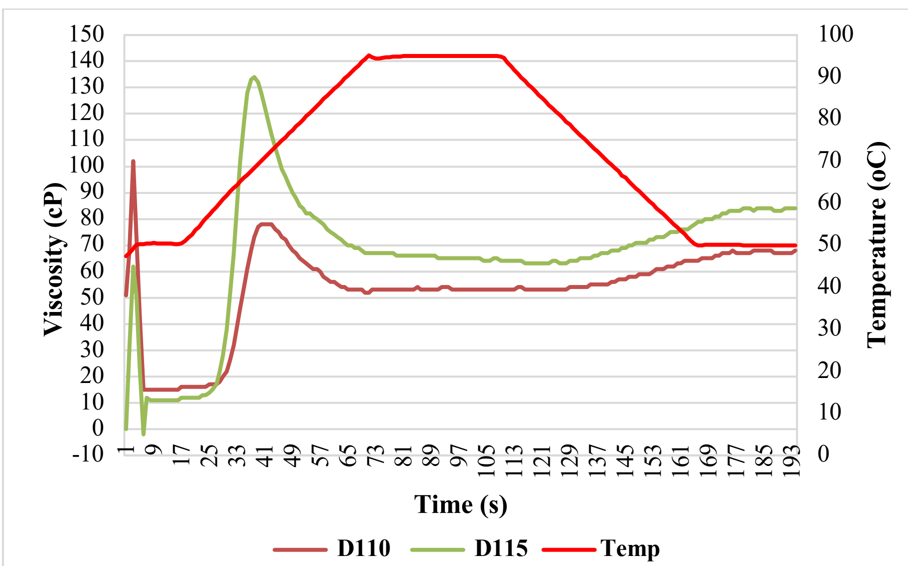

Figure 2. RVA profile of durian flour from the Monthong cultivar harvested at 110 (110D) and 115 days (115D)

The enzymatic digestibility of durian flour harvested between 110- and 115-days post-full bloom was measured in terms of glucose levels produced after digestion. The enzymatic digestibility of the two durian flour samples (110D and

115D) increased rapidly during the first 0-30 min of digestion, with glucose levels reaching nearly 10-12 mg/mL. After 60 min, glucose levels plateaued at around 14-16 mg/mL. When comparing different harvest periods. It was revealed that 115D durian flour had a glucose content higher than or similar to 110D at practically all stages of digestion, as shown in Figure 3.

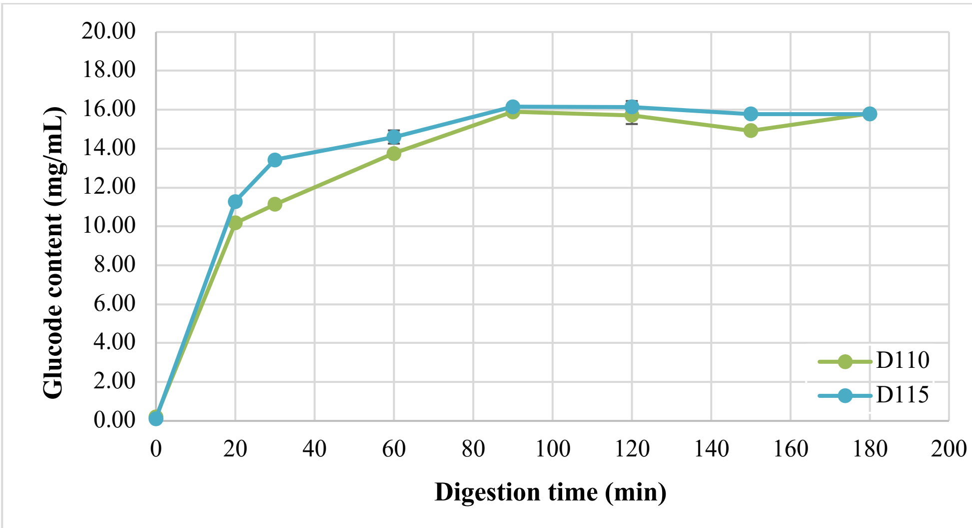

Figure 3. Enzymatic digestibility profiles of durian flour from the Monthong cultivar harvested at 110 (110D) and 115 days (115D)

The proximate composition of durian flour from durian fruits harvested at 110 and 115 days post-full bloom indicated that the moisture, protein, lipid, and crude fiber levels were elevated. A statistically significant difference ($p \leq 0.05$) was observed, with durian flour from the 115-day harvest period exhibiting a marginally greater moisture content (8.69%) compared to the 110-day period (8.32%). The protein and lipid content in starch diminished slightly from 0.95% at 110 days to 0.74% at 115 days and from 10.26% at 110 days to 10.10% at 115 days, respectively. The crude fiber content was 3.57% for the 110-day period and 3.78% for the 115-day period. The ash content and total carbohydrate content exhibited no statistically significant variations between the two harvest periods, with carbohydrate content of 74.64% and 74.49%, respectively (Table 5).

The morphological characteristics of durian flour harvested at 110 and 115 days is illustrated in Figure 4. The starch granules from both harvesting stages exhibited spherical to irregular shapes and tended to aggregate into clusters. The starch granules from fruits harvested at 115 days were larger in size and possessed smoother surfaces compared to those from 110 days.

Table 5. Proximate analysis of durian flour from the Monthong cultivar harvested at 110 (110D) and 115 days (115D)

Chemical composition	D110	D115
Moisture (%)	8.32 ± 0.04^{b}	8.69 ± 0.02^{a}
Protein (%)	0.95 ± 0.00^{a}	0.74 ± 0.01^{b}
Fat (%)	10.26 ± 0.05^{a}	10.00 ± 0.06^{b}
Crude fiber (%)	3.55 ± 0.04^{a}	3.78 ± 0.04^{b}
Ash (%)	2.28 ± 0.16^{ns}	2.30 ± 0.08^{ns}
Total carbohydrate (%)	74.64 ± 0.28^{ns}	74.49 ± 0.19^{ns}

$^{a-b}$ Mean values with different letters in each low are significantly different ($p<0.05$) according to Duncan's multiple range test.

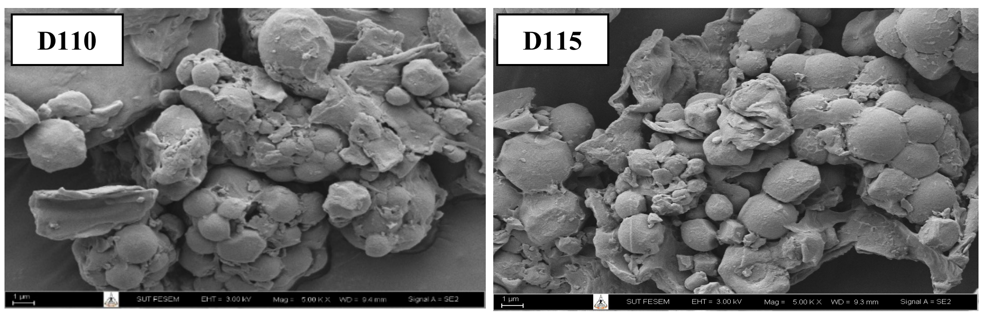

Figure 4. SEM of durian flour from the Monthong cultivar harvested at 110 (110D) and 115 days (115D)

Discussion

The color value of Monthong cultivar durian flour varies depending on the harvesting stage. The lightness value (L*) generally diminished throughout the harvesting period. The harvesting of durian fruits at a more mature stage leads to a reduction in the lightness of the flour. Additionally, the redness value (a*) declined throughout the harvesting time, suggesting a shift in color towards reduced red as the durian fruits mature. The yellowness value (b*) generally rised with the harvesting period. This implies that the intensity of the yellowness color in durian flour increased with the fruit's ripening. This finding aligns with the study conducted by Bai-Ngew *et al*. (2014), which revealed that increased ripeness of durian correlated with its maturation. The L* value decreasesd, however the redness (a*) and yellowness (b*) values increased, attributable to the non-enzymatic browning reaction. A variation in the dry weight percentage of durian flour was noted during the harvesting periods, exhibiting an increasing trend over time. This indicates that allowing durian fruits to ripen for an extended period significantly increases the solids content in the dry flour. This result is consistent with Youryon and Supapvanich (2022), which stated that fully ripe fruits contain greater levels of sugars and solids, resulting in flour with increased solids content.

The amylose content of Monthong cultivar durian flour varies according to harvest time. It increased gradually until 115 days post-full bloom before decreasing again at 120 days. It demonstrates that the amount of amylose in the starch varies with the ripeness of the durian fruit. The starch structure may change during the ripening process. Bai-Ngew *et al*. (2014) observed that starch extracted from Monthong durian flesh taken 104 days post-full bloom (unripe) and 112 days post-full bloom (completely ripe) contains negligible amylose, ranging from 0.19 to 0.75%.

The total sugar content in Monthong cultivar durian flour increased during the harvesting stage, reaching its highest level at 120 days. The ripening of the fruit has a considerable impact on the accumulation of sugar in the durian flesh, which alters the sugar content of the durian flour. The result supports previous research suggesting that fully ripened fruits contain higher levels of sugars and solids, resulting in higher solid content in their starch. Yongyut *et al*. (2025) noticed that the total sugar content in durian increases as it matures, peaking 135 days post-flowering.

The antioxidant activity of Monthong cultivar durian flour often increased with harvesting ripeness but diminished at 90 and 120 days. This result coincided with the IC_{50} values, demonstrating the concentration required to block 50% of DPPH radicals. Yongyut *et al*. (2025) reported that the antioxidant properties of durian are enhanced with maturation. This may be linked to the accelerated accumulation of phytochemicals such as flavonoids and phenolics during full ripening. According to the study of Arancibia-Avila *et al*. (2008), the concentrations of polyphenols, flavonoids, anthocyanins, and flavanols in ripe durians are significantly elevated in overripe and mature samples. These findings suggest that immature or overripe durian fruits may contain lower levels of antioxidant compounds. Harvesting at 110-115 days post-full bloom appears to be the optimal period for obtaining the highest antioxidant activity in durian flour.

Pasting properties are crucial factors related to gelatinization and short-term retrogradation during the heating and cooling of starch, which directly affect its possible applications. In this study, Monthong cultivar durian flour derived from durian fruits harvested at 115 days had higher peak, trough, and final viscosity compared to that obtained from fruits gathered at 110 days. This suggests that durian flour harvested later in the fruit's maturation cycle may have a more hydrophilic and stable structure. The higher breakdown viscosity of 115-day flour implies a more sensitive structure, since it tends to decrease with extended heating and shear, despite its higher initial viscosity. More mature durian flour is apparently more retrogradable, as the 115-day starch had a higher setback viscosity. Bai-Ngew *et al*. (2014) reported that the pasting temperature of durian starch (50-52°C) was unaffected by ripening. The maturation of durian reduces the starch content, leading to a reduction in peak viscosity, trough viscosity, final viscosity, breakdown viscosity, and gelatinization of durian flour.

The enzyme digestibility of Monthong cultivar durian flour harvested at 110 and 115 days showed similar glucose release characteristics. Within the first 30 minutes of digestion, the concentration of glucose increased rapidly. After 60 minutes, it leveled off, indicating that the majority of the rapidly digestible starch (RDS) had been broken down within the first hour. This pattern is characteristic of carbohydrates with a high rapidly digestible starch (RDS) content. Nonetheless, in terms of harvest maturity, more mature durians (115D) generated quite more glucose than their less mature counterparts (110D), or an equal amount. This could be due to the change of sugar during ripening, which makes starch less crystalline and improves enzyme accessibility and digestion. This result corresponds to the total sugar content, which increased with extended harvesting durations. The findings are consistent with previous research: banana ripening reduces the amount of starch, altering the shape of starch granules and increasing the number of soluble sugars, making them easier for enzymes to digest (Reginio *et al*., 2020). These findings indicate that harvest maturation significantly influences enzyme digestibility and glucose release in durian, which is essential for developing food products targeting both high-energy and health-conscious consumers who emphasize blood sugar management.

Carbohydrate was the primary chemical component of durian flour obtained at 110 and 115 days, followed by fat, moisture, crude fiber, ash, and protein. This finding is comparable with that of Bai-Ngew *et al*. (2014), who studied the proximate composition of durian flesh flour obtained from hot air drying (HAD) and microwave vacuum drying (MWD), indicating carbohydrates to be the predominant component, representing 63.43% to 70.85%. In terms of harvesting stages, moisture and crude fiber levels increased with harvesting time. This is consistent with previous observations: developing durian fruit contains more water. An increase in crude fiber content in later harvests could be attributed to changes in plant cell wall structure. Cellulose, hemicellulose, and lignin are the primary components of insoluble dietary fiber. Cellulose is highly crystalline, strong, and insoluble in organic solvents. This attribute causes fruit tissues to be tougher and contain more fiber (Lubis *et al*., 2018; Nordin *et al*., 2017).

The morphology of durian starch granules obtained from 110 and 115 days post-full bloom in this investigation was similar to that described by Bai-

Ngew *et al*. (2014), who found that starch granules from both unripe and fully ripe durians were polygonal and irregular in shape, forming aggregates mostly. The starch granules of durian from D115 were larger and had smoother surfaces, whereas those from D110 were smaller and more fragmented. This study demonstrates that the maturity phase of durian influences starch granule development. The more substantial and unbroken granule structure seen in D115 may result from elevated glucose levels accumulated during advanced ripening. Yongyut *et al*. (2025) pointed out that fruits ripening later generally includes higher levels of carbohydrates and polysaccharides.

In conclusion, the alterations in color, total sugar content, amylose content, and antioxidant activity of durian flour correlated with the durian fruit's maturation or harvesting stages. The durian flour from 110 days post-full bloom exhibited the high levels of protein, fat, and crude fiber. In addition, a lower level of glucose release was also observed. The findings indicate that durian flour obtained at 110 days of post-full bloom is appropriate for usage as a functional food raw material due to its antioxidant and glucose-release regulation capabilities.

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Conflicts of interest

The authors declare no conflict of interest.

References

Ali, N. A. W. A., Wong, G. R., Tan, B. C., Lum, W. S. and Mazumdar, P. (2024). Unleashing the Potential of Durian: Challenges, Opportunities, and the Way Forward. Applied Fruit Science, 67.

AOAC. (2000). Official Methods of Analysis of the Association of Official AnalyticalChemists. 15thed. Virginia: Association of Official Analytical Chemists, Inc.

Arancibia-Avila, P., Toledo, F., Park, Y. S., Jung, S. T. and Sung, G. (2008). Antioxidant properties of durian fruit as influenced by ripening. LWT - Food Science and Technology, 41:2118-2125.

Bai-Ngew, S., Therdthai, N., Dhamvithee, P. and Zhou, W. (2014). A study of the effect of the drying process on the composition and physicochemical properties of flours obtained from durian fruits of two ripening stages. International Journal of Food Science and Technology, 49:230-237.

Fox, J. D. and Robyt, J. F. (1991). Miniaturization of three carbohydrate analyses using a microsample plate reader. Analytical biochemistry, 195:93-96.

Juliano, B. O. (1984). Rice starch: production, properties and uses. In: Whistler RL, Bemiller JN. and Paschall EF Eds. Starch chemistry and technology, 2th Ed. Academic Press, Florida, pp.507-529.

Khaksar, G., Kasemcholathan, S. and Sirikantaramas, S. (2024). Durian (*Durio zibethinus* L.): Nutritional Composition, Pharmacological Implications, Value-Added Products, and Omics-Based Investigations. Horticulturae, 10:342.

Lubis, R., Saragih, S. W., Wirjosentono, B. and Eddyanto, E. (2018). Characterization of durian rinds fiber (*Durio zubinthinus*, murr) from North Sumatera. 3rd International Seminar on Chemistry AIP Conference Proceedings 2049, 020069, AIP Publishing LLC.

Na-Nakorn, K., Kulrattanarak, T., Hamaker, B. R. and Tongta, S. (2019). Starch digestion kinetics of extruded reformed rice is changed in different ways with added protein or fiber. Food & function, 10:4577-4583.

National Bureau of Agricultural Commodity and Food Standards (2003). Thai agricultural standard: Durian. Chanthaburi Provincial Agricultural Office.

Nordin, N., Shamsudin, R., Azlan, A. and Ya'acob, M. E. (2017). Dry matter, moisture, ash and crude fibre content in distinct segments of 'Durian Kampung' Husk. International Science Index, Chemical and Materials Engineering, 1-5.

Paśko, P., Leontowicz, H., Leontowicz, M., Leszczynska, T., Barbe-Schlegel, F. and Satora, P. (2011). Positive effects of durian fruit at different stages of ripening on the hearts and livers of rats fed diets high in cholesterol. European Journal of Integrative Medicine, 3:e157–e165.

Reginio Jr, F. C., Ketnawa, S. and Ogawa, Y. (2020). *In vitro* examination of starch digestibility of Saba banana [Musa 'saba'(Musa acuminata× Musa balbisiana)]: impact of maturity and physical properties of digesta. Scientific Reports, 10:1811.

Sopade, P. A. and Gidley, M. J. (2009). A Rapid In-vitro Digestibility Assay Based on Glucometry for Investigating Kinetics of Starch Digestion. Starch/Stärke. 61:245-255.

Striegel, L., Chebib, S., Dumler, C., Lu, Y., Huang, D. and Rychlik, M. (2018). Durian Fruits Discovered as Superior Folate Sources. Frontiers in Nutrition, 5:114.

Toledo, F., Arancibia-Avila, P. and Almonacid, S. (2012). Screening of the antioxidant and nutritional properties, phenolic contents and proteins of five durian cultivars. Food Chemistry, 132:1319-1324.

Yongyut, N., Baopa, P., Meetha, S., Isarangkool Na Ayutthaya, S., Chiu, C. I., Sripontan, Y. and Nampila, S. (2025). Fruit Quality and Antioxidant Content in Durian (*Durio zibethinus* Murr.) cv. Monthong in Different Maturity Stages. Horticulturae, 11:432.

Youryon, P. and Supapvanich, S. (2022). Quality comparison of naturally and artificially ripened 'Monthong'durian (*Durio zibethinus*) fruits harvested at various maturity stages. Current Applied Science and Technology, 10-55003.

Zhu, K., Zhou, H. and Qian, H. (2006). Antioxidant and free radical-scavenging activities of wheat germ protein hydrolysates (WGPH) prepared with alcalase. Process Biochemistry, 41:1296-1302.

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