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Nutritional and antioxidant profile variations in fresh durian (*Durio zibethinus* Murr.) across two ripening stages in Ben Tre province, Vietnam

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ABSTRACT

Purpose: This study evaluated how ripening stages and anatomical parts affect the nutritional composition, physicochemical attributes, and antioxidant potential of Ri6 Durian (*Durio zibethinus* Murr.). The goal was to determine the optimal harvest stage and explore full fruit utilization to reduce postharvest losses. **Research method:** Peel, flesh, and seed samples were collected at 15 weeks (mature fruit, MF) and 17 weeks (ripe fruit, RF) after flowering. Ethanol extracts were analyzed for proximate composition, pH, titratable acidity, total soluble solids, total polyphenol content (TPC), total flavonoid content (TFC), and antioxidant activity using DPPH and ABTS assays. **Findings:** Ripening increased moisture (36.7-80.8%) and sugars (16.7-55.5 mg/g DW), while reducing acidity. The peel consistently exhibited the highest bioactive levels, with TPC reaching 2.91 mg GAE/g and TFC 0.21 mg QE/g at MF. Antioxidant activity was stronger in the peel, with DPPH values up to 0.67 mg AAE/g DW, exceeding ABTS activity (0.50 mg AAE/g DW). **Research limitations:** The study was limited to one Durian cultivar (Ri6) and two ripening stages, which may restrict generalizability to other cultivars or maturity levels. **Originality/Value:** This research highlights the underutilized value of Durian peel and seed for functional food or nutraceutical development, and provides practical guidance for ripening-based harvest decisions to support sustainable postharvest strategies. The findings contribute innovative insights into full-fruit utilization and promote value addition for tropical fruits, offering practical applications for both industry and farmers.

Keywords:
Antioxidant, Durian, Nutritional, Physicochemical, Vietnam

INTRODUCTION

Fruits are an indispensable part of human nutrition, serving as a rich source of essential macro- and micronutrients, including carbohydrates, proteins, vitamins, and minerals (Khaksar et al., 2024). In addition to these vital components, fruits are also repositories of natural antioxidants bioactive compounds that combat oxidative stress, a key contributor to chronic diseases such as cancer and cardiovascular disorders (Lu et al., 2021). Among tropical fruits, Durian (*Durio zibethinus*) stands out due to its unique flavor and dense nutritional profile.

In Vietnam, particularly in Ben Tre province, Durian is not merely a fruit but an integral part of the region's socio-economic fabric. It holds significant economic value for local farmers and is deeply embedded in the culinary and cultural practices of the community (Pham et al., 2022). The Durians cultivated in this region are renowned for their distinctive aroma and nutritional quality, making them a compelling subject for scientific investigation. Numerous studies have analyzed the nutritional composition of Durian, revealing it to be rich in fats, proteins, and various vitamins such as vitamin C and B-complex vitamins (Mohd Ali et al., 2020; Nguyen et al., 2025). The fruit's mineral content including potassium, iron, zinc, and magnesium further enhances its nutritional value (Vincente et al., 2014). Research has also shown that Durian is a significant source of bioactive compounds such as flavonoids, phenolic acids, and tannins (Khaksar et al., 2024). These antioxidants are associated with a range of potential health benefits, including anti-inflammatory, anti-cancer, and anti-diabetic effects (Kunarto & Sani, 2018; Zhan et al., 2021). Ripening is a dynamic biochemical process that alters the chemical and nutritional composition of fruits (Seymour et al., 2013). While the effects of ripening on fruits such as mangoes and bananas have been well documented, comprehensive data on how ripening influences the nutrient and antioxidant profiles of Durian particularly those cultivated under the specific environmental conditions of Ben Tre remain limited (Fabi et al., 2010; Yongyut et al., 2025). Postharvest behavior of durian is particularly challenging due to its climacteric nature. After harvest, the fruit undergoes rapid softening, aroma enhancement, increased total soluble solids (TSS), and decreased titratable acidity (TA), leading to a short shelf life and storage difficulties (Ketsa, 2018; Hoang et al., 2024). These changes affect consumer acceptance and restrict transportation and export, highlighting the need to determine optimal harvest and ripening stages (Le et al., 2022). However, limited research has addressed these dynamics in Vietnamese cultivars, particularly those grown in Ben Tre. Despite extensive research on the nutritional and antioxidant properties of Durian, a critical knowledge gap persists regarding how these properties change across different stages of ripening (Arancibia-Avila et al., 2008). Most existing studies have focused on Durian varieties from Thailand and Malaysia, with limited research addressing Vietnamese cultivars, especially those from Ben Tre a region with distinctive soil and climatic characteristics (Husin et al., 2018). Given this gap, further research is warranted to understand the biochemical changes during Durian ripening in this specific agro-ecological context.

Therefore, this study aims to provide a comprehensive analysis of changes in the nutritional profile, including macro and micronutrients, of *Durio zibethinus* across various ripening stages in Ben Tre, Vietnam; and assess alterations in antioxidant levels and composition throughout the ripening process. The findings are expected to provide a scientific foundation for farmers, food processors, and consumers in identifying the optimal stage of Durian ripeness for harvest and consumption maximizing both nutritional and antioxidant benefits.

MATERIALS AND METHODS

Materials

All chemicals and reagents used in this study were of analytical grade. For antioxidant activity assays, 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) were employed for radical scavenging, with potassium persulfate used to generate the ABTS radical cation. Phenolic content was determined using Folin–Ciocalteu's reagent and sodium carbonate, while flavonoid content was quantified with aluminium chloride and potassium acetate. For mineral and titration analyses, copper (II) sulfate, iron (III) sulfate, potassium permanganate, sodium dihydrogen phosphate, sodium hydroxide, sodium potassium tartrate tetrahydrate, lead (II) acetate, and sulfuric acid were used according to the standard methods. Chloroform and hexane were used as solvents for extraction procedures. All chemicals were purchased from Sigma-Aldrich (St. Louis, MO, USA).

Samples

Durian fruits of the variety Ri6 were harvested from orchards in Ben Tre province, Vietnam, in 2024. Samples (peel, flesh, and seeds) were collected at two ripening stages: 15 weeks and 17 weeks after flowering. The 15-week stage represents the commercial maturity of Ri6 durian, typically used for market harvest due to its desirable texture and flavor. The 17-week stage corresponds to full ripeness, characterized by a stronger aroma, softer pulp, higher total soluble solids (TSS), and lower titratable acidity (TA). These time points were selected to evaluate developmental changes during ripening. For each stage, three fruits were used. After separating each part, the samples were preserved at -60 °C until further experiments. All analyses were performed on a dry weight basis in triplicate at the Laboratory of Food Science and Technology, Nguyen Tat Thanh University (Ho Chi Minh City, Vietnam).

Determination of physicochemical properties and nutritional composition

Moisture content, expressed as a percentage of the sample's wet weight, was determined following the official method of the Association of Official Analytical Chemists (AOAC, 1990). Samples were dried in a hot air oven at 105 °C until a constant weight was achieved, and moisture content was calculated based on weight loss. A detailed procedure is described by Hema et al. (2016). Total nitrogen content was analyzed using a modified Kjeldahl method, involving digestion with sulfuric acid and salicylic acid, followed by distillation and titration, as outlined by Bremner and Keeney (1965). Crude protein content was then calculated by multiplying the nitrogen value by a factor of 6.25 (Hema et al., 2016). Fat content was determined using the Soxhlet extraction method. A known amount of partially dried sample was weighed and extracted using petroleum ether. The extracted fat was dried and weighed, and the fat content was expressed as a percentage of the original sample. Sand was incorporated with the sample before drying to avoid agglomeration. Detailed protocols were based on Nielsen and Carpenter (2017). Ash content was measured by incinerating the sample in a muffle furnace at 550 °C until a consistent white ash was obtained. The ash percentage was calculated to estimate the total mineral content of the sample.

Sugar content, pH, titratable acidity (TA), and total soluble solids (TSS) were not determined in the seed samples. Total sugar content was determined volumetrically using an alkaline copper sulfate solution, in which sugars reduced Cu^{2+} to Cu_2O, forming a red precipitate. The procedure followed the method of Hema et al. (2016). For pH measurement, 5 g of the sample was mixed with 50 mL of distilled water and homogenized. The pH was measured using a digital pH meter (Hanna Instruments, USA). TSS content was determined

using a digital refractometer (ATAGO Co. Ltd., Tokyo, Japan), in accordance with Vietnamese standard TCVN 4417:1987. Titratable acidity was determined by titration against 0.1 N NaOH, and the results were expressed as grams of citric acid equivalent per 100 g of sample, following the method described by Hoang et al. (2024), with minor modifications. Color changes during ripening were measured in the CIE Lab color space, using L*, a*, and b* parameters, following the method described by Hoang et al. (2024).

Determination bioactive compounds

Determination of total polyphenol content (TPC)

Total polyphenol content (TPC) was determined using the Folin-Ciocalteu colorimetric method, as described by Hoang et al. (2024). Briefly, appropriate dilutions of the extract were mixed with Folin-Ciocalteu reagent and sodium carbonate solution. After incubation, the absorbance was measured at 765 nm using a UV-Vis spectrophotometer (Shimadzu, Japan). Gallic acid was used as a standard, and the results were expressed as milligrams of Gallic acid equivalent per gram of extract (mg GAE/g).

Determination of total flavonoid content (TFC)

Total flavonoid content (TFC) was determined according to the method of Hoang et al. (2024), with minor modifications. The extract was reacted with aluminum chloride and potassium acetate, and after incubation, the absorbance was measured at 510 nm using a UV-Vis spectrophotometer. Quercetin was used as a standard, and TFC was calculated from the quercetin standard curve. Results were expressed as milligrams of quercetin equivalent per gram of extract (mg QE/g).

Determination of antioxidant capacities

Investigation of free radical scavenging activity by DPPH· method

Free radical DPPH was used to determine the free radical inhibitory activity of the samples. The detailed method was described by Hoang et al. (2024). A volume of 1.5 mL of 0.1 mM DPPH solution was added to 0.5 mL of diluted sample solution. The mixture was incubated in the dark for 30 min, and the absorbance was measured at 517 nm. The rate of decrease in absorbance of DPPH at 517 nm with and without antioxidant was calculated to determine the reaction yield. Vitamin C (ascorbic acid) was used as the standard for comparison.

Investigation of free radical scavenging activity by ABTS·$^+$ method

ABTS is a blue free radical with maximum absorbance at 734 nm. The free radical scavenging activity was determined by the ABTS decolorization method described by Hoang et al. (2024). ABTS free radical solution was prepared by adding 10 mL of 7.4 mM ABTS solution to 10 mL of 2.6 mM $K_2S_2O_8$ solution and incubating in the dark for 24 h. The solution was then diluted with ethanol and adjusted to an absorbance of 1.1 ± 0.02 at 734 nm. A volume of 0.5 mL of the diluted sample was added to the test tube containing 1.5 mL of ABTS·$^+$ solution and the mixture were incubated in the dark for 30 min. The optical absorbance was measured at 734 nm on a UV-Vis spectrophotometer. Vitamin C (ascorbic acid) was used as the standard for comparison.

Statistical analyses

Each experiment was repeated twice, calculated and graphed using Microsoft® Office Excel 2013 software. Statistical analysis ANOVA and LSD test were used to compare the effects of factors, measured processed with JMP 13.0 software. A 95% confidence level was applied to all statistics.

RESULTS AND DISCUSSION

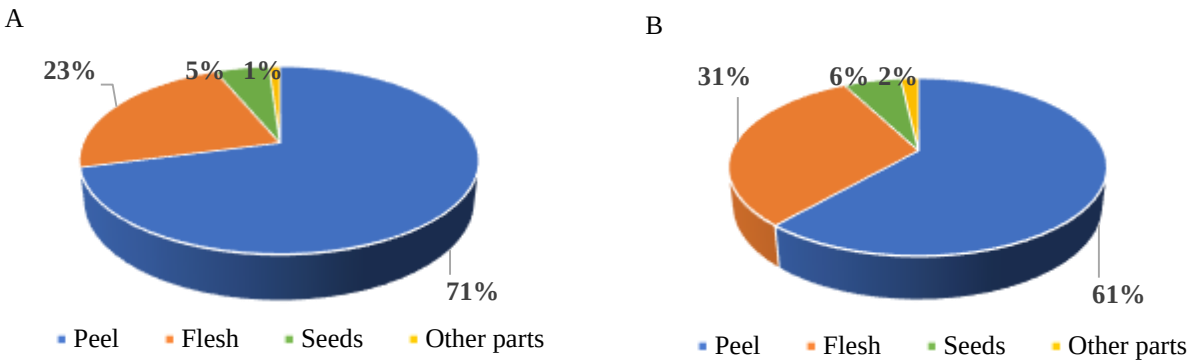
Physicochemical Properties

Table 1 presents the morphological and physical characteristics of Ri6 Durian fruits harvested at 15 and 17 weeks after flowering, corresponding to the early ripening and fully ripened stages, respectively. These two developmental stages were selected to capture the major physiological changes during fruit maturation. At 15 weeks, the fruit exhibited a dark green skin color, hard and densely packed spines, and an average width and length of 22.50 cm and 31.00 cm, respectively. By 17 weeks, the skin turned yellow to golden brown, the spines became softer, larger, and more spaced out, and fruit dimensions increased to 24.50 cm in width and 34.50 cm in length. These findings are consistent with morphological indicators of Durian ripeness reported by Wattanasan et al. (2025), which highlight spine softening and color change as key ripening markers. The average fruit weight increased from 2.40 kg at 15 weeks to 2.75 kg at 17 weeks, reflecting the cumulative biomass gain during the final stages of fruit development. Similar trends in fruit mass and dimensional growth during ripening have been reported in other Durian cultivars (Duong et al., 2025). In addition to external features, ripe Durian emits a strong and characteristic aroma, which serves as a crucial sensory indicator of maturity, although its perception may vary across consumers (Samakradhamrongthai, 2024). It is important to note that while time after flowering significantly affects fruit morphology and physicochemical properties, other factors such as cultivar, soil type, climate, fertilizer application, pest pressure, and cultivation practices also play critical roles in determining fruit size and quality (Ghimire et al., 2023). Taken together, the observed variations in color, spine morphology, size, weight, and aroma between 15 and 17-week-old fruits provide practical criteria for assessing Durian ripeness and optimizing harvest time to balance fruit quality and postharvest handling efficiency.

The percentage distribution of different anatomical parts of *Durio zibethinus* cv. Ri6 at two developmental stages is shown in Fig. 1. The peel accounted for the largest proportion in both stages, decreasing from 71% (MF) to 61% (RF). In contrast, the flesh increased from 23% to 31%, while seeds and other minor parts (including fruit stalk and separation loss) ranged from 5-6% and 1-2%, respectively. The increased proportion of edible flesh at the ripe stage reflects active cell division and expansion, which contributes to fruit softening and biomass accumulation during ripening. This component distribution is consistent with previous findings by Nordin et al. (2017), who reported that Durian fruit typically comprises 55-66% peel, 20-35% flesh, and 5-15% seeds, depending on cultivar and growing conditions. The shifting distribution highlights the importance of selecting an optimal harvest stage to maximize flesh yield and processing efficiency.

Table 1. Physical characteristics of Ri6 durian fruit at 15 and 17 weeks after flowering.

Number of weeks after flowering		15	17
Size (cm)	Length	31.00±0.87	34.50±1.02
	Width	24.50±1.34	22.50±1.20
	Fruit	2.40±0.24	2.75±0.30
Mass (kg)	Peel	1.70±0.17	1.19±0.26
	Flesh	0.55±0.08	0.85±0.05
	Seeds	0.13±0.02	0.16±0.04
Outside image			
		Dark green bark, small sharp spines.	Shell is yellow-brown, large sharp spines
Inside images			
		Light yellow	Dark yellow
Aroma		Almost no smell	Characteristic smell
Taste		Taste is bland, less sweet	Characteristic sweetness



A: Mature Fruit - MF B: Ripe Fruit - RF

Fig. 1. Percentage distribution of anatomical parts of *Durio zibethinus* Ri6 at two ripening stages: mature fruit (MF, 15 weeks) and ripe fruit (RF, 17 weeks).

Table 2. The pH, acidity, °Brix, and total soluble solids at two maturity levels in Ri6 Durian.

Sample	Maturity Levels (weeks)	pH	Acidity (%)	TSS (°Brix)
Peel	15	4.62	0.10	2.73
	17	4.51	0.11	3.70
Flesh	15	6.71	0.11	7.00
	17	5.04	0.23	19.00
Seeds	15	5.69	0.03	-
	17	5.11	0.03	-

Note: (-): Not Detected.

As shown in Table 2, the ripening process from mature to ripe stages in *Durio zibethinus* Ri6 resulted in a notable decrease in pH values across all anatomical parts of the fruit. Specifically, pH values declined from 4.62 to 4.51 in the peel, from 6.71 to 5.04 in the flesh, and from 5.69 to 5.11 in the seed. Concurrently, TA increased in both the peel (0.10% to 0.11%) and the flesh (0.11% to 0.23%), while remaining unchanged in the seed (0.03%). The observed increase in acidity and decrease in pH during ripening is likely associated with the accumulation of organic acids, the degradation of polysaccharides, oxidation of reducing sugars, and the breakdown of pectic substances and uronic acids. These trends are consistent with previous findings by Paśko et al. (2019), who reported a decrease in pH and an increase in TA during fruit ripening. The pH results in this study are comparable to those reported by Ali et al. (2021), where pH values for Durian ranged from 5.82 to 7.22. Similarly, Goswami et al. (2011) found that pH in different jackfruit varieties ranged from 5.61 to 6.45, highlighting species-specific but ripeness-related variations. The TA values obtained here (0.07-0.23%) are also within the range reported by Paśko et al. (2019), who observed values from 0.07% to 0.19% in ripe fruits. Total soluble solids (TSS, expressed in °Brix) increased significantly during ripening, particularly in the flesh (from 7.00 to 19.00 °Brix) and to a lesser extent in the peel (from 2.73 to 3.70 °Brix). This increase is attributed to the enzymatic conversion of starch into simple sugars such as glucose, fructose, and sucrose. However, TSS values observed in this study were somewhat lower than those reported in earlier studies: Paśko et al. (2019) found TSS ranging from 15.50% to 27.50%; Tan et al. (2020) reported a range of 22.1% to 28.9%; and Ali et al. (2021) observed TSS values from 19.63% to 25.15%. These discrepancies may be due to cultivar differences, environmental conditions, or ripening criteria.

Table 3. Color parameters (L*, a*, b*) of each part of Ri6 durian at different weeks after flowering.

Number of weeks after flowering (week)	Index	Peel	Flesh	Seeds
15	L*	62.28 ±10.76	85.82 ± 3.13	67.94 ± 1.98
	a*	-1.44 ± 0.26	6.07 ± 1.09	14.17 ± 0.58
	b*	19.73 ± 3.98	33.04 ± 2.75	22.41 ± 0.76
17	L*	56.98 ±5.26	78.53 ± 2.06	60.11 ± 3.16
	a*	0.35 ± 0.58	8.06 ± 0.69	16.15 ± 5.23
	b*	19.88 ± 1.94	45.07 ± 1.00	21.21 ± 0.91

Note: L*: lightness; a*: green (–) to red (+); b*: blue (–) to yellow (+). Values are expressed as mean ± standard deviation.

To objectively evaluate the color changes of Durian fruit at different developmental stages, instrumental colorimetric analysis was performed. Table 3 presents the color parameters (L*, a*, b*) of the peel, flesh, and seed of Ri6 Durian fruits harvested at 15 and 17 weeks after flowering. Overall, the L* value (lightness) exhibited a decreasing trend, while the* value (red-green axis) increased with advancing fruit age. In the flesh, the b* value (yellow-blue axis) also increased, indicating a more intense yellow coloration as the fruit ripened. Specifically, the highest L* value (85.82) was recorded in the flesh at 15 weeks, while the lowest L* value (56.98) was found in the peel at 17 weeks. The b* value in the flesh increased from 35.12 at 15 weeks to 45.07 at 17 weeks, suggesting an accumulation of yellow pigments such as carotenoids, including β-carotene and α-carotene, during fruit development. In contrast, the peel and seed parts showed no substantial variation in b* values between the two time points. Interestingly, the* value was highest in the seed and lowest in the peel at both stages, reflecting tissue-specific pigmentation differences. The reduction in L* value with ripening could be attributed to enzymatic browning reactions and the degradation of organic compounds, which are common during the senescence phase. Similarly, Ali et al. (2021) documented a wide range of color parameters in Durian cultivars, with L* values ranging from 1.80 to 86.85, depending on tissue type and maturity level. These colorimetric changes support the use of L*, a*, b* values as objective indicators for monitoring Durian ripening and may assist in the determination of optimal harvest time, particularly for applications involving visual quality, carotenoid content, or pigment-related functional properties (Ali et al., 2021).

Nutritional composition of Durian

Table 4 presents the nutritional composition of Ri6 durian seeds, peel, and flesh harvested at 15 and 17 weeks after flowering. Overall, most nutrient parameters exhibited a decreasing trend as ripening progressed. In addition to time after flowering, significant differences in nutritional content were observed among different anatomical parts.

Moisture content was highest in the peel (80.87%) at 15 weeks and lowest in the seed (37.6%) at 17 weeks. All parts demonstrated a consistent decline in moisture with ripening, which is consistent with the findings of Siriphanich, (2011), who reported water loss rates of up to 4% per day under typical tropical conditions (25-30 °C, 65-85% RH). Moisture values in this study were slightly lower than those reported by Nordin et al. (2017) (81.83%), potentially due to varietal or environmental differences (Gamay et al., 2024).

Ash content was predominantly concentrated in the flesh, reaching a maximum of 1.289% at 15 weeks, followed by the seed and peel. This aligns with results from Devalaraja et al. (2011) and (Goswami et al., 2011), who reported similar ash levels in Durian and jackfruit

(~1.1%). However, values were considerably lower than those observed in Durian peel by Nordin et al. (2017), who reported up to 6.95%.

Fiber content ranged from 1.711% to 7.138%, with the highest value found in the peel at 15 weeks and the lowest in the flesh at 17 weeks. The fiber content in the flesh was lower than that reported by Devalaraja et al. (2011) (3.8%) and Gorinstein et al. (2011) (3.2%), and notably lower than in the peel compared to values recorded by Nordin et al. (2017) (14.66%). Higher fiber content in peel is explained by its greater proportion of structural polysaccharides (cellulose, hemicellulose, lignin, and pectin). During ripening, cell-wall modifying enzymes such as pectin methylesterase, polygalacturonase, and cellulase degrade these components, resulting in tissue softening and decreased fiber values, particularly in the flesh (Gamay et al., 2024).

The fat content in durian pulp reached 1.365% at 17 weeks and was lowest in the seed (1.251% at 15 weeks), which is lower than the 5.33% reported by Devalaraja et al. (2011), This reduced lipid level may result from cultivar-specific traits and a slower accumulation of storage lipids (e.g., K, Mg, Ca-associated metabolism) during the late ripening stage (Rahmawati et al., 2021)

Protein content varied slightly across parts and stages. In general, protein increased in the flesh over time but decreased in the peel and seed. The seed consistently had the highest protein content, while the peel had the lowest. Protein content in the durian pulp was higher than the 1.47% reported by Khaksar et al. (2024) (1.47%) whereas the seed protein content was also greater than that reported by Rahmawati et al. (2021) but remained below 7.6%. Protein accumulation in seeds reflects the presence of storage proteins required for embryo development. The slight decline in seed protein content at 17 weeks may be due to partial hydrolysis and conversion of storage proteins to other metabolites, accompanied by an increase in starch and lipid deposition. In the flesh, the modest protein increase can be attributed to the synthesis of ripening-related enzymes (e.g., cell-wall hydrolases, oxidoreductases) and to concentration effects resulting from water loss during maturation (Antonets et al., 2020).

Table 4. Some nutritional indicators of Ri6 Durian in different week periods after flowering.

Number of weeks after flowering (week)	Nutritional	Peel	Seeds	Flesh
15	Moisture content (%)	$80.87^{ce} \pm 1.25$	$38.9^{ae} \pm 1.87$	$56.70^{be} \pm 0.56$
	Starch (%)	-	$34.63^{e} \pm 0.20$	-
	Protein (%)	$1.32^{bd} \pm 0.01$	$4.11^{cd} \pm 0.02$	$2.48^{cd} \pm 0.01$
	Ash (%)	$0.50^{ae} \pm 0.14$	$0.90^{be} \pm 0.14$	$1.29^{ce} \pm 0.13$
	Fat (%)	$1.28^{abd} \pm 0.06$	$1.25^{ad} \pm 0.06$	$1.35^{bd} \pm 0.05$
	Fiber (%)	$7.14^{ce} \pm 0.03$	$3.93^{be} \pm 0.03$	$2.99^{ae} \pm 0.04$
	Total sugar (mg/g)	-	-	$16.71^{d} \pm 0.24$
	Carbohydrate (%)	$15.59^{ae} \pm 1.15$	$55.83^{ce} \pm 1.16$	$37.92^{be} \pm 0.89$
17	Moisture content (%)	$78.50^{cd} \pm 0.80$	$37.6^{ad} \pm 0.79$	$46.4^{bd} \pm 0.44$
	Starch (%)	-	$32.40^{d} \pm 0.13$	-
	Protein (%)	$1.15^{be} \pm 0.01$	$4.07^{ce} \pm 0.14$	$2.85^{ce} \pm 0.01$
	Ash (%)	$0.30^{ad} \pm 0.14$	$0.69^{bd} \pm 0.14$	$0.89^{be} \pm 0.15$
	Fat (%)	$1.30^{abd} \pm 0.02$	$1.28^{ad} \pm 0.01$	$1.37^{bd} \pm 0.06$
	Fiber (%)	$5.71^{cd} \pm 0.15$	$3.51^{bd} \pm 0.02$	$1.71^{ad} \pm 0.03$
	Total sugar (mg/g)	-	-	$55.47^{e} \pm 1.10$
	Carbohydrate (%)	$17.93^{ad} \pm 0.11$	$56.49^{cd} \pm 1.20$	$47.50^{bd} \pm 0.92$

Values are expressed as mean ± standard deviation. The numbers a, b, c, d, e in the same column represent statistically significant differences ($p < 0.05$). *Note: (-): Not Detected.

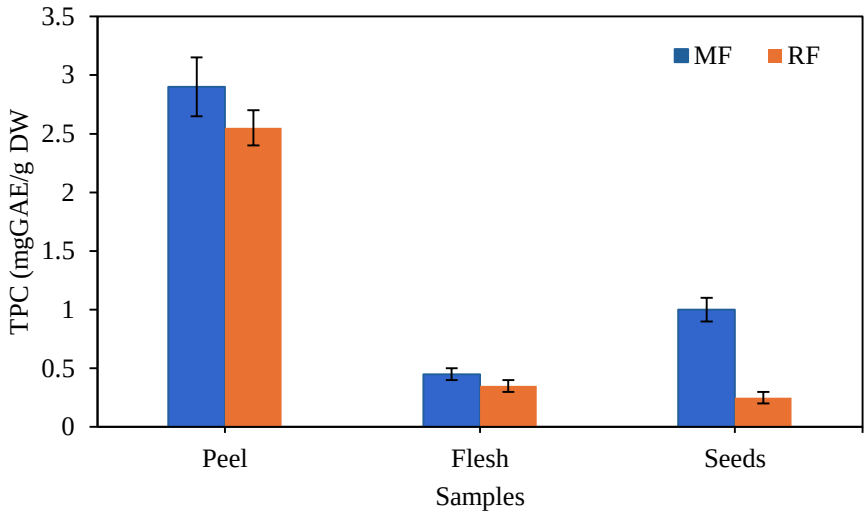


Fig. 2. Total polyphenol content (TPC) in peel, flesh, and seed of *Durio zibethinus* Ri6 at two ripening stages (MF, 15 weeks; RF, 17 weeks).

Starch content in the seed declined from 34.85% at 15 weeks to 32.43% at 17 weeks, likely due to enzymatic conversion to sugars during ripening. This trend mirrors the report by (Siriphanich, 2011), who observed starch contents ranging from 23.5% to 53.3%, and is higher than values reported for Durian (18.92%), corn (22.20%), and potato (25.2%). Sugar content in the durian pulp increased markedly from 16.71 mg/g DM at 15 weeks to 55.47 mg/g DM at 17 weeks, primarily due to starch hydrolysis into simple sugars (glucose, fructose, sucrose). These values were slightly higher than those reported by Aziz and Mhd Jalil (2019), who found 19.97 g/100 g.

Total carbohydrate content was highest in the seed (56.49%) at 17 weeks and lowest in the peel (15.59%) at 15 weeks. This distribution was confirmed by LSD analysis, which showed statistically significant differences among fruit parts. These results support those of Siriphanich (2011), who recorded a rise in carbohydrate levels from 15.00% to 36.10% with ripening. A similar carbohydrate range (18.37%-61.34%) was also observed in jackfruit by Shamla et al. (2019). Collectively, the data confirm that the nutritional profile of Ri6 Durian varies not only by fruit part but also across ripening stages, with physiological mechanisms such as mineral dilution, enzymatic cell-wall degradation, and storage protein turnover explaining the observed patterns. These findings have implications for harvest timing, processing applications, and nutritional labeling.

Bioactive compounds

Total phenolics

The TPC of Ri6 Durian showed significant variation across different anatomical parts and between the two time points after flowering (15 and 17 weeks). In general, TPC exhibited a declining trend as the fruit progressed from mature to fully ripe. Among all parts, the peel recorded the highest TPC at 15 weeks (2.9124 mg GAE/g DM), while the lowest value was found in the seed at 17 weeks (0.3100 mg GAE/g DM). This reduction in polyphenol content during ripening is likely attributed to enzymatic degradation processes, where polyphenolic compounds are broken down into smaller phenolic derivatives or oxidized by polyphenol oxidase. These results are consistent with prior studies on Durian and other tropical fruits. For example, in the Mon Thong cultivar of Durian, polyphenol content decreased significantly from 374.40 to 298.50 mg GAE/g DM as the fruit ripened to an overripe stage. Similarly, Hwang et al. (2019) observed a decline in TPC during the ripening of 'Janghee' strawberries,

from 211.68 to 182.37 mg GAE/100 g fresh weight (Hwang et al., 2019). These findings support the hypothesis that polyphenol degradation is a common biochemical pathway during fruit ripening, affecting antioxidant potential and functional quality. The data indicate that the Durian peel is a rich source of polyphenols at early stages of maturity and could serve as a potential functional ingredient if harvested and utilized before excessive degradation occurs. These observations may have implications for the selection of optimal harvest time for both fresh consumption and functional food development.

Total flavonoids

As shown in Figure 3, the peel, pulp, and seed of *Durio zibethinus* Ri6 at 15 and 17 weeks after flowering contained flavonoid levels ranging from 0.01 to 0.21 mg QE/g dry matter (DM), showing a clear decline with increasing ripeness. Similar to TPC, the highest TFC was observed in the peel at 15 weeks (0.21 mg QE/g DM), while the lowest value was recorded in the seed at 17 weeks (0.01 mg QE/g DM). Across both time points, the peel consistently contained the highest flavonoid levels, followed by the pulp and seed. The decrease in TFC with fruit maturation is attributed to enzymatic degradation of flavonoid compounds, a process likely catalyzed by oxidative enzymes such as polyphenol oxidase and peroxidase, as previously reported for polyphenol degradation during fruit ripening. These findings are consistent with similar trends in other fruit species. For instance, Luo et al. (2019) reported a decline in TFC during strawberry fruit development, particularly after sucrose treatment, which modulated secondary metabolism and flavonoid biosynthesis (Luo et al., 2019). The TFC values obtained in this study were lower than those reported for fresh Durian flesh by Leontowicz et al. (2011), who found 385.2 µg catechin equivalents (CE)/g, and by Haruenkit et al. (2010), who observed 0.5 mg CE/g. These differences may be due to variations in cultivar, sample preparation (fresh vs. dried), and analytical methods (CE vs. QE equivalents). The present data emphasize the importance of harvest timing to retain maximum flavonoid content, particularly in the peel, which may offer potential for nutraceutical or functional food applications when processed early in fruit development.

Antioxidant capacity

DPPH radical scavenging activity

The DPPH free radical scavenging activity of different anatomical parts (peel, flesh, and seed) of Ri6 Durian was evaluated at 15 and 17 weeks after flowering. The antioxidant activity, expressed as mg ascorbic acid equivalent (AAE) per g dry weight (DW), demonstrated a declining trend with increasing fruit maturity, similar to the patterns observed for TPC and TFC. The highest DPPH scavenging capacity (0.67 mg AAE/g DW) was recorded in the peel at 15 weeks, while the lowest value (0.17 mg AAE/g DW) was observed in the pulp at 17 weeks. This reduction in antioxidant capacity is likely associated with the degradation of polyphenolic compounds and flavonoids during fruit ripening. Since phenolic compounds are known to contribute significantly to free radical scavenging activity, the observed decrease in DPPH activity correlates with the parallel declines in TPC and TFC across all parts of the fruit. Among the different anatomical parts, the peel consistently exhibited the highest antioxidant activity, whereas the pulp showed the lowest, highlighting the peel as a rich source of bioactive compounds in early developmental stages. While the findings of this study support a decreasing antioxidant trend with ripening, they differ from the results reported by Paśko et al. (2019), who observed an increase in DPPH activity during fruit ripening from 3.45 to 7.48 µmol Trolox equivalents (TE)/g DW, which they attributed to enhanced biosynthesis and release of phenolic compounds and flavonoids during fruit maturation. However, similar declining trends were reported by Leontowicz et al. (2011), where DPPH

values decreased from 1.30 to 1.12 µmol TE/g as Durian matured, and by Silva et al. (2018) in apple juice, where antioxidant capacity declined from 409 to 361.5 mg/L as fruit ripened to an overripe stage. These observations reinforce the importance of harvest timing for maximizing antioxidant potential in Durian and suggest that the peel, especially at earlier maturity stages, could serve as a valuable source of natural antioxidants in functional food development.

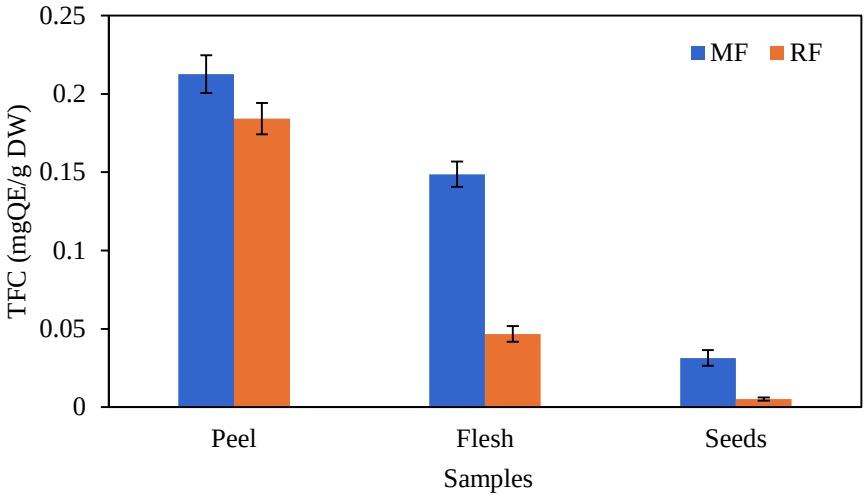


Fig. 3. Total flavonoid content (TFC) in peel, flesh, and seed of *Durio zibethinus* Ri6 at two ripening stages (MF, 15 weeks; RF, 17 weeks).

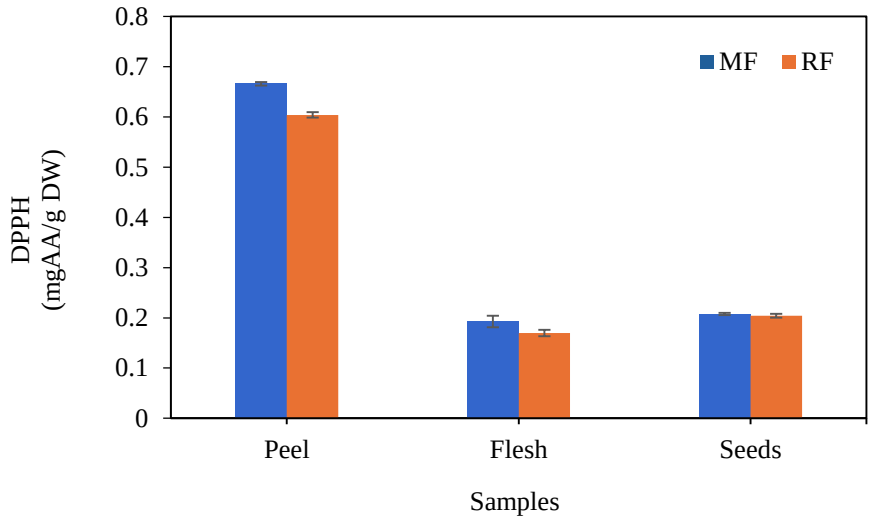


Fig. 4. DPPH radical scavenging activity in peel, flesh, and seed of *Durio zibethinus* Ri6 at two ripening stages (MF, 15 weeks; RF, 17 weeks).

ABTS radical scavenging activity

Unlike DPPH, ABTS is not inherently a free radical but requires chemical activation. In the presence of a strong oxidizing agent such as potassium persulfate ($K_2S_2O_8$), ABTS is converted into its radical cation form ($ABTS^+$), which can subsequently be reduced by antioxidant compounds present in biological samples. Figure 5 displays the $ABTS^+$ free radical scavenging activity of different parts of Ri6 Durian fruit peel, pulp, and seed at 15 and 17 weeks after flowering. A similar trend to DPPH activity was observed: as ripening progressed, antioxidant capacity declined. The highest $ABTS^+$ scavenging activity was recorded in the peel at 15 weeks (0.51 mg AAE/g dry weight), while the lowest was found in the pulp at 17 weeks (0.12 mg AAE/g DW). At both time points, the peel exhibited significantly higher antioxidant activity compared to the pulp and seed, with no statistical difference observed between the latter two. This decline in $ABTS^+$ scavenging capacity during ripening can be attributed to the enzymatic degradation of antioxidant compounds, such as polyphenols and flavonoids, as well as oxidative changes in cellular metabolism. These findings align with those of Leontowicz et al. (2011), who observed a decreasing trend in $ABTS^+$ scavenging capacity in Durian fruit as ripeness increased, from 23.49 to 11.06 µmol Trolox equivalents (TE)/g (Leontowicz et al., 2011). Similarly, Hwang et al. (2019) reported a reduction in $ABTS^+$ activity in strawberries ('Janghee' cultivar) during ripening, from 398.79 to 327.54 mg vitamin C equivalents (VCE)/100 g fresh weight (Hwang et al., 2019). These results further support the conclusion that earlier developmental stages particularly the peel retain higher antioxidant capacity, which could be exploited for functional food applications or natural antioxidant extraction.

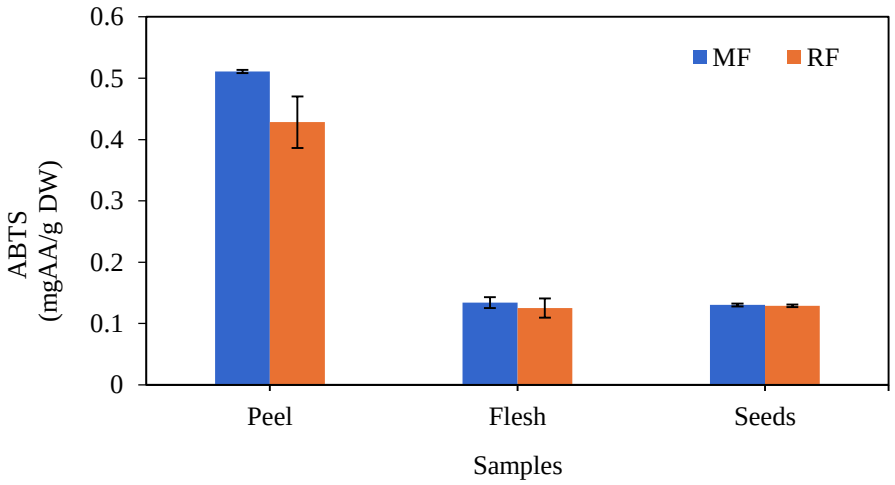


Fig. 5. ABTS•+ radical scavenging activity in peel, flesh, and seed of *Durio zibethinus* Ri6 at two ripening stages (MF, 15 weeks; RF, 17 weeks).

Table 5. Correlation coefficient between phenolics, flavonoids and free radical scavenging ability during Durian ripening.

	TPC	TFC	ABTS	DPPH
TPC	1	0.80	0.98	0.98
TFC	0.80	1	0.84	0.82
ABTS	0.98	0.84	1	1
DPPH	0.98	0.82	1	1

The corresponding units of TPC, TFC, DPPH, ABTS values are (mgGAE/g DW), (mgQE/g DW), (mgAA/g DW), (mgAA/g DW).

Correlation between phenolics, flavonoids, and radical scavenging

Table 5 presents the Pearson correlation coefficients between TPC, TFC, and two free radical scavenging assays (ABTS and DPPH) across different parts and ripening stages of *Durio zibethinus* cv. Ri6. The results indicate a strong positive correlation between TPC and antioxidant activity, with correlation coefficients of 0.98 for both DPPH and ABTS. This finding is consistent with previous studies in tropical fruits, which demonstrated that polyphenols are major contributors to antioxidant capacity (Leontowicz et al., 2011). Similarly, TFC showed strong correlations with ABTS (R = 0.84) and DPPH (R = 0.82), although slightly lower than those of TPC. The highest correlation coefficient (R = 1) was observed between ABTS and DPPH assays, suggesting that both methods are equally sensitive in detecting antioxidant potential in Durian matrices and reflect similar antioxidant mechanisms. In contrast, the weakest correlation (R = 0.80) was recorded between TPC and TFC, indicating that although both classes of compounds contribute to antioxidant activity, their accumulation and degradation may be regulated differently during ripening (Gorinstein et al., 2011). These variations may arise due to the structural diversity of phenolic and flavonoid compounds, as well as their susceptibility to oxidation and enzymatic degradation under ripening-associated physiological changes (Leontowicz et al., 2011). Storage conditions, tissue-specific metabolic activity, and enzymatic breakdown (e.g., polyphenol oxidase, peroxidase) may further affect the concentration and reactivity of these compounds. As polyphenols and flavonoids are known to degrade or transform during postharvest handling, their contribution to antioxidant capacity may not always be directly proportional or synchronous (Haruenkit et al., 2010). Therefore, while strong correlations were observed, further detailed analyses such as individual compound profiling and enzyme activity quantification are required to elucidate the exact biochemical relationships between bioactive compounds and antioxidant potential throughout Durian ripening.

CONCLUSION

This study evaluated the nutritional composition and bioactive properties of *Durio zibethinus* Ri6 at two developmental stages (15 and 17 weeks after flowering). The fruit showed notable variability in physicochemical parameters, including moisture, fat, protein, carbohydrates, pH, TA, and TSS. Both TPC and TFC declined with maturity, and antioxidant capacity measured by DPPH and ABTS assays also decreased, reflecting the close correlation between polyphenol content and free radical scavenging activity. Overall, the results highlight the nutritional richness and antioxidant potential of Ri6 durian, particularly in the peel at earlier ripening stages. These findings provide a foundation for developing functional foods, enhancing health benefits, and improving postharvest utilization. Future research should focus on harnessing the bioactive potential of durian peel through innovative processing technologies to expand its applications in functional foods and natural antioxidants.

Conflict of interest

The authors declare that there is no conflict of interest.

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