CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

Research article

EFFECTS OF FRUIT PARTS AND POST-FLOWERING TIME ON THE CHARACTERISTICS AND BIOACTIVITIES OF JACKFRUIT (*ARTOCARPUS HETEROPHYLLUS* LAM.) IN CAN THO CITY AND THE MEKONG REGION

Chi Khang Van[1,2,*], Thanh Viet Nguyen[1,2], Ho Ta Nguyen[3], Quoc Anh Le[3], Trinh Thi Nhu Hang Nguyen[1,2]

[1]*Institute of Applied Technology and Sustainable Development, Nguyen Tat Thanh University, Ho Chi Minh City, 755414, Vietnam*

[2]*Nguyen Tat Thanh University Center for Hi-Tech Development, Saigon Hi-Tech Park, Ho Chi Minh City, 755414, Vietnam*

[3]*Department of Natural Products, Faculty of Chemical Engineering and Food Technology, Nong Lam University, Ho Chi Minh City, 700000, Vietnam*

✉*Corresponding author: E-mail: vckhang@ntt.edu.vn*

ORCID Number: 0000-0001-6643-366,

https://doi.org/10.34302/crpjfst/2025.17.4.17

Article history:

Received:
October 20th, 2025

Accepted:
December 14th, 2025

Published
December 30th, 2025

Keywords
Jackfruit;
Artocarpus heterophyllus Lam;
Qualitatively;
Bioactive compound;,
Antioxidant activities.

Abstract

The study qualitatively and quantitatively analyzed bioactive compounds (alkaloids, flavonoids, phenolics & tannins, proteins, amino acids, carbohydrates, saponins, polyphenols, carotenoids) and antioxidant activities (DPPH, ABTS, TAC) in jackfruit pulp, fibers, and seeds collected from six regions of the Mekong Delta, including Thoi Lai, Can Tho (TL-CT); Phong Dien, Can Tho (PD-CT); Co Do, Can Tho (CD-CT); Cai Lay, Tien Giang (CL-TG); Chau Thanh, Hau Giang (CT-HG); and Chau Thanh, Ben Tre (CT-BT), at three maturity stages (100, 110, and 120 days). The results indicated that harvest time played a more significant role than locality. The pulp was richest in phenolics, tannins, and flavonoids at 100–110 days, the fibers contained higher levels of alkaloids and flavonoids at 120 days, while the seeds were consistently rich in proteins, amino acids, and carbohydrates at all stages. The external appearance and physical properties of jackfruit (shape, size, weight, component ratios, color, aroma, taste) increased and changed markedly with ripening, reaching optimal values at 120 days, with the highest pulp ratio, attractive color, and pronounced sweetness. The contents of bioactive compounds and antioxidant capacities generally declined with increasing maturity, with total polyphenols ranging from 0.07 to 0.32 mg GAE/gDW and flavonoids from 0.03 to 0.44 mg QE/gDW. In contrast, carotenoid content increased, ranging from 0.11 to 0.63 mg/mL. Notably, jackfruit seeds exhibited superior total antioxidant capacity (TAC) (123.67 mg AA/gDW) compared to pulp and fibers. Antioxidant activity decreased with advancing maturity, as reflected by IC_{50} values of DPPH (99.32–367.33 µg/mL) and ABTS (46.21–287.07 µg/mL), indicating that seeds and pulp demonstrated stronger antioxidant potential than rag.

1. Introduction

Jackfruit (*Artocarpus heterophyllus*), belonging to the family Moraceae and genus *Artocarpus*, is a widely cultivated fruit plant in Southeast Asia and Brazil (Sreeja Devi et al., 2021; Swami et al., 2012). Numerous cultivars of jackfruit exist, each differing considerably in fruit characteristics and properties. The fruit size varies greatly, ranging from small types weighing only 300–400 g to large types reaching several tens of kilograms. The tree is a woody perennial, typically 8–15 m in height, and begins to bear fruit after three years of age. The fruit is a syncarp, oval in shape, measuring about 30–60 cm in length and 20–30 cm in diameter. Jackfruit usually sets fruit in mid-spring and ripens by late summer (July–August). It is not only a nutritious fruit but also a plant with various medicinal applications. Several well-known cultivars include *mit mat*, *mit dai*, *mit thai*, and *mit nghe*. Jackfruit also represents an important income source for small farms through trade and serves as a nutrient-rich feed for livestock (Laishram & Ghosh, 2018; Ranasinghe et al., 2019a; Van et al., 2023a)

Jackfruit is a fleshy, sweet, and aromatic fruit. Except for the spiny rind and fibrous core, most parts of the fruit are edible. The pulp contains high sugar content and provides considerable energy (Barbosa et al., 2019). The edible bulbs are bright yellow, thick, dry, crispy-sweet, and fragrant, with small seeds and little fiber. Seeds are dark brown to brown, ellipsoid in shape, about 2–3 cm long and 1–1.5 cm in diameter, and surrounded by a thin white sheath. They are starchy and hard, with a storage capacity of about one month under low-temperature conditions. Medicinally, seeds have been reported to tonify qi, improve digestion, relieve hunger, and reduce cough, among other benefits (Palamthodi et al., 2021; Van et al., 2023b). Studies on the proportion of fruit components, including pulp, seeds, peel, and core, indicated that the inedible portion (peel and core) accounted for 59.20% of the total fruit weight. In Indonesia, the edible portion (pulp) was reported to account for 30–35%, while the peel and seeds contributed 55–62% and 8–15%, respectively (Saxena et al., 2011; Thanh et al., 2020).

Jackfruit contains a wide range of bioactive compounds, including carotenoids that act as antioxidants (Baliga et al., 2011). The antioxidant activity of jackfruit pulp extracts has been correlated with total phenolic and flavonoid contents (Jagtap et al., 2010). Both fresh pulp and seeds demonstrate antioxidant capacity comparable to ascorbic acid, with phenolic contents equivalent to 27.7 and 0.9 mg gallic acid, respectively, contributing approximately 70% of the total antioxidant activity (Soong & Barlow, 2004). Jackfruit is also a rich source of essential minerals, particularly magnesium, which plays a vital role in calcium absorption, bone strengthening, and the prevention of bone-related disorders such as osteoporosis.

The Mekong Delta is the largest fruit-producing region in Vietnam, with a cultivated area of approximately 390,000 ha, accounting for more than 33% of the country's fruit-growing area, and an annual production of about 4 million tons (Department of Agriculture and Rural Development of Can Tho City). Within this, jackfruit cultivation occupies around 30,600 ha (Department of Agriculture and Rural Development of Can Tho City). Different parts of the jackfruit have been investigated at various maturity stages and across different areas to determine the most suitable cultivation areas for achieving optimal chemical composition and bioactivity. These findings provide practical insights for farmers to expand jackfruit production, taking advantage of favorable soil, water, and alluvial conditions to improve productivity and quality.

2. Materials and methods

2.1. Materials

Thai jackfruits were collected and separated into individual components (pulp, fibers, and seeds), which were subsequently analyzed and evaluated. The jackfruits were cultivated in Dinh Mon Commune, Thoi Lai District, Can Tho City; Truong Long Commune, Phong Dien District, Can Tho City; Thoi Hung Commune, Co Do District, Can Tho City; My Thanh Nam Commune, Cai Lay District, Tien Giang Province; Dong Phuoc A Commune, Chau Thanh District, Hau Giang Province; and Tan Phu Commune, Chau Thanh District, Ben Tre Province.

2.2. Analysis methods

2.2.1. Qualitative methods

The qualitative screening of phytochemical constituents in jackfruit pulp was carried out using standard chemical tests. The presence of alkaloids, flavonoids, phenolics, tannins, proteins, organic acids, amino acids, saponins, and carbohydrates was confirmed by characteristic color changes or precipitate formation with specific reagents.

2.2.2. Determination of total carotenoid content (TCC)

One gram of the sample was homogenized with 10 mL of an acetone:water mixture (4:1) for 2 minutes until uniform. To determine the effect of ultrasonic treatment on extraction yield, the samples were sonicated for 3 minutes (5 cycles, 30 s pulse, 10 s pause) under the same conditions. The samples were placed in an ice-water bath to prevent overheating. The homogenized samples were centrifuged at 5000 rpm for 10 minutes at 20 °C. The absorbance spectra of each compound were measured and recorded at 663.6 nm for chlorophyll a, 646.6 nm for chlorophyll b, and 470.0 nm for total carotenoids.

2.2.3. Determination of total polyphenol content (TPC)

The total polyphenol content was determined using the Folin–Ciocalteu method as described by Nhi et al. (2020) . Diluted extracts (0.1 mL) were mixed with 0.5 mL of 10% Folin–Ciocalteu reagent, vortexed, and allowed to stand for 5 min. Then, 0.4 mL of 7.5% Na_2CO_3 was added, and the mixture was incubated at room temperature in the dark for 1 h. Absorbance was measured at 765 nm using a UV–Vis spectrophotometer, and gallic acid was used as the calibration standard. Results were expressed as milligrams of gallic acid equivalents per gram of extract (mg GAE/g DM).

2.2.4. Determination of total flavonoid content (TFC)

The total flavonoid content was determined using the aluminum chloride colorimetric ($AlCl_3$) method as described by Nguyen et al. (2020) with minor modifications. Diluted extracts (0.5 mL) were mixed with 4.3 mL ethanol, 0.1 mL of 10% $AlCl_3$, and 0.1 mL of 1 M CH_3COOK. The mixtures were incubated for 30 min at room temperature. Absorbance was measured at 510 nm using a UV–Vis spectrophotometer. TFC values were calculated from a quercetin calibration curve and expressed as mg quercetin equivalents per g dry matter (mg QE/g DM).

2.2.5. Determination of total acidity capacity (TAC)

The phosphomolybdenum method was performed following the modified procedure of Van et al. (2024).The reagent solution was prepared by mixing 0.6 M concentrated sulfuric acid (95–97%) with 4 mM ammonium molybdate (98%) and 28 mM sodium dihydrogen phosphate. A volume of 3 mL of reagent was transferred into test tubes, followed by the addition of 0.3 mL extract at different concentrations (100–500 μg/mL). For the negative control, 0.3 mL methanol was added instead of the extract. All tubes were incubated at 95 °C for 90 min, cooled to room temperature, and absorbance was measured at 695 nm.

2.2.6. Investigation of free radical scavenging activity by DPPH· method

The DPPH• free radical scavenging assay was performed. One gram of jackfruit sample was homogenized with 50 mL ethanol, diluted, and 0.5 mL of the extract was mixed with 1.5 mL of DPPH• solution (OD517 nm = 1.1 ± 0.02). Ethanol (99.5%) was used as the blank.

The mixtures were incubated in the dark for 30 minutes, and absorbance was measured at 517 nm using a UV–Vis spectrophotometer. IC_{50} values were determined from inhibition curves, and vitamin C (ascorbic acid) was used as the standard.

2.2.7. Investigation of free radical scavenging activity by ABTS$\cdot^+$ method

The ABTS$\bullet^+$ radical cation solution was prepared by mixing 10 mL of 7.4 mM ABTS$\bullet^+$ with 10 mL of 2.6 mM $K_2S_2O_8$ and incubating in the dark for 24 h, then diluted to an absorbance of 1.1 ± 0.02 at 734 nm. Diluted samples (0.5 mL) were transferred into test tubes and mixed with 1.5 mL of the adjusted ABTS$\bullet^+$ solution, while ethanol (99.5%) was used as the blank. The mixtures were incubated in the dark for 30 min, and absorbance was measured at 734 nm using a UV–Vis spectrophotometer. For IC_{50} determination, six test tubes were prepared, including one blank (only reagent) and five tubes containing different extract volumes (100–500 µL) with corresponding ethanol dilutions, each mixed with 1500 µL of ABTS$\bullet^+$ solution. The mixtures were incubated in the dark for 30 min and absorbance was measured at 734 nm. Vitamin C (ascorbic acid) was used as the reference standard.

2.3. Data analysis

Results were analyzed by one-way analysis of variance (ANOVA) method and significant differences among means from triplicate analyses at ($p<0.05$) were determined by Fisher's least significant difference (LSD) procedure using the Statgraphics software (Centurion XV).

3. Results and discussions

3.1. Qualitative analysis of bioactive phytochemicals in major parts of jackfruit at different post-flowering times in the Mekong delta region

Figure 1 presented the images of jackfruit parts cultivated in six areas of the Mekong Delta. Table 1 showed the qualitative analysis of bioactive compounds in jackfruit parts (aril, fiber, seed) collected from six areas of the Mekong Delta: Thoi Lai, Can Tho (TL-CT); Phong Dien, Can Tho (PD-CT); Co Do, Can Tho (CD-CT); Cai Lay, Tien Giang (CL-TG); Chau Thanh, Hau Giang (CT-HG); and Chau Thanh, Ben Tre (CT-BT). Jackfruit samples were collected at three technical maturity stages (100, 110, and 120 days after flowering) to qualitatively determine the presence of compounds such as alkaloids, flavonoids, phenolics & tannins, proteins, amino acids, carbohydrates, and saponins. The degree of presence was indicated by the symbols +, ++, +++ (with +++ representing the highest level). The study focused on evaluating the accumulation trends of these compounds across different areas and maturity stages to draw conclusions regarding the potential applications of jackfruit in the food sector. The results showed that the presence of bioactive compounds was relatively uniform among the surveyed areas, regardless of specific soil and climatic conditions. In the aril, phenolics, tannins, and flavonoids were strongly present in all six areas when jackfruits reached 100–110 days of maturity. This demonstrated that the harvest stage played a more critical role than locality in the accumulation of these compounds. Phenolics and tannins are known for their strong antioxidant capacity; therefore, jackfruit arils from any locality could be harvested at 100–110 days to optimize nutritional value and their potential use in antioxidant-rich functional foods. The fiber, which is often considered a by-product, also exhibited a significant presence of alkaloids and flavonoids in all areas, especially at 120 days of maturity. The stability of these compounds in the fiber among areas highlighted the potential for utilizing jackfruit fiber as a valuable bioresource, thereby contributing to reducing waste in the agricultural value chain.

The seeds were also remarkable for their high levels of proteins, amino acids, and carbohydrates across all six areas and maturity stages. This part of the fruit exhibited superior nutritional value and was less affected by environmental factors or harvest timing. Another compound, saponin, was detected in all jackfruit parts across all areas, with the highest levels observed at 110–120 days of maturity. The stable presence of saponins across regions indicated that jackfruit from the Mekong Delta could serve as an important natural resource for the development of health-promoting products.

Figure 1. Photograph of jackfruit parts cultivated in the mekong delta region. A: Thoi Lai, Can Tho (TL-CT), B: Phong Dien, Can Tho (PD-CT), C: Co Do, Can Tho (CD-CT), D: Cai Lay, Tien Giang (CL-TG), E: Chau Thanh, Hau Giang (CT-HG), F: Chau Thanh, Ben Tre (CT-BT).

Table 1. Qualitative analysis of compounds in different parts of jackfruit across regions and technical maturity stages

Parts	Area	TL-CT			PD-CT			CD-CT			CT-HG			CL-TG			CT-BT		
	Time (day) / Compound	100	110	120	100	110	120	100	110	120	100	110	120	100	110	120	100	110	120
Pulp	Alkaloid	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Flavonoid	+++	+++	++	+++	+++	+ +	+++	+++	+ +	+++	+++	+ +	+++	+++	+ +	+++	+++	+ +
	Phenolic và tanin	+ +	++	+	+ +	++	+	+ +	++	+	+ +	++	+	+ +	++	+	+ +	++	+
	Protein	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Amino acid	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Organic acid	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Carbohydrate	++	+	+	++	+	+	++	+	+	++	+	+	++	+	+	++	+	+
	Saponin	++	+++	+++	++	+++	+++	++	+++	+++	++	+++	+++	++	+++	+++	++	+++	+++
Rag	Alkaloid	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Flavonoid	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Phenolic & Tanin	++	+ +	+	++	+ +	+	++	+ +	+	++	+ +	+	++	+ +	+	++	+ +	+
	Protein	+	++	++	+	++	++	+	++	++	+	++	++	+	++	++	+	++	++
	Amino acid	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Organic acid	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Carbohydrate	+ +	+	+	+ +	+	+	+ +	+	+	+ +	+	+	+ +	+	+	+ +	+	+
	Saponin	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Seed	Alkaloid	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Flavonoid	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Phenolic & Tanin	++	+ +	+	++	+ +	+	++	+ +	+	++	+ +	+	++	+ +	+	++	+ +	+
	Protein	+	++	++	+	++	++	+	++	++	+	++	++	+	++	++	+	++	++
	Amino acid	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++	+	++	+++
	Organic acid	+	++	++	+	++	++	+	++	++	+	++	++	+	++	++	+	++	++
	Carbohydrate	+ +	+	+	+ +	+	+	+ +	+	+	+ +	+	+	+ +	+	+	+ +	+	+
	Saponin	+	++	++	+	++	++	+	++	++	+	++	++	+	++	++	+	++	++

3.2. Characteristics and physical properties in major parts of jackfruit at different post-flowering times in the Mekong delta region

Table 2 presented the external characteristics and physical properties of jackfruit parts from different areas and technical maturity stages. In terms of morphology, at all three maturity stages (100, 110, and 120 days after flowering), jackfruits from all areas exhibited an elongated shape with a slightly swollen middle portion. Both fruit length and width showed an increasing trend with maturity across all areas, which was consistent with the natural growth process of the crop. At TL-CT, the average length increased from 35.33 cm at 100 days to 36.65 cm at 120 days, while the width increased from 24.53 cm to 25.51 cm. This trend was also observed in other areas, with a slight increase as maturity advanced. These results indicated that the accumulation of dry matter and water in the fruit peaked at 120 days, leading to an increase in fruit size. However, slight differences in fruit size were observed among areas. At 120 days, fruit length ranged from 35.16 cm (CT-BT) to 37.46 cm (PD-CT), suggesting that growth conditions, soil type, and climate were relatively similar across regions. This supported the establishment of common quality standards for jackfruit production among areas, thereby maintaining product uniformity in the market.

Fruit weight also showed an increasing trend with maturity. Specifically, at TL-CT, fruit weight increased from 8.02 kg (100 days) to 8.54 kg (120 days). A similar trend was observed across all other areas, with fruit weight ranging from 8.02 to 8.89 kg. The increase in fruit weight with advancing maturity resulted from higher accumulation of water and dry matter, which led to maximum size and weight at 120 days.

The proportions of internal components, including aril, fiber, and seed ratios, changed markedly with maturity. The aril ratio tended to increase with maturity. At TL-CT, the aril ratio increased from 26.54% (100 days) to 30.53% (120 days), while the fiber ratio decreased from 16.05% (100 days) to 12.53% (120 days). The increase in aril ratio and decrease in fiber ratio indicated that the fruit had reached full ripeness, with the edible portion occupying a larger proportion, thereby enhancing economic value and product quality. This also reflected nutrient accumulation in the aril during ripening, which reduced fiber content and increased nutritional composition. However, aril and other component ratios showed no substantial variation among areas. Across all areas, aril ratios ranged from 26.40% to 30.70%, while fiber ratios ranged from 12.65% to 17.70%, indicating only minor differences among regions. The seed ratio exhibited a slight decrease with maturity. At 100 days, seed ratios ranged from 14.70% (CT-HG) to 14.90% (CD-CT), but declined to approximately 13.20% (PD-CT) to 13.40% (CL-TG) at 120 days. This could be explained by the disproportionate development between the aril and seed, as the aril accumulated dry matter and gained weight more rapidly than the seed during ripening. The peel ratio ranged from 16.90% (CT-HG, 110 days) to 26.40% (PD-CT, 120 days), with an overall increasing trend as maturity advanced. The ratio of other parts (including peduncle, core, and non-edible tissues) ranged from 17.25% to 25.50% and generally decreased with ripening across most areas. A similar decline was recorded elsewhere, suggesting that as the fruit ripened, nutrients were translocated from these parts to the edible portion.

Sensory attributes such as color, aroma, and taste also changed markedly with maturity. At 100 days, fruits displayed a dark green external color, which shifted to light green or slightly yellow at 120 days. Internal color also varied from pale yellow to deep yellow, reflecting increased concentrations of carotenoid pigments.

Table 2. Characteristics and physical properties of jackfruit parts across different areas and maturity stages

Area	TL-CT			PD-CT			CD-CT		
Time (Day) / Characteristic	100	110	120	100	110	120	100	110	120
Fruit length (cm)	35.33 ± 2.58^a	36.33 ± 4.53^a	36.66 ± 3.51^a	34.53 ± 2.34^a	35.74 ± 2.36^a	36.27 ± 3.72^a	35.33 ± 2.58^a	36.33 ± 4.53^a	36.94 ± 3.51^a
Fruit width (cm)	24.53 ± 2.53^a	24.58 ± 2.65^a	25.51 ± 3.74^a	23.37 ± 3.26^a	24.73 ± 2.46^a	25.15 ± 2.64^a	23.53 ± 2.53^a	23.58 ± 2.65^a	24.85 ± 3.74^a
Fruit weight (Kg)	8.02 ± 1.58^a	8.32 ± 1.21^a	8.54 ± 2.68^a	8.36 ± 1.63^a	8.52 ± 2.63^a	8.84 ± 2.68^a	8.12 ± 2.35^a	8.59 ± 2.73^a	8.89 ± 3.35^a
Pulp ratio (%)	26.54 ± 2.27^a	27.69 ± 1.43^a	30.53 ± 1.42^b	26.48 ± 2.31^a	27.80 ± 1.50^a	30.55 ± 1.40^b	26.60 ± 2.25^a	27.90 ± 1.55^a	30.70 ± 1.45^b
Rag ratio (%)	16.05 ± 1.07^a	17.69 ± 2.86^a	12.53 ± 2.31^b	16.12 ± 1.15^a	17.65 ± 2.05^a	12.60 ± 2.20^b	16.00 ± 1.20^a	17.70 ± 2.10^a	12.50 ± 2.15^b
Seed ratio (%)	14.81 ± 1.04^a	14.62 ± 1.46^a	13.25 ± 1.42^a	14.80 ± 1.05^a	14.60 ± 1.20^a	13.20 ± 1.35^a	14.90 ± 1.10^a	14.65 ± 1.25^a	13.30 ± 1.30^a
Rind ratio (%)	17.28 ± 2.15^a	16.92 ± 1.53^a	25.43 ± 1.52^b	17.30 ± 2.00^a	17.15 ± 1.80^a	26.40 ± 1.75^b	17.40 ± 2.05^a	17.00 ± 1.75^a	23.35 ± 1.80^b
Other parts (%)	25.22 ± 1.43^a	23.08 ± 2.31^a	18.26 ± 3.21^b	25.30 ± 1.85^a	22.80 ± 1.90^a	17.25 ± 2.05^b	25.10 ± 1.80^a	22.75 ± 2.05^b	20.15 ± 2.10^b
External color	Light green	Dark green	Dark green with black spots and streaks	Light green	Dark green	Dark green with black spots and streaks	Light green	Dark green	Dark green with black spots and streaks
Internal color	Pale yellow, almost white	Light yellow	Yellow	Pale yellow, almost white	Light yellow	Yellow	Pale yellow, almost white	Light yellow	Yellow
Aroma	No aroma	Slight aroma	Strong aroma	No aroma	Slight aroma	Strong aroma	No aroma	Slight aroma	Strong aroma
Taste	No taste	Slightly sweet taste	Distinctly sweet taste	No taste	Slightly sweet taste	Distinctly sweet taste	No taste	Slightly sweet taste	Distinctly sweet taste

Area	**CT-HG**			**CL-TG**			**CT-BT**		
Time (Day) / **Characteristic**	**100**	**110**	**120**	**100**	**110**	**120**	**100**	**110**	**120**
Fruit length (cm)	34.63 ± 1.56^{a}	35.83 ± 2.26^{a}	35.66 ± 3.51^{a}	34.73 ± 2.84^{a}	35.82 ± 2.57^{a}	37.46 ± 2.46^{a}	34.38 ± 3.63^{a}	35.74 ± 3.27^{a}	35.16 ± 2.63^{a}
Fruit width (cm)	24.36 ± 1.61^{a}	25.16 ± 1.58^{a}	25.93 ± 3.74^{a}	23.47 ± 1.57^{a}	24.74 ± 3.37^{a}	24.93 ± 2.75^{a}	24.73 ± 2.74^{a}	23.64 ± 1.75^{a}	25.25 ± 3.27^{a}
Fruit weight (Kg)	8.37 ± 2.47^{a}	8.64 ± 3.28^{a}	8.73 ± 3.63^{a}	8.27 ± 2.64^{a}	8.64 ± 3.47^{a}	8.93 ± 3.74^{a}	8.05 ± 1.58^{a}	8.32 ± 1.21^{a}	8.84 ± 3.73^{a}
Pulp ratio (%)	26.40 ± 2.35^{a}	27.75 ± 1.60^{a}	30.50 ± 1.50^{b}	26.50 ± 2.30^{a}	27.85 ± 1.55^{a}	30.60 ± 1.55^{b}	26.55 ± 2.28^{a}	27.87 ± 1.53^{a}	30.65 ± 1.52^{b}
Rag ratio (%)	16.20 ± 1.25^{a}	17.60 ± 2.00^{a}	12.65 ± 2.25^{b}	16.05 ± 1.30^{a}	17.68 ± 2.15^{a}	12.55 ± 2.20^{b}	16.08 ± 1.22^{a}	17.67 ± 2.12^{a}	12.57 ± 2.18^{b}
Seed ratio (%)	14.70 ± 1.15^{a}	14.55 ± 1.30^{a}	13.35 ± 1.40^{a}	14.85 ± 1.10^{a}	14.62 ± 1.35^{a}	13.40 ± 1.45^{a}	14.82 ± 1.12^{a}	14.61 ± 1.33^{a}	13.37 ± 1.42^{a}
Rind ratio (%)	17.20 ± 2.10^{a}	16.90 ± 1.80^{a}	22.55 ± 1.70^{b}	17.35 ± 2.00^{a}	16.92 ± 1.85^{a}	24.45 ± 1.80^{b}	17.32 ± 2.08^{a}	16.91 ± 1.83^{a}	25.47 ± 1.82^{b}
Other parts (%)	25.50 ± 1.75^{a}	23.20 ± 1.95^{ab}	21.25 ± 2.00^{b}	25.25 ± 1.90^{a}	22.93 ± 2.00^{b}	19.00 ± 2.15^{c}	25.23 ± 1.88^{a}	22.94 ± 2.05^{b}	17.94 ± 2.13^{c}
External color	Light green	Dark green	Dark green with black spots and streaks	Light green	Dark green	Dark green with black spots and streaks	Light green	Dark green	Dark green with black spots and streaks
Internal color	Pale yellow, almost white	Light yellow	Yellow	Pale yellow, almost white	Light yellow	Yellow	Pale yellow, almost white	Light yellow	Yellow
Aroma	No aroma	Slight aroma	Strong aroma	No aroma	Slight aroma	Strong aroma	No aroma	Slight aroma	Strong aroma
Taste	No taste	Slightly sweet taste	Distinctly sweet taste	No taste	Slightly sweet taste	Distinctly sweet taste	No taste	Slightly sweet taste	Distinctly sweet taste

a, b, c: Values represent statistically significant differences ($p < 0.05$)

This enhancement in color improved fruit attractiveness, thereby increasing market value and consumer appeal. In terms of aroma and taste, fruits at 100 days exhibited only faint or no aroma. By 120 days, the aroma became more distinct and pleasant, while sweetness was more pronounced. At all areas, fruits at 120 days consistently exhibited a strong characteristic aroma and sweetness, indicating completion of the natural ripening process and improved flavor quality. Thus, 120 days represented the optimal harvest stage for jackfruit intended for fresh consumption.

Overall, analysis of the parameters indicated that 120 days after flowering was the ideal harvest stage for jackfruit in the fresh market. At this stage, fruits exhibited the largest size and weight, the highest aril ratio, attractive color, strong aroma, and pronounced sweetness, thereby enhancing commercial value and consumer satisfaction. In contrast, earlier maturity stages (100 and 110 days) could be more suitable for processed products such as dried jackfruit or green jackfruit, meeting diverse market demands. The similarity in basic parameters across areas further demonstrated that jackfruit from different regions achieved nearly uniform quality, facilitating standardization and the development of branded products. In summary, fruit size, weight, internal component ratios, color, aroma, and taste varied significantly with maturity but remained consistent across areas. The 120-day maturity stage was the most optimal for harvesting and fresh consumption, due to superior sensory attributes and quality. The uniformity of jackfruit quality among areas provided a foundation for production standardization, enhanced competitiveness, and improved export potential of Vietnamese jackfruit.

3.3. Chemical composition and antioxidant activity in major parts of jackfruit at different post-flowering times in the Mekong delta region

Polyphenols were the major groups of compounds in the chemical composition of plants, flowers, and ripened fruits. These compounds exhibited strong biological activities and exerted positive effects on human health, such as antioxidant activity, prevention of the formation of singlet oxygen radicals, control of cancer cell proliferation, and mitigation of human diseases (Van et al., 2023a; Le et al., 2019). Table 3 presented an overview of polyphenol contents in different parts of jackfruit (flesh, fiber, and seeds) and their variations according to cultivation regions and ripening stages. In general, polyphenol content tended to decrease as the ripening stage advanced. The highest polyphenol content was recorded in jackfruit seeds cultivated in CL-TG at 100 days of maturity with a value of 0.32 ± 0.02 mg GAE/g dry weight, while the lowest value was observed in jackfruit fiber cultivated in CD-CT at 120 days with 0.07 ± 0.02 mg GAE/g dry weight. Polyphenol contents did not differ significantly among regions for the same fruit part. Table 3 showed that the polyphenol content in jackfruit seeds was considerably higher than that in flesh and fiber. This trend was consistent with the study of Jagtap et al. (2010), in which the highest TPC was reported in seeds (27.7 mg GAE/g), but it contrasted with the findings of Shrikanta et al. (2015), who reported polyphenol contents of 1.27 mg GAE/g in flesh and 1.00 mg GAE/g in seeds. The present measurements showed similarity with the polyphenol content of 0.21 mg GAE/g in ripe jackfruit flesh using methanol extract and 0.46 mg GAE/g using ethanol extract (Jagtap et al., 2010). However, these results were lower than those reported by Shrikanta et al. (2015), who obtained polyphenol levels ranging from 1.00 to 1.27 mg GAE/g for flesh and seeds.

Flavonoids were secondary phenolic metabolites mainly distributed in plants. They exhibited a wide range of biological activities in plants, animals, and even microorganisms (Khalid et al., 2019). Table 3 indicated that flavonoid contents tended to decrease as ripening progressed. The highest flavonoid content was recorded in jackfruit fiber cultivated in TL-CT at 100 days of maturity (0.44 ± 0.02 mg QE/g dry weight), whereas the lowest value was observed in seeds from CT-

BT and CD-CT at 120 days (0.03 ± 0.01 mg QE/g dry weight). Overall, flavonoid contents in jackfruit fiber were higher than those in flesh and much higher than in seeds. CT-HG and TL-CT exhibited superior flavonoid contents compared to other regions. Previous studies suggested that environmental temperatures ranging from 30 °C to 40 °C could suppress flavonoid biosynthesis, while low-light conditions could also inhibit flavonoid accumulation (Shi et al., 2022). These findings were consistent with Jagtap et al. (2010), who reported 0.24 mg RE/g (rutin equivalent) in ethanol extract. Flavonoid contents in jackfruit flesh ranged from 13.12 mg QE/100 g to 109.44 mg QE/100 g in ethyl acetate and methanol extracts, respectively (Shafiq et al., 2017). Flavonoids possessed multiple biochemical and antioxidant activities with beneficial effects against diseases such as cancer, Alzheimer's disease, and atherosclerosis (Panche et al., 2016). Similar to TPC, as the fruit ripened, increasing enzymatic activity hydrolyzed substantial amounts of flavonoids, leading to decreased TFC over time. Ranasinghe & Marapana (2019b) also reported that the seed coat and outer endosperm contained high flavonoid contents. At 100 days, the seed coat was thick, but it gradually thinned at 110 and 120 days, explaining the decline in flavonoid content in seeds.

Carotenoids were plant pigments functioning as antioxidants, hormone precursors, and natural colorants. They were found in most plant organs and tissues and determined the characteristic color of fruits. Table 3 presented carotenoid contents in jackfruit (flesh, fiber, seeds) across regions and ripening stages (100, 110, 120 days). In general, carotenoid contents increased with ripening. Jackfruit flesh contained higher carotenoid levels (0.27–0.63 mg/mL) compared to fiber (0.19–0.46 mg/mL) and seeds (0.11–0.39 mg/mL). The highest value was 0.63 ± 0.01 mg/mL in flesh at 120 days in PD-CT, while the lowest was 0.11 ± 0.01 mg/mL in seeds at 100 days in TL-CT. Differences across regions could be attributed to environmental factors such as climate, soil, cultivation practices, temperature, and light exposure. Direct exposure to sunlight and higher temperatures enhanced carotenoid biosynthesis, increasing carotenoid contents (de Azevedo & Rodriguez-Amaya, 2005). The present results agreed with previous reports by Jagadeesh et al. (2007), who reported 0.592 µg/g, and Nansereko et al. (2022), who recorded 60.47 µg/100 g.

DPPH radical was widely used to assess the antioxidant capacity of compounds. Table 3 showed IC_{50} values for DPPH radical scavenging activity in different jackfruit parts at 100, 110, and 120 days. DPPH IC_{50} values increased with ripening. The lowest IC_{50} was observed in CT-HG at 100 days (99.32 ± 2.42 µg/mL), while the highest was in CD-CT at 120 days (367.33 ± 4.72 µg/mL). Antioxidant activities in flesh and seeds were comparable and considerably higher than in fiber. These differences were likely due to variations in polyphenol, flavonoid, and carotenoid contents, which influenced antioxidant capacities (Rosa et al., 2009).

The antioxidant potential of jackfruit varied with maturity because maturity influenced enzymatic activities and nutrient levels. As seeds matured, their antioxidant levels increased, protecting them from environmental stressors such as UV radiation and pollutants. Mature seeds also contained higher essential fatty acid levels, which further contributed to antioxidant activity. However, Baliga et al. (2011) reported different values for DPPH scavenging capacity in jackfruit seed extracts, with dichloromethane–methanol (1:1) extract showing IC_{50} = 0.6433 ± 0.0029 mg/mL and acetone extract IC_{50} = 0.7867 ± 0.0104 mg/mL. Although DPPH and ABTS assays were based on radical scavenging, ABTS was not inherently a free radical and required oxidation by a strong oxidant such as $K_2S_2O_8$. Upon oxidation, ABTS lost one electron and generated the ABTS radical.

Table 3. Chemical composition and antioxidant activity of jackfruit parts across different areas and maturity stages

Parts	**Pulp**								
Area	**TL-CT**			**PD-CT**			**CD-CT**		
Time (day) / Compound	**100**	**110**	**120**	**100**	**110**	**120**	**100**	**110**	**120**
TPC (mg GAE/g DW)	0.25 ± 0.04a	0.19 ± 0.06b	0.14 ± 0.02c	0.24 ± 0.02a	0.16 ± 0.05b	0.14 ± 0.04b	0.20 ± 0.02a	0.14 ± 0.02b	0.12 ± 0.02b
TFC (mg QE/ g DW)	0.31 ± 0.01a	0.29 ± 0.05a	0.19 ± 0.03b	0.25 ± 0.00a	0.24 ± 0.05a	0.15 ± 0.01b	0.23 ± 0.02a	0.18 ± 0.05b	0.10 ± 0.00c
TCC (mg/mL)	0.30 ± 0.00a	0.33 ± 0.01a	0.53 ± 0.01b	0.29 ± 0.02a	0.41 ± 0.00b	0.63 ± 0.01c	0.31 ± 0.00a	0.44 ± 0.01b	0.61 ± 0.01c
IC50 DPPH (μg/mL)	108.59 ± 2.75a	114.08 ± 5.30b	165.16 ± 1.39c	116.52 ± 3.16a	124.23 ± 4.66b	170.21 ± 8.22c	128.29 ± 2.37a	135.10 ± 4.61b	202.34 ± 4.40c
IC50 ABTS (μg/mL)	56.60 ± 1.33a	71.40 ± 7.08b	77.64 ± 4.23c	58.61 ± 3.27a	75.36 ± 0.33b	78.55 ± 0.56b	58.65 ± 1.48a	77.32 ± 1.18b	81.54 ± 3.04c
TAC (mg AA/g DW)	113.52 ± 2.33a	44.02 ± 2.17b	35.90 ± 7.33c	93.13 ± 7.38a	36.71 ± 2.04b	34.65 ± 7.37b	87.21 ± 4.94a	32.80 ± 1.59b	29.15 ± 0.69b
Parts	**Pulp**								
Area	**CT-HG**			**CL-TG**			**CT-BT**		
Time (day) / Compound	**100**	**110**	**120**	**100**	**110**	**120**	**100**	**110**	**120**
TPC (mg GAE/g DW)	0.22 ± 0.01a	0.16 ± 0.04b	0.13 ± 0.01b	0.21 ± 0.04a	0.14 ± 0.02b	0.12 ± 0.03b	0.18 ± 0.01a	0.15 ± 0.03b	0.13 ± 0.01b
TFC (mg QE/ g DW)	0.29 ± 0.02a	0.25 ±0.04a	0.16 ± 0.01b	0.26 ± 0.01a	0.22 ± 0.03a	0.13 ± 0.01b	0.22 ± 0.03a	0.17 ± 0.02b	0.13 ± 0.01c
TCC (mg/mL)	0.28 ± 0.01a	0.37 ±0.02b	0.51 ± 0.04c	0.27 ± 0.01a	0.37 ± 0.02b	0.57 ± 0.05c	0.29 ± 0.02a	0.41 ± 0.03b	0.55 ± 0.02c
IC50 DPPH (μg/mL)	99.32 ± 2.42a	108.24 ± 4.24b	154.22 ± 2.47c	112.37 ± 2.41a	136.12 ± 2.21b	164.32 ± 3.33c	114.38 ± 1.45a	147.21 ± 3.13a	195.43 ± 4.12b
IC50 ABTS (μg/mL)	46.21 ± 2.21a	65.27 ±3.32b	76.83 ± 3.12c	49.23 ± 4.43a	68.26 ± 1.27b	80.37 ± 1.34c	54.32 ± 3.41a	71.18 ± 2.25b	77.35 ± 2.43c
TAC (mg AA/g DW)	112.34 ± 2.53a	53.35 ±1.53b	37.43 ± 4.43c	102.43 ± 3.52a	41.25 ± 4.43b	38.34 ± 3.53c	93.43 ± 2.45a	39.34 ± 4.42b	35.43 ± 3.25c

Parts	Rag								
Area	TL-CT			PD-CT			CD-CT		
Time (day) / Compound	100	110	120	100	110	120	100	110	120
TPC (mg GAE/g DW)	0.23 ± 0.02a	0.19 ± 0.05b	0.11 ± 0.01c	0.21 ± 0.03a	0.14 ± 0.01b	0.08±0.00c	0.18 ± 0.02a	0.14 ± 0.00b	0.07 ± 0.02c
TFC (mg QE/ g DW)	0.44 ± 0.02a	0.24 ± 0.06b	0.16 ± 0.02c	0.32 ± 0.09a	0.21 ± 0.09b	0.16±0.00c	0.27 ± 0.01a	0.18 ± 0.05b	0.15 ± 0.04c
TCC (mg/mL)	0.19 ± 0.00a	0.21 ± 0.00a	0.32 ± 0.02b	0.20 ± 0.00a	0.21 ± 0.00a	0.33±0.01b	0.24 ± 0.00a	0.24 ± 0.00a	0.44 ± 0.00b
IC50 DPPH (µg/mL)	264.32 ± 2.14a	293.18 ± 5.13b	334.84 ± 3.74c	294.79 ± 4.42a	304.60 ± 3.11b	366.62±3.08 c	311.03 ± 3.37a	315.86 ± 1.72b	367.33 ± 4.72c
IC50 ABTS (µg/mL)	89.13 ± 3.26a	105.24 ± 3.22b	284.32 ± 1.32c	97.55 ± 6.78a	108.82 ± 3.66b	264.97±1.41 c	122.91 ± 2.88a	130.06 ± 2.15b	287.07 ± 3.78c
TAC (mg AA/g DW)	108.31 ± 2.43a	59.32 ± 2.93b	41.39 ± 3.83c	93.13 ± 7.38a	36.71 ± 2.04b	34.65±7.37c	87.21 ± 4.94a	32.80 ± 1.59b	29.15 ± 0.69c
Parts	Rag								
Area	CT-HG			CL-TG			CT-BT		
Time (day) / Compound	100	110	120	100	110	120	100	110	120
TPC (mg GAE/g DW)	0.21 ± 0.01a	0.18 ± 0.02b	0.10±0.02c	0.23 ± 0.01a	0.17 ± 0.02b	0.09 ± 0.00c	0.20 ± 0.01a	0.16 ± 0.01b	0.08 ± 0.01c
TFC (mg QE/ g DW)	0.42 ± 0.03a	0.27 ± 0.01b	0.19 ± 0.01c	0.36 ± 0.02a	0.26 ± 0.03b	0.14 ± 0.01c	0.29 ± 0.02a	0.19 ± 0.03b	0.14 ± 0.02c
TCC (mg/mL)	0.21 ± 0.02a	0.29 ± 0.01b	0.34 ± 0.03c	0.23 ± 0.01a	0.24 ± 0.02a	0.38 ± 0.01b	0.22 ± 0.01a	0.31 ± 0.02b	0.46 ± 0.02c
IC50 DPPH (µg/mL)	273.24 ± 6.23a	303.32 ± 4.29b	352.21 ± 5.31c	283.12 ± 3.31a	301.23 ± 2.24b	346.35 ± 2.15c	317.36 ± 4.39a	319.26 ± 5.18a	352.21 ± 2.31b
IC50 ABTS (µg/mL)	91.41 ± 7.23a	109.13 ± 5.23b	264.14 ± 7.26c	96.24 ± 21.15a	104.35 ± 4.14b	271.97 ± 12.41c	114.35 ± 4.31a	135.43 ± 5.19b	276.13 ± 6.13c
TAC (mg AA/g DW)	113.52 ± 10.33a	44.02 ± 2.17b	35.90 ± 7.33c	89.34 ± 3.24a	48.43 ± 1.27b	39.49 ± 1.95c	81.34 ± 2.35a	39.42 ± 2.78b	21.87 ± 2.21c
Parts	Seed								
Area	TL-CT			PD-CT			CD-CT		
Time (day)	100	110	120	100	110	120	100	110	120

Compound									
TPC (mg GAE/g DW)	0.28 ± 0.04a	0.24 ± 0.02b	0.14 ± 0.03c	0.27 ± 0.05a	0.23 ± 0.00b	0.14 ± 0.04c	0.25 ± 0.04a	0.22 ± 0.00b	0.13 ± 0.02c
TFC (mg QE/ g DW)	0.06 ± 0.02a	0.05 ± 0.00a	0.04 ± 0.00a	0.05 ± 0.01a	0.05 ± 0.01a	0.04 ± 0.01a	0.04 ± 0.01a	0.03 ± 0.01a	0.03 ± 0.01a
TCC (mg/mL)	0.11 ± 0.01a	0.14 ± 0.01a	0.30 ± 0.01b	0.11 ± 0.02a	0.15 ± 0.01a	0.33 ± 0.03b	0.12 ± 0.02a	0.16 ± 0.01a	0.39 ± 0.03b
IC50 DPPH (µg/mL)	108.59 ± 9.75a	114.08 ± 5.30b	165.16 ± 1.39c	116.52 ± 3.16a	124.23 ± 4.66b	170.21 ± 8.22c	128.29 ± 2.37a	135.10 ± 4.61b	202.34 ± 17.40c
IC50 ABTS (µg/mL)	56.60 ± 6.33a	71.40 ± 7.08b	77.64 ± 4.23c	58.61 ± 11.27a	75.36 ± 0.33b	78.55 ± 0.56b	58.65 ± 8.48a	77.32 ± 1.18b	81.54 ± 3.04c
TAC (mg AA/g DW)	123.67 ± 3.70a	88.11 ± 5.82b	56.03 ± 2.82c	115.40 ± 4.47a	80.09 ± 2.18b	48.43 ± 2.62c	110.80 ± 3.33a	62.56 ± 3.78b	42.87 ± 5.83c
Parts	**Seed**								
Area	**CT-HG**			**CL-TG**			**CT-BT**		
Time (day) / **Compound**	**100**	**110**	**120**	**100**	**110**	**120**	**100**	**110**	**120**
TPC (mg GAE/g DW)	0.31 ± 0.02a	0.26 ± 0.03b	0.12 ± 0.01c	0.32 ± 0.02a	0.26 ± 0.01b	0.13 ± 0.02c	0.26 ± 0.02a	0.21 ± 0.01b	0.15 ± 0.01c
TFC (mg QE/ g DW)	0.09 ± 0.01a	0.06 ± 0.00b	0.05 ± 0.00b	0.11 ± 0.01a	0.07 ± 0.00b	0.06 ± 0.01b	0.08 ± 0.01a	0.05 ± 0.00b	0.03 ± 0.01b
TCC (mg/mL)	0.13 ± 0.01a	0.18 ± 0.02b	0.33 ± 0.01c	0.12 ± 0.01a	0.17 ± 0.01b	0.36 ± 0.02c	0.14 ± 0.02a	0.21 ± 0.01b	0.36 ± 0.01c
IC50 DPPH (µg/mL)	111.32 ± 2.35a	119.01 ± 3.21b	167.32 ± 3.41c	114.32 ± 2.12a	132.53 ± 4.66b	168.37 ± 3.53c	115.31 ± 2.37a	127.13 ± 3.24b	197.43 ± 4.13c
IC50 ABTS (µg/mL)	54.43 ± 3.25a	75.31 ± 4.15b	79.32 ± 2.86c	59.18 ± 3.38a	78.74 ± 1.36b	82.84 ± 1.46c	54.54 ± 2.43a	75.64 ± 3.21b	83.26 ± 2.15c
TAC (mg AA/g DW)	114.32 ± 9.21a	79.34 ± 5.22b	59.24 ± 3.29c	119.53 ± 4.14a	85.23 ± 4.35b	44.24 ± 3.21c	118.35 ± 6.12a	68.19 ± 2.61b	41.32 ± 6.14c

a, b, c: giá trị thể hiện khác biệt có ý nghĩa thống kê (p<0.05)

Table 3 indicated that the highest ABTS IC_{50} was observed in fiber (287.07 ± 3.78 µg/mL) in CD-CT, while the lowest was in flesh (46.21 ± 2.21 µg/mL) in CT-HG. Overall, ABTS IC_{50} values increased with ripening, indicating a decline in antioxidant capacity across jackfruit parts. Regional differences were also observed, similar to those found for DPPH. Values reported by Cregger et al. (2014) differed, with an IC_{50} of 7.62 ± 0.13 mg/mL, but were consistent with studies showing ABTS scavenging activity in jackfruit seed extracts with acetone and dichloromethane–methanol (1:1), yielding IC_{50} = 0.0491 ± 0.0005 mg/mL and IC_{50} = 0.0556 ± 0.0002 mg/mL, respectively.

Table 3 also illustrated the influence of ripening stages (100, 110, 120 days) and cultivation regions on total antioxidant capacity (TAC) in jackfruit. TAC values tended to decrease with ripening and varied significantly among fruit parts. The highest TAC was observed in seeds at 100 days in TL-CT (123.67 ± 3.70 mg AA/g dry weight), while the lowest was recorded at 120 days in CT-BT (21.87 ± 2.21 mg AA/g dry weight). TAC values exhibited trends consistent with IC_{50} values from DPPH and ABTS assays, with seeds and flesh showing higher antioxidant capacity than fiber. Three methods (ABTS, DPPH, TAC) were employed to evaluate antioxidant activity in jackfruit. Among them, ABTS and DPPH were more reliable compared to TAC. IC_{50} values were critical indicators of antioxidant capacity in extracts for ABTS and DPPH methods. TAC, however, did not yield IC_{50} values because the standard compound, ascorbic acid, generated H_2O_2 during oxidation, which reduced overall antioxidant potential. ABTS yielded lower IC_{50} values than DPPH, possibly because ABTS radicals were measured at 734 nm (far from the visible region), whereas DPPH radicals were measured at 517 nm (closer to the visible region), which could lead to optical interference and differences between the two methods.

From the above results, it was observed that the differences among the areas were negligible, with a consistent trend of similar bioactive compound profiles. This could be explained by the natural conditions of the Mekong Delta, where climatic, soil, and cultivation factors did not differ significantly. Such uniformity not only facilitated the consistent exploitation of the biological value of jackfruit across regions but also created favorable conditions for developing sustainable harvesting and utilization strategies, particularly by focusing on the 120-day maturity stage to achieve optimal efficiency.

4. Conclusions

The study revealed relatively uniform presence of bioactive compounds across different areas. The pulp was richest in phenolics, tannins, and flavonoids at 100–110 days of maturity. The fibers contained significant levels of alkaloids and flavonoids, particularly at 120 days. The seeds were notable for their protein, amino acid, and carbohydrate contents at all maturity stages. Saponin levels remained stable across all parts and locations, with the highest values recorded at 110–120 days. Polyphenol content tended to decrease with maturity, flavonoid content peaked in fibers (TL-CT, 100 days), while carotenoids increased with maturity. DPPH radical scavenging activity increased with maturity, whereas TAC decreased. The assessment of raw material characteristics (shape, size, weight, component ratios, color, odor, taste) in pulp, fiber, and seeds showed maturity-dependent variations, with the 120-day stage being generally optimal for fresh consumption. The study provided a comprehensive database of physicochemical properties, chemical composition, and antioxidant activities of jackfruit pulp, fiber, and seeds, serving as a basis for proposing appropriate preservation and processing methods. Furthermore, it identified cultivation regions that offered higher nutritional value, thereby suggesting potential applications in various fields.

5. References

Baliga, M. S., Shivashankara, A. R., Haniadka, R., Dsouza, J., & Bhat, H. P. (2011).

Phytochemistry, nutritional and pharmacological properties of Artocarpus heterophyllus Lam (jackfruit): A review. *Food Research International*, *44*(7), Article 7. https://doi.org/10.1016/j.foodres.2011.02.035

Barbosa, U. D. N., Marangon, A. L. P. F., Meunier, I. M. J., Marangon, L. C., De Lima, A. O., De Sena Oliveira, G. F., & Dos Santos, A. C. (2019). Fruit and Seed Biometrics and Influence on Germination of Artocarpus heterophyllus Lam. (Jackfruit). *Journal of Experimental Agriculture International*, 1–6. https://doi.org/10.9734/jeai/2019/v41i630422

Cregger, M. A., McDowell, N. G., Pangle, R. E., Pockman, W. T., & Classen, A. T. (2014). The impact of precipitation change on nitrogen cycling in a semi-arid ecosystem. *Functional Ecology*, *28*(6), 1534–1544. https://doi.org/10.1111/1365-2435.12282

de Azevedo, C. H., & Rodriguez-Amaya, D. B. (2005). Carotenoid composition of kale as influenced by maturity, season and minimal processing. *Journal of the Science of Food and Agriculture*, *85*(4), Article 4. https://doi.org/10.1002/jsfa.1993

Jagadeesh, S. L., Reddy, B. S., Swamy, G. S. K., Gorbal, K., Hegde, L., & Raghavan, G. S. V. (2007). Chemical composition of jackfruit (Artocarpus heterophyllus Lam.) selections of Western Ghats of India. *Food Chemistry*, *102*(1), Article 1. https://doi.org/10.1016/j.foodchem.2006.05.027

Jagtap, U. B., Panaskar, S. N., & Bapat, V. A. (2010). Evaluation of Antioxidant Capacity and Phenol Content in Jackfruit (Artocarpus heterophyllus Lam.) Fruit Pulp. *Plant Foods for Human Nutrition*, *65*(2), Article 2. https://doi.org/10.1007/s11130-010-0155-7

Khalid, M., Saeed-ur-Rahman, Bilal, M., & Huang, D. (2019). Role of flavonoids in plant interactions with the environment and against human pathogens—A review. *Journal of Integrative Agriculture*, *18*(1), 211–230. https://doi.org/10.1016/S2095-3119(19)62555-4

Laishram, M., & Ghosh, S. N. (2018). Nutrient management in jackfruit (Artocarpus heterophyllus Lam.) under rainfed condition. *Journal of Horticultural Sciences*, *13*(1), Article 1. https://doi.org/10.24154/jhs.v13i1.53

Le, X. D., Nguyen, M. C., Vu, D. H., Pham, M. Q., Pham, Q. L., Nguyen, Q. T., Nguyen, T. A., Pham, V. T., Bach, L. G., Nguyen, T. V., & Tran, Q. T. (2019). Optimization of Microwave-Assisted Extraction of Total Phenolic and Total Flavonoid Contents from Fruits of Docynia indica (Wall.) Decne. Using Response Surface Methodology. *Processes*, *7*(8), 485. https://doi.org/10.3390/pr7080485

Nansereko, S., Muyonga, J., & Byaruhanga, Y. B. (2022). Optimization of drying conditions for Jackfruit pulp using Refractance Window Drying technology. *Food Science & Nutrition*, *10*(5), Article 5. https://doi.org/10.1002/fsn3.2694

Nguyen, N. Q., Pham, T. N., Nguyen, V. T., Nguyen, M. T., Dung, L. T., & Bach, L. G. (2020). Phytochemical screening and antioxidant potential of crude drug "Cao Khai" in Ninh Thuan Province, Vietnam. *IOP Conference Series: Materials Science and Engineering*, *991*(1), 012016. https://doi.org/10.1088/1757-899X/991/1/012016

Nhi, T. T. Y., Phat, D. T., Quyen, N. N., Cang, M. H., Truc, T. T., Bach, L. G., & Muoi, N. V. (2020). Effects of Vacuum Concentration on Color, Polyphenol and Flavonoid Contents and Antioxidant Activity of Pomelo Citrus maxima (Burm. F.) Merr. Juice. *IOP Conference Series: Materials Science and Engineering*, *991*(1), 012060. https://doi.org/10.1088/1757-899X/991/1/012060

Palamthodi, S., Shimpi, S., & Tungare, K. (2021). A Study on Nutritional Composition and Functional Properties of

Wheat, Ragi and Jackfruit Seed Composite Flour. *Food Science and Applied Biotechnology*, *4*(1), Article 1. https://doi.org/10.30721/fsab2021.v4.i1.107

Panche, A. N., Diwan, A. D., & Chandra, S. R. (2016). Flavonoids: An overview. *Journal of Nutritional Science*, *5*, e47. https://doi.org/10.1017/jns.2016.41

Ranasinghe, R. a. S. N., Maduwanthi, S. D. T., & Marapana, R. a. U. J. (2019). Nutritional and Health Benefits of Jackfruit (Artocarpus heterophyllus Lam.): A Review. *International Journal of Food Science*, *2019*(1), 4327183. https://doi.org/10.1155/2019/4327183

Ranasinghe, R. a. S. N., & Marapana, R. a. U. J. (2019). *Effect of Maturity Stage on Physicochemical Properties of Jackfruit (Artocarpus heterophyllus Lam.) Flesh*. http://dr.lib.sjp.ac.lk/handle/123456789/12104

Rosa, L. A. de la, Alvarez-Parrilla, E., & Gonzalez-Aguilar, G. A. (2009). *Fruit and Vegetable Phytochemicals: Chemistry, Nutritional Value and Stability*. John Wiley & Sons.

Saxena, A., Bawa, A. S., & Raju, P. S. (2011). Jackfruit (Artocarpus heterophyllus Lam.). In E. M. Yahia (Ed.), *Postharvest Biology and Technology of Tropical and Subtropical Fruits* (pp. 275–299e). Woodhead Publishing. https://doi.org/10.1533/9780857092885.275

Shafiq, M., Mehmood, S., Yasmin, A., Khan, S. J., Khan, N. H., & Ali, S. (2017). Evaluation of Phytochemical, Nutritional and Antioxidant Activity of Indigenously Grown Jackfruit (*Artocarpus heterophyllus* Lam). *Journal of Scientific Research*, *9*(1), Article 1. https://doi.org/10.3329/jsr.v1i1.29665

Shi, Y., Yang, L., Yu, M., Li, Z., Ke, Z., Qian, X., Ruan, X., He, L., Wei, F., Zhao, Y., & Wang, Q. (2022). Seasonal variation influences flavonoid biosynthesis path and content, and antioxidant activity of metabolites in Tetrastigma hemsleyanum Diels & Gilg. *PLOS ONE*, *17*(4), Article 4. https://doi.org/10.1371/journal.pone.0265954

Shrikanta, A., Kumar, A., & Govindaswamy, V. (2015). Resveratrol content and antioxidant properties of underutilized fruits. *Journal of Food Science and Technology*, *52*(1), Article 1. https://doi.org/10.1007/s13197-013-0993-z

Soong, Y.-Y., & Barlow, P. J. (2004). Antioxidant activity and phenolic content of selected fruit seeds. *Food Chemistry*, *88*(3), Article 3. https://doi.org/10.1016/j.foodchem.2004.02.003

Sreeja Devi, P. S., Kumar, N. S., & Sabu, K. K. (2021). Phytochemical profiling and antioxidant activities of different parts of Artocarpus heterophyllus Lam. (Moraceae): A review on current status of knowledge. *Future Journal of Pharmaceutical Sciences*, *7*(1), Article 1. https://doi.org/10.1186/s43094-021-00178-7

Swami, S. B., Thakor, N. J., Haldankar, P. M., & Kalse, S. B. (2012). Jackfruit and Its Many Functional Components as Related to Human Health: A Review. *Comprehensive Reviews in Food Science and Food Safety*, *11*(6), 565–576. https://doi.org/10.1111/j.1541-4337.2012.00210.x

Thanh, V. T., Khang, V. C., Nhan, N. P. T., Nguyen, D. T., Nhi, T. T. B., & Quoc, N. T. (2020). Effect of Wet Milling and Purification Process on Yield and Color of Jackfruit Seed Starch. *IOP Conference Series: Materials Science and Engineering*, *991*(1), 012030. https://doi.org/10.1088/1757-899X/991/1/012030

Van, C. K., Hoang, Q. B., Nguyen, T. V., Pham, C. H., Bich Le, C. N., Nguyen, T. L., & Truong, T. N. (2023a). A review of nutrition, phytochemical compounds and biological activities of jackfruit (Artocarpus Heterophyllus Lam.). *AIP Conference Proceedings*, *2907*(1), 020004. https://doi.org/10.1063/5.0171413

Van, C. K., Nguyen, T. H., Nguyen, T. T. N. H., Nguyen, P. T. N., Tran, T. T., & Hoang, Q. B. (2023b). Comparison of the Effects of Jackfruit Seed Flour and Jackfruit Seed Starch in the Cookie Manufacturing Process. *Processes*, *11*(11), 3194. https://doi.org/10.3390/pr11113194

Van, C. K., Truong, T. N., Le, T. T. L., Nguyen, T. T. N. H., Pham, B. A., & Nguyen, C. K. (2024). EFFECTS OF THE POST-FLOWERING TIMELINES ON THE NUTRITION, PHYTOCHEMICAL COMPOUNDS AND ANTIOXIDANT ACTIVITIES OF JACKFRUIT (ARTOCARPUS HETEROPHYLLUS LAM.). *Carpathian Journal of Food Science & Technology*, *16*(3). https://doi.org/10.34302/crpjfst/2024.16.3.1

Acknowledgments

The study was funded by the Department of Science and Technology of Can Tho City.