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Nutritional Profiling of Different Maturity Stages in Jackfruit

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Abstract: The investigation was undertaken to evaluate the variations in the nutritional composition of jackfruit during its progressive stages of maturity. Its nutritional attributes vary from immature to fully ripe stages, influencing its suitability for different value-added applications. The fruits were categorized into four maturity stages; immature, mature, ripe and over-ripe, analyzed for proximate composition (moisture, protein, fat, fibre, ash, and carbohydrate), mineral content (calcium, magnesium, copper, potassium, and iron), and bioactive compounds (vitamin C, total phenols, carotenoids, and antioxidants). There was significant increase in total soluble solids, sugars, and carotenoids with advancement in maturity, whereas moisture, fibre and vitamin C contents showed a gradual decline. The mature stage exhibited balanced nutritional composition, making it suitable for culinary and process into various food products. The study highlights the dynamic changes in nutritional and biochemical parameters of jackfruit across maturity stages and provides valuable insights for optimizing harvest time, postharvest utilization and product development strategies.

Keywords: Jackfruit, Maturity stages, Nutritional composition, Proximate analysis, Bioactive compounds, Antioxidants

Jackfruit (*Artocarpus heterophyllus* Lam.) is one of the largest edible fruits in the world and a member of the family Moraceae. It is widely cultivated in tropical and subtropical regions of Asia, particularly in India, Bangladesh, Sri Lanka, Thailand, and Indonesia. Known for its versatility, jackfruit is consumed at various stages of maturity-tender, mature unripe, ripe and fully ripe-each possessing distinct sensory attributes, nutritional composition, and potential uses in food and processing industries (Chai et al., 2021). The fruit serves as a rich source of carbohydrates, dietary fibre, vitamins, minerals, and phytonutrients, while its seeds also contribute appreciable quantities of protein and starch (Ranasinghe et al., 2019). Jackfruit has recently gained global attention as a functional food owing to its health-promoting properties and its potential as a plant-based meat alternative. However, the nutritional and biochemical composition of the fruit varies considerably across different stages of maturity due to physiological and biochemical changes that occur during fruit development and ripening (Ranasinghe et al., 2019). Understanding these variations is essential for determining the optimal harvest stage for different end uses such as culinary consumption, processed food products, or industrial applications.

In India, despite being widely cultivated and recognized as a “poor man's fruit,” systematic studies on the nutritional dynamics of jackfruit across its maturity stages are limited. Characterizing these variations can help in the value addition, postharvest management, and product diversification of jackfruit, contributing to its commercialization and nutritional security. Therefore, the present study was undertaken to evaluate the nutritional profile of jackfruit at different stages of maturity. The research aims to assess the changes in proximate composition, mineral content, and biochemical parameters during fruit development, thereby providing insights into its nutritional potential and suitable utilization at each stage of maturity.

MATERIAL AND METHODS

The experiment was conducted at the Department of Postharvest Management, College of Horticulture, Bengaluru during the years 2023-2024. Jackfruits representing different stages of maturity were obtained from Bioversity International, 3HV8+788, College of Horticulture, Bengaluru. Fruits were harvested at four distinct maturity stages based on the number of days after fruit emergence (DAFE): Tender (40±2 days), Mature (80±2 days), Ripe (120±2 days), and Overripe (135±2 days). For the study five jackfruit varieties-Byra Chandra, Gumless, Royal Jack, Rudrakshi, and Thailand Pink-were selected. All the biochemical analysis were carried out using standard methods (Table 1).

RESULTS AND DISCUSSION

The nutritional and biochemical composition of jackfruit varies significantly across different varieties and stages of maturity, reflecting the dynamic physiological and metabolic changes occurring during fruit development. Carbohydrate content was increased markedly with ripening, reaching the highest level of 24.40% in the ripe stage of the Thailand Pink variety, while the tender stage of Rudrakshi exhibited the lowest carbohydrate concentration at 4.35%. This upward trend can be explained by the enzymatic breakdown of complex starch molecules into simpler, soluble sugars, which contribute to the characteristic sweetness and enhanced palatability of ripe jackfruit. Rahman et al. (1999), also documented carbohydrate contents ranging from 9.4 to 11.5% in young jackfruit and from 16.0 to 25.4% in ripe fruit, suggesting a conserved ripening-associated increase in sugar content across different genotypes.

Protein content exhibited an opposite trend, being highest (2.56%) in the tender stage of Byra Chandra and declining progressively to the lowest of 1.23% in the over-ripe stage of Thailand Pink. This reduction can be primarily ascribed to the intensified activity of proteolytic enzymes during maturation, which degrade storage and structural proteins into amino acids, peptides, and other nitrogenous compounds. Such enzymatic conversion results in a net loss of measurable total protein, a phenomenon well documented across multiple fruit species and Vazhacharickal et al. (2015). The initially higher protein content in younger fruits likely reflects the requirement for structural and metabolic proteins during active growth phases, whereas, the relative carbohydrate accumulation in later stages results in a dilution effect of protein concentration relative to the fruit mass, as described by Azeez et al. (2015).

Ascorbic acid, a vital antioxidant known for its health benefits, varied substantially among varieties and maturity stages. The Gumless variety at the tender stage exhibited the highest ascorbic acid content (12.08 mg/100g), whereas the lowest levels (3.76 mg/100g) were in the over-ripe stage of the Royal Jack variety. During ripening, biochemical pathways facilitate the breakdown of precursor molecules, releasing ascorbic acid and thereby increasing its concentration. However, prolonged maturation and senescence may lead to oxidative degradation and reduction of ascorbic acid levels. This pattern agrees with observations by Baliga et al. (2011) reported similar trends in jackfruit and other horticultural crops.

Titratable acidity, an important organoleptic parameter influencing fruit taste and preservation potential, was highest at 0.39% in the tender stages of Rudrakshi and Thailand Pink and declined to 0.21% in their over-ripe stages. The progressive decrease in acidity is linked to the metabolic conversion of organic acids, such as citric and malic acids, into sugars during ripening, thereby increasing sweetness and altering flavor profiles (Jagadeesh et al. 2010, Shafiq et al. 2017). This acid-sugar interconversion is a broadly recognized phenomenon in fruit physiology.

Dietary fiber content peaked at 4.57% in the tender stage of Rudrakshi and diminished considerably to 0.97% in the over-ripe stage of Gumless. The decline in fiber is related to the breakdown of cellulose, hemicellulose, and lignin components of the cell wall during fruit softening and maturation (Kaur et al., 2023). These structural changes reduce the fibrous texture of the pulp, as also observed by Amadi et al. (2018) and Ong et al. (2006), indicating a trade-off between textural firmness and edibility during ripening.

Ash content, indicative of total mineral matter, decreased from 3.40% in the tender Rudrakshi to 1.11% in the over-ripe Byra Chandra. The reduction in ash content reflects the dilution of minerals as the fruit accumulates water and carbohydrates in later stages of development and ripening. Similar trends have been previously reported by Amadi et al. (2018) and Ojwang et al. (2018). This suggests a shift in

Table 1.

Parameter	Method	Reference
Antioxidant capacity (mg AAE 100 g^{-1})	Ferrous ion-reducing antioxidant power (FRAP) assay	Benzie and Strain, 1996
Ascorbic acid (mg 100 g^{-1})	2,6-dichlorophenol indophenol (DCPIP) dye method	Sadasivam and Manickam, 1992
Ash content (%)	Muffle furnace	AOAC (1995).
Total carbohydrates (%)	Phenol-sulphuric acid method	AOAC, 1995
Carotene (mg 100 g^{-1})		Ranganna (2008)
Fat content (%)	Soxhlet extraction using petroleum ether	AOAC, 2006
Protein (%)	Lowry's method	Lowry et al., 1951
Mineral elements (Ca, Mg, Zn, and Fe) (mg 100 g^{-1})	Wet digestion using HNO_3–$HClO_4$ di-acid mixture	Piper, 1966
Crude fiber (%)	Double digestion	Sadasivam and Manickam, 1996
Total flavonoids (mg QE 100 g^{-1})	Aluminium chloride colorimetry	Chun et al., 2003
Total phenolics (mg GAE 100 g^{-1})	Folin–Ciocalteu method	Singleton and Rossi, 1965
Titratable acidity (%)	Titration against 0.1 N NaOH using phenolphthalein as an indicator	AOAC, 1995

metabolic priorities from mineral accumulation towards the synthesis and storage of organic compounds.

Fat content showed an incremental increase over the course of maturation, with the highest (0.82%) in ripe Thailand Pink, contrasting with the lowest fat content (0.22%) in its tender stage. The accumulation of lipids during later developmental stages may be attributed to the formation of oil bodies and lipid storage compounds within the fruit pulp. Ranasinghe et al. (2018), also highlighted a low baseline fat content in young fruits with a modest increase upon ripening.

Total carotenoid content was significantly influenced by both maturity and genotype. The ripe stage of Thailand Pink amassed the highest carotenoid concentration (0.734 mg/100g), whereas, tender Byra Chandra contained the lowest (0.129 mg/100g). Red flaked varieties consistently demonstrated elevated carotenoid levels relative to yellow-flaked genotypes. This variation is likely due to differential expression of carotenoid biosynthesis genes and pigment accumulation (Jagadeesh et al. 2010, Shyamalamma et al. 2015).

Antioxidant activity assessed using the ferric reducing antioxidant power (FRAP) assay peaked in ripe Thailand Pink (193.02 mg AAE/100g) and was lowest in tender Rudrakshi (18.84 mg AAE/100g). The total phenolic content followed a similar pattern, with maximum in ripe Thailand Pink (0.34 mg GAE/100g) and minimum in tender Gumless (0.09 mg GAE/100g). These differences underscore the relationship between phenolic accumulation and antioxidant potential and reflect genotype-dependent biosynthetic capacity and maturity-related metabolic changes, as reported by Jagtap et al. (2010) and Bakar et al. (2009). Phenolics play a crucial role in plant defence mechanisms and contribute beneficially to human health.

The total flavonoids, a subclass of phenolic compounds, showed significant increase with ripening, exemplified by the highest content found in ripe Thailand Pink (3.26 mg QE/100g) compared to the lowest in tender Rudrakshi (0.36 mg QE/100g). Such elevated flavonoid levels in mature fruits suggest enhanced secondary metabolic activity possibly related to the fruit's defence against environmental stresses (Saeed et al., 2019, Hossain et al., 2020).

The mineral composition variation was observed among genotypes and maturity stages. Potassium content was highest in ripe Rudrakshi (309.60 mg/100g), calcium peaked in tender Rudrakshi (37.88 mg/100g), magnesium was maximal in ripe Rudrakshi (21.50 mg/100g), manganese in ripe Rudrakshi (2.39 mg/100g). Copper was highest in ripe Royal Jack (0.38 mg/100g), and iron content was I in ripe Byra Chandra (3.63 mg/100g). These mineral profiles are consistent with previous studies by Amadi et al. (2018), Shyamalamma et al. (2016), and Tiwari et al. (2015), which emphasize the strong influence of genetic factors and stage

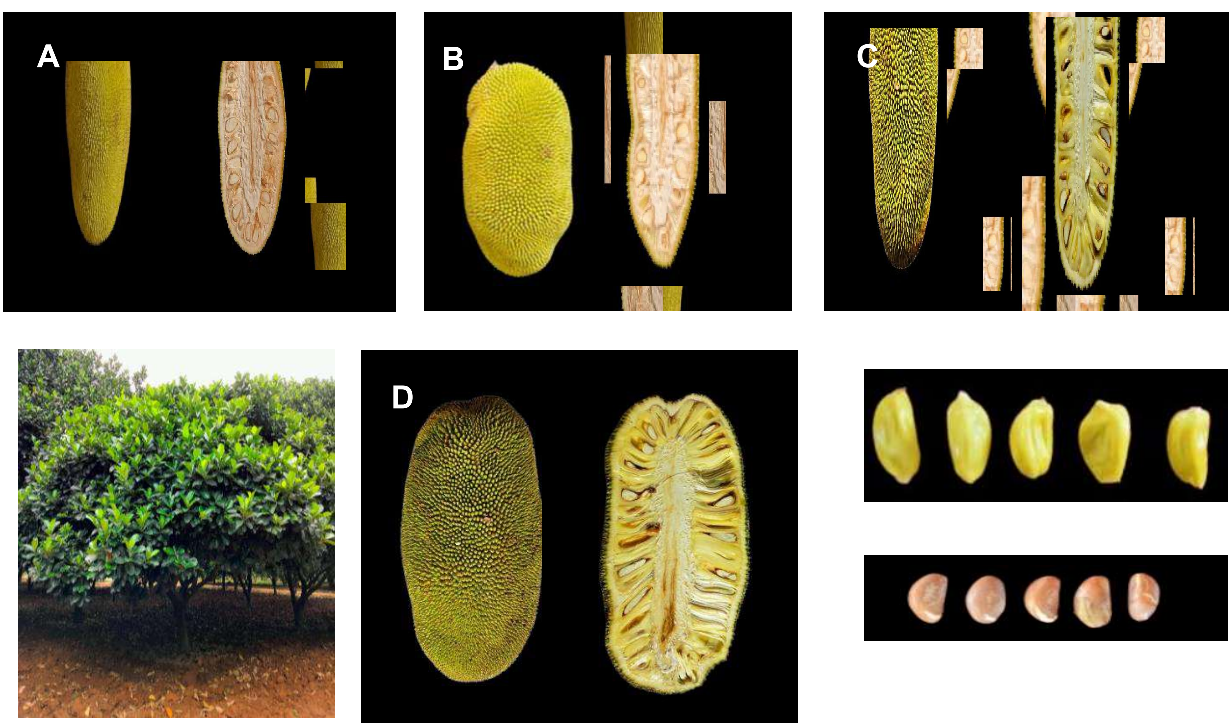

Plate 1. Different maturity stages of jackfruit (Byra Chandra) (A) Tender, (B) mature, (C) ripe and (D) over-ripe stages

Table 2. Chemical parameters of jackfruit varieties at different maturity

Variety	Maturity stages	Moisture content (%)	Titratable acidity (%)	Protein content (%)	Ash content (%)	Fibre content (%)	Total Phenol content (mg GAE 100g^{-1})	Ascorbic acid content (mg100g^{-1})	Total Carotenoid content (mg 100g^{-1})	Total carbohydrate (%)	Total Flavonoid content (mg QE 100g^{-1})	Antioxidant activity (mg AAE 100g^{-1})
Byra Chandra	Tender	85.35	0.36	2.56	2.42	3.77	0.10	8.26	0.129	6.41	0.63	37.31
	Mature	77.60	0.31	2.15	1.99	2.84	0.12	6.73	0.262	5.25	0.87	112.65
	Ripe	66.25	0.28	1.74	1.61	1.37	0.27	5.29	0.379	23.28	1.80	169.45
	Over-ripe	58.18	0.26	1.35	1.11	1.21	0.22	4.88	0.362	19.64	1.53	165.48
Gumless	Tender	84.59	0.35	2.48	2.51	3.91	0.09	12.08	0.176	6.01	0.41	28.67
	Mature	75.32	0.31	2.07	2.07	2.22	0.13	7.25	0.299	9.77	0.82	109.56
	Ripe	68.4	0.27	1.41	1.66	1.75	0.22	6.27	0.495	18.55	1.94	163.67
	Over-ripe	57.51	0.24	1.25	1.19	0.97	0.19	4.55	0.427	14.06	1.42	161.06
Rudrakshi	Tender	74.43	0.39	2.14	3.40	4.57	0.12	8.98	0.147	4.35	0.36	18.84
	Mature	68.46	0.34	2.01	2.75	2.79	0.16	5.44	0.364	9.36	1.16	97.45
	Ripe	61.35	0.26	1.77	1.85	1.53	0.26	4.32	0.541	15.53	2.02	162.92
	Over-ripe	57.83	0.21	1.50	1.47	1.25	0.21	3.88	0.505	12.39	1.54	161.21
Royal Jack	Tender	81.37	0.37	2.48	2.39	3.66	0.07	9.49	0.134	5.28	0.49	21.67
	Mature	74.36	0.33	2.25	1.79	2.47	0.17	6.43	0.379	12.06	1.11	97.54
	Ripe	63.06	0.28	1.71	1.95	1.54	0.22	6.12	0.636	17.60	2.28	172.19
	Over-ripe	52.31	0.23	1.39	1.62	1.25	0.18	3.76	0.612	14.03	1.48	168.45
Thailand Pink	Tender	83.8	0.39	2.55	3.02	3.81	0.13	11.68	0.142	4.36	0.68	39.52
	Mature	79.84	0.31	2.19	2.40	3.28	0.18	5.6	0.389	14.12	1.76	119.65
	Ripe	70.86	0.25	1.52	1.44	1.62	0.34	6.38	0.734	24.4	3.26	193.02
	Over-ripe	61.06	0.21	1.23	1.32	1.57	0.3	4.72	0.632	21.8	2.74	189.64

of maturity on mineral uptake and accumulation. The mineral nutrients analyzed are essential for both plant physiological processes and human nutrition.

Collectively, these results highlight the dynamic and complex nutritional landscape of jackfruit as influenced by variety and ripening. Such variability has critical implications for fruit utilization in fresh consumption and processing, as well as for breeding programs aimed at improving nutritional quality.

CONCLUSION

The study demonstrates that jackfruit's nutritional content varies greatly with variety and maturity. The ripe Thailand Pink variety had the highest carbohydrates, antioxidants, phenols, and carotenoids, making it a good energy-rich and healthful choice. The tender Rudrakshi variety was rich in minerals, protein, fiber, and firmness, making it ideal for early harvest and consumption. These differences highlight the importance of choosing the right variety and harvesting stage to get the desired nutritional and quality traits. Overall, these findings help in selecting jackfruit varieties and maturity stages for improved nutrition and processing.

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