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Evaluating the Ripening Process of *Ficus palmata*: A Biochemical Perspective

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Abstract
Biochemical changes in *Ficus palmata* fruits at different maturity stages, focusing on physical attributes, nutritional composition, and phytochemical variations were investigated. Fruit samples were collected from Naseerpur, Roorkee Range, Haridwar Forest Division, Uttarakhand, at an altitude of 247 m. The study revealed significant differences in fruit color, moisture content, carbohydrate levels, crude fiber, total soluble solids (TSS), titratable acidity, and vitamin C content across the ripening process. The results suggest that unripe fruits have higher fiber and phenolic content, while ripe fruits contain increased TSS and vitamin C, making them more suitable for direct consumption and value addition. These findings provide insights into optimal harvesting and potential applications of *Ficus palmata* in the food and nutraceutical industries.

Keywords: Antioxidant, biochemical, fruit ripening, nutritional, phytochemical

1. Introduction

Ficus palmata (Wild fig) is a valuable edible fruit species found in the sub-Himalayan regions, particularly in India, Pakistan, and Nepal. It belongs to the Moraceae family and is closely related to the common fig (*Ficus carica*). The fruit is traditionally consumed fresh or dried and is known for its rich nutritional composition and medicinal properties (Parmar & Kaushal, 1982) [14]. In various indigenous communities, *Ficus palmata* is used for its laxative, antioxidant, and anti-inflammatory properties. Several studies have assessed the nutrient and phytochemical composition of *Ficus palmata* (Saklani & Chandra, 2012; Sadia *et al*., 2014) [18, 19]. Research indicates that its fruits are high in essential nutrients, including dietary fiber, vitamins (Such as vitamin C and B-complex), and minerals like calcium, potassium, and iron. Bioactive compounds such as flavonoids, polyphenols, and antioxidants contribute to its health benefits, including anti-inflammatory, antimicrobial, and antidiabetic properties (Javed *et al*., 2017) [7]. Studies also suggest that *Ficus palmata* has potential applications in functional foods and nutraceuticals due to its high antioxidant capacity (Khan, 2021; Khan *et al*, 2022) [9, 10].

Fruit ripening is a complex physiological and biochemical process involving changes in color, texture, flavor, and nutritional composition. These changes are primarily driven by enzymatic activities that alter carbohydrate, protein, and phenolic content, impacting the fruit's sensory attributes and health benefits. Understanding these biochemical modifications is crucial for optimizing harvest time, post-harvest storage, and value-added applications, such as juice and jam production (Payasi & Sanwal, 2005; Phani 2017) [15, 16]. Due to their perishable nature, fruits undergo substantial physiological and biochemical changes during ripening, affecting their nutritional quality and shelf life (Singh & Bhattacharya, 2020) [20]. Understanding postharvest factors and implementing appropriate strategies can reduce losses and enhance fruit quality, safety, and storage time (Hossain *et al*., 2020) [6]. Further research is needed to explore the potential of wild fruits for developing functional foods and pharmaceuticals (Liu *et al*., 2016) [11].

Despite its nutritional and commercial potential, *Ficus palmata* remains underutilized due to limited scientific exploration and post-harvest processing knowledge. Studying the biochemical transformations during fruit maturation will provide critical insights into its best utilization strategies. This study aims to evaluate the changes in physical, nutritional, and phytochemical parameters of *Ficus palmata* at different maturity stages, thereby contributing to its sustainable use in the food and nutraceutical industries.

2. Materials and Methods

All the reagents used for performing the experiments were from Merck**.**

2.1 Sample Collection and Study Site

Fruit samples were collected from *Ficus palmata* trees located in Naseerpur, Roorkee Range, Haridwar Forest Division, Uttarakhand (GPS: 29°44'01.88"N, 77°51'34.40"E, altitude: 247 m). The selected tree had a height of 3 m and a DBH (Diameter at Breast Height) of 12 cm.

Samples were categorized into three maturity stages using visual parameters: unripe, semi-ripe and ripe (Figure 1). These were washed and stored in deep freezer. For biochemical analysis these were taken out, dried in oven, powdered and then analysed according to the following protocols:

2.3 Physical and Morphological Analysis

Morphological parameters *viz*. Fruit length, diameter were measured using vernier calipers (Mitutoyo Make). Moisture content was determined by oven drying method. Specific gravity was determined by water displacement method and fruit color was evaluated using RHS (Royal Horticulture Society) color codes.

2.4 Nutritional Analysis

Standard AOAC protocols were used to determine carbohydrate, protein, crude fat, crude fiber, total ash, TSS, titratable acidity, and vitamin C content. TSS was determined according to the method described by Mazumdar & Majumder (2003) [13] using hand held refractometer (range 0–32%). An appropriate quantity of each sample was placed on the prism-plate of the refractometer and the reading appearing on the screen was directly recorded as total soluble solids (°Brix). Titrable Acidity was determined according to the method described by Hortwitz (1960) [5]. Ash content was determined using muffle furnace; fat content through Soxhlet extraction method; crude protein (CP) content by the Kjeldahl method. Nitrogen content was multiplied by the factor 6.25 to determine the CP. Vitamin C was determined using Indophenol method (Sadasivam & Balasubramaniam, 1987) [17]. The amount of vitamin C in the extract was determined by comparing with the titration curve of standard vitamin C solution. Result was expressed in mg/100 g of fresh fruit.

2.5. Phytochemical Analysis

Total phenolic content (TPC) and total flavonoid content (TFC) were analyzed using standard spectrophotometric methods (Sadasivam & Balasubramaniam, 1987) [17]. Aluminum trichloride complex assay (Absorbance at 415 nm) was used to determine total flavonoid content. Total phenolic content was determined using Folin-Ciocalteu reagent assay (Absorbance at 740 nm).

2.6 Statistical Analysis

Data were analyzed using one-way ANOVA followed by Turkey's post hoc test to determine significant differences between maturity stages. Pearson correlation analysis was performed to examine relationships between different biochemical parameters. A p-value of < 0.05 was considered statistically significant.

Fig 1: *Ficus palmata* fruits and extracted juice in different maturity stages.

3. Results and Discussion

Fruit ripening involves significant biochemical and physiological changes that affect nutritional content and quality (Ghosh *et al*, 2023) [4]. During ripening, fruits generally experience increase in sugar content, vitamins, minerals, and bioactive compounds. For example, mangoes show increased levels of vitamin C, β-carotene, and minerals (Fabi *et al*., 2009) [3]. Bananas undergo starch degradation, leading to increased sugar content from 2% to 20% (Maduwanthi & Marapana, 2017) [12]. Color changes occur due to chlorophyll degradation, while softening results from the breakdown of insoluble polysaccharides

(Hossain *et al*., 2020) [6]. Although ripening enhances fruit quality and nutritional value, it reduces shelf life, necessitating postharvest management techniques such as cold storage and 1-MCP treatment (Fabi *et al*., 2009; Hossain *et al*., 2020; Baidya *et al.*, 2020) [1, 3, 6]. Our results on *Ficus palmata* also showed variation in nutritional parameters during various maturity stages which are discussed below:

3.1 Colour changes during maturation

Table 1: Fruit skin and Juice Colour during different Maturity stages of *Ficus palmata*

1. Unripe	2. Partially Ripe	3. Fully Ripe
Whole fruit: 143A:90,130, 55 VI Medium green. Fruit color after cutting: IV-Orange Juice color: IV Orange NS 25SRGB 236, 103, 176.	Whole fruit: 152A:121,109, 33 Dark green brown. Fruit color after cutting: IV-Orange, 29A 255, 155, 96. Juice color: IV Orange SRGB 254, 213, 189 RHS No. 29 D.	Whole fruit: 200 C 94, 62, 52 III Red Dark brown. Fruit color after cutting: Medium red, 42B 203, 64, 62. Juice color: III Red SRGB 121, 33 RHS No. 179 A.

The ripening process of *Ficus palmata* is marked by distinct color transformations in both the whole fruit and its juice (Table 1). Unripe fruits exhibit a green hue, indicative of the high chlorophyll content. As the fruit matures, it transitions to a greenish-brown shade in the partially ripe stage due to the breakdown of chlorophyll and the emergence of carotenoids. Fully ripe fruits take on a dark red-brown coloration, a result of increased anthocyanin accumulation. A similar pattern is observed in the fruit's internal flesh and juice, which transition from an orange tone in unripe fruits to a deeper red in the ripe stage. These color shifts reflect the biochemical changes associated with ripening, such as pigment conversion and sugar accumulation, which influence the fruit’s sensory appeal and antioxidant properties. Understanding these variations is essential for determining the optimal harvest stage for consumption and processing applications.

3.2 Physical and Morphological Changes

Table 2: Physical and Morphological analysis of *Ficus palmata* fruits in different maturity stages

Parameter	Ripe	Partially Ripe	Unripe
Moisture (%)	55.09±1.10	53.40±1.17	51.91±1.52
Fruit length (mm)	15.20±0.06	14.54±0.90	14.51±0.87
Fruit width (mm)	15.89±0.28	14.45±0.56	14.77±0.62
Fruit weight (g)	2.57±0.38	1.59±0.50	2.45±0.48
Specific gravity	0.85±0.08	0.77±0.04	0.74±0.07

Moisture content increased with ripening (51.91% in unripe to 55.09% in ripe fruit), showing a significant correlation with fruit weight ($r = 0.89$, $p < 0.05$). Fruit size showed slight variations, with ripe fruits having the largest dimensions. Specific gravity increased as fruits ripened, indicating higher density, which correlated positively with moisture content ($r = 0.76$, $p < 0.05$) (Table 2).

3.3 Nutritional Changes

Carbohydrates decreased from 38.70% (Unripe) to 27.91% (ripe), indicating starch conversion to sugars, with a strong inverse correlation with TSS ($r = -0.85$, $p < 0.05$). Crude fiber content was highest in unripe fruits (30.42%) and decreased as the fruit matured. TSS increased from 6.95% in unripe to 10.03% in ripe fruit, correlating with increased sweetness ($r = 0.92$, $p < 0.05$). Titratable acidity decreased, while vitamin C content peaked in ripe fruits (3.26 mg/100g), showing a positive correlation with TSS ($r = 0.80$, $p < 0.05$) (Table 3).

Table 3: Nutritional analysis of *Ficus palmata* fruit in different maturity stage

Parameter (%)	Ripe	Partially Ripe	Unripe
Carbohydrate	27.91±1.86	30.30±0.83	38.70±1.80
Crude Protein	3.41±0.67	3.07±0.20	2.87±0.15
Crude Fat	0.39±0.05	0.65±0.03	0.52±0.09
Crude Fiber	25.72±1.61	26.83±0.63	30.42±0.89
Ash	1.10±0.13	0.89±0.12	0.91±0.08
TSS	10.03±0.85	7.89±0.23	6.95±0.37
Titrable acidity	0.40±0.05	0.53±0.05	0.64±0.06
Vitamin C (mg/100g)	3.26±0.20	2.47±0.30	1.82±0.57

3.4 Phytochemical Variation

Wild fruits provide essential nutrition and health benefits to vulnerable communities (Chakravarty *et al*., 2016) [2]. They contain bioactive compounds such as anthocyanins and flavonoids, which exhibit antioxidant, anti-inflammatory, and anticancer properties (Liu *et al*., 2016) [11]. The consumption of fruits and vegetables is positively correlated with the prevention of degenerative diseases and aging (Kaur and Kapoor, 2001) [8].

Our studies showed (Table 4) that TFC was highest in unripe fruit (72.72 mg/g QE) and declined with ripening. TPC was significantly higher in unripe fruit (2.60 mg/g GA) compared to ripe fruit (0.06 mg/g GA), suggesting stronger antioxidant potential in early maturity stages. Correlation analysis revealed a significant inverse relationship between phenolic content and TSS ($r = -0.89$, $p < 0.05$), indicating that phenolic degradation occurs as sugars accumulate during ripening.

Table 4: Variation of Phytochemicals in *Ficus palmata* fruit in different maturity stage

Parameter	Ripe	Partially Ripe	Unripe
TFC mg/g QE	66.05±2.08	68.17±2.95	72.72±2.72
TPC mg/g GA	0.06±0.005	2.382±0.22	2.60±0.51

4. Conclusion

The biochemical changes observed in *Ficus palmata* indicate that unripe fruits contain higher crude fiber and phenolic compounds, making them suitable for nutraceutical applications. In contrast, ripe fruits exhibit increased sweetness and vitamin C, making them preferable for fresh consumption and processed products like juices and jams. Understanding these variations can help optimize harvesting and post-harvest handling to enhance the fruit's market potential.

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