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Impact of ripening stage on the nutritional and antioxidant potential of fruit consumed by diabetics at the Abidjan Anti-Diabetic Centre

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Abstract

Diet can play an important role in the management and prevention of type 2 diabetes. Fruit is packed with essential nutrients and health-promoting micronutrients. What's more, the nutritional value of fruit can vary depending on its ripeness. The aim of this study was to evaluate the nutritional value of ripe and very ripe fruits (sweet bananas, papayas, Kent mangoes, apples, and oranges) regularly consumed by diabetics at the Abidjan Diabetes Center. To this end, the physicochemical (pH, acidity and mineral composition) and biochemical (proteins, lipids, citrates, polyphenols, flavonoids etc.) characteristics of the five fruits were determined at ripe and very ripe stages using standardized methods. The results indicate that the ripening process affects the biochemical composition of the fruit at different stages. A decrease in titrable acidity, vitamin C, protein, lipid, total carbohydrate, energy, and mineral contents was observed. An increase in the content of polyphenols, flavonoids, tannins, and antioxidant activity was observed. Compared to oranges, papayas had more flavonoids (155.7 ± 0.7 mg/100 g) and polyphenols (465.4 ± 3.1 mg/100 g). Oranges, on the other hand, had more vitamin C (47.97 ± 3.6 mg/100 g) and antioxidant activity (44.2 ± 0.1 mg/100 g), calcium (38.60 ± 2.06 mg/100 g), and zinc (0.15 ± 0.02 mg/100 g). Similarly, ripe bananas were richer in potassium (406.2 ± 3.13 and 301.2 ± 4.04 mg/100 g), sodium (2.30 ± 0.06 mg/100 g), manganese (0.38 ± 0.01 mg/100 g), and iron (0.37 ± 0.01 mg/100 g). In conclusion, these results could help diabetics make informed food choices and manage degenerative diseases.

Keywords: Diabetes; Ripe and very ripe fruit; Nutritional properties; Local fruit

1. Introduction

Diabetes is a serious chronic disease characterized by high blood glucose concentrations, caused by abnormalities in β-cells and insulin function [1,2]. However, according to the latest estimates, the number of people with diabetes worldwide is set to rise from 529 million in 2023 to around 1.3 billion by 2050 [1]. The prevalence of diabetes has been rising rapidly, particularly in low- and middle-income countries [1]. Côte d'Ivoire ranks as the sub-Saharan African country where diabetes is most prevalent, with a prevalence of 4.93 % of the population [3, 4]. In Côte d'Ivoire, it has been estimated that the cost of treatment represents 70 % to 96 % of the family budget for the poorest patients and 25 % to 55 % for those with average incomes [5,6].

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Indeed, type 2 diabetes is mainly treated and managed with pharmacological drugs that often have various side effects [7, 8, 9]. Consequently, lifestyle interventions such as diet and physical activity are often explored as strategies for the prevention and management of type 2 diabetes [10]. Furthermore, many experts agree that diet can be an important tool in the management and / or prevention of type 2 diabetes, with a particular emphasis on optimizing fiber intake. It is well established that fresh fruits are rich in fiber and a variety of phytochemicals, vitamins, minerals, and bioactive compounds that can help optimize human health [11,12]. However, a study by [13], which assessed diabetic patients' knowledge of the nutritional benefits of fruit, revealed that 26.7 % had no knowledge of the benefits of fruit consumption. They were unaware that fruit contains essential nutrients and micronutrients such as vitamins, minerals, fiber, and compounds with antioxidant potential that play an important role in their health. For example, over half of them (51.5 %) didn't know that fruit contains sugar. This lack of knowledge may be due to the fact that very few diabetic patients have attended the nutrition training courses provided by the dieticians at the Abidjan Anti-Diabetic Center. Furthermore, the same study showed that those who did consume it preferred ripe and very ripe fruit. What's more, there are currently no publications on the nutritional values of oranges, bananas, mangoes, papayas, and apples sold at two stages of ripeness (ripe and very ripe) in Côte d'Ivoire. This lack of information makes it difficult for dieticians in Côte d'Ivoire to design meal plans and improve advice to prevent and manage obesity and other chronic diseases, such as diabetes.

In this study, it would be interesting to determine the physico-chemical and nutritional characteristics of sweet banana, papaya, Kent mango, golden apple, and orange fruits consumed at ripe and very ripe stages of maturity by diabetic patients at the Abidjan Anti-Diabetic Centre.

2. Material and methods

2.1. Material

The plant material consisted of the fruits most commonly consumed by diabetic patients at the Abidjan Anti-Diabetic Center. These were four local fruits (orange (*Citrus sinensis* L.), dessert banana (*Musa triploid* AAA, Cavendish, cv. Grande Naine), kent mango (*Mangifera indica* L.), and papaya (*Carica papaya* L.)), as well as one imported fruit (golden apple (Malus domestica)). The fruits were purchased at a green stage of maturity from the SOCOFRAIS supermarket in Treichville (Abidjan) for the local fruits and from the fruit terminal of the autonomous port of Abidjan for the golden apple. After collection, the fruits were transported to the Biotechnology Laboratory (UFR Biosciences) of the Université Félix Houphouët-Boigny in Abidjan, where they were stored in crates at a laboratory temperature of 25 ± 2 °C until they reached the desired ripening stage.

2.2. Methods

2.2.1. Determination of fruit ripening degrees

Fruit commercial maturity was subjectively observed at two ripening stages, according to pericarp coloration: the ripe stage and the very ripe stage. The coloration of sweet bananas at ripe (yellow-green) and very ripe (bright yellow) stages was determined using the method of [14], and that of papaya at ripe (more green than yellow) and very ripe (yellow with traces of green) stages using the method of [15]. The determination of kent mango color from the ripe (green-orange) to the very ripe (yellow-orange) stage was done according to the method of [16], while that of apple color from the ripe (green) to the very ripe stage (mottled yellow) was done according to the method of [17]. The identification of the color of oranges from the ripe (green) to the very ripe (bright yellow) stage was described using the method of [18].

2.2.2. Sample preparation

The fruit studied underwent several processing stages. Firstly, they were homogenized and divided into two 10-kg batches at different ripening stages. Next, the fruit was sorted to eliminate defective fruit (rotten or damaged), then washed and rinsed with tap water. The washed fruit was peeled and cut into thin strips using a stainless steel knife. The resulting strips were spread out on a tray lined with baking paper and dried in an oven at 50 °C for 72 hours. After drying, the flakes were ground into flour using an Ilux mixer (NO: LX-176P/AC: 220-240V, 50Hz, 350W). The powder obtained was stored in clean glass jars at ambient laboratory temperature, 25 °C, for analysis.

2.2.3. Biochemical composition of the fruits studied

The methods of the [19] were used to carry out the following analyses: water content, total protein, lipids, ash, pH value, and titratable acidity. The total carbohydrate content was calculated by difference according to the FAO method [20]. The energy value was calculated using the specific coefficients of [21].

2.2.4. Phytochemical composition and anti-free radical activity of studied fruits

Phenolic compounds were extracted with methanol according to the method described by [22]. The polyphenol content was determined according to the Folin-Ciocalteu method [22]. Flavonoids were determined by the method described by [23]. Tannins were determined by the method described by [24]. For vitamin C, the method described by [25] was used. The anti-free radical activity of the different fruits was evaluated using DPPH (diphenyl picrylhydrazyl) as a relatively stable free radical, according to the protocol described by [26]. In this test, antioxidants reduce the purple DPPH to a yellow compound, and the intensity of the color is inversely proportional to the proton donating capacity of the antioxidants present in the medium [27].

2.2.5. Determination of mineral content

The mineral content was determined by atomic absorption spectrophotometry. Ash (0.1 g) was weighed into platinum crucibles to which 1 mL of distilled water was added. To each crucible, 5 mL of 50 % hydrofluoric acid and 2 drops of sulfuric acid (v/v) were added. The whole was homogenized and heated to 100 °C until complete evaporation. The residue obtained was dissolved in 10 mL of 50 % hydrochloric acid. The solution was allowed to stand on the bench for 10 minutes and the final volume was made up to 100 mL.

2.2.6. Statistical Analysis

The results were expressed as the mean ± standard deviation and were presented in tabular form. Analyses were performed with STATISTICA 7.1 software. Comparisons between the groups were made using the Student's t-test, and a one-way analysis of variance (ANOVA) was used within the groups. The significance level was set at $\alpha = 0.05$. Statistical differences with a probability value of less than 0.05 ($p < 0.05$) were considered to be significant.

3. Results

3.1. Biochemical composition and energy value of ripe and very ripe fruit

The macromolecular and energy profiles of the five fruits studied, namely orange, banana, apple, mango, and papaya, at different stages of ripeness are presented in Table 1. All of the parameters studied show a significant statistical difference ($p < 0.05$), with the exception of papaya (lipids and ash) and mango for crude lipids. Protein, fat, and ash contents were low for all five ripe and very ripe fruits. On the other hand, both ripe and very ripe fruits had high water contents, ranging from 76.10 ± 1.3 g/100 g (ripe banana) to 86.12 ± 1.3 g/100 g (ripe papaya) for ripe fruits and from 78.20 ± 1.4 g/100 g (very ripe banana) to 87.27 ± 1.2 g/100 g (very ripe papaya) for very ripe fruits.

In terms of crude lipids and proteins, levels were generally below 1 g/100 g, with the exception of ripe bananas, which recorded a crude protein level of 1.49 ± 0.1 g/100 g. In addition, the lipid content of all fruits decreased significantly ($p < 0.05$) from the ripe to the very ripe stage. However, the protein content did not change significantly for bananas (0.11 ± 0.0 g/100 g) and papayas (0.07 ± 0.0 g/100 g), no matter what stage of ripening they were in.

In terms of ash content, the highest levels were found in very ripe orange pulp (4.20 ± 0.1 g/100g), ripe mango (4.20 ± 0.1 g/100g), and ripe papaya (4.20 ± 0.1 g/100g), while the lowest content was found in banana pulp, with an average value of 1.08 ± 0.0 g/100g.

These fruits have an inverse relationship between pH and titratable acidity. In fact, pH is generally acidic, ranging from 3.47 (ripe banana) to 5.93 (very ripe papaya). All fruits show lower pH values at the ripe stage (3.47 to 5.40) than at the very ripe stage (3.97 to 5.93). Titratable acidity values were very high at the ripe stage (0.53 ± 0.0 mEq/g for ripe papaya to 06.91 ± 0.1 mEq/g for ripe orange), decreasing at the very ripe stage with values ranging from 0.03 ± 0.0 mEq/g for very ripe papaya to 00.68 ± 0.0 mEq/g for very ripe orange.

Finally, as these fruits ripened, their carbohydrate content and energy value decreased. Total carbohydrates vary from 12.58 ± 2.3 to 8.79 ± 1.4 g/100g in oranges, from ripe to very ripe, and from 21.18 ± 1.2 to 19.49 ± 2.3 g/100g in bananas over the same period. Similarly, energy obtained from oranges fell from 52.80 ± 4.3 Kcal/100g (ripe stage) to 38.99 ±

3.4 Kcal/100g (very ripe stage), while in bananas it fell from 92.05 ± 4.3 Kcal/100g (ripe stage) to 82.87 ± 2.4 Kcal/100g (very ripe stage).

Table 1 Biochemical composition (g/100g) and energy value (Kcal/ 100 g) of ripe and very ripe fruit

Fruits	Moisture	Fat	Protein	Ash	Carbohydrate	pH	TA	Energy
Orange								
Ripe	84.93 ± 1.5ᶜ	0.14 ± 0.1ᵇ	0.64 ± 0.0ᶜ	02.00 ± 0.1ᶠ	12.58 ± 2.3ᵈ	03.60 ± 0.1ʰ	06.91 ± 0.1ᵃ	52.80 ± 4.3ᵉ
Very ripe	86.23 ± 1.4ᵇ	0.11 ± 0.0ᶜ	0.38 ± 0.0ᵉ	4.20 ± 0.1ᵃ	8.79 ± 1.4ᶠ	03.97 ± 0.1ᵍ	00.68 ± 0.0ᵈ	38.99 ± 3.4ᵍ
Sweet Banana								
Ripe	76.10 ± 1.3ᵍ	0.16 ± 0.0ᵃ	1.49±0.1ᵃ	1.08 ± 0.0ʰ	21.18 ± 1.2ᵃ	3.47 ± 0.1ⁱ	4.08 ± 0.1ᵇ	92.05 ± 4.3ᵃ
Very ripe	78.20 ± 1.4ᶠ	0.13 ± 0.1ᵇ	0.95±0.1ᵇ	1.24 ± 0.1ᵍ	19.49 ± 2.3ᵇ	04.07 ± 0.1ᶠ	00.32 ± 0.0ᶠ	82.87 ± 2.4ᵇ
Apple fruit								
Ripe	81.13 ± 1.4ᵉ	0.12 ± 0.0ᵇ	0.43±0.1ᵈ	4.00 ± 0.2ᵇ	14.33 ± 1.2ᶜ	3.50 ± 0.1ⁱ	2.54 ± 0.0ᶜ	60.06 ± 4.3ᶜ
Very ripe	83.17 ± 1.2ᵈ	0.10 ± 0.0ᶜ	0.39±0.0ᵉ	3.60 ± 0.1ᵈ	12.74 ± 1.5ᵈ	4.20 ± 0.2ᵉ	0.29 ± 0.0ᵍ	53.41 ± 5.3ᵉ
Mango								
Ripe	81.37 ± 1.2ᵈ	0.10 ± 0.0ᶜ	0.5±0.0ᵈ	4.20 ± 0.2ᵃ	14.02 ± 1.8ᶜ	4.60 ± 0.0ᵈ	2.53 ± 0.1ᶜ	58.22 ± 3.6ᵈ
Very ripe	83.23 ± 1.3ᵈ	0.11 ± 0.0ᶜ	0.32±0.1ᵉ	3.80 ± 0.2ᶜ	12.35 ± 1.1ᵈ	5.17 ± 0.1ᶜ	0.16 ± 0.0ʰ	52.44 ± 3.2ᵉ
Papaya								
Ripe	86.12 ± 1.3ᵇ	0.07 ± 0.0ᵈ	0.62±0.1ᶜ	4.20 ± 0.2ᵃ	9.09 ± 0.5ᵉ	5.4 ± 0.1ᵇ	0.53 ± 0.0ᵉ	39.04 ± 2.3ᵍ
Very ripe	87.27 ± 1.2ᵃ	0.07 ± 0.0ᵈ	0.52±0.2ᵈ	2.40 ± 0.1ᵉ	9.64 ± 0.4ᵉ	5.93 ± 0.2ᵃ	0.03 ± 0.0ⁱ	41.68 ± 4.2ᶠ

Values in the table are averages of three trials, with standard deviations. Values on the same column assigned to different alphabetical letters are significantly; different according to Duncan's test at the 5 % threshold; those assigned to the same letters are not. TA : Titratable Acidity

3.1.1. Bioactive compound content of ripe and very ripe fruit

The results for DPPH radical activity, vitamin C content and phenolic content such as total phenolic (TPC), total flavonoids (TFC) and total tannins in the 5 ripe fruits are presented in Table 2. These parameters vary significantly ($P < 0.05$) from one fruit to another. Ripe papayas showed the highest levels of total polyphenols (465.4 ± 3.1 mg/100g), flavonoids (156.5 ± 0.7 mg/100g) and tannins (1042.6 ± 7 mg/100g). Ripe oranges had the highest DPPH free radical activity (22.1 ± 0.1 %) and the highest vitamin C content (68.5 ± 4.5 mg/100g).

Table 2 Antioxidant content and antioxidant activity in ripe fruit

Parameters (mg/100g)			Fruits		
	Orange	Sweet Banana	Papaya	Mango	Apple fruit
Polyphenols	399.2 ± 8.2 ᶜᵈ	424.7 ± 10.1ᵇᶜ	465.4 ± 3.1ᵃ	385.7 ± 4.1ᵈ	448.4 ± 5ᵃᵇ
Flavonoids	93.2 ± 2.0ᵈ	135.8 ± 2.1ᶜ	156.5 ± 0.7ᵃ	47.1 ± 2.0ᵉ	145.8 ± 1.1ᵇ
DPPH (%)	22.1 ± 0.1ᵃ	6.5 ± 0.02ᵇ	5.1 ± 0.1ᵈ	6.2 ± 0.1ᶜ	5.4 ± 0.1ᵈ
Tannins	696.8 ± 7.1ᵈ	896.1 ± 10.2ᶜ	1042.6 ± 7ᵃ	644.1 ± 5.1ᵉ	976.9 ± 7.0ᵇ
Vitamin C	68.5 ± 4.5ᵃ	14.4 ± 2.0ᵈ	57.6 ± 0.5ᶜ	64.8 ± 0.05ᵇ	8.4 ± 1.6ᵉ

Values on the same line with different alphabetical letters are significantly different according to Duncan's test at the 5 % level.

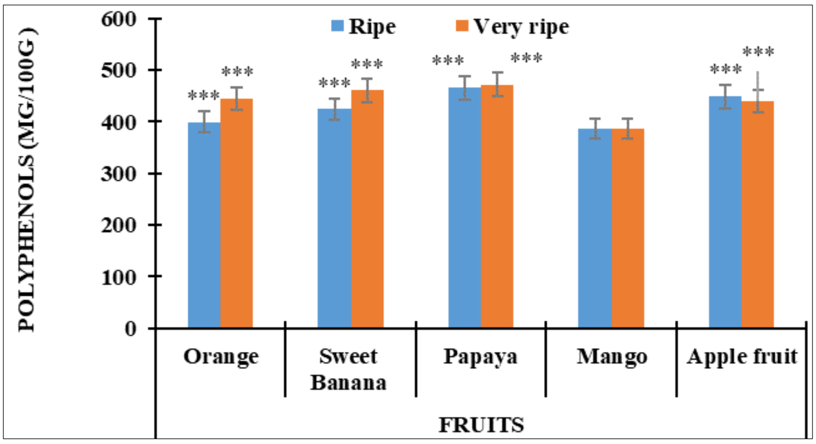
The results for DPPH radical activity and polyphenolic components, total flavonoids, tannins and vitamin C of the 5 very ripe fruits are presented in Table 3. A significant variation ($P < 0.05$) of the parameters is observed between the different fruits. Very ripe papayas were distinguished by the highest levels of total polyphenols (471.8 ± 5.0 mg/100g) and flavonoids (155.7± 0.7 mg/100g), while very ripe bananas were distinguished by the highest levels of tannins (1048 ±

6.1 mg/100g). Ripe oranges had the highest DPPH free radical activity (44.2 ± 0.1 %) and the highest vitamin C content (47.97 ± 3.6 mg/100g).

Table 3 Antioxidant content and antioxidant activity in very ripe fruit

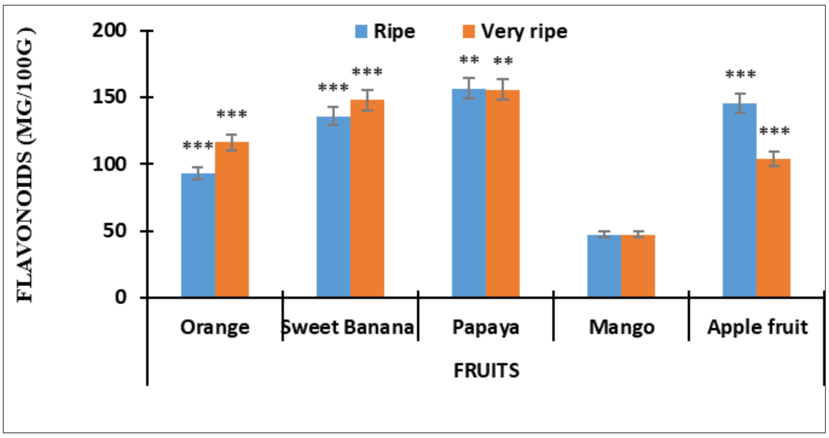
Parameters			Fruits		
	Orange	Sweet Banana	Papaya	Mango	Apple fruit
Polyphenols	445.1 ± 6.1[c]	460.2 ± 6.1[b]	471.8 ± 5.0[a]	385.58 ± 4.1[e]	439.2 ± 3.1[d]
Flavonoids	116.2 ± 1.1[c]	147.8 ± 1.0[b]	155.7 ± 0.7[a]	47.20 ± 2.2[e]	104.0 ± 3.1[d]
DPPH (%)	44.2 ± 0.1[a]	5.4 ± 0.1[d]	6.2 ± 0.1[c]	6.12 ± 0.1[c]	7.6 ± 0.1[b]
Tannins	787.3± 8.1[d]	1048 ± 6.1[a]	1039.3 ± 9[b]	644.3 ± 4.1[e]	922.1 ± 9.1[c]
Vitamin C	47.97 ± 3.6[a]	8.67 ± 2.1[d]	29.87 ± 1.6[c]	38.68 ± 3.02[b]	4.68 ± 1.01[e]

Values on the same line with different alphabetical letters are significantly different according to Duncan's test at the 5 % level.



Bars with the same symbols (***) do not differ significantly at the α= 0.0001 threshold according to Student's T-test.

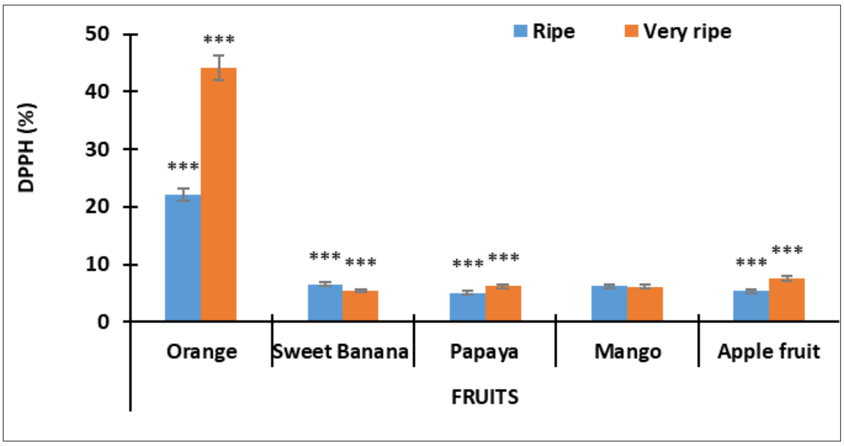
Figure 1 Polyphenol concentrations in ripe and very ripe fruit



Bars with the same symbols (***) differ significantly at threshold α= 0.0001 according to Student's T-test; Bars with the same symbols (**) differ significantly at threshold α= 0.001 according to Student's T-test.

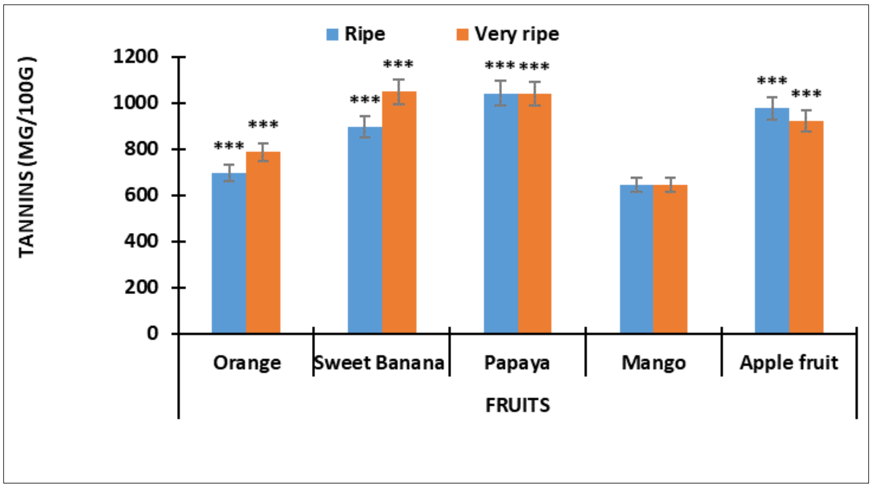
Figure 2 Flavonoids concentrations in ripe and very ripe fruit

The results of comparisons between ripe and very ripe fruits are presented in Figures 1 to 5. It was observed that ripe orange and banana fruit exhibited significantly lower concentrations ($p < 0.05$) of polyphenols, flavonoids, and vitamin C tannins than very ripe fruit. Conversely, ripe papaya and ripe apple contained higher concentrations of flavonoids and tannins. A non-significant difference ($p > 0.05$) was observed between ripe and very ripe mango in polyphenols, flavonoids, DPPH, and tannins. However, vitamin C levels were significantly higher ($p < 0.05$) in ripe fruit than in very ripe fruit.



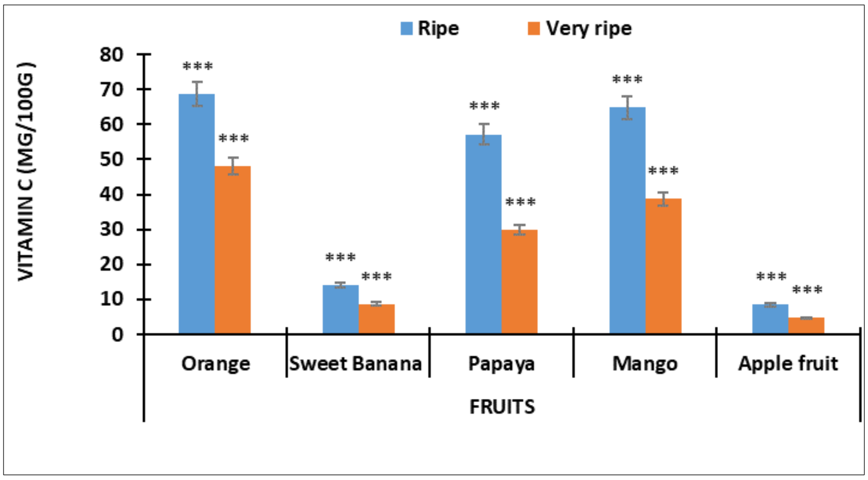
Bars with the same symbols (***) differ significantly at the α= 0.0001 threshold according to Student's T-test.

Figure 3 Antioxidant capacities in ripe and very ripe fruit



Bars with the same symbols (***) differ significantly at the α= 0.0001 threshold according to Student's T-test.

Figure 4 Tannin concentrations in ripe and very ripe fruit



Bars with the same symbols (***) differ significantly at the α= 0.0001 threshold according to Student's T-test.

Figure 5 Vitamin C concentrations in ripe and very ripe fruit

3.2. Mineral Composition of Ripe and Very Ripe Fruits

The mineral content of the five ripe and very ripe fruits is presented in Table 4. A statistically significant difference ($p < 0.05$) was observed for all parameters studied. Potassium (K) remained the most abundant mineral in all five ripe and very ripe fruits, with concentrations ranging from 108.4 ± 3.57 mg/100 g (very ripe apple) to 406.2 ± 3.13 mg/100 g (ripe banana). Conversely, the iron (Fe), zinc (Zn), and manganese (Mn) content was relatively low for these different ripe and very ripe fruits. For instance, the iron (Fe) content exhibited a range of 0.01 ± 0.01 mg/100 g (very ripe mango) to 0.37 ± 0.01 mg/100 g (ripe banana), while the zinc (Zn) content oscillated between 0.04 ± 0.01 mg/100 g (very ripe orange) to 0.40 ± 0.01 mg/100 g (very ripe apple), and the manganese (Mn) content varied from 0.01 ± 0.01 mg/100 g (very ripe orange) to 0.38 ± 0.01 mg/100 g (ripe banana). Furthermore, the calcium (Ca) and magnesium (Mg) content demonstrated particular interest at the ripe stage. The calcium (Ca) content exhibited a wide range, from 0.95 ± 0.06 mg/100 g (very ripe banana) to 38.60 ± 2.06 mg/100 g (ripe orange). Similarly, the magnesium (Mg) content varied considerably, from 0.88 ± 0.03 mg/100 g (very ripe apple) to 32.59 ± 0.26 mg/100 g (ripe banana). The sodium (Na) content of the samples ranged from 0.01 ± 0.01 mg/100 g (very ripe mango) to 2.30 ± 0.06 mg/100 g (ripe banana).

Table 4 Mineral composition (mg/100g) of ripe and very ripe fruit

Fruits	Potassium	Sodium	Calcium	Iron	Magnesium	Zinc	Manganese
Orange							
Ripe	156.6 ± 6.19^{e}	0.66 ± 0.03^{d}	38.60 ± 2.06^{a}	0.14 ± 0.01^{c}	11.35 ± 0.15^{e}	0.15 ± 0.02^{b}	0.05 ± 0.01^{c}
Very ripe	126.2 ± 5.06^{h}	0.16 ± 0.01^{f}	27.06 ± 1.01^{b}	0.03 ± 0.01^{e}	4.45 ± 0.18^{f}	0.04 ± 0.01^{d}	0.01 ± 0.01^{d}
Sweet Banana							
Ripe	406.2 ± 3.13^{a}	2.30 ± 0.06^{a}	5.87 ± 0.11^{f}	0.37 ± 0.04^{a}	32.59 ± 0.26^{a}	0.03 ± 0.01^{d}	0.38 ± 0.01^{a}
Very ripe	301.2 ± 4.04^{b}	0.05 ± 0.02^{g}	0.95 ± 0.06^{h}	0.03 ± 0.02^{e}	18.96 ± 0.64^{b}	0.10 ± 0.01^{c}	0.03 ± 0.01^{d}
Apple fruit							
Ripe	128.5 ± 5.53^{g}	1.26 ± 0.02^{b}	6.44 ± 0.17^{e}	0.15 ± 0.05^{c}	2.95 ± 0.06^{g}	0.11 ± 0.01^{c}	0.05 ± 0.01^{c}
Very ripe	108.4 ± 3.57^{j}	0.33 ± 0.12^{e}	4.42 ± 0.23^{g}	0.07 ± 0.02^{d}	0.88 ± 0.03^{h}	0.40 ± 0.06^{a}	0.03 ± 0.02^{d}
Mango							
Ripe	167.7 ± 4.93^{d}	0.97 ± 0.03^{c}	14.33 ± 0.14^{c}	0.35 ± 0.02^{a}	14.34 ± 0.11^{d}	0.10 ± 0.01^{c}	0.12 ± 0.03^{b}
Very ripe	111.30 ± 3.01^{i}	0.01 ± 0.01^{g}	10.15 ± 0.16^{d}	0.01 ± 0.01^{e}	14.34 ± 0.10^{d}	nd	0.02 ± 0.01^{d}
Papaya							
Ripe	199.2 ± 4.61^{c}	1.27 ± 0.07^{b}	14.21 ± 0.19^{c}	0.28 ± 0.01^{b}	16.44 ± 0.19^{c}	0.14 ± 0.02^{b}	0.03 ± 0.01^{d}
Very ripe	141.2 ± 3.11^{f}	0.03 ± 0.01^{g}	6.29 ± 0.10^{ef}	0.03 ± 0.02^{e}	4.14 ± 0.10^{f}	0.10 ± 0.01^{c}	nd

Values in the table are averages of three trials, with standard deviations. Values in the same column assigned to different alphabetical letters are significantly different according to Duncan's test at the 5 % threshold; those assigned to the same letters are not. nd: not detected.

Figure 6 presents the principal component analysis results on the physicochemical and antioxidant composition of ripe and very ripe fruits. This figure allows us to visualize the effect of ripeness on the biochemical and antioxidant composition of different fruits. We see that very ripe fruits are characterized by a high content of polyphenols (very ripe papaya and very ripe apple), tannins and flavonoids (very ripe banana), and moisture (very ripe orange and very ripe mango). Ripe fruits (ripe apple, ripe banana, and ripe mango) are characterized by a richness of mineral elements (manganese, magnesium, sodium, iron, potassium) and biochemical compounds (proteins, carbohydrates, and lipids) with high titratable activity. However, ripe oranges are characterized by their vitamin C and calcium content.

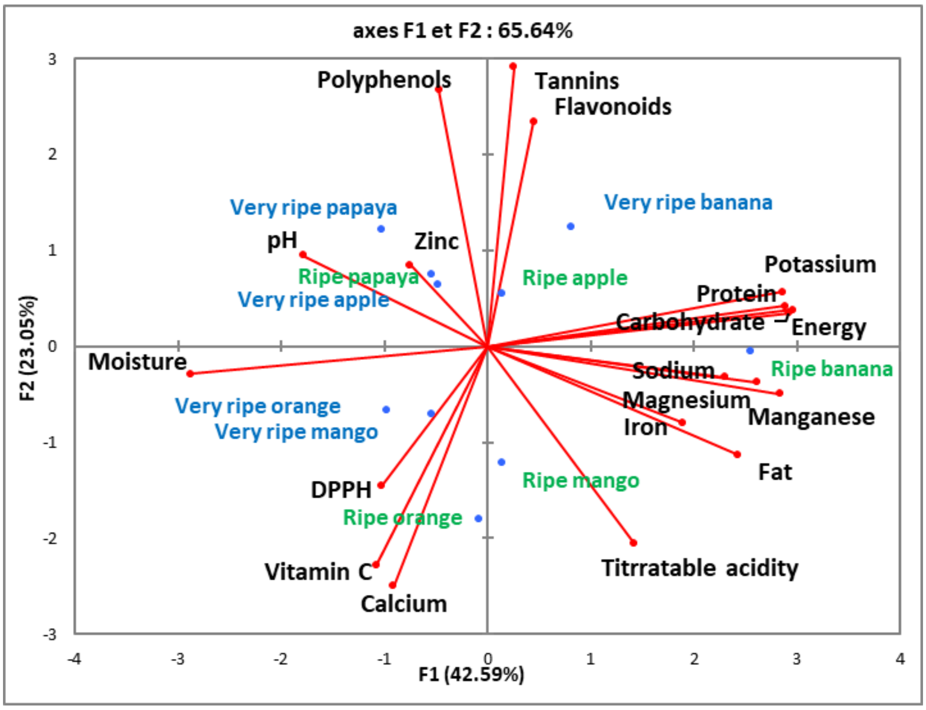


Figure 6 Two-dimensional representation of biochemical variables of ripe and very ripe fruit (individuals)

4. Discussion

This study identified the nutritional differences between various fruits, including sweet banana, papaya, Kent mango, golden apple, and orange, at two stages of ripeness: ripe and very ripe. The results of the biochemical parameters and principal component analysis (PCA) indicate that very ripe papaya and very ripe orange stand out from the other fruits due to their significantly higher water content. This discrepancy in water content may account for the greater sense of satiety experienced by those consuming very ripe fruits compared to those consuming ripe fruits. These findings are consistent with those of [28], who observed that very ripe papaya has a higher water content (88.10%) compared to ripe bananas (79.67%).

The results indicated a decrease in protein and lipid content as the fruit ripened. This reduction may be attributed to the action of proteases and lipases, which hydrolyze proteins and lipids in the fruit flesh during ripening. Consequently, the protein content of the fruit decreases over time, as fruit proteins primarily function as enzymes rather than reserves [29]. This decline in protein content is in accordance with the findings of [30]. Their findings revealed that the protein content decreased from 1.46 % in unripe papaya to 0.64 % in ripe papaya and 0.29 % in very ripe papaya.

The carbohydrate content of fruits tends to decrease as they progress from one stage of ripening to another. Chukwuka et al. [30] observed this trend in their study on unripe, ripe, and very ripe papaya, with respective carbohydrate values of 18.47 %, 14.63 %, and 9.65 %. This decline can be attributed to the breakdown of starch into simple sugars, such as glucose and fructose, which leads to an increase in sugar content as fruits ripen [31]. Plant hormones, such as ethylene, and specific enzymes, such as amylase and pectinase, regulate this ripening process.

Nevertheless, an increase in total polyphenols is observed as the ripening process progresses. This increase can be attributed to several factors, including the activation of enzymes involved in the biosynthesis of phenols and the degradation of cell walls, which release phenolic precursors. These findings are consistent with previous studies that have demonstrated a reduction in phenol content in date palm fruit as ripening progresses [32,33].

The results indicate that the activity of DPPH in preventing oxidation of living molecules ranges from 5.1 ± 0.1 % for ripe papaya to 44.2 ± 0.1 % for very ripe orange. These findings suggest that the potential for antioxidant activity in certain fruits, as previously noted by [34]. Free radicals are generated through a multitude of reactions involved in both physiological and pathological processes. The role of antioxidants in preventing diseases caused by free radicals has been clearly established by several studies [35]. Consequently, antioxidants are vital for humans, as their ingestion can assist in the prevention or even treatment of diseases associated with oxidative stress. With regard to vitamin C, the values obtained in this study are higher than those reported by [36] for orange (53.2 mg/100 g), pineapple (15.4 mg/100 g), mango (27.7 mg/100 g), avocado (7.9 mg/100 g) and banana (9.1 mg/100 g). Shaun et al. [37] also proposed that vitamin C might be involved in regulating blood glucose levels.

For consumers, the mineral composition of ripe and very ripe fruits is a significant factor. This study's findings indicate that these fruits are a valuable source of minerals. Ripe bananas are notable for their high sodium, potassium, magnesium, iron, and manganese content. Consequently, the ingestion of this fruit could result in the body receiving considerable quantities of macronutrients and trace elements. Notably, potassium is the most prevalent macroelement in the fruits studied, while sodium is the least abundant. As previously noted by [38], a diet rich in potassium and low in sodium can help reduce the risk of cardiovascular diseases. Furthermore, the sodium-to-potassium ratio for all fruits was below 1, indicating that consuming these fruits, irrespective of their stage of ripeness, could be beneficial for individuals with high blood pressure [39].

Given the association between high blood pressure and diabetes, eating these fruits could also be beneficial for diabetics. With regard to calcium, ripe and very ripe oranges had the highest levels, with values of 38.60 ± 2.06 mg/100 g and 27.06 ± 1.01 mg/100 g, respectively. These results are higher than those reported by [40] for oranges (25.50 ± 1.90 mg/100 g).

As stated by [41], calcium and magnesium can help reduce the risk of type 2 diabetes due to their role in modulating insulin resistance, pancreatic beta cell function, and inflammation. A magnesium deficiency can impair cellular defenses against oxidative damage, leading to diminished resistance to the oxidative stress induced by diabetes, which can accelerate the progression toward diabetes-related complications.

In addition, trace elements, including iron and zinc, were also present in the studied fruits at relatively low levels. The iron values ranged from 0.01 ± 0.01 mg/100 g (for very ripe mango) to 0.37 ± 0.01 mg/100 g (for ripe banana), while zinc values varied from trace levels in very ripe mango to 0.40 ± 0.01 mg/100 g in very ripe apple.

Zinc plays a pivotal role in cellular signaling and processes such as cell division and apoptosis. It has been postulated that disruptions in zinc homeostasis may be linked to the development of diabetes and insulin resistance. Iron is a vital element, but excessive iron can be toxic [42]. Some epidemiological studies have indicated that excess iron may also be associated with an increased prevalence of metabolic syndrome and type 2 diabetes [43,41].

5. Conclusion

The present study has provided interesting results on the biochemical properties of fruits consumed at the ripe and very ripe stages. The analyses carried out on these fruits showed that they have good nutritional values.

The study showed that apples, sweet bananas, papayas, mangoes and oranges vary widely in their biochemical parameters from ripe to very ripe. From this variability, the biochemical contributions that each ripe and very ripe fruit could make could be determined. Very ripe fruit was characterized by high water content, sugar content, antioxidant activity and high concentrations of polyphenols, flavonoids and tannins. Ripe fruit stands out for its high protein, mineral and vitamin C content. As a result, eating ripe fruit is more beneficial to human health, providing the body with more minerals and nutrients. Overall, the presence of phytonutrients and other crucial molecules makes these fruits favorable for the treatment of type 2 diabetes. In view of their nutritional value, further studies are needed to explore the glycemic index and glycemic load of these ripe and very ripe fruits.

Compliance with ethical standards

Disclosure of conflict of interest

All authors declare that they have no conflicts of interest.

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