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Characterization of the leaves, seeds and seed oils of yellow (*Passiflora edulis flavicarpa*) and purple (*Passiflora edulis*) passion fruits

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Abstract

This study investigated the nutritional, phytochemical, antioxidant, antinutrient, and fatty acid compositions of the leaves and seeds of yellow (*Passiflora edulis flavicarpa*) and purple (*Passiflora edulis*) passion fruits. While the pulp is widely consumed, the leaves and seeds are often discarded as waste despite their potential value. The yellow leaves were nutritionally superior, with relatively high protein (9.92%) and fiber (14.88%) contents, whereas the seeds of both cultivars were rich in fiber (up to 50.43%) and fat, with yellow seeds having the highest lipid content (37.40%). Mineral analysis revealed appreciable levels of iron and zinc with negligible amounts of toxic metals. The yellow leaves also presented higher vitamin A (1537.66 µg RAE) and vitamin C (125.34 mg/g) contents. Phytochemical and antioxidant assays confirmed the presence of bioactive compounds, with yellow seeds exhibiting higher phenolic contents and purple seeds showing greater flavonoid contents and FRAP activity. Fatty acid profiling identified linoleic, oleic, palmitic, and stearic acids as major components. These findings highlight passion fruit leaves and seeds as promising resources for food, nutraceutical, and pharmaceutical applications.

Key words: *Passion fruit, Leaves, Seeds, Antioxidants, Bioactive compounds, Fatty acids*

1. Introduction

Fruits are an important part of the human diet and have several nutritional and health benefits. They are good sources of essential elements such as water, vitamins, minerals, and organic compounds that are very important for proper functioning of the body and are great sources of antioxidants responsible for scavenging free radicals.

The passion fruit is a member of the *Passiflora* genus and comprises approximately 500 species; it is believed to be the largest in the Passifloraceae family. The passion fruit stands out and is unique to the Passifloraceae family as a result of its economic and medicinal usefulness (Rocky and Goutam, 2020). Like many other fruits, passion fruit is an important source of many nutrients, including calcium, fiber, vitamin C and folic acid.

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These nutrients in fruits are vital for the health and maintenance of the human body. Within this species, there are two distinct forms: purple passion fruit, distinguished as *Passiflora edulis*, and yellow passion fruit, distinguished as *Passiflora edulis, f. flavicarpa*, which differ not only in color but also in certain other features (Kumar *et al*., 2017).

Purple passion fruit is preferred for consumption fresh, whereas yellow passion fruit is preferred for juice processing and use as a preservative. The fruit is delicious and is a rich source of antioxidants, minerals, vitamins and fiber. Passion fruit is a nutritious fruit, and the juice extracted from it is of high nutritional value and great importance to human health. It is a rich source of vitamin A and vitamin C and contains fair amounts of iron, potassium, phosphorus and magnesium (Thokchom and Mandal, 2017). Passion fruit juice also has anti-inflammatory, anticonvulsant, antimicrobial, anticancer, antidiabetic, antihypertensive, antisedative, and antioxidant properties and has been used for treating conditions such as osteoarthritis and asthma and acts as a colon cleanser (Zas and John, 2016).

The biochemical compositions of the seeds and leaves of yellow and purple passion fruit varieties differ significantly. While research has focused primarily on fruit pulp because of its high nutritional value, its leaves and seeds have been less studied. However, these plants, which are mostly considered wastes, may be rich in functional food ingredients and natural bioactive compounds with potential health benefits.

The objectives of this study were to analyze the proximate, mineral, and vitamin compositions of passion fruit leaves and seeds; evaluate the phytochemical and antioxidant activities of their ethanolic extracts; assess their antinutrient levels; and determine the fatty acid compositions of their oil extracts.

2. Materials and methods

2.1. Sample collection

The samples were collected from the Akure South Local Government in Ondo State, Nigeria. The yellow and purple passion fruits and leaves were washed with distilled water to remove any adhering contaminants and then drained through folded filter paper. The samples were identified in the laboratory and preserved in the refrigerator prior to analysis within two days.

2.2. Sample treatment

In the laboratory, yellow and purple passion fruits were dissected, and the seeds were separated from the juice. The leaf and fruit seeds were sun-dried, crushed, subsequently ground into powder using a silver crest (SC-1589) electric blending machine and sieved through a 459 µm sieve. The powdery samples were packed into 3 different plastic containers, which were properly labeled and stored prior to analysis.

2.3. Proximate analysis of plant leaves and fruit seeds

For the first portion of the powdery samples, proximate analysis was carried out to analyze the moisture content, ash content, crude fiber content, crude fat content, protein content and carbohydrate content. The proteins were detected according to the method adopted by the AOAC (2023).

2.4. Moisture content analysis

The empty dish and lid were dried in an oven at 105 °C for 3 hours, transferred to desiccators to cool and then weighed (W_1). The samples were placed in a dish and weighed (W_2). The sample in the dish was transferred to a thermosetting oven at approximately 105 °C for approximately 24 hours. After drying, the dish was transferred to a desiccator to cool for approximately 1 hour. The dish was reweighed and dried (W_3).

Calculation

$$\% \text{ Moisture} = \frac{Loss\ in\ weight}{Weight\ of\ sample\ before\ drying} \times 100$$

$$\% \text{ Moisture} = \frac{W2 - W3}{W2 - W1} \times 100$$

where:

W_1= weight of empty dish.

W_2= weight of dish + sample.

W_3= weight of dish + dried samples.

2.5. Ash content analysis

The crude material and lid were placed in a muffle furnace at 5500 °C for approximately 15 minutes so that the impurities on the surface of the crucible could be burned. The crucible was cooled in the desiccators for approximately 1 hour and weighed (W_1). The sample (2.0 g) was weighed into a crucible (W_2) and placed inside a muffle furnace. The temperature was slowly increased from 2000-4500 °C to avoid incomplete ashing. The sample was ashed until it became whitish in color. The sample was removed from the furnace, transferred to a desiccator and allowed to cool to room temperature. The ash in the crucible was weighed (W_3).

Calculation

$$\% \text{ Ash} = \frac{W3 - W1}{W2 - W1} \times 100$$

where:

W_1 = Weight (g) of the empty crucible.

W_2 = Weight (g) of crucible + sample.

W_3 = Weight of crucible + ashed sample.

2.6. Crude fiber analysis

A total of 2.0 g of the residue (W_1) from the fat extraction was taken and put into a 500 ml conical flask. Two hundred milliliters of 1.25% H_2SO_4 was added, and the mixture was boiled within 1 minute and allowed to boil gently for 30 minutes. The mixture was then filtered and rinsed well with hot distilled water, and the sample was separated back into the flask with a spatula. Two hundred millilitres of 1.25% NaOH and a few drops of antifoaming agent were added, boiled within 1 minute, and boiled gently for 30 minutes. The mixture was then filtered and washed with hot distilled water and rinsed 4 times with hot distilled water, once with 10% HCl, 4 times again with hot distilled water, and 3 times with petroleum ether. The residue was salvaged into a crucible after draining, dried in an oven at 105 °C, cooled in a desiccator and weighed (W_2). The cooled residue was placed in a muffle furnace at approximately 36 °C for approximately 30 minutes, transferred to a desiccator, allowed to cool to room temperature and then weighed again (W_3).

Calculations

$$\% \text{ crude fiber} = \frac{W2 - W3}{W1} \times 100$$

Weight of sample = W_1.

Weight of insoluble matter = W_2.

Weight of ash = W_3.

2.7. Crude fat analysis

A round bottom flask was placed in the heating mantle, and filter paper was weighed (W_1). A total of 3.0 g of the sample was added to weighed filter paper (W_2), tied with thread and inserted into the thimble. The flask was sufficiently filled with N–hexane so that the filter floated. A condenser was fixed and refluxed while it was placed on a heating mantle, and it was extracted for 5 hours. The sample was removed and dried in an oven at 10 °C for 5 minutes, transferred to a desiccator, cooled and then weighed (W_3). The filter paper was dried to a constant weight at 50 °C in an oven. The percentage of extracted lipids or fat is given as the difference between the initial weight and the final weight of the filter paper.

Calculation

$$\text{Fat (\%)} = \frac{Weight\ of\ fat}{Weight\ of\ sample} \times 100$$

2.8. Crude protein analysis

The sample (1.0 g) was placed in a digestive flask, and Kjeldahl catalysts (5.0 g) and 200 ml of concentrated H_2SO_4 (0.023 M) were added. A tube containing the chemicals listed below was prepared without a blank, placed in an inclined position, heated gently until the mixture was depleted, and the mixture was boiled hastily until the result was disrupted. Additionally, 60 ml of distilled water was added precisely after cooling. The beaker was connected to a condenser and immersed in standard acid, and 5 drops of index were added. The receiver was removed, and the tip of the condenser was washed and titrated with redundant standard acid.

Calculations

$$\text{Protein (\%)} = \frac{(A - B) \times N \times 1.4007 \times 6.25}{W}$$

where:

A = the volume (ml) of 0.2 N HCl used in sample titration.

B = Volume (ml) of 0.2 N HCl used in blank titration.

N = Normality of HCl.

W = Weight (g) of sample.

1.4007 = Atomic weight of nitrogen.

6.25 = Protein nitrogen conversion factor and its byproduct.

2.9. Carbohydrate analysis

The aforementioned parameter values were subtracted from 100 to obtain this value (i.e., the difference method).

% Carbohydrate = 100 – (%moisture + %ash + %crude fat + %crude fiber + % crude protein).

2.10. Mineral analysis

The compositions of mineral elements such as Ca, Ni, Pb, Zn, Cr, Mg, Cu, Cd, Mn and Fe were determined from the ash obtained during proximate analysis according to the procedures of the AOAC (2023).

Four grams of well pulverized sample was weighed into a 250 ml conical flask. A total of 20 ml of hot HNO_3 was added, and the mixture was placed on a heater and heated slowly for approximately 30 minutes. Then, the volume was increased to medium heat for approximately 15 minutes, and finally, high heating was applied until complete digestion was achieved. The flask was subsequently rotated at intervals until the digest was clear (white fumes). The heating was continued for several minutes to ensure complete digestion, i.e., a clear solution was evidence of complete digestion. The mixture was then allowed to cool, and the sample residue was washed and filtered. The digest was added to a 100 ml volumetric flask. The sample bottle was filled with the digested sample, and the heavy metal concentration was determined by gently introducing the extracted sample to a 210 VGP Atomic Absorption Spectrophotometer (AAS).

2.11. Analysis of the vitamin contents of plant leaves and fruit seeds

2.11.1. Vitamin C content

The vitamin C content of the various parts of the plant was determined via the modified UV visible spectrophotometer method described previously (AL Majidi and AL Qubury, 2016). Approximately 2 g of each blended sample and the filtered sample was transferred into a 100 mL volumetric flask and homogenized by

using 50 mL acetic acid solution with shaking. Four to five drops of bromine water were added until the solution became colored, and then a few drops of thiourea solution were added to it to remove the excess bromine; thus, a clear solution was obtained. Then, a solution of 2,4-dinitrophenyl hydrazine was added thoroughly to the various sample solutions, and the various standard solutions and the blank were added separately. The solutions were then mixed with 100 mL of acetic acid, and the absorbances of the resulting solutions were measured via a UV visible spectrophotometer at 520 nm to determine the concentrations of ascorbic acid in the various samples from the standard calibration curve.

2.11.2. Vitamin A content

A weighed quantity of the sample containing no more than 1 g of fat and at least 240 units of vitamin A was mixed with 30 ml of absolute alcohol and 3 ml of 5% potassium hydroxide. The mixture was gently boiled under reflux for 30 minutes in a stream of oxygen-free nitrogen. After refluxing, the solution was rapidly cooled, and 30 ml of water was added. The mixture was then transferred to a separatory funnel and washed with 3 × 50 ml portions of ether. Vitamin A was extracted by shaking the mixture for 1 minute. After complete separation, the lower aqueous layer was discarded. The ether extract was subsequently washed with 4 × 50 ml portions of water and mixed carefully, especially during the first two washes, to prevent emulsion formation. The washed ether extract was then evaporated to approximately 5 ml, and the remaining ether was removed by passing a stream of nitrogen over the solution at room temperature. The residue was dissolved in sufficient isopropyl alcohol to prepare a solution containing 9-15 units of vitamin A per milliliter. The extinction of the solution was measured at 300, 310, 325, and 334 nm, and the wavelength of maximum absorption was also recorded (Achikanu *et al*., 2013).

2.12. Extraction of plant leaves and fruit seeds

For the second portion of the dried powdery samples, 20 g was weighed into 250 ml beakers. Ethanol was then added to each beaker, and the mixtures were left for 72 hours with intermittent shaking. The resulting mixture was filtered through a 0.45 µm nylon membrane filter, and the filtrates were air-dried under a ventilated cover until a dry extract was obtained.

2.13. Phytochemical tests of plant leaf and fruit seed extracts

Preliminary phytochemical tests were performed on the ethanolic extracts to detect the presence of several chemical compounds, including tannins, flavonoids, saponins, steroids, phenols, terpenoids, cardiac glycosides, and anthraquinone. The proteins were detected according to the method adopted by Jacob *et al*. (2021).

2.13.1. Test for tannins

Approximately 0.2 g of the extract was removed, and 2 mL of 10% ferric chloride was added. The color changes to blue black, which indicates the presence of tannins.

2.13.2. Test for flavonoids

Approximately 0.2 g of the extract was taken; dilute sodium hydroxide was added to create an intense yellow color, which, upon the addition of concentrated hydrochloric acid, turned colorless, indicating the presence of flavonoids.

2.13.3. Test for steroids (Lierbermann Burchardt test)

To approximately 0.2 g of the extract, 1 mL of chloroform was added, 3 mL of acetic anhydride was added from the sides of the test tube, and then two drops of concentrated sulfuric acid were added. The appearance of a dark green color confirmed the presence of steroids.

2.13.4. Test for cardiac glycosides (Keller-Killiani test)

Approximately 0.2 g of the extract was removed, 1 mL of glacial acetic acid was added, and 1 mL of 10% ferric chloride was added. Then, 1 mL of concentrated sulfuric acid was added to the sides of the test tube. The formation of a green/blue precipitate indicates the presence of cardiac glycosides.

2.13.5. Test for saponins

Approximately 0.2 g of the extract was added to 5 mL of distilled water and shaken for 30 s, and the presence of foam indicated the presence of saponin.

2.13.6. Test for phenol

Two milliliters of distilled water followed by a few drops of 10% ferric chloride was added to approximately 0.2 g of the extract. A blue or green color formed, which indicates the presence of phenol.

2.13.7. Test for anthraquinone

To approximately 0.2 g of the extract, 1 mL of concentrated sulfuric acid was added. The red color indicates the presence of quinone.

2.13.8. Test for terpenoids (Salkowski test)

Approximately 3 mL of chloroform was added to approximately 0.2 g of the extract, and then concentrated sulfuric acid was added from the sides of the test tube. The presence of a reddish-brown color at the interface indicates the presence of terpenoids in the extract.

2.14. Antioxidant properties of plant leaves and fruit seed extracts

Antioxidant property analysis was carried out on the ethanolic extracts to detect antioxidants such as DPPH (1,1-diphenyl-2-picryhydrazyl), ABTS (2, 2′-azino-bis (3-ethylbenthiazoline-6-sulphonic acid), FRAP (ferric reducing property), total phenols and total flavonoids via a 721 UV/visible spectrophotometer.

2.14.1. Total flavonoids

The total flavonoid content of the extract was determined via a colorimeter assay developed by Bao *et al.* (2005). First, 0.2 g of the extract was added to 0.3 ml of 5% $NaNO_3$ at time zero. After 5 min, 0.6 ml of 10% AlCl3 was added, and after 6 min, 2 ml of 1 M NaOH was added to the mixture, followed by the addition of 2.1 ml of distilled water. The absorbance was read at 510 nm against the reagent blank, and the flavonoid content was expressed as mg rutin equivalent.

2.14.2. Total phenol content

The total phenol content of the extract was determined according to the methods of Jacob *et al*. (2021). First, 0.2 g of the extract was mixed with 2.5 ml of 10% Folin-Ciocalteu's reagent and 2 ml of 7.5% sodium carbonate. The reaction mixture was subsequently incubated at 45 °C for 40 min, and the absorbance was measured at 700 nm with a spectrophotometer. Gallic acid was used as a standard phenol. The total phenolic contents were expressed in terms of the Gallic Acid Equivalent (GAE) (standard curve equation).

2.14.3. ABTS scavenging ability

The 2,2′-azino-bis(3-ethylbenthiazoline-6-sulphonic acid) (ABTS) scavenging ability was determined via a modified method (Lalhminghlui and Jagetia, 2018). ABTS aqueous solution with $K_2S_2O_8$ (2.45 mM LG1 final conc.) was added in the dark for 16 hours, and the absorbance was adjusted from 734 nm to 0.700 with ethanol. To 0.2 g of the extract or standard, 1.0 mL of distilled DMSO and 0.16 mL of ABTS solution were added, and the mixture was incubated for 20 min, after which the absorbance of the solutions was measured spectrophotometrically at 734 nm. The TROLOX equivalent antioxidant capacity was subsequently calculated. (548.88 g).

2.14.4. Ferric Reducing Antioxidant Power (FRAP)

The reducing properties of the extracts were determined via a modified method (Pulido *et al*., 2018). This method is based on the reduction of (Fe3+) ferricyanide in stoichiometric excess relative to that of antioxidants. First, 0.2 g of the extract was mixed with 1.0 mL of 200 mM sodium phosphate buffer (pH 6.6) and 1.0 mL of 1% potassium ferricyanide [$K_3Fe(CN)_6$]. The mixture was incubated at 50 °C for 20 min; thereafter, 1.0 mL of freshly prepared 10% TCA was quickly added and centrifuged at 2000 rpm for 10 min, and 1.0 mL of the supernatant was mixed with 1.0 mL of distilled water, after which 0.25 mL of 0.1% $FeCl_3$ solution was added. Distilled

water was used for the blank without the test sample, whereas the control solution contained all other reagents except 0.1% potassium ferricyanide. The absorbances were measured at 700 nm via a spectrophotometer.

$$\text{Ferric reducing antioxidant power (\%)} = \frac{Abs_{control} - Abs_{sample}}{Abs_{control}} \times 100$$

2.14.5. 1,1-diphenyl-2-picryhydrazyl (DPPH)

The free radical scavenging ability of the extract against DPPH (1,1-diphenyl-2-picryhydrazyl) was evaluated via the (Jacob *et al.*, 2021) method. First, 0.1 g of the extract was mixed with 1 ml of a 0.4 mM methanolic solution of DPPH, and the mixture was left in the dark for 30 min before the absorbance was measured at 516 nm.

$$\text{DPPH radical scavenging ability (\%)} = \frac{Abs_{sample}}{Abs_{control}} \times 100$$

2.15. Antinutrient properties of plant leaves and fruit seed extracts

Antinutrient property analysis was performed on the ethanolic extracts to detect nutrients such as phytate, oxalate, saponin and tannin.

2.15.1. Tanin analysis

The tannin content was determined via the methods of Marker and Goodchild (1996) method. Approximately 0.2 g of the extract was weighed into a 50 ml sample bottle. Next, 10 ml of 70% aqueous acetone was added, and the mixture was covered properly. The bottle was placed in an ice bath shaker and shaken for 2 hours at 30 °C. Each solution was then centrifuged, and the supernatant was stored on ice. A total of 0.2 ml of each solution was pipetted into the test tube, and 0.8 ml of distilled water was added. Standard tannic acid solutions were prepared from a 0.5 mg/ml stock solution, and the resulting solution was diluted to 1 ml with distilled water. A total of 0.5 ml of Folin-Ciignau reagent was added to both the sample and standard, followed by 2.5 ml of 20% Na_2CO_3. The mixture was then vortexed and allowed to incubate for 40 min at room temperature, and its absorbance was read at 725 nm against a reagent blank concentration of the same solution from a standard tannic acid curve, which was prepared via a 721 UV/Visible Spectrophotometer.

2.15.2. Phytate analysis

Phytate was determined via the Wheeler and Ferrel (1971) method. Approximately 0.2 g of the extract was soaked in 100 ml of 2% HCl for 3 hrs and then filtered through No. 1 Whatman filter paper. A total of 25 ml of the filtrate was removed and placed inside a conical flask, and 5 ml of 0.3% ammonium thiocyanate solution was added as an indicator. Then, 53.5 of distilled water will be added to achieve the proper acidity, which will be titrated against 0.00566 g per milliliter of standard iron (III) chloride solution that contains approximately 0.00195 g of iron per milliliter until a brownish yellow coloration persists for 5 min.

$$Phytate(mg/g) = Titre\ Value \times 2.32$$

2.15.3. Oxalate analysis

The oxalate content was determined via the Harborne (Harborne, 1998) method. Approximately 0.2 g of the extract was weighed into a 100 ml conical flask, to which 75 ml of 1.5 N H_2SO_4 was added. The solution was stirred intermittently with the aid of a magnetic stirrer for approximately one hour and then filtered through Whatman No. 1 filter paper. Twenty-five (25) ml of filtrate was titrated against 0.1 N $KMnO_4$ solution until an end point (the paint pink color persisted for at least 30 sec) was reached. The oxalate concentration was calculated as follows:

$$Oxalate(mg/g) = Titre\ Value \times 0.09004$$

2.15.4. Saponin analysis

Saponin was determined via the spectrophotometric method of Brunner (1984). Approximately 0.2 g of the

extract was weighed into a 250 ml beaker, and 100 ml of isobutyl alcohol or But-2-ol was added. The mixture was shaken for 5 hours to ensure uniform mixing. The mixture was then filtered with No. 1 Whatman filter paper into a 100 ml beaker containing 20 ml of a 40% saturated solution of magnesium carbonate ($MgCO_3$). The mixture obtained again was filtered through No. 1 Whatman filter paper to obtain a clean colorless solution. One milliliter of the colorless solution was transferred to a 50 ml volumetric flask via a pipette, and 2 ml of 5% iron (III) chloride ($FeCl_3$) solution was added and mixed with distilled water. The mixture was allowed to stand for 30 min for color development. The absorbance was read against the blank at 380 nm via a 721 UV/ Visible Spectrophotometer.

Statistical analysis: All the analyses were carried out in duplicate and subjected to one-way analysis of variance (ANOVA) at the 95% confidence level. The means were separated via the Duncan multiple range test via the Statistical Package for Social Sciences (SPSS 21.0).

3. Results and discussion

The proximate compositions of yellow passion fruit leaves and purple passion fruit seeds revealed significant differences in their macronutrient profiles. Yellow Passion Fruit Leaves (YPFL) presented the highest protein content (9.92%), which significantly surpassed that of Purple Passion Fruit Leaves (PPFL), which presented a protein content of 6.11%. This observation is consistent with (de Lima *et al.*, 2021), who noted that yellow passion fruit genotypes tend to accumulate more proteins, possibly due to differences in metabolic activity and leaf physiology. The fiber content followed a similar trend, with a YPFL of 14.88%, whereas that of PPFL was 5.59%, indicating the potential of YPFL as a better source of dietary fiber. In contrast, the seed samples presented markedly higher fiber contents: PPFS (70.65%) and YPFS (81.34%). This aligns with prior findings that passion fruit seeds are inherently rich in nondigestible fiber, making them suitable for functional food development (Faleiro *et al.*, 2020).

The fat content was significantly greater in YPFS (37.43%) than in PPFS (10.45%), confirming the suitability of yellow passion fruit seeds as a potential source of edible oil. The higher lipid concentration in yellow variants may be genetically driven, as supported by studies on passion fruit oil extraction (Silva *et al.*, 2022). The carbohydrate content, calculated by difference, was highest in PPFL (54.32%), suggesting greater energy-providing potential than in the other samples.

The Coefficient of Variation (CV) values for moisture, ash, protein, fiber, fat, and carbohydrates (ranging from 0.56-3.00%) generally indicate low measurement variability and robust reproducibility of the proximate analysis data. These findings suggest that yellow passion fruit, particularly their leaves and seeds, possess superior macronutrient profiles, making them more advantageous for nutritional and industrial applications. Purple varieties, however, may still hold promise in formulations where carbohydrate-rich or antioxidant-rich components are desired.

Table 1: Proximate composition of yellow and purple passion fruit leaves and seeds

Samples	Moisture content (%)	Ash content (%)	Protein (%)	Fiber (%)	Fat (%)	Carbohydrate (%)
YPFL	14.12±0.00^{d}	1.71±0.02^{b}	9.92±0.000^{c}	14.88±0.07^{b}	29.51±0.13^{b}	29.54±0.66^{c}
PPFL	9.46±0.08^{c}	1.49±0.02^{a}	6.110±0.17^{b}	5.59±0.02^{a}	31.22±0.11^{c}	46.11±0.10^{d}
PPFS	9.20±0.02^{b}	4.14±0.05^{d}	6.15±0.00^{b}	50.43±0.26^{d}	22.50±0.49^{a}	7.85±0.78^{b}
YPFS	8.23±0.13^{a}	3.34±0.07^{c}	4.78±0.42^{a}	41.40±0.35^{c}	37.40±0.14^{d}	4.85±1.11^{a}
CV (%)	0.56	1.50	2.19	0.62	0.72	3.00

Note: The values are presented as the means ± standard deviations of replicates. Means with different superscripts within the column are significantly different ($p < 0.05$). CV: Coefficient variation; YPFL: Yellow passion fruit leaves; PPFL: Purple passion fruit leaves; PPFS: Purple passion fruit seeds; YPFS: Yellow passion fruit seeds.

Table 2 shows the mineral analysis of yellow and purple passion fruit (*Passiflora edulis*) cultivars, highlighting the nutritional superiority of the yellow variant, particularly in the seeds and leaves. Yellow passion fruit

seeds had the highest zinc (Zn) concentration (2.45 mg/g), supporting immune function and antioxidant defense, as emphasized by Lonnerdal (2000) in his review of zinc bioavailability in plant foods. The yellow leaves contained the highest iron content (3.67 mg/g), which is crucial for hemoglobin formation and energy metabolism, which aligns with the recommendations of James *et al*. (2003) for plant-based iron sources with low antinutritional interference. Magnesium (Mg) levels were also higher in yellow leaves (5.54 mg/g), which are essential for neuromuscular and cardiovascular health, which is consistent with (Volpe and Fabiano, 2013) emphasis on the systemic benefits of magnesium.

Yellow leaves also presented relatively high calcium concentrations, promoting bone health. Importantly, both cultivars were free from heavy metals such as lead (Pb) and cadmium (Cd), ensuring consumer safety and compliance with the FAO/WHO (2011) Codex Alimentarius standards.

These findings suggest that yellow passion fruit seeds and leaves, with their high mineral profile and low antinutritional factors, could be used in the development of fortified foods, nutraceuticals, and dietary supplements, particularly in regions facing micronutrient deficiencies, as also noted by Figueiredo *et al*. (2021) in their characterization of Brazilian passion fruit varieties.

Table 2: Mineral contents of yellow and purple passion fruit leaves and seeds

Samples	Co	Ni	Pb	Zn	Cr	Mg	Cu	Cd	Mn	Fe
YPFL	ND	ND	ND	1.26±0.01	0.010±0.01	5.31±0.02	0.31±0.03	0.03±0.05	0.95±0.01	3.67±0.04
PPFL	ND	ND	ND	0.50±0.01	0.20±0.02	5.04±0.00	0.10±0.05	ND	0.33±0.00	0.27±0.01
YPFS	ND	ND	ND	2.45±0.00	0.15±0.01	5.54±0.00	0.563±0.05	0.04±0.08	0.78±0.01	1.76±0.03
PPFS	ND	ND	ND	2.44±0.04	0.12±0.01	5.51±0.01	0.05±0.04	0.21±0.02	1.03±0.01	2.21±0.02
CV (%)	0	0	0	0.90	26.49	0.14	16.62	53.57	0.97	1.26

Note: The values are presented as the means ± standard deviations of replicates. Means with different superscripts within the column are significantly different ($p < 0.05$). CV: Coefficient variation; YPFL: Yellow passion fruit leaves; PPFL: Purple passion fruit leaves; PPFS: Purple passion fruit seeds; YPFS: Yellow passion fruit seeds.

Table 3 shows the results of the vitamin analysis, which revealed significant differences in the micronutrient compositions of the yellow and purple passion fruit cultivars, particularly in their leaves and seeds. The Yellow Passion Fruit Leaves (YPFL) presented the highest concentrations of both vitamin A (1537.66 µg RAE) and vitamin C (125.34 mg/g), significantly exceeding the values reported for the Purple Passion Fruit Leaves (PPFL), which included 1235.14 µg RAE of vitamin A and 94.25 mg/g of vitamin C. These findings suggest that YPFL may be a more potent contributor to combating vitamin A deficiency, a public health concern in many developing regions (WHO, 2023). Seeds from both cultivars presented considerably lower vitamin contents than did the leaves. Notably, Yellow Passion Fruit Seeds (YPFS) contained only 9.35 mg/g vitamin C, highlighting their limited role in ascorbic acid supplementation. In contrast, purple seeds (PPFS) presented

Table 3: Vitamin content of yellow and purple passion fruit leaves and seeds

Samples	Vitamin A (mcg (RAE))	Vitamin C (mg/g)
YPFL	1537.66 ± 41.35^{c}	125.34 ± 1.43^{d}
PPFL	1516.88 ± 40.80^{c}	113.96 ± 1.59^{c}
PPFS	699.22 ± 18.80^{a}	25.68 ± 0.31^{b}
YPFS	1012.99 ± 27.25^{b}	9.35 ± 0.48^{a}
CV (%)	2.69	1.39

Note: Value is mean ± standard deviation of replication. Mean with different superscripts within the column are significantly different ($p < 0.05$). CV: Coefficient variation; YPFL: Yellow passion fruit leaves; PPFL: Purple passion fruit leaves; PPFS: Purple passion fruit seeds; YPFS: Yellow passion fruit seeds.

slightly higher vitamin C levels (15.54 mg/g), although this value was too low for significant nutritional intervention. These differences may be attributed to varietal genetic expression and physiological partitioning of nutrients within the plant (Rodrigues *et al.*, 2022). Furthermore, the high β-carotene content in the yellow variants aligns with findings of Akinwale (2000), who linked yellow pigmentation in fruits with elevated provitamin A concentrations. Similarly (Nguyen *et al.*, 2021) emphasized the nutritional utility of leafy vegetables such as passion fruit leaves in addressing micronutrient deficiencies in resource-poor settings owing to their rich ascorbic acid and carotenoid profiles.

The current findings reinforce that the leaves of yellow passion fruit, in particular, represent an underutilized yet highly valuable dietary component, with potential applications in food fortification, nutraceutical development, and public health nutrition programs.

Table 4 shows the result of the phytochemical screening of yellow and purple passion fruit cultivars. These results revealed a rich and diverse profile of secondary metabolites, reinforcing the potential therapeutic and nutraceutical value of these plant parts. Qualitative assays detected the strong presence (+++) of key phytoconstituents such as saponins, terpenoids, flavonoids, and steroids in the leaves of both cultivars—Yellow Passion Fruit Leaves (YPFL) and Purple Passion Fruit Leaves (PPFL). These bioactive compounds are widely known for their antioxidant, anti-inflammatory, antimicrobial, and cardio protective effects (Atanasov *et al.*, 2021).

The presence of flavonoids, in particular, underscores the antioxidant capacity observed in earlier assays, as these polyphenolic compounds are central to free radical neutralization and oxidative stress modulation (Panche *et al.*, 2016). Saponins and terpenoids, on the other hand, are linked to cholesterol-lowering and immunomodulatory effects, while steroids contribute to hormonal balance and membrane integrity. Their robust detection in both leaf samples and seeds suggest that passion fruit leaves are not only nutrient-dense but also pharmacologically active, supporting their use in traditional and modern herbal medicine. The seeds displayed a different phytochemical profile, with cardiac glycosides and anthraquinones predominantly observed in Purple Passion Fruit Seeds (PPFS) and to a lesser extent in YPFS. Cardiac glycosides, known for their role in regulating heart rhythms and improving cardiac output, hint at the cardiotonic potential of the seeds. Meanwhile, anthraquinones, which exhibit laxative, antimicrobial, and anti-cancer properties, were notably more concentrated in PPFS. These seed-specific phytochemicals highlight a wider pharmacological spectrum that differentiates seeds from leaves and emphasizes cultivar-specific bioactivity. Such compositional differences may stem from genotypic variation, environmental influences, and the functional differentiation of plant organs. These findings are consistent with the ethnobotanical documentation of *Passiflora* species, where various parts of the plant are employed to treat anxiety, hypertension, insomnia, and digestive disorders (Dhawan *et al.*, 2004). The diversity and abundance of these secondary metabolites further validate the inclusion

Table 4: Qualitative phytochemical constituents of yellow and purple passion fruit leaves and seeds

Samples	YPFL	PPFL	YPFS	PPFS
Saponin	+++	+++	+	+
Tannin	+	++	++	++
Phenol	+	++	++	++
Terpenoid	+++	+++	+	+++
Flavonoid	+++	+++	++	++
Steroid	+++	+++	+++	+++
Cardiac glycosides	_	_	+++	+++
Anthraquinone	_	_	+++	_

Note: (+++): highly present; (++): moderately present; (+): low present; (-): absent. YPFL: Yellow passion fruit leaves; PPFL: Purple passion fruit leaves; PPFS: Purple passion fruit seeds; YPFS: Yellow passion fruit seeds.

of both leaves and seeds—especially of the purple cultivar—in future pharmacological screening and drug discovery initiatives.

Table 5 shows the antioxidant properties of yellow and purple passion fruit cultivars, which reveal striking cultivar- and tissue-specific variations, underscoring the nutritional and functional relevance of these bio resources. Quantitative assessments revealed that Yellow Passion Fruit Seeds (YPFS) presented the greatest DPPH radical inhibition (98.10±0.24%), confirming their robust free-radical neutralization ability. They also demonstrated a substantially high total phenolic content of 933.25±16.24 mg GAE/g, in line with their potent FRAP values (257.60±0.16 mg AAE/g) and ABTS activity (120.49±0.27 mM Trolox eq/g). This biochemical profile strongly supports YPFS as a superior antioxidant source, predominantly because of its high phenolic density, which is well known to be correlated with radical scavenging and redox potential (Chen *et al*., 2020). In contrast, Purple Passion Fruit Seeds (PPFS) displayed slightly lower DPPH inhibition (96.47±0.12%) but presented the highest FRAP (288.02±0.96 mg AAE/g) and ABTS capacity (125.49±0.18 mM Trolox eq/g), along with a substantial TPC (688.84±31.10 mg GAE/g). Notably, PPFS also presented the highest flavonoid content (52.87±1.82 mg/g) across all the samples. Flavonoids, which are particularly abundant in PPFS, are recognized for their vasoprotective, anti-inflammatory, and neuroprotective effects, suggesting that PPFS may offer a broader spectrum of biological activity beyond its antioxidant effects alone. Among the leaf samples, Purple Passion Fruit Leaves (PPFLs) outperformed yellow leaves in almost every antioxidant parameter except DPPH. PPFL presented a FRAP value of 227.24±1.03 mg AAE/g, an ABTS activity of 117.59±0.27 mM Trolox eq/g, and a phenolic concentration of 345.36±14.63 mg GAE/g, nearly 2.5 times greater than that of YPFL. Furthermore, their total flavonoid content reached 48.40±0.99 mg/g, making PPFL a potential source of anti-aging and cardio-supportive bioactive compounds, especially where seed utilization is limited. Although Yellow Passion Fruit Leaves (YPFL) presented the lowest antioxidant capacity among all the samples, with a TPC of 141.21±13.72 mg GAE/g and a FRAP of 98.34±2.79 mg AAE/g, they still presented respectable DPPH activity (94.22±0.37%) and flavonoid levels (33.89±4.11 mg/g). In summary, seeds from both cultivars represent an underutilized but potent antioxidant source, with YPFS excelling in phenolic-based radical scavenging and PPFS leading to flavonoid-related antioxidant potential. These insights are not only consistent with the growing evidence on the functional roles of passion fruit byproducts but also highlight their potential inclusion in nutraceutical, pharmaceutical, and functional food formulations.

Table 5: Antioxidant properties of yellow and purple passion fruit leaves and seeds

Samples	DPPH (% inhibition)	FRAP (mg AAE/g)	ABTS (mM Trolox eq/g)	Total Phenol (mg GAE/g)	Total Flavonoid
YPFL	94.22±0.37^{a}	98.34±2.79^{a}	63.47±2.63^{a}	141.21±13.72^{a}	33.89±4.11^{a}
PPFL	93.80±0.24^{a}	227.24±1.03^{b}	117.59±0.27^{b}	345.36±14.63^{b}	48.40±0.99^{b}
PPFS	96.47±0.12^{b}	288.02±0.96^{d}	125.49±0.18^{c}	688.84±31.10^{c}	52.87±1.82^{b}
YPFS	98.10±0.24^{c}	257.60±0.16^{c}	120.49±0.27^{bc}	933.25±16.24^{d}	29.63±0.82^{a}
CV (%)	0.25	0.57	0.78	3.59	4.70

Note: The values are presented as the means ± standard deviations of replicates. Means with different superscripts within the column are significantly different ($p < 0.05$). CV: Coefficient variation; YPFL: Yellow passion fruit leaves; PPFL: Purple passion fruit leaves; PPFS: Purple passion fruit seeds; YPFS: Yellow passion fruit seeds.

Table 6 shows the quantified presence of antinutrients such as tannins and saponins. YPFL contained the highest levels of saponins (35.63 mg/g) and tannins (20.87 mg/g), which could reduce the bioavailability of some nutrients. However, at moderate levels, these compounds have pharmacological benefits, such as cholesterol-lowering effects. The seed samples, particularly YPFS (73.95 mg/g tannins), also presented high tannin contents, which could influence taste and digestibility if consumed without processing. The phytate and oxalate levels were relatively low across all the samples, suggesting a minimal impact on mineral bioavailability. Most antinutrients, such as oxalates, cannot be eliminated from the urinary tract once ingested. Excessive intake of oxalates may lead to the accumulation of kidney stones, as well as symptoms such as weakness and abdominal pain.

Table 6: Antinutrient content of yellow and purple passion fruit leaves and seeds

Samples	Saponin (mg SE/g)	Phytate (mg TAE/g)	Oxalate (mg/g)	Tannin (mg/g)
YPFL	266.36±6.59^{c}	6.59±0.00^{d}	0.63±0.13^{b}	20.20±1.22^{b}
PPFL	190.00±1.29^{b}	4.12±1.17^{ab}	0.36±0.00^{a}	16.70±0.28^{a}
PPFS	17.55±2.57^{a}	2.47±1.17^{a}	0.81±0.13^{a}	66.93±0.56^{c}
YPFS	194.55±7.71^{b}	4.12±1.17^{ab}	0.36±0.00^{b}	73.95±0.20^{d}
CV (%)	2.72	20.29	12.04	1.27

Note: The values are presented as the means ± standard deviations of replicates. Means with different superscripts within the column are significantly different ($p < 0.05$). CV: Coefficient variation; YPFL: Yellow passion fruit leaves; PPFL: Purple passion fruit leaves; PPFS: Purple passion fruit seeds; YPFS: Yellow passion fruit seeds.

Table 7 shows that fatty acid analysis of the four passion fruit samples revealed a significant difference between the leaves and the seed oils. The two leaf samples, identified as Yellow Passion Fruit Leaf (YPFL) and Purple Passion Fruit Leaf (PPFL), presented remarkably low total fatty acid contents of 0.49% and 0.20%, respectively. The primary fatty acid in both samples was palmitic acid (C16:0), a common saturated fatty acid. These findings indicate that passion fruit leaves are not a viable source for extracting valuable fatty acids. In contrast, the seed oil samples were excellent sources. The Yellow Passion Fruit Seed (YPFS) oil and Purple Passion Fruit Seed (PPFS) oil samples contained total fatty acid concentrations of 23.53% and 94.56%, respectively. The fatty acid profile of the seed oil was dominated by unsaturated fatty acids, with linoleic acid (C18:2n-6) being the most prominent fatty acid, accounting for 15.85% and 80.64% of the yellow and purple passion fruit seed oils, respectively. This high concentration of linoleic acid, an essential fatty acid that is crucial for human health, is consistent with the findings of a study by Ojha *et al*. (2023). The study revealed that passion fruit oil contained the highest amount of linoleic acid among several vegetable oils, with a concentration of 66.23%. Other significant fatty acids identified included oleic acid (C18:1n-9), saturated palmitic acid (C16:0) and stearic acid (C18:0). The presence of other compounds, such as linoelaidic acid (a trans-isomer of linoleic acid) and octanoic acid, in the purple passion fruit seed oil sample highlights its more complex composition. These findings, particularly the high concentration of linoleic acid in the seed oil, emphasize the

Table 7: Fatty-acid analysis (%) of yellow and purple passion fruit leaves and seed oils

	YPFL	PPFL	YPFS	PPFS	Mean	SD	CV (%)
Palmitic acid $CH_3(CH_3)_{14}COOH$	0.49	0.20	3.35	9.34	3.35	3.67	109.80
Linoleic acid $CH_3(CH_2)_4CH{=}CHCH_3CH{=}CH\ (CH_2)_7COOH$	0.00	0.00	15.85	80.64	24.12	33.27	137.90
Oleic acid $CH_3(CH_2)_5CH{=}CH(CH_3)_7COOH$	0.00	0.00	2.45	0.34	0.70	1.02	146.40
Stearic acid $CH_3(CH_3)_{16}COOH$	0.00	0.00	1.88	3.76	1.41	1.56	110.60
Linoelaidic acid $CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	0.00	0.00	0.00	0.14	0.04	0.06	173.10
Octanoic acid $CH_{3(}CH_2)_6COOH$	0.00	0.00	0.00	0.34	0.09	0.15	173.20
Σ	0.49	0.20	23.53	94.56	29.70	38.65	130.10
Σ Saturated	0.49	0.20	5.23	13.44	4.84	5.35	110.50
Σ Unsaturated	0.00	0.00	18.30	81.12	24.86	33.34	134.10

Note: SD: Standard deviation; CV: Coefficient variation; YPFL: Yellow passion fruit leaves; PPFL: Purple passion fruit leaves; PPFS: Purple passion fruit seeds; YPFS: Yellow passion fruit seeds.

potential of passion fruit seed oil as a valuable and sustainable resource for various industries. As seeds are often a byproduct of the juice industry, their utilization promotes a circular economy and adds significant value to the agricultural sector, as confirmed by a review from Corleto *et al*. (2020). The variations in fatty acid content between samples can be attributed to factors such as the specific fruit variety, geographical origin, and extraction methods, as noted by Passos *et al*. (2020).

4. Conclusion

This study revealed that the leaves and seeds of yellow and purple passion fruit, which are often considered waste, are valuable sources of nutrients, bioactive compounds, and essential fatty acids. Yellow leaves are particularly rich in vitamins A and C, whereas seeds contain high levels of fiber and linoleic acid, supporting their potential roles in immunity, cardiovascular health, and cholesterol reduction. The presence of phytochemicals and antioxidants further underscores their functional food value, while the manageable levels of antinutrients indicate safety for consumption after simple processing. Overall, these findings highlight the potential of passion fruit byproducts to increase human nutrition, support health, and provide sustainable raw materials for the food, nutraceutical, and pharmaceutical industries.

Data availability

All data generated or analyzed during this study are included in this published article.

Conflict of Interest

No conflict of interest with any institution/organization.

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