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Investigation on Phytochemicals and Nutritional Values of Three Passion Fruit Species Planted in Lam Dong Plateau

Le-Son Hoang [1, a], Nguyen-Kim-Thanh Le [1,*, a]

[1]Department of Applied Biochemistry, Faculty of Biotechnology, International University- National University, Ho Chi Minh City, 70000, Vietnam

ABSTRACT: This study comprehensively evaluated and compared the nutrient contents, total phenolic content, total flavonoid content, antioxidant activity, and anti-nutritional factors of three passion fruit species, namely purple passion fruit (*Passiflora edulis* f. edulis), yellow passion fruit (*Passiflora edulis* var. flavicarpa), and sweet granadilla fruit (*Passiflora ligularis*). The passion fruit samples were collected from various gardens throughout the Lam Dong plateau - Vietnam. The analyses were performed as per standard test methods. *Passiflora edulis* f. edulis had high contents of carbohydrates, fat, vitamin K1, potassium, phosphorus, and iodine whereas *Passiflora edulis* var. flavicarpa was rich in carbohydrates and vitamins group B including B3, B6, and B9. *Passiflora ligularis*, on the contrary, primarily provided essential nutrients of protein, vitamins A, and C, and minerals including sodium, potassium, calcium, magnesium, and iron. All three studied passion fruit species generally possessed moderate values of phenolics, flavonoids, and antioxidants; the same pattern was also observed with antinutrients as all three studied passion fruit species were found to contain low concentrations of phytate, tannin, and oxalate. These findings scientifically contribute to the food database system and can be exploited for diet planning.

1. INTRODUCTION

Passion fruit (PF) is a member of the genus *Passiflora* belonging to the Passifloracea family. This plant is widely cultivated in the tropical and subtropical regions of Africa, Asia, and America (Yockteng et al., 2011). There are over 500 scientifically identified species; of which, approximately 80 species are edible (Schotsmans & Fischer, 2011), (Pérez & D'eeckenbrugge, 2017). PF is commonly used as an ingredient or flavoring agent in a large variety of foods and beverages such as cocktails, smoothies, ice cream, tea, wine, vinegar, fermented drinks, yogurt, cake, pudding, salad, and jam (Ulmer & Macdougal, 2004). PF is reportedly composed of alkaloids, phenols, flavonoids, carbohydrates, protein, vitamins, and minerals, particularly rich in vitamin C, lycopene, carotene, and dietary fiber (Hernández-Santos et al., 2015). PF has been traditionally utilized for the treatment of insomnia, anxiety, bronchitis, and asthma (Zibadi & R, 2004). Contemporary scientific studies have shown that PF exerts various significant pharmacological properties, including anti-hyperlipidemia (He et al., 2020), antioxidant (Ramli et al., 2020), antihypertensive (Panelli et al., 2018), antidiabetic (Kuete et al., 2016), anti-inflammatory (Silva et al., 2015), antimicrobial, antidepressant, and anti-carcinogenic activities (Ingale & Hivrale, 2010).

Three distinct species of PF are commonly cultivated in the Lam Dong plateau, namely *Passiflora edulis* f. edulis, *Passiflora edulis* var. flavicarpa, and *Passiflora ligularis* (Figure 1). *Passiflora edulis* f. edulis (*P. edulis*), commonly known as purple PF (PPF), is a tropical highland fruit crop, native to southern Brazil, northern Argentina, and Paraguay (Feuillet & Macdougal, 1806). Previous studies (Alves et al., 2021) have highlighted its significant contributions in many industries, including pharmaceuticals, cosmetics, and food, owing to its high fatty acid content which confers high bioavailability. Moreover, the high content of fiber also makes PPF a potential alternative source of pectin in food formulations (Dam & Nguyen, 2013).

Passiflora edulis var. flavicarpa (*P. flavicarpa*), commonly known as yellow PF (YPF), is a pantropical fruit crop, native to South America, especially Brazil and northern Argentina (Feuillet & Macdougal, 1806). YPF is famous for its high vitamin C content and balanced flavor. This is the most popular species of PF, accounting for approximately 95% of global production. Previous studies have shown that YPF contains a high amount of potassium (Zhao et al., 2023) and also possesses antioxidant activity, which helps protect

* Corresponding author.
E-mail address: lnkthanh1996@gmail.com (Nguyen-Kim-Thanh Le)
[a] Equal contribution as a first author.

Figure 1. Passion fruit species: (A) *Passiflora edulis* f. edulis; (B) *Passiflora edulis* var. flavicarpa; and (C) *Passiflora ligularis*.

cardiovascular health from free radicals and regulate blood pressure. A study by Pereira et al. (2019) revealed the high iron content in YPF, providing enough recommended daily iron intake.

Passiflora ligularis (*P. ligularis*), or sweet granadilla fruit (SGF), is usually cultivated in central and south American tropical highlands, origin from the Andes, especially in Bolivia, Colombia, Ecuador, and Peru (Feuillet & Macdougal, 1806). Previous research indicated that this species is particularly rich in organic acids like citric acid, malic acid, and ascorbic acid, contributing to its potential benefits for overall metabolic function (Espinosa et al., 2018).

The variation in nutrient contents of PF is attributed chiefly to various factors including plant species, genotypes, botanical origin, climatic conditions, cultivation methods, and processing techniques. A comparative analysis of nutrient values across these PF species essentially contributes to the understanding of the nutritional diversity within this fruit genus, potentially identifying species with unique or superior nutritional profiles. In addition, by highlighting the nutritional differences among species, this study could stimulate interest in cultivating and consuming underutilized passion fruit varieties, promoting agricultural diversity and food security. In this regard, this study thus primarily aimed to quantitatively assess and compare the nutrient contents of three different species of PF planted in the Lam Dong plateau including total phenolic content and total flavonoid content, antioxidant activity, and anti-nutritional factors were also subjected to the investigation in this study.

2. MATERIALS AND METHODS

2.1. Chemicals and reagents

All chemicals and reagents were provided by the Pharmaceutical Chemistry Laboratory and Applied Biochemistry Laboratory of the Applied Biochemistry Department of International University HCMC. 2,2-Diphenyl-1-picrylhydrazyl (DPPH); Folin–Ciocalteu; gallic acid; quercetin; and sulfuric acid were purchased from Sigma-Aldrich.

2.2. Selection and preparation of materials

The mature *P. edulis*, *P. flavicarpa*, and *P. ligularis* were randomly harvested for each species from various trees belonging to eight different gardens in Lam Dong plateau – Vietnam (Figure 2), including gardens Chuc Trinh (12°01'41.9"N 108°24'55.2"E), Duong Chi Thanh (11°34'10.0"N 107°58'08.7"E), Huy Quyen (11°34'25.7"N 108°24'56.0"E), Lan Tuan (11°32'13.9"N 107°51'47.9"E), Quang Thao (11°52'11.4"N 108°36'06.5"E), Son Hai (11°51'04.1"N 108°17'46.7"E), Thanh Trung (11°23'32.4"N 107°39'26.5"E), and Truong Anh (11°24'49.9"N 107°36'27.5"E). The harvest was simultaneously conducted during the fruiting season (November to December 2023). Fully ripe PF had a shiny, even skin with dark purple for *P. edulis*, yellow mixed green for *P. flavicarpa*, and orange-yellow for *P. ligularis*. It was smooth, with no wilting, stamping (damage), or visible cracks on the outside. After harvesting, all samples were stored at a temperature of 8 ± 2°C throughout the study period.

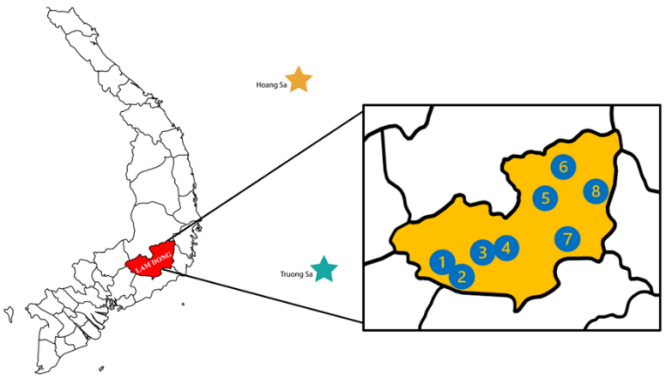

Figure 2. Passion fruit harvesting locations in the Lam Dong plateau (Lam Dong Portal, n.d.).

2.2.1 *Preparation of samples*

Each species of PF was screened to remove substandard fruits, then washed, drained, and randomly divided into three groups. The PF in each group was then cut in half, and the edible part was scooped out from the peel with a spoon. The pulp was separated from the seeds using a sieve and then mixed homogenously prior to storing at -18°C in a sealed bag for further analysis.

2.2.2 *The supernatant preparation*

One gram of PF sample was weighed and extracted with 10 mL of 80% (v/v) methanol in a Falcon tube. The sample was then sonicated for 25 minutes at 60°C and centrifuged at 4000 rpm for 10 minutes. The supernatant was collected for later analysis.

2.3. Determination of total carbohydrate content

The total carbohydrate content of the PF sample was determined using colorimetric method (Nielsen, 2010), (AOAC 988.12, 1990). The assay was prepared by mixing 5 g of PF sample with 45 mL of 80% ethanol in a beaker covered with glass and then incubated for 15 minutes. Once the system had been cooled down, the mixture was transferred to a 50-mL volumetric flask, filling up the volume with 80% ethanol. Thereafter, the mixture was filtered to obtain 10 mL of filtrate. The analysis was conducted by mixing 1 mL of diluted filtrate with 1 mL of 5% phenol and 5 mL of concentrated sulfuric acid, followed by incubation in a water bath for 10 minutes, and then allowed to cool down for 5 minutes. The absorbance was measured against the blank at 490 nm using a spectrophotometer. The 100 μg/mL of glucose solution was used as a standard for the calibration curve. The total carbohydrate content was reported as glucose equivalent (GE) per gram of sample (mg GE/g) and as a percentage of the sample.

2.4. Determination of protein content

The protein content of the PF sample was determined using the Kjeldahl method (AOAC, 2005a, 2005c). 1 g of PF sample was weighed into a Kjeldahl flask, followed by the addition of 1 g of catalyst (a mixture of potassium sulfate and copper sulfate in a ratio of 9:1) and mixing well with 10 mL of concentrated sulfuric acid. The sample was then digested by heating at 230°C until it turned to a clear green color. The digested sample was then diluted with distilled water in a 100-mL volumetric flask and then transferred to a distillation apparatus. Once adding 25 mL of 40% sodium hydroxide solution to the system, the mixture was distilled until 100 mL of distillate was collected in a conical flask containing 15 mL of 4% boric acid solution. A few drops of bromocresol green indicator were added to the distillate prior to titration against 0.1 N hydrochloric acid until the color changed from green to pink. The protein content was expressed as a percentage in the sample with a conversion factor of 6.25.

2.5. Determination of total crude fat content

The total crude fat content of the PF sample was determined using Randall extraction-submersion method AOAC (2005b) (AOAC 2003.05, 2005), (AOAC 2003.06, 2005). 4.5 g of the dried ground sample was accurately weighed into a thimble of the Soxhlet extractor, followed by the addition of 250 mL of n-hexane to a clean and dried flat-bottomed flask under the Soxhlet extractor. The system was then heated, and the petroleum ether was refluxed through the sample with an average reflux rate of 5 drops per second for approximately 6 hours. The flask containing fat was then removed from the Soxhlet extractor and placed in a 70°C oven overnight to remove moisture and excessive solvent, followed by the cooling period in a desiccator prior to weighing. The total crude fat content was present as a percentage in the sample.

2.6. Determination of crude fiber content

The crude fiber content of the PF sample was determined using Weeden method (AOAC 978.10, 2000). 2 g of the dried sample was weighed into a conical flask containing 200 mL of 0.128 M sulfuric acid, and then incubated for 30 minutes, shaking periodically. Thereafter, the filtrate was collected and then washed to remove all acid residues with hot water. The filtrate was then boiled and washed again using 200 mL of 0.313 M sodium hydroxide in a separate conical flask. The filtrate was collected in a clean and dried crucible and the excessive water was evaporated on a hot plate. Once dried in the oven at 105°C for 2 hours and cooled down in a desiccator for 20 minutes, the crucible containing fiber was weighed and recorded as W1. The crucible set was then placed in a muffle furnace and heated at 500°C for 2 hours. Once removing the crucible from the furnace and cooling in the desiccator for 20 minutes, the crucible holding ash was reweighed and noted as W2. The crude fiber content was calculated from the equation:

$$\% \text{ crude fiber} = \frac{W1-W2}{2} \times 100\%$$

2.7. Determination of moisture content

The moisture content of the PF sample was determined using gravimetric method (AOAC 931.04, 2000). 1 g of PF sample was weighed and placed in a glass petri dish. The petri dish was then placed in a food dehydrator and dried at 105°C for 3 hours. Once removed from the oven, and allowed to cool down in a desiccator, the sample was weighed again. The moisture content was shown in percentage.

2.8. Determination of ash content

The ash content of the PF sample was determined using gravimetric method (AOAC 940.26, 2000), (Thiex et al., 2012). Crucibles were completely dried by the furnace at 100°C for 20 minutes and then weighed as W1. 20 g for each wet sample was then placed into those crucibles, weighing each of those to obtain W2. Crucible holding samples were placed into the muffle furnace (Model LEF-230P) at 500°C for 2 hours, followed by weighing for the values of W3. The ash percentage was calculated by:

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

2.9. Determination of vitamin contents

The vitamin contents of PF samples were analyzed primarily based on various AOAC methods. The liquid chromatography method was applied for the quantification of vitamins C and E. Vitamins A, E, D3, K1, C, and vitamins group B including B1, B2, B3, B6, and B12 were determined by the high-performance liquid chromatography method (HPLC) (AOAC 2001.13, 2011), (Delmonte et al., 2013; Hossain et al., 2019;

Mann et al., 2005; Vries et al., 1979). Vitamins B5 and B9 were evaluated by the ultra-performance liquid chromatography-tandem mass spectrometry method (Andrieux et al., 2013). The vitamin contents were expressed per 100 grams of sample.

2.10. Determination of mineral contents

The determination of mineral contents in PF samples was conducted as per standard test methods. Sodium (Na) and potassium (K) were determined by the flame photometric method (AOAC 969.23, 2005). Calcium (Ca), magnesium (Mg), zinc (Zn), copper (Cu), and iron (Fe) were quantified by the atomic absorption spectrophotometric method (AOAC 968.08, 2000). Sulfur (S), manganese (Mn), chromium (Cr), cobalt (Co), and nickel (Ni) were assessed by the inductively coupled plasma-mass spectrometry method (Nelson et al., 2019). The phosphorus (P) analysis was conducted by the spectrophotometric method. Chlorine (Cl) analysis was conducted by the Volhard method (Nordtest, 1996).

2.11. Determination of total phenolic content

The total phenolic content (TPC) was assessed based on levels of gallic acid and expressed as gallic acid equivalents (GAE) per gram of sample (mg GAE/g) by Folin–Ciocalteu method (Siddiqui et al., 2017). The prepared supernatant was used for TPC analysis. The assay was prepared by mixing 150 μL of diluted sample with 375 μL of Folin-Ciocalteu reagent and 375 μL of Na_2CO_3 7.5% solution. The mixture was vortexed for 5 minutes and incubated in the dark at room temperature for 30 minutes. The absorbance was spectrophotometrically measured against the blank at 765 nm.

2.12. Determination of total flavonoid content

The total flavonoid content (TFC) of the PF sample was determined using aluminum chloride method (Chang et al., 2020; Shraim et al., 2021). The prepared supernatant was used for TFC analysis. The assay was prepared by mixing 100 μL of diluted sample with 560 μL of distilled water, 300 μL of 80% methanol solution, 20 μL of 10% $AlCl_3$ solution, and 20 μL of 1M CH_3COOK solution. The mixture was vortexed for 5 minutes and incubated in the dark at room temperature for 30 minutes. Quercetin served as a standard for the calibration curve. The absorbance was measured against the blank at 430 nm using a spectrophotometer. TFC was expressed as quercetin equivalents (QE) per gram of sample (mg QE/g).

2.13. Determination of antioxidant activity

The 1,1-diphenyl-2- picrylhydrazyl (DPPH) was used as an indicator in the antioxidant activity assay (Baliyan et al., 2022). The prepared supernatant was used for the investigation of antioxidant activity. 750 μL of 0.1 mM DPPH solution was added to 250 μL of the diluted sample or standard. The tubes were shaken vigorously and then incubated in the dark at room temperature for 30 minutes. The absorbance was measured in a 96-well plate at 517 nm using a spectrophotometer. The antioxidant activity was calculated as IC_{50}, which was the concentration of the sample required to inhibit 50% of the DPPH free radicals.

2.14. Determination of anti-nutritional factors

2.14.1 Determination of total phytate content

The determination of the phytate content of the PF sample was performed using colorimetric method (Gao et al., 2007). 0.5 g of dried sample was treated with 10 mL of 2.4% hydrochloric acid in a Falcon tube, followed by the centrifugation at 1000 rpm at 10°C for 20 minutes. Thereafter, 0.5 g of sodium chloride was added to the mixture and then centrifuged again at 350 rpm for 20 minutes. The mixture was then incubated at 4°C for an hour, followed by centrifuging at 1000 rpm at 10°C for 20 minutes. The supernatant was obtained and diluted by distilled water with a ratio of 1:24 prior to analysis.

The standard was established by serially diluting a phytic acid solution as sodium salt hydrate. Prior to analysis, a mixture was prepared by mixing 3 mL of diluted sample, 1 mL of Wade solution consisting of 0.03% iron (III) chloride hexahydrate, and 0.3% sulfosalicylic acid in distilled water, followed by centrifuging at 1000 rpm at 10°C for 10 minutes. The absorbance of the mixture was spectrophotometrically measured at 500 nm (Latta & Eskin, 1980).

2.14.2 Determination of total oxalate content

The oxalate content of the PF sample was quantitatively evaluated by titration method (Karamad et al., 2019). 0.25 g of PF sample was weighed into a 250-mL Erlenmeyer flask containing 50 mL of distilled water, followed by adding 5 mL of concentrated sulfuric acid, and then incubated in a water bath at 80°C. Prior to the titration, 0.1N standard solution of oxalic acid was used to standardize 0.1N potassium permanganate. Once the filtration of the treated sample through the Whatman No.1 filter paper had been complete, the filtrate was titrated against 0.1N standardized $KMNO_4$ until the color changed to pale pink and must persist for at least 30 seconds.

2.14.3 Determination of total tannin content

The determination of total tannin content was conducted using colorimetric method (Siqueira et al., 2012). The prepared supernatant was used for total tannin analysis. A standard curve was calibrated using a serial dilution of 0.1 mg/mL tannic acid stock solution. 0.1 mL of PF sample was added to a test tube containing 500 μL of Folin-Ciocalteu reagent, followed by 1 mL of Na_2CO_3 35% solution, and filled up with distilled water to a final volume of 10 mL. The mixture was vortex for 5 minutes before incubated in the dark at room temperature for 30 minutes. The absorbance of the sample was spectrophotometrically measured against the blank at 725 nm. The total tannin content was expressed as tannic acid equivalent (TAE) per gram of sample (mg TAE/g).

2.15. Statistical analysis

All experiments were triplicated for each species of PF. The data were statistically analyzed by the Kruskal-Wallis test and Dunn's test with the threshold of statistical significance at $\rho < 0.05$ and expressed as the MEAN ± STDEV.

3. RESULTS AND DISCUSSION

3.1. Essential Nutrients

Table 1
The essential nutrient contents of three passion fruit species.

Sample	*Passiflora edulis* f. edulis	*Passiflora edulis* var. flavicarpa	*Passiflora ligularis*
Carbohydrate (g/100g)	13.44 ± 0.39^{a}	12.35 ± 0.49^{ab}	8.44 ± 0.31^{b}
Protein (g/100g)	1.08 ± 0.15^{a}	1.45 ± 0.21^{ab}	1.96 ± 0.10^{b}
Fat (g/100g)	0.26 ± 0.02^{a}	0.25 ± 0.04^{a}	0.11 ± 0.03^{a}
Crude fiber (g/100g)	0.29 ± 0.03^{a}	2.67 ± 0.16^{b}	1.14 ± 0.07^{ab}
Moisture (%)	80.09 ± 0.94^{a}	78.64 ± 1.98^{a}	84.94 ± 0.11^{a}
Ash (%)	3.82 ± 0.08^{ab}	3.60 ± 0.03^{a}	4.01 ± 0.06^{b}
Energy (kcal/100g)	60.38 ± 0.93^{a}	57.46 ± 1.76^{ab}	42.56 ± 1.44^{b}

^{a,b,ab} Different letters in the same row indicate significant differences ($\rho < 0.05$).

All three studied PF species generally had high values of carbohydrates, but low concentrations of total fat and protein (Table 1). PPF pulp was found to have the highest total carbohydrate content, followed by YPF and SGF, consistently corresponding to the energy content recorded in this study (60.38 ± 0.93, 57.46 ± 1.76 and 42.56 ± 1.44 kcal/100 g, respectively). PF is commonly known not to be rich in fat and protein content. Indeed, the protein content was documented at low concentrations ranging from 1.08 to 1.96 mg per 100 g while fat content was recorded from 0.11 to 0.26 mg per 100 g.

PF is known as a fruit that provides high fiber content which helps slow down food digestion, creates a feeling of fullness for a long time, and helps control weight. Besides, insoluble fiber helps enhance intestinal motility, prevents constipation, and reduces LDL cholesterol in the blood. It also slows down the absorption of sugar into the blood, effectively controlling blood sugar levels for overweight and diabetic people. In this research, YPF pulp was found to be the highest crude fiber content of 2.67 ± 0.16 mg/100 g, which is commonly accounted to provide approximately 7 to 10% of the recommended daily intake in men and women from 19 to 50 years old, respectively. There were generally no significant differences in moisture and ash content among the three tested PF species.

3.2. Vitamin and Mineral Contents

The three PF samples were generally rich in fat-soluble vitamins including A and K1, but not D3 and E as analysis revealed both these vitamins were lower detection limits (Table 2). Vitamin A helps enhance the immune system and promotes skin cell regeneration and collagen production. Besides, it plays a crucial role in reproductive health, especially regulating menstruation in women. Previous research figured out vitamin A may help reduce the risk of certain types of cancer, including lung cancer, breast cancer, and colon cancer (Paganini-Hill et al., 1987). In this study, SPF was found to have the highest value of vitamin A, followed by YPF and PPF.

Vitamin K1, on the other hand, plays a vital role in improving memory for the elderly and reducing insulin resistance for people with diabetes (Presse et al., 2013), (Yoshida et al., 2008). In this study, PPF pulp was recorded to consist of the highest content of vitamin K1 (50.280 ± 5.591 μg/kg), which was approximately thrice as much as that of YPF; however, there was no detection of vitamin K1 in SGF, indicating the significant differences in vitamin K1 values among the three studied PF species.

Except for vitamins B1 and B12, all other studied vitamins group B were quantitatively detected but at low concentrations. As expected, vitamin C was recorded to be the highest value among water-soluble vitamins. Vitamin C is best known as a strong antioxidant, helping to protect the body from free radicals and reducing the risk of some chronic diseases such as cancer or cardiovascular disease. According to Food and Nutrition Board U.S, 2013, the Recommended Dietary Allowance (RDA) amount of vitamin C is 90 mg per day, approximately equal to the daily consumption of 300 g of P. edulis or 500 g of *P. flavicarpa*.

As can be seen from Table 3, not all microminerals were detected as analysis revealed the void of Zn, Cu, and Co in all three PF species. Meanwhile, Ni was insignificantly detected in both PPF and SPF. All three PF species contained Fe, Mn, and I, but at moderate concentrations of Fe and low concentrations of both Mn and I. Iodine is best known as a key element in thyroid function and helps regulate the menstrual cycle (Kessler, 2004) with the recommended daily intake at 0.15 mg. In this study, all PF species provided high iodine content ranging from 0.24 to 0.29 mg per 100 g raw material, denoting a potential source of iodine in daily diet.

In contrast to microminerals, all studied macro-minerals, except for chlorine which was found in SPF only, were quantitatively detected in all three PF species. Remarkably, there were extremely high values of potassium in PPF and SPF which were approximately 10 times greater than that of YPF. The three PF species were generally not rich in calcium and magnesium compared to other common fruits such as blackberries (up to 44 mg of calcium per 100 g raw material).

Phosphorus and calcium function to build and maintain strong bone and tooth structures. In addition, it participates in muscle contraction and nerve transmission, helping the kidneys filter waste from the body (Foster et al., 2008). In this research, PPF pulp had the highest phosphorus content among the PF species, approximately thrice as much as that of YPF and twice greater than that of SGF.

Table 2
Vitamin contents in three passion fruit species.

Vitamin contents	*Passiflora edulis* f. edulis	*Passiflora edulis* var. flavicarpa	*Passiflora ligularis*
A (IU/100 g)	728 ± 14.422^{b}	935 ± 13.892^{c}	1272 ± 15.631^{a}
D3 (μg/kg)	-ND-	-ND-	-ND-
E (mg/100 g)	-ND-	-ND-	-ND-
K1 (μg/kg)	50.280 ± 5.591^{a}	17.040 ± 0.121^{b}	-ND-
B1 (mg/100 g)	-ND-	-ND-	-ND-
B2 (mg/100 g)	0.120 ± 0.023^{a}	0.130 ± 0.017^{a}	0.110 ± 0.017^{a}
B3 (mg/100 g)	1.510 ± 0.236^{a}	2.350 ± 0.101^{a}	1.310 ± 0.038^{a}
B5 (mg/100 g)	0.100 ± 0.006^{a}	0.110 ± 0.010^{a}	0.110 ± 0.006^{a}
B6 (mg/100 g)	0.058 ± 0.006^{a}	0.059 ± 0.006^{a}	0.110 ± 0.017^{a}
B9 (mg/100 g)	0.014 ± 0.004^{b}	0.620 ± 0.139^{a}	0.380 ± 0.065^{ab}
B12 (mg/100 g)	-ND-	-ND-	-ND-
C (mg/100 g)	29.160 ± 1.256^{ab}	17.850 ± 0.209^{b}	32.110 ± 1.830^{a}

^{a,b,c,ab} Different letters in the same row indicate significant differences ($\rho < 0.05$). ND stands for not detected.

Table 3
Mineral contents in three passion fruit species.

Mineral contents (mg/100 g)	*Passiflora edulis* f. edulis	*Passiflora edulis* var. flavicarpa	*Passiflora ligularis*
Sodium (Na)	4.270 ± 0.810^{ab}	3.650 ± 0.118^{b}	17.390 ± 0.036^{a}
Potassium (K)	386.000 ± 10.149^{a}	43.008 ± 3.512^{a}	447.00 ± 12.124^{a}
Calcium (Ca)	3.460 ± 0.275^{ab}	2.880 ± 0.411^{b}	4.610 ± 0.098^{a}
Magnesium	18.390 ± 1.505^{b}	20.600 ± 0.521^{ab}	22.310 ± 0.323^{a}
Sulfur (S)	18.390 ± 0.822^{a}	25.110 ± 0.035^{a}	17.770 ± 0.291^{a}
Phosphorus (P)	37.280 ± 0.541^{a}	12.360 ± 0.454^{b}	20.920 ± 0.830^{ab}
Zinc (Zn)	-ND-	-ND-	-ND-
Copper (Cu)	-ND-	-ND-	-ND-
Iron (Fe)	0.530 ± 0.044^{ab}	0.430 ± 0.070^{b}	1.330 ± 0.075^{a}
Manganese (Mn)	0.070 ± 0.002^{a}	0.060 ± 0.007^{a}	0.060 ± 0.003^{a}
Chloride (Cl)	-ND-	-ND-	0.110 ± 0.017
Iodine (I)	0.290 ± 0.017^{a}	0.280 ± 0.012^{a}	0.240 ± 0.021^{a}
Chromium (Cr)	-ND-	-ND-	0.030 ± 0.003
Cobalt (Co)	-ND-	-ND-	-ND-
Nickel (Ni)	0.050 ± 0.002^{b}	-ND-	0.080 ± 0.002^{a}

^{a,b,ab} Different letters in the same row indicate significant differences ($\rho < 0.05$). ND stands for not detected.

Table 4
Phytochemicals in three passion fruit species.

Sample	**TPC** (mg GAE/g)	**TFC** (mg QE/g)
Standard curve (R^2)	y = 0.0098x - 0.0105 R^2 = 0.9960	y = 0.0027x - 0.0125 R^2 = 0.9962
Passiflora edulis f. edulis	21.12 ± 0.34^{a}	22.66 ± 0.66^{a}
Passiflora edulis var. flavicarpa	22.66 ± 0.39^{a}	14.72 ± 1.06^{ab}
Passiflora ligularis	25.53 ± 0.08^{ab}	17.07 ± 0.77^{b}

^{a,b,ab} Different letters in the same row indicate significant differences ($\rho < 0.05$). ND stands for not detected.

3.3. Phytochemicals and DPPH free-radical scavenging activity

Polyphenols and flavonoids are known to be anti-inflammatory and antioxidant compounds, helping to reduce the risk of inflammation and chronic conditions such as cardiovascular disease. Using gallic acid and quercetin solutions to establish a standard curve for quantifying TPC and TFC, the results show that all three PF species had moderate amounts of TPC and TFC; however, significant differences in concentration were noted, typically PPF had the highest content of TFC (22.66 ± 0.66 mg QE/g) whereas SGF exerted the lowest value of TFC (17.07 ± 0.77 mg QE/g) (Table 4).

Table 5
Antioxidant activity in three passion fruit species.

Sample	**Linear regression equation**	**IC_{50} (μg/mL)**
Ascorbic acid	y = 1.6686x + 3.0511 (R^2 = 0.9953)	27.99 ± 0.71
Passiflora edulis f. edulis	y = 0.3561x + 2.7655 (R^2 = 0.9942)	132.55 ± 0.12
Passiflora edulis var. flavicarpa	y = 0.4618x + 0.0083 (R^2 = 0.9970)	112.35 ± 3.79
Passiflora ligularis	y = 0.4794x – 0.7236 (R^2 = 0.9956)	107.68 ± 2.38

The antioxidant activity of three PF species was expressed as the concentration of the sample required to inhibit 50% of the DPPH free radicals (IC_{50}). Being correlated with phenolic and flavonoid content as has been previously reported in the

scientific literature review, the antioxidant activity of all three studied PF species was apparently recorded as moderate ability compared to that of ascorbic acid (Table 5). However, there was a significant difference in antioxidant activity among the three PF species ($\rho < 0.05$). SGF pulp had the strongest antioxidant activity (IC50 = 107.68 ± 2.38 μg/mL) whereas PPF pulp exerted the weakest IC_{50} of 132.55 ± 0.12 μg/mL. Notably, the correlation between TPC and IC50 was negative whereas a positive correlation between the TFC and IC50 was noted, suggesting the flavonoids present in all three PF species would be of interest to future research.

3.4. Anti-nutritional factors

All three studied PF species generally possessed low values of antinutrients, including phytate, oxalate, and tannin (Table 6). However, there were significant differences in phytate and tannin among the three PF species. PPF had the highest value of phytate, approximately four times greater than that of SPF. On the other hand, SPF exerted the highest value of tannin, approximately three times greater than that of YPF.

Table 6
Anti-nutritional factors (mg/100g) in three passion fruit species.

Sample	Phytate	Oxalate	Tannin
Passiflora edulis f. edulis	1.150 ± 0.052^a	0.440 ± 0.015^a	0.053 ± 0.007^a
Passiflora edulis var. flavicarpa	0.920 ± 0.035^a	0.420 ± 0.030^a	0.026 ± 0.005^b
Passiflora ligularis	0.270 ± 0.059^b	0.250 ± 0.007^b	0.075 ± 0.008^c

^{a,b,c} Different letters in the same row indicate significant differences ($\rho < 0.05$).

Phytate is well-known as a digestive enzyme inhibitor and forms complexes with proteins, starches, and sugars, causing reduced digestion (Abu-Baker et al., 2014). However, previous research initially showed that phytate is an antioxidant, has anti-inflammatory properties, and helps prevent coronary artery disease and some types of cancer (Turner et al., 2002). As scientifically reviewed elsewhere, in general, 2 mg of phytate in foods may affect iron absorption by 18%, and approximately 82% of iron was not absorbed when consuming 250 mg of phytate (Hallberg et al., 1989).

The American Academy of Nutrition and Dietetics recommends limiting dietary intake of oxalates to under 50 mg per day in patients with kidney stones (Bernardino & Parmar, 2017). The oxalate values recorded in the three species of PF were very low and had no significant differences between P. edulis and P. flavicarpa ($\rho = 0.1797$) but the P. ligularis ($\rho = 0.0073$) as described in Table 6. Nevertheless, suffice it to say it is safe for people with kidney stones as all three PF species have low oxalate concentrations.

The daily intake of tannin is limited to 1 g per day in the US. However elsewhere in other countries, it is at 1.5 - 2.5 g per day. Daily intake of tannin below this range is safe for humans and causes no side effects but beyond this consumption may be responsible for low absorption of iron from the diet (Sharma et al., 2021). The tannin content found in all three PF species is relatively low, ranging from 0.026 ± 0.005 to 0.075 ± 0.008 mg/100 g, which is generally considered safe for human consumption.

4. CONCLUSION

All three studied PF species, namely *P. edulis*, *P. flavicarpa*, and *P. ligularis*, are scientifically proven to be potential sources of essential nutrients, partially meeting a high percentage of the recommended daily allowances. *P. edulis* had high contents of carbohydrates, fats, vitamin K1, and minerals (such as P, and I) whereas *P. flavicarpa* was a great source of carbohydrates and vitamins group B including B3, B6, and B9. P. ligularis was significantly rich in a variety of minerals (including Na, K, Ca, Mg, and Fe). All three studied PF species generally possessed moderate values of phenolics, flavonoids, and antioxidants and low concentrations of antinutrients in terms of phytate, tannin, and oxalate contents.

This investigation partially elucidates the nutritional variation and phytochemical diversity within this genus and informs dietary recommendations while their limitations such as sample size and analytical methods should be considered. In addition to essential nutrients, these findings scientifically provide data on phytochemicals, antioxidant activity, and antinutrients which would be beneficial to nutritionists/dietitians, food manufacturers as well as consumers. Future research should expand more studies on geographical scope, investigating nutrient bioavailability, assessing health benefits, developing novel food products, and considering types of material based on environmental factors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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ORCID

Le-Son Hoang 0000-0002-3385-6169
Nguyen-Kim-Thanh Le 0000-0003-4745-4600

AUTHOR CONTRIBUTIONS

Both the authors contributed equally to this research.

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