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Original Article

Phytochemical characterization, antioxidant capacity and pectin properties of *Passiflora edulis* fruits cultivated under dry subtropical conditions of the Absheron peninsula

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Abstract

The introduction of tropical fruit species into new agroecological zones may significantly influence their phytochemical composition and bioactive potential. The aim of this study was to evaluate the phytochemical profile, antioxidant activity, mineral composition, and physicochemical properties of pectin extracted from fruits of *Passiflora edulis* cultivated under the dry subtropical conditions of the Absheron Peninsula (Azerbaijan). Lipophilic bioactive compounds were quantified using HPLC. The fruit pericarp exhibited a high β-carotene content (23.56 ± 3.17 µg/g), moderate lycopene levels (1.60 ± 0.31 µg/g), and detectable amounts of vitamins A and E (1.46 ± 0.22 and 0.56 ± 0.05 µg/g, respectively). ICP-OES analysis revealed adequate levels of K, Mg, Fe, and Zn, confirming the fruit's nutritional relevance. Total phenolic (2.22 ± 0.03 mg GAE/g), flavonoid (1.41 ± 0.01 mg QE/g), and tannin contents were determined spectrophotometrically. Antioxidant capacity assessed via DPPH, ABTS, FRAP, CUPRAC, β-carotene-linoleic acid acid assays demonstrated considerable radical scavenging and reducing activity, particularly in methanolic extracts. Pectin isolated from fruit by-products showed an intrinsic viscosity of 0.38, molecular weight of 5247 g/mol, and Huggins constant of 0.14, indicating favorable polymer characteristics for potential pharmaceutical and hydrogel applications. The results demonstrate that *P. edulis* fruits cultivated under Absheron conditions retain significant bioactive and functional properties, highlighting their potential as nutraceutical ingredients and as a source of value-added biopolymers. This study contributes to understanding the metabolic adaptation of introduced tropical species and supports their industrial valorization in arid subtropical environments.

Keywords: Carotenoids, Antioxidant activity, Phenolic compounds, Pectin, Dry subtropical climate, Nutraceutical potential

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Introduction

Azerbaijan has a very rich environment in terms of climate and species diversity. Thus, the mild winter and long sunny and warm summer months increase the potential for the growth of some tropical fruits. Presently, the cultivation of new tropical and subtropical fruit plants in Azerbaijan is of urgent scientific and practical importance. At the same time, the study of the bioecological characteristics, productivity indicators and biochemical composition of tropical fruits is of great scientific importance in terms of their adaptation to local conditions (Abdel-Hamid et al., 2019; He et al., 2020).

In the last two centuries, some fruits have been used in medicine as a remedy for dry cough, severe thirst, and sore throat. In the last few years, the demand for new functional foods has increased, and probiotics are widely used all over the world and are considered one of the main functional food products (Dos Reis et al., 2018; Abdel-Hamid et al., 2019). In general, scientists have recently paid great attention to the study of the correspondence between the systematic state of the plant and its chemical composition (Kandandapani et al., 2015; Abdel Aziz et al., 2021).

Currently, tropical fruits occupy a special place in the global agricultural sector, accounting for 62% of the world's fresh fruit supply (FAO, 2022; Badalova et al., 2023). Global production of *P. edulis*, a tropical fruit, was estimated at 1.5 million tons in 2017 (FAO, 2018). In general, Brazil is the largest producer of *P. edulis* in the world, with production reaching 690.4 thousand tons in 2020. *P. edulis* is a sour fruit that is eaten raw with its cellulose seeds inside. In Brazil, one of the main producers and consumers of the fruit, this fruit is widely used not only for raw consumption, but also for the preparation of concentrates and juices (Da Silva et al., 2021).

The genus *Passiflora* L. is a broad-spectrum plant family with approximately 520 species distributed in the tropical regions of America, Asia and Africa (Ulmer and MacDougal, 2004). According to general rules, when searching for new medicinal plants, plant species that are botanically related according to the phylogenetic method have similar chemical composition and show the same pharmacological effect. In this regard, in our article, the composition of the fruits of only one species (*P. edulis* L.) was studied *in vitro*. According to scientific studies, *P. edulis* is rich in bioactive compounds such as flavonoids, phenolic compounds and carotenoids (Santos et al., 2016; Duarte et al., 2021). These compounds in the fruit are associated with potential health benefits in the prevention of chronic non-communicable diseases such as cancer and cardiovascular diseases (Badalova et al., 2021b; Ignat et al., 2011; Zucolotto et al., 2012). These bioactive compounds, including luteolin, chlorogenic acid, beta carotene, lycopene and neochlorogenic acid, are mainly found in the peel (excreta) of *P. edulis* (Thawabteh et al., 2019). All of them are known for their potential health benefits. Polyphenols obtained from P.edulis are also rich in α and β-tocopherol, and the oils obtained from these compounds have been reported to have high antioxidant activity (Ignat et al., 2011; De Santana et al., 2015). *P. edulis* has gained global popularity due to its rich nutritional content and flavonoids (Duarte et al., 2021; Viera et al., 2022). The fruits also have strong antioxidant properties. Antioxidants are important compounds that can deactivate reactive oxygen species (ROS) by donating electrons to them, protecting important molecules such as proteins, lipids, and DNA from damage due to oxidative stress (Xiao et al., 2016). In addition, lycopene, which belongs to the carotenoids in the plant, has strong antioxidant properties and is one of the main components that increase the biological value of P. edulis . Its amount is closely related to the geography of the area where the fruit is grown, the degree of ripening, and storage conditions.

In general, the lands of Azerbaijan have a rich flora, and a significant part of the plants distributed here are of rich medicinal value (Alakbarli, 2006). The climate and soil diversity existing in the republic create conditions for the formation of medicinal and food plants (Kandandapani et al., 2015; Huang et al., 2019). Biologically active food supplements, the elimination of deficiencies in the body of components included in the class of essential nutritional compounds (vitamins, minerals), the study of new medicinal and nutritional plants with rich composition in terms of supporting specific physical functions or ensuring the normal functioning of the body, and their cultivation in our country are currently relevant topics. In this regard, for several years, extensive research has been conducted on the introduction of *P. incarnata* L., *P. caerulea* L., *P. edulis* L., *P. ligularis* L. species belonging to the genus *Passiflora* L., native to America, to the Absheron Peninsula, their cultivation under various conditions, and the phytochemical study of the aboveground parts of the plant and ripe fruits. Additionally, methanolic extracts of *P. edulis* fruits

demonstrated broad antioxidant activity (DPPH, ABTS, FRAP, CUPRAC) as well as potential anticancer properties, emphasizing the bioactive potential of the fruit (Badalova et al., 2021a).
Currently, the cultivation of new tropical and subtropical fruit plants in Azerbaijan is of urgent scientific and practical importance. At the same time, the study of the bioecological characteristics, productivity indicators and biochemical composition of tropical fruits is of great scientific importance in terms of their adaptation to local conditions (Afzal et al., 2022; He et al., 2020). Since *P. edulis* is new to Azerbaijan, the study of the introduction, acclimatization and bioecological characteristics of some promising species of the genus *Passiflora* L. in the dry subtropical climate of Absheron, assessment of their prospects, phytochemical study of the studied species, microbiological analysis, detection of macro- and microelements and some biologically active substances in their composition, use in medicine, food industry and other areas of industry are among the priority issues we have set. The aim of the research was to analyze the phytochemical composition of the fruits of the newly introduced *P. edulis* species, study the antioxidant and pectin content, and based on these results, determine whether the chemical composition of the fruit meets international standards, as well as its suitability for industry.

Material and Methods

Study area and material

Absheron is characterized by a dry subtropical climate. The average annual temperature at the study area is about +12-15˚C. The absolute minimum temperature in winter is +2-4˚C, while the maximum in summer reaches +36–38 °C. The transition of the average daily temperature above 4 °C occurs during the first and second ten-days of March. A period with stable average daily air temperatures below 0˚ C is extremely rare. Precipitation amount up to 560mm. These research works on introduced species were carried out at the experimental site of the Institute of Dendrology of the Republic of Azerbaijan. The Institute of Dendrology is located in the northeastern part of the Absheron Peninsula, in the village of Mardakan. The area of the institute is 12.5 hectares and is located at an altitude of 0-50m above sea level. Places near the sea are 80-85% limestone, sandy soil. In elevated areas far from the sea, the soil consists of a mixture of medium sand and heavy clay, and its thickness ranges from 0.5 to 1.5 m. (Aliyeva et al., 2025; Mammadov et al., 2010).

Figure-1. Study area- Absheron peninsula, Azerbaijan.

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The research object comprised *P. edulis* L. (*Passifloraceae*) fruits, introduced to the Absheron Peninsula starting from 2018.

Phytochemical analyses

Phytochemical analyses were performed in modern laboratories at Muğla Sıtkı Koçman University, Turkey, and the Department of Pharmaceutical Chemistry, Azerbaijan Medical University. Both classical methods and modern computational techniques were applied, incorporating contemporary European and American methodologies. The research used both classical and modern methods of European and American scientists, utilizing advanced computer technologies (Marco, 1968; AOAC, 2000, 2005). During phytochemical analyses, secondary metabolites (antioxidant activity, total amount of flavonoids, phenols and tannin) were determined using DPPH, ABTS, ß-carotene, CUPRAC, FRAB, etc. Methods (Singleton and Rossi, 1965; Pellegrini et al., 1999). All chromatographic analyses were performed using a Cecil 1100 series High-Performance Liquid Chromatography (HPLC) system, equipped with a Cotati 7125 manual injector, Cecil 68174 UV detector, and HP 3395 integrator. Chemicals used in laboratory analyses were obtained from Merck. Separation was performed on a C18 column under a flow rate of 1.0 ml/min and monitored via UV detection. For analysis, passion fruits were washed, dried, and homogenized under pressure. Approximately 1.0 g of the homogenized sample was placed into a polyethylene bag, and 5.0 mL of ethanol was added and vortexed. The mixture was then centrifuged for 5 minutes. After centrifugation, 1.0 mL of n-hexane was added to the supernatant and mixed to extract β-carotene, vitamins A and E, and lycopene into the n-hexane phase. The n-hexane extracts, obtained in two replicates, were evaporated under a nitrogen stream to dryness. The remaining residue was dissolved in 200 mL of methanol and prepared for HPLC analysis. During the determination of β-carotene, vitamins A, E and lycopene, a Supercosil LC-18 column and a mobile phase consisting of a methanol-water mixture were used. The flow rate of the mobile phase was adjusted to 1.0 ml/min and kept constant throughout the analysis, which ensured uniform distribution of the mobile phase and led to accurate separation and determination of the analyzed components. Detection was performed based on the maximum absorbance wavelengths: β-carotene at 495 nm, vitamin A at 326 nm, vitamin E at 296 nm, and lycopene at 472 nm (Miller et al., 1984).

Chromatographic analyses

All chromatographic analyses were conducted using the YEMX-HPLC method, employing a high-pressure pump system to maintain a constant flow rate through the column. This system, known for its high resolution and reproducibility, is widely used for the qualitative and quantitative determination of low-molecular-weight organic compounds, including phytochemical components such as phenolics, flavonoids, and carotenoids.

Determination of microelements

The mineral composition of *Passiflora* fruits was determined using ICP-OES (Inductively Coupled Plasma–Optical Emission Spectrometer). Total nitrogen content was determined by sample digestion using wet combustion, followed by analysis with a Kjeldahl apparatus. Other macro- and microelements were determined by wet digestion in a microwave system, followed by reading on the ICP-OES instrument.

In this study, both fruit residues and purified pectin from passion fruit were used. For extraction, 450 g of dried, chopped raw material (3–5 mm pieces) was treated with 70% ethanol to remove low-molecular-weight components and pigments. The residue was then extracted with 1% citric acid. Pectin was precipitated from the extract using 96% ethanol and further purified by gel-filtration chromatography on Sephadex G-75 (100 g). To maximize pectin purification, the sample was dissolved in water at 60 °C, loaded onto a Sephadex G-75 column, and eluted with water. Fractions were collected, and pectin presence was confirmed by precipitation with 96% ethanol. The pectin-containing fractions were combined and concentrated under vacuum at 75–80 °C until 1/5 of the original volume remained. The concentrated solution was precipitated again with 96% ethanol, spread as a thin layer on a glass plate, dried in a thermostat at 45–50 °C, and then powdered. The intrinsic viscosity and molecular weight of pectin were measured using an Ostwald capillary viscometer (viscometric method). Solutions of different concentrations were prepared, and relative, specific, and reduced viscosities were calculated from flow times. Intrinsic viscosity was determined from the extrapolation of reduced viscosity versus concentration to zero concentration.

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Data analysis

The amount of lycopene in *P. edulis* was calculated using the following formula:

$$\textbf{Lycopene (mg/kg)} = \frac{A \times V \times 10}{\varepsilon \times l \times m}$$

Where: A – absorbance, V – volume of extract (ml), m – sample weight (g), ε- specific absorption coefficient of lycopene, l – optical path of the flask.
Lycopene is highly soluble in organic solvents such as hexane, acetone, and 96% ethanol. In this study, lycopene was extracted from passion fruit using a solvent mixture of hexane:acetone:ethanol (2:1:1). The amount of lycopene in *P.edulis* was determined spectrophotometrically at a wavelength of 503 nm after extraction with organic solvents. The amount of lycopene was calculated based on its specific absorption coefficient.
During the experiments, the Mark-Hauvink-Kun equation was used to calculate the molar mass of pectin (Mark, 1938).

$$[\eta] = K \cdot M\alpha$$

At the same time, the viscosity constant was calculated. The Huggins constant was found to be the tangent of the bending angle of the straight line obtained from the dependence:

$$C{:}tg\alpha = \eta_{az} - (C/tg\alpha) = Kx/\eta^2$$

As a result of the analysis, the molar mass of purified pectin and the Huggins constant were determined (Houwink, 1940).

Statistical analysis

A one-dimensional ANOVA test was used for the variation analysis of the obtained results. The Minitab notation was used to calculate the significant difference between the mean values of the variations and was rated at $p<0.05$ according to the Tukey Test for Pairwise Mean Comparisons. The results obtained are shown as the mean value ± standard deviation (mean ± SD). All analyses were performed in triplicate (n = 3).

Results

P. edulis peel is considered a significant source of β-carotene and other carotenoids, and the level of carotenoids in the peel is higher than in the fruit pulp. General descriptions of the fruit peel containing both β-carotene and lutein and other carotenoids have been reported in some literature (Britton, 2020). *P. edulis* is a fruit with a moderate vitamin E (*tocopherol*) content, which, together with β-carotene, exhibits antioxidant synergism (Table 1). The peel's higher lipid fraction and the protective role of its antioxidants result in considerably greater bioactive compound levels compared to the pulp.

Table-1. Content of vitamins A, E, β-carotene and lycopene in the peel (pericarp) of *Passiflora edulis* grown in Absheron conditions.

Fruit Part	Vitamin A (µg/g)	Vitamin E (µg/g, FW)	β-Carotene (µg/g, FW)	Lycopene (µg/g, FW)
Passion fruit (peel/pericarp)	1.46 ± 0.22	0.56 ± 0.05	23.56 ± 3.17	1.60 ± 0.31

Note: Values are presented as mean ± standard deviation (SD) from three independent replicates (n = 3), FW- fresh weight.

During the analysis of the components of passion fruit *(P. edulis* L.), the contents of macro- and microelements as well as total nitrogen were determined, with results recorded using a Kjeldahl apparatus. In general, mineral substances in plants are classified into two groups: a) macroelements (K, Na, Ca, Mg, Mn, Cl, P, Si), which are present in amounts of at least 0.01% (on an ash basis), and b) microelements (I, Ba, Cu, Co, Fe, Zn), which are present at levels below 0.001% (on an ash basis). Analysis of the mineral composition of the fruits revealed that magnesium (Mg), iron (Fe), potassium (K), zinc (Zn), manganese (Mn), and total nitrogen (N) in *P. edulis* L. fruits were within the normal range, whereas the levels of other macro- and microelements were slightly below the reference values (Table 2).

Reference ranges were compiled based on published literature data and are provided for comparative purposes only, differences may reflect differences in genotype, growing conditions, environmental factors, and nutrient absorption efficiency. The observed variations in mineral concentrations may reflect differences in nutrient availability, plant uptake efficiency, genotype-specific characteristics, and local environmental conditions. Previous studies have shown that mineral accumulation in passion fruit depends not only on soil nutrient status but also on climatic factors, plant physiology, and cultivation methods. Therefore, the observed mineral profile in fruits grown in Absheron conditions likely results from the combined effects of environmental adaptation and nutrient acquisition processes. (Türemiş and Sayğı, 2016; Rodrigues et al., 2020; Israel et al, 2024).

Table-2. Mineral composition of *Passiflora edulis* fruits grown in Absheron conditions (average values, n = 3).

Element	Method	Normal Range	Results	Comparative assessment
Total Nitrogen (N) %	Kjeldahl	0.25 – 0.70	0.25	Within range
Phosphorus (P) %	ICP-OES	3.30 – 4.80	0.51	Below reference range
Potassium (K) %	ICP-OES	3.30 – 5.00	3.53	Within range
Calcium (Ca) %	ICP-OES	0.60 – 1.50	0.28	Below reference range
Magnesium (Mg) %	ICP-OES	0.20 – 0.70	0.20	Within range
Iron (Fe) ppm	ICP-OES	60.00 – 200.00	115.93	Within range
Copper (Cu) ppm	ICP-OES	8.00 – 50.00	6.09	Below reference range
Manganese (Mn) ppm	ICP-OES	35.00 – 200.00	35.83	Within range
Zinc (Zn) ppm	ICP-OES	20.00 – 200.00	20.88	Within range
Boron (B) ppm	ICP-OES	25.00 – 75.00	15.17	Below reference range

In the present study, the composition of passion fruit (maracuya) was simultaneously analyzed starch, sugars, extractives, nitrate compounds, and dry matter content (Table 3). The analysis revealed that passion fruit contained a relatively high amount of nitrate compounds (29.13 mg/kg) and dry matter (21.35%).

Table-3. Physicochemical characteristics of *Passiflora edulis* fruits grown in Absheron conditions *(average values, n = 3).*

Parameter	Unit	Method Applied	Result
Starch	%	Determined by specific gravity	1.30
Sugar	%	Refractometer	10.27
Extractive substances	%	Refractometric–Polarimetric method	10.45
Nitrate	mg/kg	Nitrate meter	29.13
Dry matter	%	Dried in thermostat at 105 °C	21.35
Average fruit weight (g)	g	–	43.05
Calorific value	kcal	–	105.3

Note: Values represent the mean of three independent determinations (n= 3).

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The physicochemical characteristics of *P. edulis* fruits indicate satisfactory fruit quality under the dry subtropical conditions of the Absheron Peninsula. The observed sugar and dry matter contents are consistent with fruit ripening and contribute to flavor, nutritional value, and processing suitability. These characteristics, together with the moderate starch and nitrate contents, suggest that the introduced plants successfully completed fruit development under local environmental conditions.

Using a viscometric method, the study demonstrated that passion fruit is rich in pectins. The average molecular weight of the isolated pectins was calculated using established formulas, and the results were recorded (Table 4). Considering the molecular weight of pectin and its monomer, galacturonic acid (176 g/mol), the average degree of polymerization of the purified pectin was determined. Taking into account the inverse relationship between the hepatoprotective activity of pectin and its molecular weight, the purified pectin can be expected to exhibit a more pronounced hepatoprotective effect. As a result, water is considered a more favorable solvent for purified pectin. Based on all of the above, it can be concluded that purified pectin creates a solid basis for the preparation of targeted preparations.

Table-4. Molecular weight analysis of purified pectin from passion fruit (average values, n 3).

Purified Pectin	[η] Intrinsic Viscosity	M Molecular Weight, g/mol	Kx Huggins Constant
Passion fruit	0.38	5247	0.14

The purified pectin mass was obtained from the waste of *P.edulis* grown in Absheron. As a result of the analysis, the molecular weight and viscosity constant were calculated. As a result of the study, the viscosity constant of the purified pectin was 0.38, the molar mass was 5247 g/mol, and the Haggins constant was 0.14 (Table 4). Based on the experiments we conducted, we can conclude that *P.edulis* is a unique tool for the development of pectin-based preparations. The molecular weight of purified pectin obtained from *P.edulis* (5247 g/mol) was lower than values typically reported for commercial citrus and apple pectins, which typically range from 30,000 to 100,000 g/mol. Lower molecular weight pectins are often characterized by improved aqueous solubility and increased bioavailability, which may be beneficial for pharmaceuticals and controlled-release systems. However, such pectins may have lower gelling capacity compared to high-molecular-weight commercial pectins. Therefore, pectin isolated from *P.edulis* may be considered a promising raw material for specific pharmaceutical and functional applications, although further physicochemical and technological studies are needed to fully evaluate its industrial potential (Rubio-Martin del Campo et al., 2025).

Literature data indicate that passion fruit is rich in the same flavonoids and phenolic compounds. To quantify them, the total phenol content was determined according to the method developed by Singleton and Rossi (Singleton and Rossi, 1965; Guseinov et al., 2019). This method was developed to determine the total phenol content of antioxidants, and at the same time, it shows the total flavonoid content of the extracts.

The results obtained from the analysis of the total secondary metabolites of *Passiflora* ethanol extracts during the study are given in Tables 5 and 6.

Table-5. Total content of phenolic compounds, flavonoids and tannins in ethanol extracts obtained from the peel of *Passiflora edulis* grown under Absheron conditions (*mean ± standard deviation, n = 3*).

Plant species and raw material	Total Phenol Content (mg GAE/g)	Total Flavonoid Content (mg QE/g)	Total Tannin Content (mg CE/g)
P. edulis **(fruit)**	2.22 ± 0.03	1.41 ± 0.01	0.45 ± 0.02

Table-6. Antioxidant activity of ethanol extracts obtained from *Passiflora edulis* peel compared with the synthetic antioxidant BHA (mean ± standard deviation, n = 3).

Plant species and raw material	DPPH (IC_{50}, mg/mL)	ABTS (IC_{50}, mg/mL)	β-carotene/ linoleic acid (%)	FRAP (mg/mL)	CUPRAC (mg/mL)
Passion fruit (*P. edulis* L.)	2.35 ± 0.06	0.56 ± 0.01	77.06 ± 1.36	0.62 ± 0.06	9.67 ± 0.20
BHA	0.008 ± 0.0002	0.0083 ± 0.004	88.19 ± 0.84	1.64 ± 0.03	4.54 ± 0.48

Note: BHA-butylated hydroxyanisole (positive antioxidant control), DPPH- 2,2-diphenyl-1-picrylhydrazyl; ABTS-2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); FRAP-ferric reductive antioxidant power; CUPRAC- cupric ion reducing antioxidant capacity.

DPPH was 2.35±0.06 mg/mL, ABTS was 0.56±0.01 mg/mL, FRAP was 0.62±0.06 mg/mL, and ß-carotene - linoleic acid was 77.06 ±1.36 % in the ethanol extracts of *P.edulis*. During phytochemical analyses, the results of the CUPRAC (copper II ion reduction effect) analysis of the extracts varied between 9.67±0.20 mgTE/g. $CuSO_4$ (copper II sulfate), used in the analysis, forms a complex with protein or antioxidant in an alkaline medium. When folin phenol reagent is added, folin reagent combines with protein. Cu (II) ion, which is removed from the reaction with protein or antioxidant, reduces the molybdate/tungstate reagent to heteropoly blue and changes its color from yellow to blue. When the reaction is complete, the sample absorbance is measured at 750 nm. This method is based on the formation of a colored complex with Folin's reagent in an alkaline medium of phenolic compounds soluble in water and other organic solvents, and measures the strength of the sample. Researchers have determined that extracts of passiflora species contain about 20 flavonoid-containing compounds, of which 9 flavonoid compounds are isovitexin, vitexin, rutoside, hyperoside, luteolin, kaempferol, kaempferitrin, orientin and isoorientin (Guseinov et al., 2019; Polyakov and Kispert, 2025).

During the experiments, the antioxidant activity of methanol extracts of *P.edulis* was also studied, and the results obtained (Badalova et al., 2023) were recorded (Table 7).

Table-7. Antioxidant activity of methanol extracts obtained from the peel of Passiflora edulis grown under Absheron conditions compared to the positive control BHA (*mean ± standard deviation, n = 3*).

Sample	DPPH (IC_{50}, mg/mL)	ABTS (IC_{50}, mg/mL)	β-Carotene / linoleic acid (%)	FRAP (mg/mL)	CUPRAC (mg/mL)
***P. edulis* L.**	31.25 ± 0.17	17.77 ± 0.84	87.39 ± 0.31	1.61 ± 0.12	2.22 ± 0.03
BHA	96.61 ± 0.63	83.98 ± 1.50	91.14 ± 0.23	ND	ND

Note: FRAP and CUPRAC values for BHA were not determined (ND); BHA-butylated hydroxyanisole (positive antioxidant control), DPPH- 2,2-diphenyl-1-picrylhydrazyl; ABTS-2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); FRAP-ferric reductive antioxidant power; CUPRAC-cupric ion reducing antioxidant capacity.

According to the results of laboratory analysis, methanol extracts of *P.edulis* fruits showed high biological activity in all antioxidant activity experiments. (DPPH, 31.25±0.17 IC_{50}, mg/mL , ABTS, 17.77±0.84 IC_{50}, mg/mL, β-carotene, 87.39±0.31%, FRAP, 1.61±0.12, mg/mL, CUPRAC, 2.22±0.03 mg/mL). The results obtained during our study show that passionflower extracts are not only sedative but also have high antioxidant activity (Badalova et al., 2021a).

Much literature reports that the antioxidant properties of *Passiflora* species are due to the flavonoids they contain (Masteikova et al., 2008; Rudnicki et al., 2007; Silva et al., 2019).

The results of our in vitro analyses proved that the extracts of *P.edulis* are rich in bioactive compounds that are important from a medical point of view and the plant has been used in the treatment of various diseases since ancient times. The positive results obtained from the phytochemical analyses of *P. edulis* of the *P. edulis* species will make great contributions to the country's healthcare and the development of the pharmaceutical industry in the future. The introduction of valuable medicinal and food plants to Absheron will eliminate our country's dependence on foreign countries in terms of the supply of medicinal raw materials in the future.

The aim of the study was to obtain the mass of pectin from the waste of the *P. edulis* L. species introduced to Absheron, to study its molecular mass, molecular composition and viscosity constant. At the same time, one of the priority issues is to determine the amount of flavonoids, total phenolic substances and tannins in the extracts obtained from the studied raw materials (*P. edulis*), and to determine their antioxidant activity. The advantage of the conducted study is that the unique fruit called *P. edulis* is not known in our country to this day and there are no sources of scientific literature.

Masteikova et al. (2008) compared the antioxidant activities of aqueous and 70% ethanolic *P. incarnata* L. leaf extracts and reported that ethanolic extracts were more effective free radical scavengers than aqueous extracts.

The results of our studies differed from the analysis results of other researchers. Thus, Tandoro Yohanes in his studies, the total phenol content of passiflora leaf extracts was 22.92±0.18 mg GAE/g, the total flavonoid content was 7.01±0.10mg QE/g, the DPPH scavenging activity was 2.77±0.02 IC_{50}, mg/mL and the iron reducing power (FRAB) was 3.20±0.04 mg/mL, while the total phenol content of fruit extracts was 6.53±1.02 mg GAE/g, the total flavonoids were 1.56±0.27 mg QE/g, the DPPH free radical scavenging activity was 1.00±0.15 IC_{50}, mg/mL, and the iron reducing power was 1.12±0.17 mg/mL (Yohanes, 2020).

Discussion

The presented research shows that *P. edulis* pulp contains bioactive compounds, such as flavonoids, phenolic compounds, and carotenoids, which can be used for potential health benefits in the prevention of cancer and heart disease, as well as other chronic noncommunicable (NCDs) diseases. One of the carotenoids in the fruit is β-carotene (Paiva and Russell, 1999; Dos Reis et al., 2018; Badalova et al., 2021a,b; Alves et al., 2022). The relatively high concentration of β-carotene observed in fruits grown in Absheron may represent an adaptive response to increased solar radiation and summer heat stress. Carotenoids function as photoprotective pigments, capable of neutralizing reactive oxygen species (ROS) generated during environmental stress. Their accumulation helps protect cellular structures from oxidative damage and may increase plant resistance to adverse environmental conditions. Similar responses have been observed in plants exposed to high radiation and drought, where carotenoid biosynthesis plays a key role in antioxidant defense mechanisms (Badalova et al., 2021a; Panorjit et al., 2025; Siripat et al., 2026). The addition of oxygen to the intermediates of the β-carotene radical is thought to be the chain termination mechanism. The carotenoid β-carotene and other carotenoids are thought to have disease-preventing properties by scavenging reactive free radicals (Shi and Le Maguer, 2010). Studies on lycopene have reported that lycopene is beneficial in cardiovascular diseases, bone, skin, and eye diseases (Pereira et al., 2024; Silva et al., 2019; Zeraik et al., 2016; Birben et al., 2012).

Dry subtropical conditions are typically associated with increased oxidative stress in plants due to high solar radiation, elevated temperatures, and periodic water stress. Under such conditions, plants often activate antioxidant defense systems and increase the biosynthesis of secondary metabolites, including phenolic compounds, flavonoids, and carotenoids. These compounds promote the detoxification of reactive oxygen species (ROS), protect cellular components from oxidative damage, and support plant adaptation to environmental stressors (Fu et al., 2025; Sood, 2025). Therefore, the accumulation of antioxidant metabolites observed in *P. edulis* fruits grown in Absheron may partially reflect physiological adaptation to local climatic factors.

Studies on lycopene have confirmed that lycopene has an effect on cardiovascular diseases, bone, skin and eye health (Birben et al., 2012; Silva et al., 2013; Yohanes, 2020; Vuolo et al., 2020) and prevents many types of cancer (Houwink, 1940; De Santana et al., 2015; He et al., 2020).

Mineral nutrients play a crucial role in plant metabolism, enzyme activation, antioxidant protection, and fruit quality. The adequate levels of K, Mg, Fe, Zn, and Mn found in this study indicate that *P. edulis* has successfully adapted to the arid subtropical conditions of Absheron and maintained a

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balanced mineral nutrition. The observed variations in some elements may be related to differences in nutrient uptake, nutrient transport efficiency, and environmental conditions, rather than to any single limiting factor. Similar variability in mineral composition was observed in passion fruit grown under different environmental conditions (Habibi et al., 2025; Khamis et al., 2025).

The *P. edulis* fruits we studied are a very rich source of biologically active substances, including polysaccharides (Stahl and Sies, 2012; Laxa et al., 2019 Britton, 2020). It is known that plant polysaccharides - pectins are used both as biologically active substances in the treatment of various diseases and as a carrier material in the preparation of new drug forms that can meet modern requirements. The preparation of targeted hydrogel therapeutic systems of pectins depends largely on their purity, molecular mass and other physicochemical properties. Its purity and degree of esterification play an important role as a decisive factor in the preparation of drug forms, especially therapeutic gels. Considering the therapeutic and carrier properties of pectins at the same time, the preparation of drug forms with prolonged effect and high therapeutic effect is one of the current problems. The relatively low molecular weight observed in this study suggests potential suitability for pharmaceutical and biomedical applications where high solubility and controlled release properties are desirable (Getu et al., 2024; Panorjit et al., 2025).

According to the research results, passion fruit waste contains bioactive compounds such as flavonoids, phenolic compounds and carotenoids, which are associated with potential health benefits in the prevention of cancer and heart disease, as well as other chronic non-communicable diseases.

The relatively high antioxidant activity observed in *P. edulis* extracts may be due to the presence of phenolic compounds, flavonoids, and carotenoids. Previous studies have shown that these classes of metabolites significantly contribute to free radical scavenging and reducing capacity, suggesting that the antioxidant capacity measured in this study likely results from their combined effects. Interestingly, the ethanol extract showed a higher CUPRAC value than the reference BHA extract. This observation suggests that the extract's restorative capacity may be the result of the synergistic action of several natural antioxidants, rather than a single active compound (Getu et al., 2024; Panorjit et al., 2025; Lisjak et al., 2026; Di Salvo et al., 2026).

The methanol extract also demonstrated significant antioxidant activity, although its free radical scavenging ability was lower than that of the synthetic antioxidant BHA. However, the substantial inhibition observed in the β-carotene decolorization test indicates effective protection against lipid peroxidation, confirming the presence of bioactive antioxidant components in the peel extract (Khamis et al., 2025; Habibi et al., 2025; Lisjak et al., 2026).

Polyphenols, abundant in *P. edulis*, have been widely studied for their pharmacological properties, including strong antioxidant effects and the ability to prevent important diseases (Thawabteh et al., 2019; Pratima, 2019; Birben et al., 2012; De Oliveira Militão et al., 2025). The results obtained emphasize the need for further investigation of the antioxidant and other bioactive potential of *P. edulis*, especially at different stages of ripening.

The analysis of the literature data and the comparison of the results of various studies show that the fruits of *P. edulis* are considered an important bioactive raw material in relation to carotenoids. Lycopene and β-carotene are among the main carotenoid components in both the pulp and the peel of the fruit.

A limitation of this study is that the fruits were collected from a single introduction site, located on the Absheron Peninsula. However, *Passiflora edulis* is a recently introduced species in Azerbaijan and is not yet cultivated in other regions of the country. Therefore, this work represents the first assessment of its phytochemical and functional characteristics under local dry subtropical conditions. Future research, including cultivation trials in different ecological regions and comparisons with fruits grown in natural production areas, will provide a broader understanding of the environmental influence on fruit quality and the accumulation of bioactive compounds.

Conclusion

The soil and climatic conditions of the Absheron Peninsula had a positive impact on the accumulation of biologically active substances in *Passiflora edulis* fruits. Phytochemical parameters, mineral composition, pectin characteristics, and antioxidant activity confirmed the successful adaptation and bioecological compatibility of this species to the dry subtropical conditions of the region. The introduction of *P. edulis* to Absheron can be considered promising

from bioecological, biochemical, and economic perspectives.
Our results contribute to our understanding of the mechanisms by which subtropical fruit species adapt to new environmental conditions and provide valuable information on their phytochemical composition and functional properties. The relatively high content of phenolic compounds, carotenoids, and pectin indicates that the fruits and their byproducts may represent a promising source of biologically active substances for future use in functional foods and nutraceuticals.
However, further studies involving different ecological regions, detailed technological characterization, toxicological evaluation and pilot testing are needed to fully evaluate commercial use and large-scale industrial application.

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Contribution of Authors
Badalova V: Execution of research, statistical analysis, analysis and discussion of the results and manuscript writing.
Mammadova Z: Conceived idea and designed the experiment.
Aliyeva G: Analysis and discussion of the results, manuscript preparation and translation.
Hasanova M: Analyzed data and discussion of the results
Mustafayeva L Analyzed data and manuscript editing.
Maharramov S: Scientific discussion and critical revision of the manuscript
Bagirova S: Contributed to data interpretation, scientific discussion and critical revision of the manuscript.
Karimova T, Guliyeva S, Mammadova G & Qafarova M: Analysis and discussion of the results, financial support
Mammadova V: Methodological recommendations and laboratory analysis.
Alakbarov R: Contributed to data interpretation,
Gulmammadova S: Interpretation and discussion of the results.
Mammadova I & Mirjalalli I: Feeding experiments, collected data and assisted in laboratory analysis.
Ahmadova V & Alibayli K: Collection and processing of materials.

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