

Nutritional composition and functional potential of aktala'huat (*Parathesis psychotrioides*), a wild fruit traditionally consumed by Totonac communities in Mexico

Composición nutricional y potencial funcional de aktala'huat (*Parathesis psychotrioides*), un fruto silvestre consumido tradicionalmente por comunidades Totonacas en México

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ABSTRACT

Parathesis psychotrioides, known as *aktala'huat* in the Totonac language, is a wild fruit traditionally consumed by indigenous communities in the Sierra Norte of Puebla, Mexico. The aim of this study was to characterize ripe fruits to determine their nutritional value and potential as a source of bioactive compounds. Official AOAC methods were applied for proximal analysis, ICP-MS for mineral determination, and spectrophotometric techniques to quantify functional compounds. The fruits showed high contents of phenolic compounds (475.35 ± 11.68 mg GAE/100 g), flavonoids (208.72 ± 7.52 mg CE/100 g), anthocyanins (173.50 ± 2.15 mg C3G/100 g), and condensed tannins (166.94 ± 8.25 mg CE/100 g). Antioxidant capacity was remarkable (ABTS: $5536.21 \mu\text{mol TE}/100 \text{ g}$; FRAP: $3395.45 \mu\text{mol TE}/100 \text{ g}$; DPPH: $3218.11 \mu\text{mol TE}/100 \text{ g}$; IC_{50} DPPH: $55.71 \pm 1.17 \mu\text{g/mL}$). In addition, the fruits stood out for their potassium, phosphorus, magnesium, iron, and zinc content. These results demonstrate the potential of *P. psychotrioides* as a functional food and a source of compounds with nutraceutical and biotechnological applications. The knowledge generated contributes to the preservation of traditional knowledge, promotes the use of local resources, and supports sustainable strategies for conservation and food security.

Keywords: Nutraceutical potential, wild edible fruits, capulín del monte, functional food, conservation of plant genetic resources.

RESUMEN

Parathesis psychotrioides, conocido como *aktala'huat* en la lengua totonaca, es un fruto silvestre consumido tradicionalmente en comunidades indígenas de la Sierra Norte de Puebla, México. El objetivo de este estudio fue caracterizar los frutos maduros para determinar su valor nutricional y su potencial como fuente de compuestos bioactivos. Se aplicaron métodos oficiales (AOAC) para el análisis proximal,

ICP-MS para la determinación mineral y técnicas espectrofotométricas para cuantificar compuestos funcionales. Los frutos mostraron contenidos elevados de compuestos fenólicos (475.35 ± 11.68 mg EAG/100 g), flavonoides (208.72 ± 7.52 mg EC/100 g), antocianinas (173.50 ± 2.15 mg C3G/100 g) y taninos condensados (166.94 ± 8.25 mg EC/100 g). La capacidad antioxidante fue notable (ABTS: $5536.21 \mu\text{mol ET}/100 \text{ g}$; FRAP: $3395.45 \mu\text{mol ET}/100 \text{ g}$; DPPH: $3218.11 \mu\text{mol ET}/100 \text{ g}$; IC_{50} DPPH: $55.71 \pm 1.17 \mu\text{g/mL}$). Asimismo, destacaron por su contenido de potasio, fósforo, magnesio, hierro y zinc. Estos resultados evidencian el potencial de *P. psychotrioides* como alimento funcional y fuente de compuestos con aplicaciones nutraceuticas y biotecnológicas. El conocimiento generado contribuye al rescate de saberes tradicionales, promueve el uso de recursos locales y fortalece estrategias de conservación y seguridad alimentaria sustentables.

Palabras clave: Potencial nutraceutico, frutos silvestres comestibles, capulín del monte, alimento funcional, conservación de los recursos genéticos vegetales.

INTRODUCTION

The genus *Parathesis* (Primulaceae) comprises 96 species that are native to Mexico, Central America, the Caribbean, and northwestern South America (Ricketson and Pipoly, 2008). This genus includes *P. psychotrioides* Lundell, a shrub native to central, northeastern, southeastern, and southwestern Mexico that produces violet-colored drupes when ripe (Plants of the World Online, 2025). In the Sierra Norte de Puebla region of Mexico, these fruits are known as 'capulín del monte', 'aktala'huat' in the Totonaca language, and 'xalcapolin' in the Nahuatl language (GBIF Backbone Taxonomy [no date]).

P. psychotrioides belongs to a group of wild fruits that includes *Ardisia compressa*, *Ardisia escallonioides*, *Prunus serotina*, and *Muntingia calabura*. These fruits are commonly referred to as "capulín or capulí" in different regions of Latin

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America. Despite sharing this popular name, these species belong to distinct botanical families and exhibit diverse properties, uses, and chemical compositions (Lascurain *et al.*, 2010; Mahmood *et al.*, 2014; Pathania *et al.*, 2022). Research on some of these species has revealed notable nutritional and nutraceutical properties. For example, *P. serotina* fruits have high antioxidant and antihypertensive potential (Luna-Vázquez *et al.*, 2013), and *A. compressa* has been reported as a tropical source of natural pigments and phenolic compounds (Joaquín-Cruz *et al.*, 2015). However, unlike these species, *P. psychotrioides* has received little scientific attention, lacks commercial value and remains underutilized.

Edible wild fruits are closely connected to the cultural identity and traditions of indigenous and rural communities (Mahapatra and Panda, 2012; Ahmed *et al.*, 2022). Their presence in rituals, festivities, and daily diets reflects not only a cultural, but also resilience to social and environmental change (Ahmed *et al.*, 2022). However, modernization and environmental changes threaten the traditional knowledge associated with these resources and their uses. Beyond their cultural significance, wild fruits are essential for dietary diversity and nutrition, particularly during times of food scarcity (Ahmed *et al.*, 2022). In rural, marginalized or hard-to-reach areas, these fruits can complement or even substitute conventional crops when harvests fail or resources are scarce (Mahapatra and Panda, 2012; Ahmed *et al.*, 2022). Their accessibility and low cost make them a safety net for vulnerable households. In several regions, they also represent an important source of household income through commercialization (Mahapatra and Panda, 2012; Ahmed *et al.*, 2022; Jabeen *et al.*, 2024).

Globally, underutilized fruits are attracting increasing attention as potential functional foods and for their contribution to food security, sustainable diets and biodiversity conservation (Dwivedi *et al.*, 2017). Numerous wild plants are recognized as sources of macronutrients, micronutrients, vitamins, minerals, fiber, and bioactive compounds, including phenolic compounds, flavonoids, and anthocyanins. These compounds have been associated with significant antioxidant capacity and the prevention of chronic diseases (Glew *et al.*, 2005; Martinez *et al.*, 2023). However, information on the physicochemical composition and nutraceutical potential of *P. psychotrioides* is limited, creating a critical knowledge gap that threatens the sustainable conservation and valorization of this species. This study aimed to evaluate the nutraceutical potential of *P. psychotrioides* fruits by analyzing their physicochemical, nutritional, and antioxidant properties. The study focused on describing the characteristics of ripe fruits, analyzing their nutritional and mineral composition, and quantifying their functional compounds and antioxidant capacity. Additionally, the study explored the cultural significance of these fruits within Totonac communities. This approach encourages the consumption of native fruits as a conservation strategy and helps preserve local food heritage.

MATERIAL AND METHODS

Obtaining ethnobotanical information

Information on *P. psychotrioides* fruits and their use in the

preparation of traditional foods, was obtained through participant observation and semistructured interviews conducted in the indigenous Totonaca community of Santiago Ecatlán, municipality of Jonotla, Puebla. The interviews focused mainly on the matriarchs of the families, women over 50 years of age who are responsible for household nutrition. The questions focused on aspects such as the common names of the fruits in the Totonaca and Spanish languages, the characteristics of the plant's growing environment, the season and traditional methods of harvesting, the forms of consumption and the preparation of traditional foods based on these fruits. The study received informed consent from all participants.

Sample collection and preparation

P. psychotrioides fruits were collected in April 2024 from home orchards in Santiago Ecatlán (20° 3'11.336" N and 97° 33'29.192" W). The fruits were selected at maturity, determined visually by their dark purplish coloration, according to criteria used by local inhabitants. Prior to fruit collection, during the flowering stage of the plant, identification and botanical determination of the species were carried out. The specimen was herborized and deposited in the Hortorio Jorge Espinosa Salas Herbarium (JES) of the Biology Area of the Universidad Autónoma Chapingo under registry number 26076.

A portion of the collected fruits was stored at 4 ± 0.2 °C for subsequent physicochemical analysis. Another portion was subjected to manual desizing and freeze-drying (Free-Zone 2.5 L Labconco) at 0.035 mbar. The freeze-dried fruits were ground, sieved and stored for subsequent analyses.

Compound extraction

First, 0.2 g of lyophilized sample were mixed with 25 mL of 80 % methanol and acidified to pH 3.0 with 0.1 N HCl, following the methodology of Hernández-Rodríguez *et al.* (2016). The resulting extracts were subjected to spectrophotometric analyses to quantify total phenolic compounds (Singleton and Rossi, 1965), flavonoids (Kubola and Siriamornpun, 2011), anthocyanins (Lee *et al.*, 2005), and condensed tannins (Wallace and Giusti, 2010). Antioxidant capacity was assessed through ABTS (Re *et al.*, 1999), FRAP (Benzie and Cepas, 1996) and DPPH (Brand-Williams *et al.*, 1995) assays. Absorbance readings were performed using a Synergy 2 microplate reader (BioTek Instruments), under conditions specific to each assay.

Morphological and physicochemical characterization

Average weight: One hundred ripe fruits were randomly selected for average weight determination. Weight was recorded using a high-precision analytical balance (Sartorius BCE224I-1S). For each fruit, the whole fruit, endocarp and seed were weighed separately (Alemán-Villa *et al.*, 2024; Sosa *et al.*, 2025).

Dimensions and sphericity index: The polar and equatorial diameters were measured with a digital Vernier caliper (Truper 14388 CALDI-6MP), and the ratio of these values was

calculated (Alemán-Villa *et al.*, 2024; Sosa *et al.*, 2025).

Total soluble solids (TSS): TSS were determined with a digital refractometer (ATAGO PAL-1) in degrees Brix (°Brix) (Sosa *et al.*, 2025).

Titrateable acidity (TA) and pH: The filtered juice was titrated with 0.1 N NaOH to reach a pH of 8.2. The pH was measured with a Conductronic pH120 meter. TA is expressed as the percentage weight/volume (% w/v) of citric acid (Felts *et al.*, 2019; Sosa *et al.*, 2025).

Maturity Index (TSS/TA): The maturity index was calculated by dividing total soluble solids (TSS) by titrateable acidity (TA) and expressing the result as °Brix/% citric acid (Sosa *et al.*, 2025).

Moisture content: The moisture content of the edible part of the fruit (epicarp and mesocarp), was determined. The samples were analyzed using a thermobalance (Ohaus MB 45) heated to 100 °C until a constant weight was reached (Alemán-Villa *et al.*, 2024).

Determination of nutritional properties

Proximal analysis: Proximal analysis was performed according to the official AOAC methods for protein (960.52), fat (920.39), ash (900.02) and dietary fiber (985.29). The carbohydrate content was obtained by subtracting the percentages of the other components. Metabolizable energy was calculated using Atwater's conversion factors: 4 kcal/g for protein and carbohydrates, and 9 kcal/g for lipids (AOAC - Association of Official Analytical Chemists 2016). All analyses were performed in triplicate.

Total gross energy: The gross energy of the edible portion of the *P. psychotrioides* fruits was determined by measuring the heat of combustion released during complete oxidation (Hopper *et al.*, 2024) using a Parr isoperibolic automatic calorimeter (model 6400).

Mineral content: The mineral content was determined following the method described by Lordache *et al.* (2022). Acid digestion of the plant and soil samples was performed using HNO₃, HF, H₂O₂ and a 2:1 (v/v) solution of HNO₃ and HCl, with the inclusion of internal standards (Y, In, Ir, and Bi). The digestion process included cold and hot steps, followed by reconstitution in 2 % v/v HNO₃. Elemental analysis was performed using inductively coupled plasma-mass spectrometry (ICP-MS, KED mode) with multielemental standards. The methodology was validated in terms of recovery (90 – 110 %) and precision (RSD < 5 %).

Determination of the total phenolic, total flavonoid, total anthocyanin, and condensed tannin contents and antioxidant capacity

Total phenolic content: The phenolic content was determined following the method of Singleton and Rossi (1965). A standard curve was prepared using gallic acid solutions at concentrations of 0.00125 to 0.01125 mg/mL. The coefficient of determination (R²) of the gallic acid standard curve was 0.9952. The results are expressed as mg of gallic acid equivalents (GAE)/100 g of fresh weight (FW).

Total flavonoid content: The flavonoid content was determined following the method of Kubola and Siriamornpun (2011). A standard curve was prepared with catechin solutions in the concentration range of 0.00101 to 0.0160 mg/mL. The R² value of the catechin standard curve was 0.9990. The results are expressed as mg of catechin equivalents (CE)/100 g FW.

Concentration of monomeric anthocyanins: A previously reported differential pH method was used to determine the anthocyanin concentration (Lee *et al.*, 2005). The values obtained were used to calculate the anthocyanin concentration in mg of cyanidin-3-O-glucoside (C3G)/100 g of FW.

Determination of condensed tannins (proanthocyanidins): The condensed tannins in each sample were quantified using the 4-dimethylaminocinnamaldehyde (DMAC) method (Wallace and Giusti, 2010). A standard curve was prepared using catechin standard solutions with concentrations ranging from 0.050 to 0.500 mg/mL. The R² value of the catechin curve was 0.9964. The results are expressed as mg CE/100 g FW.

Antioxidant capacity (ABTS method): The method described by Re *et al.* (1999) was used for the ABTS assay. A standard curve of 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was constructed in the concentration range of 0.050 to 0.599 µmol/mL. The R² value of the Trolox standard curve was 0.9971. The results are expressed as µmol of Trolox equivalents (TE)/100 g FW.

Antioxidant capacity (FRAP method): The methodology proposed by Benzie and Ceba (1996) was used for the FRAP assay, in addition to the previously described Trolox standard curve. The R² value of the Trolox standard curve was 0.9988. The results are expressed as µmol TE/100 g FW.

Antioxidant capacity (DPPH method): The antioxidant capacity was determined using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) method, as described by Brand-Williams *et al.* (1995), with slight modifications. Aliquots of 200 µL of extract at various concentrations (12-180 µmol/L) were mixed with 50 µL of a 500 µmol/L DPPH solution. The mixture was then incubated at room temperature in the dark for 30 minutes. Absorbance was measured at 515 nm. A Trolox calibration curve (0.005-0.030 µmol/mL) was constructed, yielding an R² value of 0.9927. The results were expressed as µmol TE/100 g FW and as IC₅₀ values, which are defined as the extract concentration (mg/mL) required to achieve 50 % scavenging of the DPPH radical. Additionally, the IC₅₀ value was expressed as the amount of sample (ng) required per nmol of DPPH to provide a normalised measure that is independent of the initial DPPH concentration used in the assay (Martínez-Morales *et al.*, 2020).

Statistical analysis

All experimental data are presented as the mean ± standard deviation (n = 3). Descriptive analyses were conducted using R software (version 4.4.2; R Core Team, 2024). Comparisons with previously published data were made qualitatively, without statistical inference.

RESULTS AND DISCUSSION

Ethnobotanical importance

P. psychotrioides grows wild or is tolerated in home gardens, pastures, and ranches without agronomic management. Fruiting is seasonal and concentrated between April and May, which limits its availability. Owing to the high perishability of the fruit, consumption is restricted to harvest time, making it highly valued in the local food calendar. The fruit of *P. psychotrioides*, known locally as aktala'huat, plays a fundamental role in the diet and culture of the Totonaca community of Santiago Ecatlán, municipality of Jonotla, Puebla, Mexico. The fruits are often consumed directly from the bush, especially among those who work in family gardens or ranches, as a snack. However, the most common way to use the fruits is through the preparation of atole and aguas frescas.

Atole is a drink prepared from the juice of the fruit mixed with nixtamalized corn dough, which has symbolic value for the community's inhabitants. It is predominantly made by older women, who have detailed knowledge of the harvesting, selection and processing of the fruit. Atole preparation and consumption are closely linked to family gatherings, where its consumption strengthens social ties and contributes to intergenerational cohesion. In various indigenous cultures, beverages made from local fruits play symbolic roles in agricultural rituals, seasonal transitions, or giving thanks to nature (Lasso García *et al.*, 2024). The traditional knowledge associated with the use of this fruit not only highlights the importance of biodiversity in the cultural resilience of indigenous people, but also emphasizes the symbiotic relationship between communities and their natural environment.

Morphological characteristics of the fruit

The fruit of *P. psychotrioides* is an ovoid drupe, with an equatorial diameter of 8.67 ± 0.60 mm, greater than the polar diameter of 7.04 ± 0.48 mm, which translates into a sphericity index of 0.81 ± 0.030 . The average weight of the fruits collected was 0.274 ± 0.055 g, of which 0.087 ± 0.024 g corresponded to the seeds. The edible fraction (pulp and epicarp) represented 68.32 % of the total weight, equal to 0.187 ± 0.060 g. Figure 1 shows images of a *P. psychotrioides* plant and its fruits.

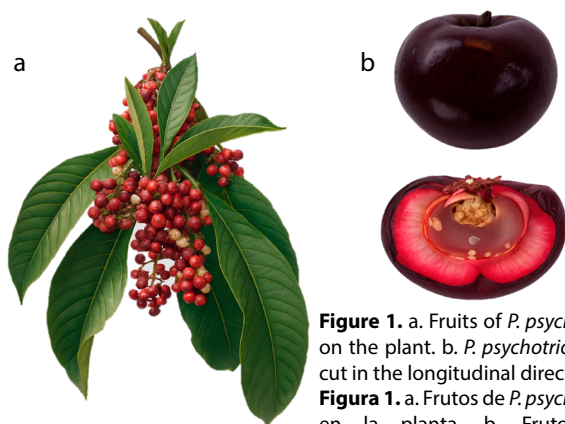


Figure 1. a. Fruits of *P. psychotrioides* on the plant. b. *P. psychotrioides* fruit cut in the longitudinal direction.

Figure 1. a. Frutos de *P. psychotrioides* en la planta. b. Fruto de *P. psychotrioides* cortado en dirección longitudinal.

Physicochemical characteristics of the fruit

The percent TSS, pH, percent TA and TSS/TA ratio values determined for the *P. psychotrioides* fruits are presented in Table 1, which also includes data from other species commonly referred to as capulín, including *A. compressa* (Primulaceae) (Joaquín-Cruz *et al.*, 2015), *P. serotina* (Rosaceae) (Rios-Corripio *et al.*, 2024) and *M. calabura* (Muntingiaceae) (Pereira *et al.*, 2016), with which *P. psychotrioides* is often confused owing to their external appearance.

According to the data in Table 1, there are more TSS in *P. psychotrioides* fruits than in *M. calabura* and *A. compressa* fruits (Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016), suggesting a greater concentration of dissolved compounds, mainly sugars. However, the sugar content of *P. psychotrioides* fruits is lower than that of *P. serotina* fruits (Rios-Corripio *et al.*, 2024). The TSS value of *P. psychotrioides* fruits suggests that they are sweeter than other fruits, such as strawberry (6–7 °Brix) (Pineli *et al.*, 2011) and raspberry (8–10 °Brix) (Wrolstad *et al.*, 1993), although they are not as sweet as blueberries (10–15 °Brix) (Bett-Garber *et al.*, 2015) and grapes (16–25 °Brix) (Fernandes *et al.*, 2015; Jamali *et al.*, 2024). With respect to pH, *P. psychotrioides* fruits are slightly acidic, with a pH value higher than *A. compressa* fruits but lower than *M. calabura* fruits (Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016). Compared with blueberries (pH 3.0–3.5) (Bett-Garber *et al.*, 2015), raspberries (pH 3.0–3.5) (Wrolstad *et al.*, 1993), strawberries (pH 3.3–3.7) (Pineli *et al.*, 2011) and grapes (pH 3.2–4.0) (Fernandes *et al.*, 2015; Jamali *et al.*, 2024), *P. psychotrioides* fruits exhibit lower acidity. Although this characteristic may favor its organoleptic acceptability, it also makes the fruits more susceptible to the proliferation of microorganisms, which could negatively affect its conservation and reduce its postharvest shelf life (Redding *et al.*, 2023).

The TA of *P. psychotrioides* fruits was notably lower than that of *A. compressa* fruits, the species with the highest TA among the wild fruits analyzed, but higher than that of the fruits of *M. calabura* and *P. serotina* (Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016; Rios-Corripio *et al.*, 2024). Similarly, the TA values obtained for *P. psychotrioides* were within the ranges reported for fruits such as blueberry (0.7–1.2) (Bett-Garber *et al.*, 2015), strawberry (0.7–1.1) (Pineli *et al.*, 2011) and grape (0.5–0.8) (Fernandes *et al.*, 2015; Jamali *et al.*, 2024), which are generally expressed as percentages of citric or tartaric acid. Although the TSS/TA ratio of *P. psychotrioides* fruits was lower than that of *P. serotina* and *M. calabura* fruits, it was considerably higher than that of *A. compressa* fruits (Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016; Rios-Corripio *et al.*, 2024). A higher TSS/TA ratio indicates a sweeter and less acidic sensory profile, which is generally preferred by consumers (Jayasena and Cameron, 2008), suggesting that *P. psychotrioides* fruits, despite their relatively high TSS content, do not exhibit such a pronounced sweetness perception due to their acidity.

Proximate and mineral composition

Table 2 compares the proximate composition of *P. psychotrioides* fruits with fruits of other species, such as *A. com-*

Table 1. Physicochemical characterization of the fruits of *P. psychotrioides* and other capulín species**Tabla 1.** Caracterización fisicoquímica de los frutos de *P. psychotrioides* y de otras especies de capulín

Species	TSS	pH	TA	TSS/AT	Reference
<i>Parathesis psychotrioides</i>	11.41±0.69	4.07±0.0	0.82±0.02	13.88±0.95	Present study
<i>Ardisia compressa</i>	9.7±1.1	2.73±0.0	2.56±0.03	3.79±0.43	Joaquín-Cruz <i>et al.</i> (2015)
<i>Prunus serotina</i>	16.2±0.02	4.57±0.0	0.57±0.01	28.42±0.50	Rios-Corripio <i>et al.</i> (2024)
<i>Muntingia calabura</i>	10.24±0.48	5.64±0.0	0.11±0.01	93.76±0.67	Pereira <i>et al.</i> (2016)

The results are expressed as °Brix for total soluble solids (TSS), % w/v citric acid for titratable acidity (TA), and as the °Brix/% citric acid ratio for the maturity index (TSS/TA).

Los resultados se expresan como °Brix para los sólidos solubles totales (SST), % p/v de ácido cítrico para la acidez titulable (AT), y como la relación °Brix/% de ácido cítrico para el índice de madurez (SST/AT).

pressa, *P. serotina* and *M. calabura* (Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016). The fruits of *P. psychotrioides* had a high moisture content, which was lower than that of *A. compressa* fruits but higher than that of *P. serotina* and *M. calabura* fruits, which is characteristic of fresh fruits. The carbohydrate content of *P. psychotrioides* fruits was higher than that of *A. compressa* fruits, comparable to the content in *P. serotina* fruits, but notably lower than that of *M. calabura* fruits (Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016). This indicates that *P. psychotrioides* fruits are a moderate energy source, surpassing fruits such as strawberry (7.96 g/100 g FW) and approaching the carbohydrate concentration of raspberry (12.9 g/100 g FW) and blueberry (14.6 g/100 g FW) (U.S. Department of Agriculture 2025). The lipid content of *P. psychotrioides* fruits was low, similar to that of *A. compressa* fruits. However, it was higher than the lipid content in *P. serotina* fruits and considerably lower than that of the fruits of *M. calabura* (Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016). This low level of lipids is characteristic of wild fruits and suitable for hypocaloric diets. In terms of protein content, *P. psychotrioides* fruits presented a greater value than did *A. compressa* fruits but a lower value than the fruits of *P. serotina* and *M. calabura* (Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016). However, the protein content of *P. psychotrioides* fruits exceeded that reported in strawberry (0.64 g/100 g FW) and blueberry (0.7 g/100 g FW) (U.S. Department of Agriculture, 2025). The crude fiber content of *P. psychotrioides* fruits was the lowest among the species compared, suggesting a moderate content of dietary fiber; however, this level is still appropriate for regulating intestinal transit and maintaining digestive health (Wrick *et al.*, 1983).

On the other hand, the ash content in *P. psychotrioides* fruits was higher than that in the other species (Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015; Pereira *et al.*, 2016), indicating a higher concentration of minerals. Ash represents the inorganic fraction of a plant sample, the minerals remaining after combustion. Therefore, a high ash content is a direct indicator of a greater total concentration of essential elements such as calcium, magnesium, potassium, and phosphorus (Smółka-Danielowska and Jabłońska, 2022). However, the specific mineral composition can vary considerably based on factors such as plant species, the part of the plant analyzed, soil type, and growing conditions (Hill, 2013). Furthermore, this value in *P. psychotrioides* fruits far exceeded those reported for strawberry (0.34 g/100 g FW), raspberry (0.35 g/100 g FW) and blueberry (0.23 g/100 g FW) (U.S. Department of Agriculture 2025). The *P. psychotrioides* fruits metabolizable energy was comparable to that for apple (61 kcal/100 g FW), raspberry (57 kcal/100 g FW) and blueberry (64 kcal/100 g FW) fruits and higher than that reported for strawberry (36 kcal/100 g FW) (U.S. Department of Agriculture 2025), which reinforces the nutritional potential of *P. psychotrioides* fruits, especially in diets seeking energy balance without excessive caloric intake. Finally, the gross energy of the *P. psychotrioides* fruits, as determined by bomb calorimetry, was 60.41±0.29 kcal/100 g FW. This value is approximately 15.8 % greater than the metabolizable energy reported in Table 2. This result was expected since the Atwater method reflects the energy theoretically usable by the organism, whereas the calorimetric method quantifies the total energy contained in the food without distinguishing between the usable fraction and the fraction not available for human metabolism (Sánchez-Peña *et al.*, 2020).

Table 2. Proximal analysis of *P. psychotrioides* fruits and other capulín species.**Tabla 2.** Análisis proximal de los frutos de *P. psychotrioides* y de otras especies de capulín.

Component	<i>P. psychotrioides</i>	<i>A. compressa</i>	<i>P. serotina</i>	<i>M. calabura</i>
Humidity	84.44±1.24	86.85±0.49	81.18±0.87	77.36±2.23
Carbohydrates	11.26±1.25	9.64±0.24	12.23±0.79	14.64±2.40
Fats	0.41±0.04	0.54±0.07	0.05±0.01	2.34±0.30
Proteins	0.87±0.01	0.77±0.01	2.10±0.01	2.64±0.18
Crude Fiber	1.20±0.11	1.62±0.02	3.58±0.03	1.75±0.30
Ash	1.82±0.13	0.58±0.005	0.86±0.11	1.28±0.16
Metabolizable energy	52.19±5.02	46.5±1.15	57.77±3.16	90.18±10.00
Reference	Present study	Joaquín-Cruz <i>et al.</i> (2015)	Luna-Vázquez <i>et al.</i> (2013)	Pereira <i>et al.</i> (2016)

The results are expressed as g/100 g fresh weight (FW), except for metabolizable energy, which is presented as kcal/100 g FW.

Los resultados se expresan en g/100 g de peso fresco (PF), excepto la energía metabolizable, que se presenta en kcal/100 g PF.

Table 3 presents the mineral profiles of *P. psychotrioides* and other capulin species fruits, in relation to the mineral concentrations of the soil where this plant grows, which may allow the identification of patterns of selective accumulation. Although the soil presented elevated levels of some minerals, such as phosphorus, potassium and iron, these increases were not proportionally reflected in the mineral content of the fruit. Previous studies have suggested that plants can selectively accumulate certain minerals in their tissues independent of the high concentrations of these minerals in the soil, probably because physiological mechanisms that regulate mineral uptake, translocation, and accumulation, are influenced by factors such as ion bioavailability, element competition in roots, and specific metabolic needs (Karley and White, 2009; Yamamoto *et al.*, 2024).

The results indicated that *P. psychotrioides* fruits are an outstanding source of potassium (K), with 2.4 times that in *A. compressa*, and 4.3 times that in *P. serotina* (Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015) fruits, even double that in bananas (358 mg/100 g FW) (U.S. Department of Agriculture, 2025), one of the main reference fruits for this mineral, which regulates blood pressure and heart rate (Razzaque and Wimalawansa, 2025). The phosphorus (P) content in *P. psychotrioides* fruits was also 2.2 times higher than that in *A. compressa* fruits and 2.35 times higher than that in *P. serotina* fruits (Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015) and exceeding that in other fruits such as guava (40 mg/100 g FW) (U.S. Department of Agriculture, 2025). This mineral plays a fundamental role in the growth and development of bones and teeth and contributes to blood pH regulation and energy storage (Razzaque and Wimalawansa, 2025). In contrast, the calcium content of *P. psychotrioides* fruits is limited considering calcium availability in the soil, indicating its low accumulation efficiency in the fruit. Although the calcium content recorded for *P. psychotrioides* fruits was lower than that reported for *A. compressa* fruits (Joaquín-Cruz *et al.*, 2015), it was within the typical range for fruits such as strawberries (17 mg/100 g FW) (U.S. Department of Agriculture, 2025). The magnesium (Mg) content of *P. psychotrioides* fruits was twice

that of *A. compressa* fruits and 3.3 times greater than that of *P. serotina* fruits (Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015). This mineral is important for energy metabolism and protein synthesis, and contributes to cardiovascular health (Razzaque and Wimalawansa, 2025). Although the iron content of *P. psychotrioides* fruits was considerably lower than that of the soil, it was triple that of *A. compressa* fruits and even exceeded that of foods traditionally rich in this mineral, such as spinach, being 5.3 times higher (1.05 mg/100 g FW) (U.S. Department of Agriculture, 2025). This result is important for populations at risk of anemia, since a 100 g serving of this fruit would include 39 % of the recommended daily intake of iron (14 mg/day) (Official Journal of the European Union, 2011). The zinc content in *P. psychotrioides* fruits was higher than that reported for *A. compressa*, and comparable to that of avocado (0.46 mg/100 g FW). However, it remained substantially lower than the levels typically found in nuts (5.07 mg/100 g FW), which are well recognized for their high zinc content (U.S. Department of Agriculture, 2025). Zinc is essential for immunological and enzymatic functions (Razzaque and Wimalawansa, 2025), and this concentration represents 46 % of the recommended daily intake (10 mg/day) (Official Journal of the European Union, 2011). Although manganese and copper are present at relatively low concentrations in *P. psychotrioides* fruits, they contribute to the complete mineral profile of the fruit. These findings suggest that the edaphic characteristics of the ecosystem where *P. psychotrioides* grows, positively influence its nutritional profile (Karley and White, 2009; Yamamoto *et al.*, 2024) and, in this sense, the mineral richness of the soil seems to favor the accumulation of essential nutrients in the fruit.

The levels of heavy metals in *P. psychotrioides* fruits were compared with the maximum values allowed by the Codex Alimentarius for fruits and fruit juices (FAO and WHO, 2001). Notably, the concentrations of cadmium (0.01 mg/kg), arsenic (0.01 mg/kg), mercury (0.00 mg/kg), cobalt (0.04 mg/kg), chromium (0.085 mg/kg) and nickel (0.084 mg/kg) were found to be below the reference values, indicating low toxicological risks. With respect to lead, although its concentration

Table 3. Mineral contents of *P. psychotrioides* and other capulin species.

Tabla 3. Contenido mineral de *P. psychotrioides* y de otras especies de capulín.

Mineral	Soil analysis	<i>P. psychotrioides</i>	<i>A. compressa</i>	<i>P. serotina</i>
P	833.19±201.53	66.04±5.22	30	28.10±0.40
K	2429.85±131.15	785.73±43.07	328	184.30±3.50
Ca	377.84±27.81	9.86±0.35	41	12.90±1.90
Mg	1023.39±5.93	70.59±1.97	35	21.20±0.20
Fe	5396.04±480.65	5.55±0.34	3.4	—
Zn	52.38±5.07	4.65±0.54	0.07	—
Mn	179.94±27.62	0.40±0.03	0.24	—
Cu	10.51±2.04	0.085±0.002	—	—
Reference	Present study	Present study	Joaquín-Cruz <i>et al.</i> (2015)	Luna-Vázquez <i>et al.</i> (2013)

Values are expressed as mg/100 g fresh weight (FW), except for soil analysis, which is reported on a dry weight basis (mg/100 g DW). A long dash (—) indicates data not reported in the cited source.

Los valores se expresan en mg/100 g de peso fresco (PF), excepto para el análisis de suelo, que se presenta en base a peso seco (mg/100 g PS). Un guion largo (—) indica que los datos no fueron reportados en la fuente citada.

in the edible fraction (0.33 mg/kg) exceeded the maximum limit for fruit juices (0.05 mg/kg), regular consumption of the whole fruit does not present a significant risk. This is because ingesting the tolerable daily intake of lead, determined by the FAO/WHO, would require the consumption of 221.94 g of whole fruit (810 fruits) per day to pose a risk. Furthermore, the limit referred to applies to processed juices (higher volumetric consumption), not to fresh fruit.

Functional compounds

Table 4 shows that the phenolic content of *P. psychotrioides* fruits is higher than that of different commercial blueberry varieties (*Vaccinium corymbosum*) and falls within the range reported for wild species (*Vaccinium myrtillus*). It also exceeds the levels recorded in *P. serotina* fruits. However, the phenolic content of *P. psychotrioides* is 2.2-fold lower than that reported for *A. compressa* fruits (Giovanelli and Buratti, 2009; Luna-Vázquez *et al.*, 2013; Joaquín-Cruz *et al.*, 2015) and remains below the values described for certain strawberry cultivars (1150 ± 50 mg/100 g FW) (Dragišić Maksimović *et al.*, 2015).

The flavonoid content of *P. psychotrioides* fruits was similar to that observed in *P. serotina* fruits and comparable to the highest values reported for plum cultivars (237 ± 6.3 mg CE/100 g FW) [26]. When compared with blueberries, the flavonoid content of *P. psychotrioides* was 1.9 times greater than that reported for *V. corymbosum* var. Bluecrop, and 1.79 times greater than that of the wild blueberry *V. myrtillus* (Giovanelli and Buratti, 2009); however, these values were expressed as quercetin equivalents (QE), which may limit direct quantitative comparisons (Bunea *et al.*, 2011). Additionally, the dry weight (DW) equivalence of condensed tannins (1073 ± 53 mg CE/100 g DW) was within the range reported for wild and cultivated blueberries (1110 ± 500 to 1430 ± 140 mg CE/100 g DW), among which wild varieties contain more condensed tannins (Hellström *et al.*, 2024).

The anthocyanin content of *P. psychotrioides* fruits was slightly higher than that of commercial blueberries but lower than that of wild blueberries (Table 4). Moreover, it was markedly lower than the levels reported for *A. compressa* fruits (Giovanelli and Buratti, 2009; Joaquín-Cruz *et al.*, 2015), but considerably higher than the values reported for strawberry (29.29 ± 3.23 mg/100 g FW) (Pineli *et al.*, 2011). In *P. psychotrioides* fruits, approximately 79 % of the total phenolic

compounds were comprised of flavonoids and condensed tannins. Of these, anthocyanins constituted 36.49 % of the total phenolic compounds and 83.12 % of the total flavonoids. Flavonoids, condensed tannins or proanthocyanidins and anthocyanins are recognized for their antioxidant and anti-inflammatory properties and contribute to the prevention of chronic diseases and the maintenance of general health. Additionally, proanthocyanidins are responsible for the astringent taste of fruits and act as a defense against pathogens and herbivores (Nile and Park, 2014).

The values shown in Table 4 indicate that *P. psychotrioides* fruits had high antioxidant capacity according to the ABTS, FRAP, and DPPH assays. In the ABTS test, the antioxidant capacity of *P. psychotrioides* was higher than that of *A. compressa* (Joaquín-Cruz *et al.*, 2015). According to Bunea *et al.* (2011), the value obtained for *P. psychotrioides* exceeds the range of wild blueberries (*V. myrtillus*, 4308-5665 $\mu\text{mol TE}/100$ g PF) and is considerably higher than that of commercial *V. corymbosum* cultivars (2433-3796 $\mu\text{mol TE}/100$ g PF). In the FRAP method, the reducing capacity of *P. psychotrioides* exceeded that of commercial blueberry varieties and *P. serotina*, although it was lower than that of wild blueberries. This antioxidant capacity is similar to that of red cabbage, with values of 5420 ± 260 $\mu\text{mol TE}/100$ g FW (ABTS) and 3060 ± 150 $\mu\text{mol TE}/100$ g FW (FRAP), but it is below those of acerola (*Malpighia emarginata*), reported to be 49400 ± 1100 $\mu\text{mol TE}/100$ g FW (ABTS) and 43400 ± 3500 $\mu\text{mol TE}/100$ g FW (FRAP) (Nilsson *et al.*, 2005).

In the DPPH assay, the values obtained for *P. psychotrioides* were higher than those for *P. serotina* and the ranges reported for commercial and wild blueberries (Table 4). Expressed as IC_{50} , the value was 55.71 ± 1.17 $\mu\text{g/mL}$ (445.73 ± 9.39 ng/nM DPPH), indicating that a low concentration of extract is required to inhibit 50 % of the radical. This value is considerably lower than those recorded for blackberry (280 $\mu\text{g/mL}$), raspberry (760 $\mu\text{g/mL}$), and blackcurrant (200 $\mu\text{g/mL}$) (Zorzi *et al.*, 2020), suggesting the high efficiency of *P. psychotrioides* as a free radical scavenger.

Overall, the results show that the antioxidant capacity of *P. psychotrioides* does not depend solely on the total phenol content, as this was lower than that of *A. compressa* and wild blueberries (Table 4). This suggests that its antioxidant efficacy may depend more on the structural characteristics

Table 4. Functional components of the fruits of *P. psychotrioides* and other capulín species.

Tabla 4. Componentes funcionales de los frutos de *P. psychotrioides* y de otras especies de capulín.

Component	<i>P. psychotrioides</i>	<i>A. compressa</i>	<i>P. serotina</i>	<i>V. corymbosum</i> (commercial)	<i>V. myrtillus</i> (wild)
Total phenols	475.35 $\pm$ 11.68	1051.3 $\pm$ 43.5	362.2 $\pm$ 11.6	251-310	577-614
Flavonoids	208.72 $\pm$ 7.52	—	201.8 $\pm$ 12.1	—	—
Anthocyanins	173.50 $\pm$ 2.15	796.0 $\pm$ 2.3	—	92-129	330-344
Condensed tannins	166.94 $\pm$ 8.25	—	—	—	—
ABTS	5636.21 $\pm$ 273.02	4488 $\pm$ 4.47	—	—	—
FRAP	3395.45 $\pm$ 151.17	—	1455.2 $\pm$ 92.5	2130-2640	5320-5720
DPPH	3218.11 $\pm$ 17.63	—	2056.7 $\pm$ 108	379-549	1079-1096
Source	Present study	Joaquín-Cruz <i>et al.</i> (2015)	Luna-Vázquez <i>et al.</i> (2013)	Giovanelli and Buratti (2009)	Giovanelli and Buratti (2009)

Antioxidant capacity: ABTS, FRAP and DPPH ($\mu\text{mol TE}/100$ g FW), total phenols (mg GAE/100 g FW), total flavonoids and condensed tannins (mg CE/100 g FW) and anthocyanins (mg C3G/100 g FW). A long dash (—) indicates data not reported in the cited source.

Capacidad antioxidante: ABTS, FRAP y DPPH ($\mu\text{mol ET}/100$ g PF), fenoles totales (mg EAG/100 g PF), flavonoides totales y taninos condensados (mg EC/100 g PF) y antocianinas (mg C3G/100 g PF). Un guion largo (—) indica que los datos no fueron reportados en la fuente citada.

and reactivity of its phytochemical compounds than on their total concentration (Moazzen *et al.*, 2022).

When the levels of total phenols, flavonoids, and anthocyanins and the antioxidant capacity of wild and commercial blueberry varieties were compared (Giovanelli and Buratti, 2009; Bunea *et al.*, 2011), the wild fruits tended to have higher concentrations, which was also found in other studies comparing wild and commercial fruit varieties (Cosmulescu *et al.*, 2017; Drózdź *et al.*, 2017; Hellström *et al.*, 2024). This may be explained by the environmental stress to which these plants are exposed in their natural environment, which stimulates the synthesis of secondary metabolites (Cosmulescu *et al.*, 2017). However, the differences observed between individuals of the same species can be attributed to genetic, edaphoclimatic and agronomic management factors, making it difficult to standardize their functional profiles (Pinto *et al.*, 2022).

CONCLUSIONS

P. psychotrioides is a wild plant that produces fruits with an exceptional nutritional profile. They are characterized by their high carbohydrate content, moderate protein and dietary fiber content, and significant levels of essential minerals, including potassium, phosphorus, magnesium, iron, and zinc. They also have a high concentration of phenolic compounds and notable antioxidant capacity. This suggests that they could be considered a functional food that could improve the nutritional quality of rural and indigenous communities. The results underscore the importance of promoting the sustainable use and biotechnological valorization of underutilized native plant resources. Furthermore, this study emphasizes the importance of recognizing local wild fruits as valuable resources for food security, public health, and biocultural conservation.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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