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Traditional knowledge, nutritional composition and bioactive compounds of edible flowers consumed by indigenous communities in Oaxaca, Mexico

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Summary

This study determined the nutritional composition of the following native flower species consumed in rural and indigenous communities in Oaxaca, Mexico: *Chamaedorea atrovirens* Mart., *Chamaedorea tepejilote* Liebm., *Cryosophila nana* (Kunth) Blume ex Salomon, *Agave potatorum* Zucc., *Yucca filifera* Chabaud, *Acanthocereus tetragonus* (L.) Hummelinck, *Hylocereus undatus* (Haw.) Britton & Rose, *Disocactus speciosus* (Cav.) Barthlott, *Cucurbita argyrosperma* K. Koch, *Cucurbita pepo* L., *Diphysa americana* (Mill.) M. Sousa, *Erythrina americana* Mill., *Phaseolus coccineus* L., and *Quararibea funebris* (La Llave) Vischer. Information on preparation methods was collected, and the proximate composition, minerals, total phenolic and flavonoid contents were quantified. The flowers are commonly consumed boiled, roasted, fried, pickled, as filling for quesadillas, or used in beverages. The species exhibited high fiber and mineral contents, mainly of K, Mg, and Ca. *Diphysa americana* (Mill.) M. Sousa, *Erythrina americana* Mill., and *Phaseolus coccineus* L. showed the highest concentrations of total phenols and flavonoids, which correlated positively with greater antioxidant capacity. Our results demonstrate that the edible flowers analyzed remain deeply rooted in the local gastronomy of Oaxaca's communities and are rich in nutrients and bioactive compounds.

Keywords: Bioactive properties, ethnobotany, food security, minerals, nutritional composition, traditional knowledge

Introduction

Flowers have been integral to the diets of various ethnic groups in Mexico for generations. The Mexican nation ranks fourth in the world in terms of floral diversity, with an estimated 22,126 species of flowering plants (Villaseñor, 2016). The Ethnobotanical Database of Plants of Mexico currently lists 2,168 species with various food-related uses (Mapes and Basurto, 2016).

Mexican edible flowers are important components of the food systems of indigenous peoples due to their accessibility in the local environment, their cultural acceptability (Kuhnlein and Receveur, 1996), and their historical interaction with the worldview and ways of life of local ethnic groups (Trichopoulou et al., 2007).

The use of flowers in Mexican cuisine dates back to pre-Hispanic times and is part of the customs, rituals, and stories of communities. For example, in the Florentine Codex, Friar Bernardino de Sahagún documented the consumption of edible flowers such as *ayoxochquilitl*, which is the pumpkin flower (*Cucurbita* sp.), and *huaquilitl*, which is the huazontle (*Chenopodium berlandieri*).

Nowadays, flowers are prepared and consumed in various forms and dishes: roasted, like the chocho flower (*Astrocaryum mexicanum*), in quesadillas, like the pumpkin flower (*Cucurbita* sp.), or fried with onion or egg, like the cuachepil or izote flowers (*Diphysa americana*, *Yucca filifera*). Some flowers are boiled with salt, like the agave buds (*Agave potatorum*), prepared in broths, like the chepil and pumpkin flowers (*Crotalaria longirostrata*, *Cucurbita* sp.), battered, like huazontle (*Chenopodium berlandieri*), or steamed, like begonia (*Begonia nelumbiifolia*) (Pascual-Mendoza et al., 2021; Santiago-Martínez et al., 2023).

Flowers are also used in traditional dishes such as tamales—a preparation made from masa, a dough of nixtamalized corn, typically filled with meats, sauces, or other ingredients and wrapped in corn husks or banana leaves. Some tamales are made with flowers, such as *Acacia acatlensis* (cornizuelo) and *Calathea marantifolia* (chochogo). Other flowers are incorporated into traditional beverages, including *Quararibea funebris* (rosita), used in *tejate*, and *Plumeria rubra* (flor de mayo), used in atole *bu'pu* (Sánchez-Trinidad, 2017; Mulík and Ozuna, 2020; Pascual-Mendoza et al., 2021; Santiago-Martínez et al., 2023).

Regarding nutritional composition, Sotelo et al. (2007) determined the nutritional and antinutritional content of edible flowers in Mexico, including *Agave salmiana*, *Aloe vera*, *Arbutus xalapensis*, *Cucurbita pepo*, *Erythrina americana*, *Erythrina caribaea*, *Euphorbia radians*, and *Yucca filifera*. The results showed similar compositions to those of edible African flowers, and the authors highlighted that the traditional cooking process and discarding the broth helps reduce or eliminate the toxic substances present. In a later study, Chávez-Quiñones et al. (2009) reported that Mexican flowers consumed in indigenous communities in Chiapas are rich in fiber, such as the bushna (*Spathiphyllum friedrichsthalii*) and flor de mayo (*Plumeria rubra*). In a separate study, Centurión-Hidalgo et al. (2009) analyzed the nutritional composition of inflorescences from the wild palms *Astrocaryum mexicanum*, *Chamaedorea alternans*, and *Chamaedorea tepejilote*. They found that the highest calcium content was in the inflorescences of *C. alternans* and *C. tepejilote*, while the highest values of magnesium, potassium, sodium, total dietary fiber, and insoluble dietary fiber were found in the inflorescence of *A. mexicanum*.

Additionally, Pinedo-Espinoza et al. (2020) described the edible flowers from the semi-arid regions of Mexico, such as the flowers of *Agave salmiana*, *Aloe vera*, *Erythrina americana*, and *Myrtillocactus geometrizans*, which are traditionally consumed. The authors found that these flowers are rich in carbohydrates, proteins, and minerals, with a high content of phenolic compounds and antioxidant activity, especially in *M. geometrizans*. They suggested that edible flowers are a good source of nutrients and bioactive compounds beneficial for health. Another study on flowers, this time from the genus *Dahlia*, reported that they have a high concentration of bioactive compounds

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and a nutritional composition that contributes beneficially to health (Rivera-Espejel et al., 2019). Flowers contain biochemical compounds, such as polyphenols and flavonoids, with functional properties, including antioxidant, anti-inflammatory, antimicrobial, anticancer, neuroprotective, antidiabetic, uricosuric, and anti-hemolytic effects (Prabawati et al., 2021).

The previously described studies highlight the nutritional value that flowers add to the human diet; the bioactive compounds contained therein provide health benefits. Therefore, both the ethnobotanical documentation of traditional recipes made with flowers and the analysis of their nutritional contribution are necessary efforts today.

Modern diets are increasingly made up of industrialized, energy-dense, nutrient-poor foods rich in refined flours, fats, and sugars, which poses serious health risks. Healthy and diverse diets largely based on plant-derived foods can reduce diet-related diseases (Dwivedi et al., 2017). On the other hand, the consumption of edible flowers strengthens food security, preserves traditional knowledge, diversifies the diet, contributes to the intake of micronutrients, and has beneficial effects on health. Therefore, the present study aimed to document the ethnobotanical knowledge of fourteen edible flower species native to Oaxaca, Mexico, and to determine their proximate composition, mineral content, bioactive compounds (total phenols and flavonoids), and antioxidant activity (ABTS and DPPH assays).

Materials and methods

Research design

This study employed a mixed-methods approach. The initial phase utilized a qualitative research design focused on ethnobotanical interviews to document local knowledge related to edible flowers, including harvesting sites, preparation methods, and seasonal availability. The subsequent phase involved quantitative laboratory analyses to determine the nutritional composition, mineral content, bioactive compounds, and antioxidant activity of selected flower species.

Sampling of interviewees

A snowball sampling technique was employed to identify key informants with extensive ethnobotanical knowledge of edible plants across multiple municipalities in Oaxaca, Mexico, including Ixtlán de Juárez, San Juan Juquila Vijanos, San Pedro Mixtepec, San Pedro Teozacoalco, Miahuatlán de Porfirio Díaz, San Miguel Etla, San Juan Tabaá, Villa de Zaachila, Ocotlán de Morelos, San Sebastián Coatlán, and Cuilapam de Guerrero. A total of 10 participants were interviewed per community. The majority of informants were homemakers actively engaged in the collection and preparation of edible plant species.

Collection and identification of study species

Based on ethnobotanical information provided by the interviewees, fourteen species of edible flowering plants native to Mexico were selected in accordance with the *Checklist of the Native Vascular Plants of Mexico* (Villaseñor, 2016). Some species were identified in the field, while others were collected as herbarium specimens, pressed, and deposited at the CIIDIR-IPN Oaxaca herbarium for subsequent taxonomic identification.

Proximate and mineral content analysis

Sample preparation

Six kilograms of flowers from each species were collected between January and November of 2024. The samples were washed thoroughly, cut into smaller pieces, and dried in an oven at 40 ºC until a constant weight was attained. Subsequently, the dried samples were ground using a pestle and mortar, stored in amber glass bottles, and stored at room temperature until further analysis.

Proximate analysis

The moisture, ash, fiber, fat, protein, and energy contents of the flower samples were determined following the standard procedures outlined by the Association of Official Analytical Chemists (AOAC, 2000). Moisture content was assessed by drying the samples in an oven at 105 °C until a constant weight was obtained. Ash content was determined by incinerating the residue at 550 °C for 8 hours. Total dietary fiber was quantified by sequential acid and alkaline digestion using H_2SO_4 and NaOH, followed by incineration of the residual material. Fat content was measured using the Soxhlet extraction method, while protein concentration was determined via the Kjeldahl method Total carbohydrate content was estimated by difference (100 g minus the sum of moisture, ash, fiber, fat, and protein). Results were expressed as grams per 100 grams of fresh weight (g/100 g FW).

The caloric energy content of each sample was calculated using standard conversion factors: 9 kcal g^{-1} for fat, and 4 kcal g^{-1} for both protein and carbohydrates.

Mineral content analysis

The concentrations of macrominerals—potassium (K), calcium (Ca), phosphorus (P), magnesium (Mg), and sodium (Na)—and micromine-rals—iron (Fe), manganese (Mn), and zinc (Zn)—were determined. A total of 400 grams of dried, powdered sample from each species was subjected to acid digestion using a mixture of HNO_3/$HClO_4$/H_2O_2 and H_2SO_4/$HClO_4$/H_2O_2.

Potassium and sodium concentrations were quantified using flame emission spectrophotometry (Lachat Instruments). Phosphorus content was determined by UV-visible spectrophotometry (Jenway 61715), while calcium, magnesium, iron, manganese, and zinc were measured using atomic absorption spectrophotometry (GBC Scientific Equipment, Mexico). All results were calculated and expressed as milligrams per 100 grams of fresh weight (mg/100 g FW).

Total phenolic content, flavonoids, and antioxidant capacity

Extracts were prepared by mixing 10 mg of powdered flower sample with 90% methanol and adjusting the volume to 20 mL. These extracts were used for the quantification of total phenolic content, flavonoids, and antioxidant activity by the ABTS and DPPH radical scavenging assays (Do et al., 2014; Godínez-Santillán et al., 2019). Absorbance measurements were performed using a Shimadzu UV-1800 spectrophotometer (Shimadzu, Japan).

Total phenolic content

The total phenolic content was determined using the Folin-Ciocalteu method, with slight modifications (Singleton and Rossi, 1965). Briefly, 1 mL of distilled water, 1 mL of 5% Na_2CO_3, and 1 mL of either diluted gallic acid (for the calibration curve) or the supernatant from the methanolic extract were added to a vial, followed by 1 mL of Folin-Ciocalteu reagent. The mixture was incubated at room temperature for 1 hour in the dark. Absorbance was measured at 750 nm using a UV-visible spectrophotometer. The total phenolic content was calculated based on a gallic acid calibration curve and expressed as milligrams of gallic acid equivalents per 100 grams of fresh weight (mg GAE/100 g FW).

Total flavonoid content

The total flavonoid content was determined following the method described by Chang et al. (2002), with minor modifications. In a vial, 150 µL of $NaNO_2$ and 2 mL of either quercetin solution (for the calibration curve) or methanolic flower extract were added and allowed to stand for 5 minutes. Subsequently, 150 µL of $AlCl_3 \cdot H_2O$ was added, and the mixture was left to rest for 6 minutes, protected from light. Finally, 1 mL of 1 M NaOH was added, and the mixture was shaken thoroughly. Absorbance was measured at 490 nm using a UV-visible spectrophotometer. Flavonoid content was calculated based

on a quercetin calibration curve and expressed as milligrams of quercetin equivalents per 100 grams of fresh weight (mg QE/100 g FW).

Antioxidant activity

Antioxidant capacity was assessed using two methods: the inhibitory activity of the 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radical (ABTS·+) and the radical-scavenging capacity of the 2,2-diphenyl-1-picrylhydrazyl (DPPH·) radical. The ABTS and DPPH results were expressed as μmol Trolox equivalents (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) per gram of fresh sample (μmol TE/g FW).

The determination of antioxidant activity in the samples was performed using the ABTS radical technique (Re et al., 1999) with some adjustments. The ABTS was prepared by oxidation with $K_2S_2O_8$ and left in the dark for 16 hours. The mixture was then diluted with methanol to adjust its absorbance to 0.7 at 734 nm. Next, 900 μL of the ABTS radical solution was mixed with 100 μL of extract and left in the dark for 30 minutes. Different concentrations of Trolox were used for the calibration curve (50, 100, 200, 300, 400, 500 μL of Trolox). Absorbance was measured at a wavelength of 734 nm.

The evaluation of antioxidant capacity using the DPPH assay was performed according to the method described by Brand-Williams et al. (1995) with some adjustments. In a vial, 100 μL of extract and 2.9 mL of DPPH solution (adjusted to an absorbance of 1.25 mL at a wavelength of 517 nm) were added. The mixture was incubated for 30 minutes at room temperature, and absorbance was read at 517 nm. For the calibration curve, different concentrations of Trolox were used (0, 100, 200, 300, 400, 500, 600 μL of Trolox).

Statistical analysis

The results are presented as mean ± standard deviation. All analyses—including nutritional composition, mineral content, total phenolics, flavonoids, and antioxidant capacity—were conducted in triplicate for each species. Data distribution was assessed using the Shapiro-Wilk normality test. In cases where data followed a normal distribution, the analysis of variance (ANOVA) was performed, followed by Tukey's post hoc test. For non-normally distributed data, the Kruskal–Wallis test was applied, followed by a series of Mann-Whitney U tests with Bonferroni correction for multiple comparisons. Additionally, Pearson correlation analyses were conducted to assess the relationships between total phenolic content, flavonoid content, and antioxidant activity (DPPH and ABTS assays), with results expressed as correlation coefficients. Statistical significance was set at $p < 0.05$. All analyses were performed using R statistical software (version 4.4.2) and RStudio (version 2024.12.0+467).

Results and discussion

This study analyzed fourteen species of native edible flowers consumed in eleven rural and indigenous communities of Oaxaca, Mexico. These species belong to six botanical families: Arecaceae, Asparagaceae, Cactaceae, Cucurbitaceae, Fabaceae, and Malvaceae.

The consumption of these flowers persists within indigenous and rural communities and remains an integral part of traditional Oaxacan cuisine. The edible flowers included in this study are harvested from diverse agroecosystems, including home gardens, *milpas* (traditional maize fields), and coffee plantations, as well as from natural ecosystems such as dry forests, tropical forests, and other humid environments. Furthermore, their consumption extends across a wide geographical range, from coastal areas to mountainous regions of Oaxaca. These flowers are prepared and consumed in various traditional ways: roasted, cooked with eggs, pickled, boiled with salt, added to salads, used as fillings for *quesadillas*, fried, or incorporated into traditional beverages such as *tejate*, as detailed in Tab. 1.

Proximate analysis

The proximate composition of the flowers is described in Tab. 2. The flowers showed high moisture content, ranging from 81.33 ± 0.38 g/100 g FW in *D. speciosus* to 92.07 ± 0.79 g/100 g FW in *H. undatus*, similar to what has been described for wild edible flowers in the states of Puebla and Hidalgo in Mexico (Sotelo et al., 2007). In the studied communities, fresh consumption is common, with most flowers being cooked shortly after harvesting. However, in some cases, preservation methods such as pickling are used—for example, with papalomé (*A. potatorum*) and tepejilote (*C. tepejilote*) flowers.

The species with the highest ash contents were *C. nana*, *C. undatus*, *C. atrovirens*, and *Y. filifera*, with 2.18 ± 0.11 g/100 g FW, 2.16 ± 0.04 g/100 g FW, 2.06 ± 0.11 g/100 g FW, and 1.93 ± 0.09 g/100 g FW, respectively. These values were higher than those reported for other edible flower species such as sunflower (*Helianthus annuus*), calendula (*Calendula officinalis*), and Hawaiian hibiscus (*Hibiscus rosa-sinensis*), which range from 0.72 to 1.40 g/100 g FW (Bahuguna et al., 2018; De Lima-Franzen et al., 2019).

The highest fiber content was found in *C. nana* (3.54 ± 0.18 g/100 g FW), followed by *P. coccineus* (2.81 ± 0.14 g/100 g FW), *D. americana* (2.13 ± 0.08 g/100 g FW), and *C. atrovirens* (1.87 ± 0.11 g/100 g FW). Comparable fiber levels have been reported in other dahlias consumed in Mexico (Lara-Cortés et al., 2014) and in flowers from the Zingiberaceae family consumed in Thailand (Rachkeeree et al., 2018). Dietary fiber contributes significantly to gastrointestinal health through its structural and physicochemical properties, making it particularly relevant in managing obesity and metabolic syndrome (Deehan et al., 2024).

The studied flowers exhibited low fat concentrations, ranging from 0.12 ± 0.03 g/100 g FW in *H. undatus* to 0.55 ± 0.04 g/100 g FW in *C. nana*. The low-fat content of edible flowers is a desirable trait in natural and health-oriented foods. The growing demand for low-fat, low-calorie products reflects increasing public efforts to address health concerns, manage body weight, and adopt healthier dietary patterns (Sandrou and Arvanitoyannis, 2000).

P. coccineus had the highest protein content, with 2.95 ± 0.15 g/100 g FW, followed by *Q. funebris* (2.53 ± 0.09 g/100 g FW), *C. atrovirens* (2.34 ± 0.13 g/100 g FW), and *Y. filifera* (2.27 ± 0.15 g/100 g FW). These species provide an additional source of protein, helping to complement the traditional Mexican diet, and their content is similar to that reported in other studies on edible flowers (Rachkeeree et al., 2018; De Lima-Franzen et al., 2019).

The carbohydrate content ranged from 2.90 ± 0.12 g/100 g FW in *H. undatus* to 13.81 ± 0.67 g/100 g FW in *D. speciosus*. The average carbohydrate content of the species studied was similar to that found in edible plants from traditional markets in southern Mexico (Bautista-Cruz et al., 2011; Pascual-Mendoza et al., 2023). These resources are thus an excellent option for those looking to control their carbohydrate intake, such as people with diabetes or those following a low-carbohydrate diet.

The species with the highest energy content were *D. speciosus* (63.88 ± 3.04 kcal/100 g FW), *C. atrovirens* (52.49 ± 2.04 kcal/100 g FW), *P. coccineus* (52.40 ± 2.06 kcal/100 g FW), and *Q. funebris* (47.30 ± 0.79 kcal/100 g FW). Evidence supports the benefits of plant-based diets for weight management, cardiovascular health, and diabetes prevention and treatment. However, to maximize these benefits, such diets must be carefully planned to ensure adequate intake of essential micronutrients (Viroli et al., 2023).

Mineral contents

Minerals play essential roles in the human body, participating in a wide range of physiological functions—from the formation of strong bones to the transmission of nerve impulses—and thereby contribute significantly to overall health (Gharibzahedi and Jafari, 2017).

Tab. 1: Ethnobotanical description of edible flowers traditionally consumed in indigenous communities of Oaxaca, Mexico.

Botanical family & scientific name	Common Name	Collection Site	Habitat	Form of Consumption	Coordinates, Climate classification, Herbarium ID	Flowering season
Arecaceae						
Chamaedorea atrovirens Mart.	Flor de tepejilote chico/chaparro	Ixtlán de Juárez, Sierra Norte	Coffee plantations, family gardens, humid forests, and dry forests.	The inflorescence is roasted on the grill or cooked scrambled with eggs.	17°24'28"N 96°31'34"W Cwb OAX-SPM1	January-May
Chamaedorea tepejilote Liebm.	Flor de tepejilote grande	San Juan Juquila Vijanos, Sierra Norte	Coffee plantations, family gardens, humid forests, and dry forests.	The inflorescence is roasted on the grill and used in the preparation of pickled chilies.	17°21'36"N 96°18'08"W Cwb OAX-SPM2	January-May
Cryosophila nana (Kunth) Blume ex Salomon	Flor de coateco, soyamiche	San Pedro Mixtepec, Costa	Tropical forest, humid forest.	The inflorescence is cooked on the coals or boiled.	16°00'35"N 97°03'26"W Aw OAX-SPM3	November-March
Asparagaceae						
Agave potatorum Zucc.	Flor de papalomé	San Pedro Teozacoalco, Mixteca	House courtyards, plantations, deciduous tropical forests.	The flower buds are consumed boiled with salt, scrambled with eggs, or pickled.	17°00'39"N 97°16'43"W Cwb OAX-SPM4	August-December
Yucca filifera Chabaud	Flor de izote	Miahuatlán de Porfirio Díaz, Sierra Sur	Family gardens, roadsides, shrublands, and grasslands.	The flowers are consumed boiled with salt or scrambled with eggs.	16°23'52"N 96°32'38"W Cwb OAX-SPM5	February-June
Cactaceae						
Acanthocereus tetragonus (L.) Hummelinck	Flor de cruceta	San Miguel Etla, Valles Centrales	Nopal or other edible cactus fields, roadsides, dry forests.	The inflorescence is consumed boiled with salt or served in a salad with tomato and onion.	17°12'54"N 96°46'53"W Cwb OAX-SPM6	March-August
Hylocereus undatus (Haw.) Britton & Rose	Flor de pitahaya	San Juan Tabaá, Sierra Norte	Family gardens, coffee plantations, other plantations, dry forests.	The flowers are consumed boiled with salt or added to molcajete salsa with beans.	17°18'08"N 96°11'35"W Cwa SPM7	June-August
Disocactus speciosus (Cav.) Barthlott	Flor de junco	Villa de Zaachila, Valles Centrales	Family gardens, dry forests.	The flowers are boiled with salt and garlic, then added to the bean pot during the final boiling stage.	16°56'12"N 96°50'45"W Cwb OAX-SPM8	May-August
Cucurbitaceae						
Cucurbita argyrosperma K. Koch	Flor de chilacayota	San Juan Juquila Vijanos, Sierra Norte	Family gardens, milpas.	The flowers are used to fill quesadillas and are prepared in stews.	17°21'26"N 96°18'07"W Cwb OAX-SPM9	April-August
Cucurbita pepo L.	Flor de calabaza	Ocotlán de Morelos, Valles Centrales	Family gardens, milpas.	The flowers are used to fill quesadillas and are prepared in stews.	16°48'44"N 96°43'33"W Cwb OAX-SPM10	April-September
Fabaceae						
Diphysa americana (Mill.) M. Sousa	Flor de gallito, cuachepil	San Sebastián Coatlán, Sierra Sur	Family gardens, coffee plantations, milpas, roadsides.	The flowers are consumed boiled with salt or fried with eggs.	16°12'17"N 96°49'47"W Cwb OAX-SPM11	March-July
Erythrina americana Mill.	Flor de zompantle, machetitos, gasparín	San Juan Juquila Vijanos, Sierra Norte	Family gardens, coffee plantations, edges of the milpa, deciduous tropical forests, scrublands, roadsides.	The flowers are consumed boiled with salt, fried with eggs, or eaten with beans.	17°21'28"N 96°18'11"W Cwb OAX-SPM12	March-May
Phaseolus coccineus L.	Flor de frijolón	San Juan Juquila Vijanos, Sierra Norte	Family gardens, milpas.	The flowers are consumed boiled with salt, fried with eggs, in beans, or in other stews like *amarillo* (a thick sauce made with tomato, masa, guajillo chili, onion, and hoja santa (*Piper auritum* Kunth)).	17°21'29"N 96°18'03"W Cwb OAX-SPM13	May-August
Malvaceae						
Quararibea funebris (La Llave) Vischer	Flor rosita de cacao	Cuilapam de Guerrero, Valles Centrales	Family gardens, edges of the milpa.	The flowers are roasted on a griddle, then ground with cacao, corn, and mamey seeds to produce the paste used in the preparation of the traditional beverage *tejate*.	16°58'52"N 96°46'08"W Cwb OAX-SPM14	March-June

The results of the mineral content analysis of the studied flowers are presented in Tab. 3.

Regarding macrominerals, the concentrations of potassium (K), calcium (Ca), phosphorus (P), magnesium (Mg), and sodium (Na) were comparable to those reported in other studies on edible flowers and leafy vegetables consumed by various populations (Gharibzahedi and Jafari, 2017; González-Barrio et al., 2018; Rop et al., 2012; Pascual-Mendoza et al., 2023; Jadhav et al., 2023). Notably, the flowers exhibited low sodium content, ranging from 8.44 ± 0.26 mg/100 g FW in *C. pepo* to 65.15 ± 1.43 mg/100 g FW in *Y. filifera*. This is nutritionally relevant, as low-sodium diets are associated with reduced blood pressure and lower risk of cardiovascular complications, underscoring the importance of strategies to limit sodium intake at the population level (Suckling and Swift, 2015).

The highest iron (Fe) contents were found in *C. argyrosperma* (3.58 ± 0.15 mg/100 g FW), *C. tepejilote* (3.32 ± 0.18 mg/100 g FW), *Q. funebris* (2.36 ± 0.12 mg/100 g FW), and *A. tetragonus* (1.93 ± 0.04). These values exceed those reported for edible flowers like *Tropaeolum majus*, *Tagetes erecta*, and *Spilanthes oleracea* (Navarro-González et al., 2014). These differences may be attributed to variations in soil composition, pH, organic matter, and other environmental factors influencing iron uptake (Grusak and Dellapenna, 1999).

Manganese (Mn) content ranged from 3.45 ± 0.22 mg/100 g FW in *D. americana* to 0.35 ± 0.04 mg/100 g FW in *E. americana*. These flowers may provide the recommended daily manganese intake for adult women and men (1.8 and 2.3 mg/day, respectively) (Institute of Medicine, 2006).

Tab: 2: Nutritional composition of fourteen native edible flowers traditionally consumed in indigenous communities of Oaxaca, Mexico.

Native edible flower	Moisture (g/100 g FW)	Ash (g/100 g FW)	Fiber (g/100 g FW)	Fat (g/100 g PF)	Protein (g/100 g FW)	Carbohydrate (g/100 g FW)	Energy (Kcal/100 g FW)
C. atrovirens	83.43 ± 0.40i	2.06 ± 0.11ab	1.87 ± 0.11cd	0.38 ± 0.02abc	2.34 ± 0.13bc	9.92 ± 0.34b	52.49 ± 2.04b
C. tepejilote	85.71 ± 0.60h	1.86 ± 0.04bcd	1.62 ± 0.08def	0.21 ± 0.06cde	1.99 ± 0.07de	8.62 ± 0.41bc	45.25 ± 2.39cd
C. nana	88.22 ± 0.11ef	2.18 ± 0.11a	3.54 ± 0.18a	0.55 ± 0.04a	1.52 ± 0.10ghi	4.04 ± 0.16gh	27.03 ± 1.13gh
A. potatorum	90.43 ± 0.33bcd	1.82 ± 0.07cd	1.12 ± 0.06hi	0.15 ± 0.08de	1.38 ± 0.07hij	5.09 ± 0.28fg	28.15 ± 2.14g
Y. filifera	87.16 ± 0.39fg	1.93 ± 0.09bc	1.34 ± 0.15fgh	0.27 ± 0.03bcde	2.27 ± 0.15bcd	7.03 ± 0.33de	39.66 ± 2.27de
A. tetragonus	89.53 ± 0.35cd	0.92 ± 0.03g	1.71 ± 0.09de	0.18 ± 0.04de	1.66 ± 0.11fgh	6.08 ± 0.24ef	32.28 ± 1.56f
H. undatus	91.45 ± 0.11ab	2.16 ± 0.04a	1.56 ± 0.12ef	0.12 ± 0.03e	1.83 ± 0.05efg	2.90 ± 0.12h	19.84 ± 1.45i
D. speciosus	81.33 ± 0.38j	1.76 ± 0.13cd	1.45 ± 0.15efg	0.41 ± 0.08av	1.24 ± 0.13ij	13.81 ± 0.67a	63.88 ± 3.04a
C. argyrosperma	92.07 ± 0.79a	1.64 ± 0.12de	1.24 ± 0.03ghi	0.45 ± 0.06ab	1.38 ± 0.16hij	3.21 ± 0.09h	22.39± 2.14hi
C. pepo	90.50 ± 0.31bc	1.49 ± 0.12ef	0.96 ± 0.02i	0.16± 0.07de	1.85 ± 0.12ef	5.04 ± 0.23fg	29.03 ± 2.14fg
D. americana	86.37 ± 0.40gh	1.90 ± 0.06bcd	2.13 ± 0.08c	0.17 ± 0.05de	2.09 ± 0.18cde	7.38 ± 0.24cd	39.40 ± 2.88e
E. americana	89.30 ± 0.20de	1.83 ± 0.08bcd	1.67 ± 0.16de	0.18 ± 0.03de	1.14 ± 0.08j	5.90 ± 0.31ef	29.73 ± 1.68fg
P. coccineus	83.40 ± 0.29i	0.97 ± 0.17g	2.81 ± 0.14b	0.22 ± 0.08cde	2.95 ± 0.15a	9.66 ± 0.14b	52.40 ± 2.06b
Q. funebris	86.20 ± 0.15gh	1.26 ± 0.13f	1.19 ± 0.11hi	0.29 ± 0.04bcd	2.53 ± 0.09b	8.64 ± 0.10bc	47.30 ± 0.79c

All values are expressed as means ± standard deviation (n = 3). Ash and fiber contents were analyzed using ANOVA followed by Tukey's post hoc test. The remaining nutrients were evaluated using the Kruskal–Wallis test, with pairwise comparisons conducted via the Mann–Whitney U test and Bonferroni correction. Different letters within the same column indicate statistically significant differences between species ($p < 0.05$).

Tab. 3: Macro- and micromineral composition of fourteen native edible flowers consumed in indigenous communities of Oaxaca, Mexico.

Species	Macrominerals					Microminerals		
	K (mg/100 g FW)	Ca (mg/100 g FW)	P (mg/100 g FW)	Mg (mg/100 g FW)	Na (mg/100 g FW)	Fe (mg/100 g FW)	Mn (mg/100 g FW)	Zn (mg/100 g FW)
C. atrovirens	343.18 ± 3.54g	44.27 ± 1.68j	64.95 ± 0.63d	38.06 ± 1.52h	45.35 ± 1.92c	0.92 ± 0.04gh	0.50 ± 0.02efgh	0.58 ± 0.07hi
C. tepejilote	640.45 ± 4.12c	84.63 ± 2.21g	27.82 ± 0.60i	93.99 ± 1.34e	56.16 ± 2.06b	3.32 ± 0.18b	1.78 ± 0.13c	2.75 ± 0.05a
C. nana	347.37 ± 3.39g	176.50 ± 2.81a	123.41 ± 0.52a	221.74 ± 3.19a	23.48 ± 0.63e	0.88 ± 0.06h	0.48 ± 0.03fgh	0.91 ± 0.04f
A. potatorum	422.14 ± 5.60e	55.91 ± 1.54i	37.39 ± 0.96g	46.43 ± 1.03g	8.67 ± 0.35h	1.15 ± 0.09fg	1.28 ± 0.10d	0.78 ± 0.05fg
Y. filifera	837.56 ± 2.82a	115.84 ± 3.44e	65.02 ± 0.47d	31.10 ± 1.38ij	65.15 ± 1.43a	0.56 ± 0.03i	0.58 ± 0.04efgh	1.45 ± 0.08d
A. tetragonus	179.20 ± 2.26k	63.39 ± 1.01h	27.88 ± 0.87i	32.80 ± 1.26hi	18.63 ± 0.42f	1.93 ± 0.04d	0.69 ± 0.07efg	0.52 ± 0.06hi
H. undatus	281.74 ± 2.55h	97.34 ± 2.05f	97.24 ± 1.07b	89.70 ± 1.56e	26.36 ± 0.97e	0.87 ± 0.04h	0.45 ± 0.03gh	0.78 ± 0.06fg
D. speciosus	223.20 ± 3.51j	55.24 ± 1.66i	85.54 ± 0.66c	155.32 ± 3.49c	10.61 ± 0.48gh	1.42 ± 0.05e	2.72 ± 0.16b	1.18 ± 0.25e
C. argyrosperma	191.15 ± 3.64k	36.55 ± 1.17k	21.26 ± 0.80j	25.44 ± 0.71j	31.40 ± 0.66d	3.58 ± 0.15a	0.58 ± 0.05efgh	0.68 ± 0.07gh
C. pepo	236.32 ± 2.71i	45.68 ± 2.10j	19.43 ± 0.96j	18.78 ± 0.46k	8.44 ± 0.26h	1.70 ± 0.06d	0.84 ± 0.09e	0.43 ± 0.03i
D. americana	683.95 ± 1.59b	143.02 ± 2.88c	46.15 ± 0.34f	57.31 ± 0.58f	9.45 ± 0.28h	0.54 ± 0.05i	3.45 ± 0.22a	2.36 ± 0.12b
E. americana	582.71 ± 2.45d	36.37 ± 2.25k	65.49 ± 0.62d	44.45 ± 1.36g	23.68 ± 1.02e	0.96 ± 0.06gh	0.35 ± 0.04h	0.83 ± 0.07f
P. coccineus	245.90 ± 2.08i	126.94 ± 2.40d	60.04 ± 0.56e	107.86 ± 2.35d	13.32 ± 0.40g	1.35 ± 0.08ef	0.62 ± 0.04efgh	1.79 ± 0.06c
Q. funebris	387.28 ± 2.84f	159.84 ± 2.31b	31.62 ± 1.05h	185.67 ± 3.32b	12.74 ± 0.45g	2.36 ± 0.12c	0.80 ±0.06ef	0.89 ± 0.05f

All values are presented as means ± standard deviation (n = 3). Mineral contents were analyzed using the Kruskal–Wallis test, followed by a series of Mann–Whitney U tests with Bonferroni correction as a post hoc analysis. Species with different letters within the same column indicate statistically significant differences in their means ($p < 0.05$).

The flowers with the highest zinc (Zn) content were *C. tepejilote* (2.75 ± 0.05 mg/100 g FW), *D. americana* (2.36 ± 0.12 mg/100 g FW), *P. coccineus* (1.79 ± 0.06 mg/100 g FW), and *Y. filifera* (1.45 ± 0.08 mg/100 g FW), which is consistent with results reported for flowers cultivated in family gardens by farmers in India (Bahuguna et al., 2018). In developing countries, mineral deficiencies severely impact health by reducing disease resistance and causing problems such as blindness and intellectual disabilities (FAO, 2010). Traditional Mexican edible flowers represent an accessible source of essential minerals that may contribute to the prevention of these health issues.

Phenolic compounds, flavonoids, and antioxidant capacity

Polyphenols are one of the most common and widespread groups of metabolites in flowering plants, produced in all vegetative organs as well as in flowers and fruits. They are considered secondary metabolites involved in the chemical defense of plants (Ferrazzano et al., 2011). Polyphenols are characterized by the presence of one or more aromatic rings with two or more hydroxyl groups (De Araújo et al., 2021). These compounds include flavonoids, phenolic acids, coumarins, stilbenes, and lignans (Hano and Tungmunnithum, 2020).

Tab. 4 summarizes the total phenolic content, flavonoid concentration, and antioxidant capacity of the studied flower species. Overall, phenolic levels were higher than flavonoid concentrations across all samples. The phenolic concentrations found in this study are consistent with previous reports on edible flowers from Poland, Japan, and Portugal (Stefaniak and Grzeszczuk, 2019; Chensom et al., 2019; Gonçalves et al., 2020). The highest phenolic values were observed in *D. speciosus* (28.34 ± 0.10 mg GAE/g FW), *E. americana* (23.10 ± 0.56 mg GAE/g FW), and *P. coccineus* (20.72 ± 0.34 mg GAE/g FW). Variations in phenolic content may be attributed to variations in metabolic activity and environmental conditions. Phenolic synthesis is known to be influenced by factors such as UV radiation, temperature, and altitude (Brahmi et al., 2022), while soil composition, precipitation, and other ecological variables also play a role in the accumulation of these compounds (Zargoosh et al., 2019).

The flavonoid content ranged from 3.0 ± 0.21 mg QE/g FW in *C. pepo* to 16.12 ± 0.19 mg QE/g FW in *D. speciosus*. These results are comparable to the total flavonoid concentrations reported for edible flowers consumed in Italy (Loizzo et al., 2016) and traditional Mexican dahlia flowers (Rivera-Espejel et al., 2019).

These flowers have been valued in traditional medicine for centuries, likely due to the potential health benefits conferred by their bioactive compounds, which include anti-inflammatory, antioxidant, and neuroprotective effects (Abbaszadeh et al., 2025). Their biological activities are mainly attributed to their ability to scavenge or inhibit reactive oxygen and nitrogen species, transfer electrons to free radicals, and activate antioxidant enzymes. Moreover, they help mitigate oxidative stress and inflammation, showing promising effects in the prevention of various diseases such as diabetes, obesity, cancer, cardiovascular diseases, osteoporosis, and neurodegenerative disorders (De Araújo et al., 2021).

Antioxidant capacity evaluation

The antioxidant capacity was evaluated using DPPH and ABTS techniques. The species with the highest antioxidant capacities using the DPPH method were *D. speciosus* (12.61 ± 0.12 µmol TE/g FW), *P. coccineus* (10.25 ± 0.21 µmol TE/g FW), *E. americana* (11.23 ± 0.12 µmol TE/g FW), and *Q. funebris* (9.34 ± 0.14 µmol TE/g FW). This is consistent with the antioxidant capacity obtained using the DPPH method for edible flowers produced under organic farming, without pesticides, fertilizers, or other flower bloom intensifiers (Gonçalves et al., 2020), similar to the methods by which the flowers in this study are typically cultivated.

Regarding the results obtained using the ABTS technique, the species with the highest antioxidant capacities were *P. coccineus* (9.48 ± 0.36 µmol TE/g FW), *D. speciosus* (8.27 ± 0.24 µmol TE/g FW), and *E. americana* (7.33 ± 0.27 µmol TE/g FW), which aligns with the antioxidant capacity of flowers consumed in Poland (Gonçalves et al., 2020).

Correlation between total phenolic content, flavonoid content, and antioxidant capacity

A strong correlation was observed between the total phenolic content

Tab. 4: Concentrations of phenolic compounds, flavonoids, and antioxidant capacity in fourteen edible flowers consumed by indigenous communities in Oaxaca, Mexico

Native edible flower	TPC (mg GAE/g FW)	TFC (mg QE/ 100 g FW)	DPPH (µmol TE/g FW)	ABTS (µmol TE/g FW)
C. atrovirens	9.23 ± 0.88gh	6.39 ± 0.48f	3.95 ± 0.44gh	2.90 ± 0.15ghi
C. tepejilote	7.40 ± 0.40i	5.25 ± 0.40h	5.28 ± 0.36f	3.17 ± 0.22g
C. nana	10.04 ± 0.72g	7.81 ± 0.16de	4.47 ± 0.25g	3.04 ± 0.15gh
A. potatorum	12.14 ± 0.51f	8.19 ± 0.31d	5.49 ± 0.23f	4.44 ± 0.23f
Y. filifera	8.43 ± 0.27hi	4.61 ± 0.34g	3.33 ±0.19hi	2.35 ± 0.09i
A. tetragonus	9.58 ± 0.44gh	5.24 ± 0.08g	5.62 ± 0.22f	3.21 ± 0.06g
H. undatus	14.12 ± 0.16e	11.25 ± 0.14c	7.48 ± 0.31d	6.50 ± 0.30d
D. speciosus	28.34 ± 0.10a	16.12 ± 0.19a	12.61 ± 0.12a	8.27 ± 0.24b
C. argyrosperma	4.53 ± 0.26j	3.36 ± 0.18j	3.23 ± 0.09hi	2.45 ± 0.20hi
C. pepo	3.50 ± 0.27j	3.00 ± 0.21i	2.70 ± 0.14i	2.52 ±0.08hi
D. americana	12.25 ± 0.20f	7.39 ± 0.14e	6.38 ± 0.16e	5.47 ± 0.20e
E. americana	23.10 ± 0.56b	15.23 ± 0.42b	10.25 ± 0.21a	7.33 ± 0.27c
P. coccineus	20.72 ±0.34c	14.50 ± 0.31b	11.23 ± 0.12b	9.48 ± 0.36a
Q. funebris	16.50 ± 0.47d	11.30 ± 0.16c	9.34 ± 0.14c	6.73 ± 0.15d

All values are expressed as means ± standard deviation (n = 3). All bioactive compounds were analyzed using the Kruskal–Wallis test, followed by a series of Mann–Whitney U tests with Bonferroni correction as a post hoc analysis. Species with different letters within the same column indicate statistically significant differences in their means ($p < 0.05$).

TPC, total phenolic content; TFC, total flavonoid content; DPPH, 2,2-diphenyl-1-picrylhydrazyl; ABTS, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); GAE, gallic acid equivalents; QE, quercetin equivalents; ET, Trolox equivalents.

(TPC) and flavonoid content (r = 0.964), as well as between TPC and antioxidant capacity, measured by both DPPH (r = 0.965) and ABTS (r = 0.908) assays. These findings suggest that phenolic compounds play a crucial role in the antioxidant activity of the flowers. This relationship between TPC and antioxidant activity has been consistently reported in other studies on edible flowers, where strong positive correlations were also found, with polyphenols identified as the primary contributors to the observed antioxidant effects (Demasi et al., 2019; Kritsi et al., 2022). Chensom et al. (2019) further highlighted that the antioxidant activity of edible flowers is largely determined by the number and arrangement of hydroxyl groups in the phenolic compounds, which enhances their radical-scavenging capacity.

The consumption of foods rich in polyphenols and flavonoids, and with high antioxidant capacity, has gained significant interest in recent years due to their beneficial effects. There is a growing demand for functional foods in the global market, making it essential to investigate how to process edible flowers to preserve their quality and produce functional foods from them (Prabawati et al., 2021).

The nutritional assessment of native foods or edible native flowers in communities is an important step following the documentation of traditional knowledge, which helps protect culinary heritage as well as cultivation and collection spaces. Nutritional quantification helps assess the contribution of local foods at the community, regional, or national level and may inform public policies that promote their nutritional and health benefits.

Conclusion

This study highlights the nutritional and functional significance of traditional edible flowers in indigenous communities of Oaxaca. The consistent presence of fiber, essential minerals, and antioxidant compounds in these flowers suggests they are not only culturally significant but also nutritionally valuable. Their inclusion in local diets represents a sustainable and health-promoting food source that aligns with global trends toward functional and plant-based diets. These findings reinforce the need to preserve and promote traditional food systems and encourage their incorporation into public health and nutrition policies focused on local and culturally relevant resources.

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Conflict of interest

The authors declare that there are no potential conflicts of interest.

Ethical approval

The study was approved by the Institutional Ethics Review Board of the first author's university on January 10, 2023.

Informed consent, both oral and written, was obtained prior to participation, with the women being informed about the study's purpose.

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