applied sciences

MDPI

Article

Phenolic Compounds and Antioxidant Activity in Edible Flower Species from Oaxaca

Rubí Marcos-Gómez [1], Araceli M. Vera-Guzmán [1,*], Mónica L. Pérez-Ochoa [1], Laura Martínez-Martínez [1], Sanjuana Hernández-Delgado [2], David Martínez-Sánchez [1] and José L. Chávez-Servia [1,*]

[1] CIIDIR-Oaxaca, Instituto Politécnico Nacional, Santa Cruz Xoxocotlán 71230, Oaxaca, Mexico; rmarcosg2100@alumno.ipn.mx (R.M.-G.); mperezo1800@alumno.ipn.mx (M.L.P.-O.); lamartinez@ipn.mx (L.M.-M.); damartinezs@ipn.mx (D.M.-S.)

[2] Centro de Biotecnología Genómica, Instituto Politécnico Nacional, Reynosa 88710, Tamaulipas, Mexico; shernandezd@ipn.mx

* Correspondence: avera@ipn.mx (A.M.V.-G.); jchavezs@ipn.mx (J.L.C.-S.)

Abstract: In Mexico, the tradition of consuming flowers dates to pre-Columbian times, and flower consumption persists today; however, this practice is typically unknown outside the regions where flowers are used in local gastronomy. The aim of this work was to evaluate the variation in polyphenol and flavonoid contents and antioxidant activity in inflorescence samples. Samples of izote (*Yucca filifera*), maguey pulquero (*Agave salmiana*), cuachepil or guachepil (*Diphysa americana*), and tepejilote or pacaya (*Chamaedorea tepejilote*) were collected from different communities and regions of Oaxaca, Mexico, during 2022. Specifically, ten to eleven inflorescence samples were collected per species, and their polyphenol and flavonoid contents and antioxidant activity were evaluated using UV–visible spectrophotometry and reference standards. Significant differences were detected between and within samples depending on their geographical origin (collection locations); the environment and site influenced the composition of the samples for each species. Across all species, significant and positive correlations of the polyphenol and flavonoid contents were identified with the antioxidant activity detected via the DPPH and FRAP methods. The high variability in phenolic compound contents and antioxidant activity within each species shows that the nutritional and nutraceutical potential of flowers may complement diets at the family and communitarian levels.

Keywords: edible inflorescences; functional compounds; quelites; bioactive compounds

Citation: Marcos-Gómez, R.; Vera-Guzmán, A.M.; Pérez-Ochoa, M.L.; Martínez-Martínez, L.; Hernández-Delgado, S.; Martínez-Sánchez, D.; Chávez-Servia, J.L. Phenolic Compounds and Antioxidant Activity in Edible Flower Species from Oaxaca. *Appl. Sci.* **2024**, *14*, 3136. https://doi.org/10.3390/app14083136

Academic Editors: Ivona Elez Garofulić and Maja Repajić

Received: 19 March 2024
Revised: 5 April 2024
Accepted: 5 April 2024
Published: 9 April 2024

1. Introduction

Edible flowers are used in the gastronomy of all cultures and give dishes a wide range of colors, flavors, aromas, and nutritional and nutraceutical values. There are approximately 300,000 floral species globally, with an estimated 21,000 to 26,000 species in Mexico [1]. In Mexico, Mapes and Basurto [2] estimated that more than 100 species with edible flowers were grouped into 49 genera and 25 families, among which the families Agavaceae, Leguminosae, Arecaceae, Cactaceae, and Cucurbitaceae stand out. In general, in recent decades, the use of flowers in gastronomy has increased. However, in Mexico, it has been common in traditional cuisine since pre-Columbian times; for example, the inflorescences of huauzontle, tepejilote, maguey, izote, dahlia, maize, pumpkin, and others have been used. However, there is also ancient evidence of the consumption of flowers in Asia, ancient Greece, and Rome and, in the last decade, the consumption of dandelion (*Taraxacum officinale* (L.) Weber ex F.H. Wigg.) has become popular in Europe [3].

From a nutritional point of view, edible flowers can be grouped according to their contributions of pigments (e.g., carotenoids, anthocyanins, and chlorophylls), proteins, essential amino acids, minerals, saturated and unsaturated lipids, vitamins, and antioxidant bioactive compounds, although the concentrations vary according to the preparation used, from fresh to processed. One of the factors that has received the most attention in

recent research has been the use of flowers as sources of bioactive compounds, especially phenolic acids and flavonoids, which have functional potential in the prevention of chronic degenerative diseases, such as Alzheimer's disease and type II diabetes; they may also have antimicrobial, anti-cancer, and antiobesity effects, along with gastroprotective, cardioprotective, and diuretic properties [4–8]. However, the biosynthesis and accumulation of phenolic compounds in plants varies among species, populations, and phylogenetic origins, and their interactions with environmental factors (e.g., temperature, radiation, nutrition, and irrigation) as well as ontogenetic factors inherent to each plant species also have impacts [9–11].

One of the least-explored or unexplored aspects of edible flowers is the effect of environmental conditions during the growth of wild, ruderal, or backyard species on their contents of bioactive antioxidant compounds. Bautista et al. [12] noted that stressful environmental conditions induce the generation of reactive oxygen species, modify the activation of enzymatic and nonenzymatic systems, and, consequently, modify the processes of biosynthesis, translocation, and accumulation of bioactive compounds such as phenolic compounds, especially flavonoids, which are directly related to antioxidant activity. In this case, ecological conditions, the physicochemical characteristics of soils, and variations in soil moisture and climate conditions induce changes in the concentrations of phenolic compounds. Moore et al. [13] highlighted that the secondary metabolites present in a specific plant or organ can vary between and within individuals of the same species or population and are linked to micro- and macroenvironmental variations, plant ontogeny, and genetic variations.

The consumption of the inflorescence of izote (*Yucca filifera* Chabaud), maguey pulquero (*Agave salmiana* Otto ex Salm-Dyck), cuachepil (*Diphysa americana* (Mill.) M. Sousa), and tepejilote (*Chamaedorea tepejilote*) is common in Mexican gastronomic culture. The quantity and frequency of consumption of these flowers varies among regions, but the consumption of these flowers is preserved in traditional diets [6,14]. Different concentrations of vitamins, minerals, fiber, crude protein, amino acids, fatty acids, and phenolic compounds, such as quercetin, coumaric acid, ferulic acid and kaempferol, have been reported in izote flowers [15,16]. High contents of fiber, proteins, amino acids, phenolic acids, flavonoids, carotenoids, ascorbic acid, and minerals have been detected in maguey inflorescences [15,17,18]. Cuachepil flowers contain minerals, phenolic compounds, and flavonoids [19]. The tender inflorescences of tepejilote contain minerals and vitamins B2, B3, and C, and inflorescence extracts have blood sugar reducing effects [20].

In different regions of Oaxaca, the use and consumption of different species of edible flowers have been reported, but little or very little is known about their phenolic compound contents and antioxidant activity, and the variations in phytochemical composition due to the ecogeographic environmental growth conditions of the species remain unknown. In this context, the objective of this work was to evaluate the variation in polyphenol and flavonoid contents and the antioxidant activity of inflorescence samples from izote (*Y. filifera*), maguey pulquero (*A. salmiana*), cuachepil or guachepil (*D. americana*), and tepejilote or pacaya (*C. tepejilote*) collected from different communities and regions of Oaxaca, Mexico.

2. Materials and Methods

2.1. Plant Material and Sample Evaluations

Based on a review of edible flowers in Mexico and the traditional forms of consumption in Oaxaca, four species with contrasting floral morphologies and natural distribution patterns were selected for the collection and analysis of biochemically different inflorescence samples in 2022.

(a) Izote (*Yucca filifera* Chabaud, Asparagaceae) is an arborescent plant that reaches more than 10 m high and is branched with linear–oblanceolate leaves that are 55 cm long and 3.6 cm wide (Figure 1a). It presents edible inflorescences with a cylindrical, pendulous panicle shape, up to 1.5 m long; each flower is made up of six petals; and the fruit is hanging, oblong, and ends in a beak [21]. It blooms from the end of April to the end of

May, but the timing varies by region. It is located at elevations of 500 and 2400 m in different types of soils, develops in patches associated with other species or alone, and is also common in backyards as an ornamental plant [22]. In this work, 11 inflorescence samples were collected from backyards, farmland edges, and roadsides at elevations ranging from 1481 to 2107 in hot and dry to temperate climates (Table 1).

(b) The maguey pulquero or agave (*Agave salmiana* Otto ex Salm-Dyck, Agavaceae) is endemic to Mexico and grows regularly at elevations of 1230 to 2460 m in a temperate climate, forming colonies or patches or growing individually; mead, which is the raw material for pulque, is obtained from this plant species. The bunches of edible inflorescences rest on a vertical flower stalk or quiote that reaches 3 to 9 m high [23] (Figure 1b). The quiote or floral axis develops in the center of the plant after 5 to 13 years of growth. The flowers or inflorescences are known as cacayas, bayusa, golumbos, dembos, or maguey trotters; they are commercialized regionally and prepared in various ways for consumption [2]. In total, 10 inflorescence samples were collected in the Mixtec region of Oaxaca at elevations ranging from 2127 to 2573 m. In this region, a temperate climate prevails with roadsides or cultivated lands and it is found in clearings of pine–oak forest, regularly occurring in shallow soils with low fertility (Table 1).

(c) Guachepil or cuachepil (*Diphysa americana* (Mill.) M. Sousa; syn: *D. robinioides* and *D. carthainensis*, Fabaceae) is a medium-sized, deciduous tree with an irregular extended crown (Figure 1c); it produces inflorescences with yellow flowers in axillary clusters that completely cover the tree at the beginning or end of the rainy season [24]. In total, 11 inflorescence samples were collected from Sierra Sur de Oaxaca at elevations ranging from 1518 to 2271 m above sea level, where a warm and dry climate prevails. This species is regularly used in fencing and in backyards as a shade tree or ornament (Table 1).

(d) Tepejilote (*Chamedorea tepejilote* Liebm., Arecaceae) is a solitary palm tree that reaches 2 to 7 m high (Figure 1d). At the base of the internodes, it produces flowers in inflorescences that are 25 to 60 cm long within enveloping leaves [25]. The tender inflorescences are edible and have socioeconomic importance in Chinantla, Oaxaca because they are sold in regional markets [26]. The Papaloapan region comprises Jalapa de Diaz, Valle Nacional, Santa Maria Jacatepec, Santiago Jocotepec, and Ayotzintepec, with elevations of 77 to 591 m. Eleven tender tepejilote inflorescences were collected from an area where the climate is warm and humid with abundant rains of up to 3500 mm (Table 1).

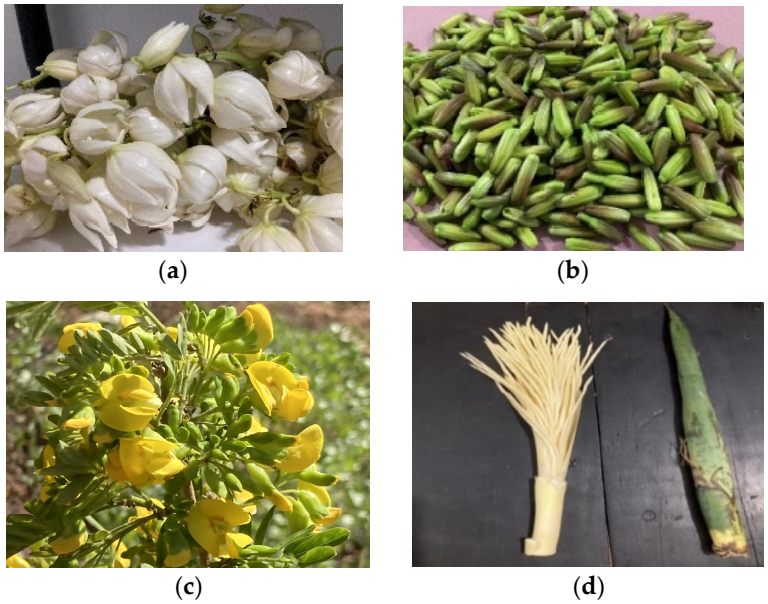

Figure 1. Flowers and inflorescences: (**a**) izote (*Y. filifera*); (**b**) maguey pulquero (*A. salmiana*); (**c**) cuachepil (*D. americana*); (**d**) tepejilote (*C. tepejilote*).

Table 1. List of the locations from which samples of inflorescences of izote (*Y. filifera*), maguey (*A. salmiana*), cuachepil (*D. americana*), and tepejilote (*C. tepejilote*) were collected in different regions of Oaxaca, Mexico during 2022.

ID-Pob./ Species	Location or Community of Sample Origin in Oaxaca, Mexico	Latitude (N)	Longitude (W)	Elevation (m)	Temp. (°C) [1]	Precip. (mm) [1]	Climate
Y. filifera (izote, local name):							
IZ1-01 *	Magdalena Jaltepec	17°18′50.9″	97°14′47.9″	1967	16–18	600–800	
IZ1-01A	Magdalena Jaltepec	17°18′50.9″	97°14′47.9″	1967	16–18	600–800	
IZ1-01b	Magdalena Jaltepec	17°18′50.9″	97°14′47.9″	1967	16–18	600–800	
IZ1-01c	Magdalena Jaltepec	17°18′50.9″	97°14′47.9″	1967	16–18	600–800	Semidry to subhumid temperate
IZ1-02a	Magdalena Jaltepec	17°21′9.9″	97°13′29.4″	2107	14–16	600–800	
IZ1-02b	Magdalena Jaltepec	17°21′9.9″	97°13′29.4″	2107	14–16	600–800	
IZ1-02c	Magdalena Jaltepec	17°21′9.9″	97°13′29.4″	2107	14–16	600–800	
IZ-VA1	Santa Ana Miahuatlan	17°08′10.9″	97°42′29.1″	1547	12–14	1000–1200	Semidry to semiwarm
IZ-SS1	Santo T. Tamazulapan	16°14′25.4″	96°36′48.9″	1651	16–18	600–800	Semidry to semiwarm
IZ-SS2	Santa Maria Sola	16°35′12.6″	97°01′17.8″	1481	20–22	800–1000	Subhumid temperate to semiwarm subhumid
IZ-VA2	Ejutla de Crespo	16°34′47″	96°42′46.2″	1522	18–20	600–800	Semidry to semiwarm
A. salmiana (maguey pulquero):							
CA-MI1	San Esteban Atatlahuca	17°03′55″	97°40′38″	2388	14–16	1000–1200	
CA-MI2	San Pedro Mills	17°06′23.7″	97°33′52.4″	2474	14–16	800–1000	
CA-MI3	San Jose Monte Verde	17°29′37″	97°43′28″	2573	14–16	800–1000	
CA-MI4	Santa Cruz Nundaco	17°10′20″	97°43′25″	2302	14–16	1000–1200	
CA-MI5	Chalcatongo de Hgo.	16°53′06″	97°34′56″	2442	14–16	1000–1200	Subhumid temperate
CA-MI6	Santo Tomas Ocotepec	17°08′40″	97°45′45″	2127	16–18	1000–1200	
CA-MI7	San Juan Teposcolula	17°32′24.2″	97°25′51.8″	2288	14–16	600–800	
CA-MI8	San Pedro Tidaa	17°20′25″	97°22′36″	2280	14–16	600–800	
CA-SS1	Santa Lucia Monte Verde	16°58′4.5″	97°39′56.6″	2353	14–16	1000–1200	
CA-SS2	Santa Cruz Itundujia	16°47′18″	97°38′12″	2449	14–16	1000–1200	Subhumid temperate
D. americana (cuachepil):							
GU-SS0	San Andres Paxtlan	16°12′48.8″	96°30′33.9″	2271	16–18	800–1000	Subhumid temperate
GU-SS1	San Felipe Zapotitlan	16°50′48″	97°13′55″	1642	18–20	800–1000	Subhumid temperate to semiwarm subhumid
GU-SS2	Santa Cruz Xitla	16°19′17″	96°40′20″	1804	16–18	600–800	Semidry to semiwarm
GU-SS3	Santa Cruz Xitla	16°19′17″	96°40′20″	1804	16–18	600–800	Semidry to semiwarm
GU-SS4	Santa Cruz Xitla	16°19′17″	96°40′20″	1804	16–18	600–800	Semidry to semiwarm
GU-SS5	Agua Fria Sola de Vega	16°33′21.1″	96°57′05.9″	1596	18–20	800–1000	Subhumid temperate to semiwarm subhumid
GU-SS6	Reyes Sola de Vega	16°29′19.9″	96°59′04.6″	1518	18–20	800–1000	Subhumid temperate to semiwarm subhumid
GU-SS7	Reyes Sola de Vega	16°30′4.7″	96°59′10.3″	1508	18–20	800–1000	Subhumid temperate to semiwarm subhumid
GU-SS8	Agua Fria Sola de Vega	16°33′20.9″	96°57′14.5″	1594	18–20	800–1000	Subhumid temperate to semiwarm subhumid

Table 1. *Cont.*

ID-Pob./ Species	Location or Community of Sample Origin in Oaxaca, Mexico	Latitude (N)	Longitude (W)	Elevation (m)	Temp. (°C) [1]	Precip. (mm) [1]	Climate
GU-CO1	San Pedro El Alto	16°46′16.7″	97°03′32.3″	1594	16–18	800–1000	Semiwarm subhumid
GU-SS10	Santa Lucia Miahuatlan	16°11′7.53″	96°37′23.48″	1916	14–16	600–800	Temperate subhumid
C. tepejilote (tepejilote):							
TE-PA1	San J. B. Valle Nacional	17°50′23″	96°22′05″	366	22–24	2500–3000	
TE-PA2	San Fpe. Jalapa de Diaz	18°04′18.9″	96°32′4.5″	78	24–26	3000–3500	
TE-PA3	San Fpe. Jalapa de Diaz	18°04′18.9″	96°32′4.5″	78	24–26	3000–3500	
TE-PA4	San Fpe. Jalapa de Diaz	18°05′53″	96°33′20″	335	24–26	3000–3500	
TE-PA5	Ayotzintepec	17°45′43.8″	96°08′19.0″	591	22–24	2500–3000	
TE-PA6	Ayotzintepec	17°45′43.8″	96°08′19.0″	591	22–24	2500–3000	Hot humid
TE-PA7	Ayotzintepec	17°45′42.3″	96°04′41.9″	96	24–26	2500–3000	
TE-PA8	Santa Maria Jacatepec	17°52′34.2″	96°12′19″	129	24–26	2500–3000	
TE-PA9	Santa Maria Jacatepec	17°50′47.9″	96°12′49.7″	77	24–26	3000–3500	
TE-PA10	Santa Maria Jacatepec	17°51′13.1″	96°15′4.6″	289	22–24	2500–3000	
TE-PA11	Santiago Jocotepec	17°38′59″	95°59′15″	100	24–26	2500–3000	

[1] Corresponds to the annual mean ranges of temperature and precipitation, respectively INEGI [27].

2.2. Inflorescence Samples for Analysis

Edible flower samples were collected under natural conditions and/or in residential backyards. Collection was carried out based on previous identification of the distribution regions and flowering seasons of each species (Table 1, Figure 2). Inflorescence samples were collected and, later, flower subsamples free of physical and/or insect damage were dried in the shade at room temperature. The final drying process was performed in a food dryer at temperatures below 45 °C. The dry samples were ground using an electric mill (Moongiantgo® model HO-150, Seattle, WA, USA) in 30 s pulses and stored in amber flasks at −20 °C until analysis.

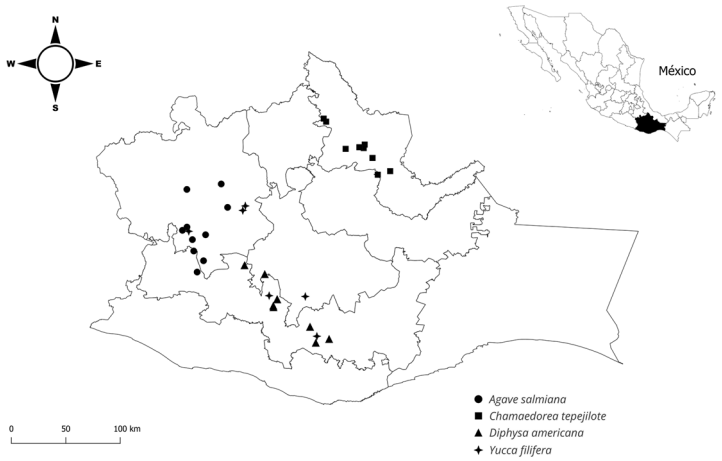

Figure 2. Origin sites of the analyzed samples based on specie distributions in Oaxaca, Mexico.

2.3. Evaluation of Phenolic Compounds and Antioxidant Activity

2.3.1. Preparation of Extracts

A total of 0.1 to 0.3 g of ground sample was weighed and mixed with 60% ethanol using a homogenizer (Ultra Turrax T25 digital IKA, Staufen, Germany) for 90 s; subsequently, the mixture was sonicated for 30 min and centrifuged at 16,639× *g* (11,000 rpm) for 15 min at 4 °C in a refrigerated centrifuge (Eppendorf AG, Model 5811F, Hamburg, Germany). The final supernatant was subjected to analysis of its phenolic compound content and antioxidant activity.

2.3.2. Analysis of the Total Polyphenol Content

Polyphenol analysis was carried out following the methodology described by Singleton and Rossi [28]. A total of 400 µL of the extract was placed in amber vials, mixed with deionized water and Folin–Ciocalteu reagent, and allowed to stand for 5–8 min, after which a 7% solution of Na_2CO_3 was added. The mixture was vortexed (Genie 2T model SI-T236, Scientific Industries, Inc., Bohemia, NY, USA) and allowed to incubate for one hour at room temperature. Subsequently, absorbance readings were taken using a spectrophotometer (UV–Vis Velab model VE-5600UV PC, Pharr, TX, USA) at a wavelength of 750 nm. The concentration of phenolic compounds was calculated with reference to a standard curve of gallic acid (0.021 to 0.165 mg mL^{-1}; r^2 = 0.9999) in triplicate samples and was expressed in mg equivalents of gallic acid per gram of dry weight (mg GAE g^{-1} dw).

2.3.3. Analysis of the Total Flavonoid Contents

The concentrations of flavonoids were estimated with reference to two standards: catechin and quercetin. For the former, following the methodology reported by Zhishen et al. [29], 5% sodium nitrite ($NaNO_2$) was added to 250 µL of the sample extract, and the mixture was vortexed and incubated for 5 min; subsequently, 10% aluminum chloride ($AlCl_3$) was added, after which the mixture was left to stand for 1 min. Finally, 1 M sodium hydroxide (NaOH) was added, and deionized water was added to generate a final volume of 3 mL.

The mixture was vortexed, and the absorbance was evaluated at 510 nm. The quantification of flavonoids was performed with reference to a standard curve of the flavanol catechin (0.008–0.5 mg mL^{-1}; r^2 = 0.9987). The evaluations were performed in triplicate, and the results are expressed in mg equivalents of catechin per gram of dry sample (mg CE g^{-1} dw). The analysis of quercetin equivalent flavonoids was performed based on the methodology proposed by Lin and Tang [30]. To 500 µL of extract, 95% ethanol and 10% $AlCl_3$ solution were added, and the mixture was incubated for 5 min. Subsequently, 100 µL of a 1 M CH_3CO_2K solution and 2.8 mL of deionized water were added, after which the mixture was vortexed and incubated for 40 min. Finally, the absorbance was evaluated at a wavelength of 415 nm. The quantification of flavonoids was performed based on the standard curve of the flavonol quercetin (0.01–0.17 mg mL^{-1}; r^2 = 0.9994) in triplicate, and the results are expressed as mg equivalents of quercetin per gram of dry weight (mg QE g^{-1} dw).

2.3.4. Analysis of Antioxidant Activity

The evaluation of antioxidant activity was carried out using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and FRAP (iron reduction antioxidant power) methods. The estimation using the DPPH method was made based on the methodology reported by Brand-Williams et al. [31]. DPPH reagent (2.9 mL) was added to 100 µL of sample extract, the absorbance was measured at 517 nm, and quantification was performed based on a standard curve of 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) (0.133–1.332 µmol mL^{-1}; r^2 = 0.9976). The analysis was performed in triplicate, and the results are expressed as µmol equivalents of Trolox per gram of dry weight (µmol TE g^{-1} dw). Evaluation using the FRAP method was carried out based on the methodology described by Benzie and Strain [32]. The FRAP reagent was added to 100 µL of sample extract and, subsequently, the absorbance at 593 nm was evaluated. The antioxidant activity was estimated with reference to a Trolox calibration curve (0.1–1 µmol mL^{-1}; r^2 = 0.9982). The analysis was performed in triplicate, and the results are expressed as µmol equivalents of Trolox per gram of dry weight (µmol TE g^{-1} dw).

2.4. Statistical Analysis

After the phenolic compound contents and antioxidant activity were evaluated for each sample, a database was constructed for the evaluated species, and analyses of variance were performed based on a completely random linear model in which the repetitions were adjusted according to the number of formulated extracts, and laboratory replicas or equipment readings were nested within the extracts. In addition, multiple mean comparisons were made using the Tukey method ($p \leq 0.05$). Finally, for each species, the Pearson correlation coefficient between the phenolic compound concentrations and antioxidant activity was obtained. All of the statistical analyses were performed using the SAS statistical package [33].

3. Results

According to the analysis of variance, significant differences ($p \leq 0.01$) in the contents of polyphenols and equivalent flavonoids in catechin (CE) and quercetin (QE) were detected. The antioxidant activity was evaluated using the DPPH and FRAP methods between the localities of origin for the samples from izote (*Y. filifera*), maguey pulquero (*A. salmiana*), cuachepil or guachepil (*D. americana*), and tepejilote or pacaya (*C. tepejilote*). According to the magnitude of the variance in the linear model for all of the evaluated species, the greatest variation was due to the sampled populations or localities and, to a lesser extent, to the effect of the evaluated extract and laboratory replications. These findings indicate that plant growth conditions significantly influence the concentration of phenolic compounds and antioxidant activity (Table 2).

Table 2. Significance of square means of the analysis of variance for the phenolic compound contents and antioxidant activity in inflorescence samples of *Y. filifera*, *A. salmiana*, *D. americana*, and *C. tepejilote* collected from different communities and regions in Oaxaca, Mexico.

Sources of Variation	Total Polyphenols	Flavonoids		Antioxidant Activity	
		CE [1]	QE [1]	DPPH	FRAP
Yucca filifera (izote, local name)					
Sampling locations	34.4 **	10.2 **	6.54 **	138.8 **	2977.2 **
Extracts (E)	0.07 [ns]	<0.00 [ns]	0.01 [ns]	2.56 [ns]	24.5 [ns]
Laboratory replicates/E [2]	0.47 [ns]	0.01 [ns]	0.02 [ns]	2.76 [ns]	118.0 [ns]
Error	1.77	0.32	0.33	13.2	173.1
Coeff. variation (%)	10.6	15.9	21.5	9.4	19.2
Agave salmiana (maguey pulquero, local name)					
Sampling locations	11.67 **	1.107 **	1.49 **	143.8 **	241.39 **
Extracts (E)	0.05 [ns]	0.02 [ns]	0.008 [ns]	2.6 [ns]	0.04 [ns]
Laboratory replicates/E [2]	0.02 [ns]	0.01 [ns]	0.007 [ns]	1.9 [ns]	2.97 [ns]
Error	0.11	0.02	0.005	2.22	4.55
Coeff. variation (%)	2.4	3.8	1.8	3.8	
Diphysa americana (cuachepil or guachepil, local name)					
Sampling locations	332.4 **	191.5 **	93.3 **	6499.6 **	29,332 **
Extracts (E)	2.0 [ns]	0.001 [ns]	0.21 [ns]	17.5 [ns]	243 [ns]
Laboratory replicates/E [2]	1.1 [ns]	0.15 [ns]	0.61 *	49.2 [ns]	403 [ns]
Error	1.47	0.45	0.205	27.2	170.8
Coeff. variation (%)	2.5	2.5	3.2	2.1	3.2
Chamaedorea tepejilote (tepejilote or pacaya, local name)					
Sampling locations	2.36 **	0.199 **	0.41 **	20.25 **	98.72 **
Extracts (E)	0.008 [ns]	0.001 [ns]	0.04 [ns]	0.29 [ns]	0.27 [ns]
Laboratory replicates/E [2]	<0.001 [ns]	0.002 [ns]	0.03 [ns]	0.51 **	0.87 **
Error	0.004	0.005	0.03	0.09	0.12
Coeff. variation (%)	2.3	3.1	12.7	2.2	3.3

[ns] Not significant ($p > 0.05$); * significant at $p \leq 0.05$; ** significant at $p \leq 0.01$; [1] CE and QE, catechin and quercetin equivalents, respectively; [2] laboratory replicates were nested within formulated extracts.

3.1. Phenolic Compounds and Antioxidant Activity in the Inflorescences of Y. filifera

Significant differences were detected in the contents of polyphenols and flavonoids and in the antioxidant activity between the localities of origin of the samples. For example, for the contents of polyphenols, the sample from Magdalena Jaltepec 1 differed significantly from the samples from Tamazulapan, Ejutla, Santa Ana Miahuatlan, and Santa Maria Sola; this pattern was also observed for the contents of catechin- and quercetin-equivalent flavonoids and antioxidant activity. The polyphenols varied between the samples, with concentrations ranging from 10.1 to 14.6 mg GAE g^{-1} for flavonoids, from 2.45 to 4.65 mg CE g^{-1} for catechin, and from 1.34 to 3.33 mg QE g^{-1} for quercetin. Variation was also observed in the antioxidant activity. According to the results of the DPPH method, the concentration ranged from 35.1 to 43.1 µmol TE g^{-1}, while the results of the FRAP method revealed concentrations of 45.5 to 86.0 µmol TE g^{-1} (Table 3).

The contents of polyphenols and flavonoids in the izote inflorescence samples were significantly and positively correlated with the antioxidant activity, as evaluated using the DPPH ($0.31 < r < 0.79$, $p < 0.01$) and FRAP ($0.65 < r < 0.91$, $p < 0.01$) methods. The results showed that the concentrations of polyphenols and flavonoids in izote inflorescences significantly contributed to the antioxidant capacity of the plants, in addition to the other compounds not detected in this study.

Table 3. Average total polyphenol and flavonoid contents and antioxidant activity in inflorescences of *Y. filifera* collected from different communities in Oaxaca, Mexico.

Communities of Origin of Samples Evaluated	Total Polyphenols (mg GAE g^{-1})	Flavonoids (mg g^{-1})		Antiox. Activity (μmol TE g^{-1})	
		CE [1]	QE [1]	DPPH	FRAP
Magdalena Jaltepec 1 (IZ1-01, ID)	14.6 a [2]	4.65 a	3.06 ab	41.9 ab	86.0 a
Magdalena Jaltepec 2 (IZ1-02)	11.6 b	3.32 b	3.33 a	35.6 c	67.5 ab
Santo Tomas Tamazulapan	11.5 b	2.58 bc	1.68 cd	35.3 c	49.6 bc
Ejutla de Crespo	10.1 b	2.45 c	1.34 d	35.1 c	45.5 c
Santa Ana Miahuatlan	11.5 b	2.79 bc	1.91 cd	37.0 bc	51.1 bc
Santa Maria Sola	11.4 b	2.67 bc	2.21 bc	43.1 a	60.8 bc

[1] CE and QE indicate catechin and quercetin equivalents, respectively; [2] within columns, means with the same letter indicate no significant difference (Tukey's test, $p \leq 0.05$).

3.2. Phenolic Compounds and Antioxidant Activity in the Inflorescences of A. salmiana

The comparison of the contents of phenolic compounds and antioxidant activity between samples of maguey pulquero inflorescences revealed significant differences depending on the geographical origin. For example, the samples from Chalcatongo, Santa Cruz Nundaco, and Santa Cruz Itundujia had higher contents of polyphenols and flavonoids and greater antioxidant activity than did the samples collected from San Esteban Atatlahuca, Santa L. Monte Verde, Santo T. Ocotepec, and San Pedro Molinos. The variation in polyphenol content ranged from 12.1 to 16.6 mg GAE g^{-1}; for catechin-equivalent flavonoids, it ranged from 3.40 to 4.73 mg CE g^{-1}; and for quercetin-equivalent flavonoids, it ranged from 2.73 to 4.32 mg QE g^{-1}. The antioxidant activity evaluated using the DPPH method ranged from 34.4 to 47.5 μmol TE g^{-1}, while the antioxidant activity evaluated using the FRAP method ranged from 47.7 to 68.0 μmol TE g^{-1} (Table 4).

Table 4. Average total polyphenol and flavonoid contents and antioxidant activity in inflorescences of *A. salmiana* collected from different communities in Oaxaca, Mexico.

Communities of Origin of Samples Evaluated	Total Polyphenols (mg GAE g^{-1})	Flavonoids (mg g^{-1})		Antiox. Activity (μmol TE g^{-1})	
		CE [1]	QE [1]	DPPH	FRAP
San Esteban Atatlahuca	12.7 ef [2]	3.42 de	3.57 c	35.4 d	47.9 e
Chalcatongo de Hidalgo	16.6 a	4.73 a	4.20 a	47.5 a	68.0 a
Santa Cruz Itundujia	14.5 c	3.70 bc	4.32 a	45.4 ab	56.8 b
San Pedro Mills	13.4 d	3.44 c–e	3.55 c	35.0 d	48.1 de
Santa Cruz Nundaco	15.6 b	3.95 b	4.27 a	42.8 bc	59.4 b
Santo Tomas Ocotepec	12.8 de	3.18 e	3.86 b	35.1 d	47.7 e
San Jose Monte Verde	13.3 de	3.63 cd	4.26 a	41.1 c	57.1 b
Santa Lucia Monte Verde	12.1 f	3.53 cd	3.54 c	36.8 d	52.1 cd
San Juan Teposcolula	14.6 c	3.40 de	2.73 d	34.4 d	57.3 b
Saint Peter Tidaa	14.3 c	3.64 cd	3.61 c	35.2 d	55.7 bc

[1] CE and QE, catechin and quercetin equivalents, respectively; [2] within columns, means with the same letter do not differ significantly (Tukey's test, $p \leq 0.05$).

The contents of polyphenols and flavonoids were significantly correlated with the antioxidant activity according to the DPPH ($0.65 \leq r \leq 0.76$; $p < 0.01$) and the FRAP ($0.35 \leq r \leq 0.82$; $p < 0.01$) methods, which indicates that part of the antioxidant activity determined using DPPH and FRAP was due to the contents of polyphenols and flavonoids in the inflorescences of maguey pulquero. It should be noted that other compounds also influence antioxidant activity.

3.3. Phenolic Compounds and Antioxidant Activity in Inflorescences of *D. americana*

The composition of cuachepil inflorescences showed high variability and different response patterns depending on the origin of the samples. For example, in terms of polyphenol content, the samples differed significantly and frequently within the same locality or municipality, such as in the cases of Santos Reyes, Sola de Vega, and the municipality of Santa Cruz Xitla; the same pattern was observed for flavonoid content and antioxidant activity. However, for the concentration of polyphenols, the samples from Santo Reyes and Sola de Vega 2 and the three samples from Santa Cruz Xitla stand out; this is also the case for catechin-equivalent flavonoids and antioxidant activity evaluated using the FRAP and DPPH methods. In terms of the concentration of quercetin-equivalent flavonoids, Agua Fria Sola de Vega 2 and Santo Reyes Sola de Vega 2 stand out. In contrast, lower contents of polyphenols and flavonoids and antioxidant activity were frequently observed in samples from San Felipe Zapotitlan, San Pedro El Alto, San Andres Paztlan, Agua Fria Sola de Vega 1, and Santos Reyes Sola de Vega 1. The variability in the polyphenol contents ranged from 38.7 to 59.6 mg GAE g^{-1}, the concentration of catechin equivalents ranged from 18.8 to 38.1 mg CE g^{-1}, and the concentration of quercetin equivalents ranged from 11.2 to 24.9 mg QE g^{-1}. The antioxidant activities evaluated using DPPH and FRAP ranged from 185.7 to 299.6 and from 290.4 to 508.7 μmol TE g^{-1}, respectively (Table 5).

Table 5. Average total polyphenol and flavonoid contents and antioxidant activity in inflorescences of *D. americana* collected from different communities of Oaxaca, Mexico.

Communities of Origin of Samples Evaluated	Total Polyphenols (mg GAE g^{-1})	Flavonoids (mg g^{-1})		Antiox. Activity (μmol TE g^{-1})	
		CE [1]	QE [1]	DPPH	FRAP
Agua Fria Sola de Vega 1 (GU-SS5, ID)	45.8 d [2]	24.8 f	13.8 d	254.8 de	373.0 e
Agua Fria Sola de Vega 2 (GU-SS8)	45.6 d	28.2 de	24.9 a	259.1 cd	436.3 c
San Andres Paxtlan	45.3 d	24.4 f	13.1 de	246.7 e	375.5 e
Santos Reyes Sola de Vega 1 (GU-SS6)	38.7 f	19.5 h	11.4 f	215.4 g	306.5 f
Santos Reyes Sola de Vega 2 (GU-SS7)	59.6 a	29.3 cd	17.3 b	299.6 a	482.6 b
Santa Cuz Xitla 1 (GU-SS2)	57.3 ab	38.1 a	13.2 de	293.4 a	508.7 a
Santa Cruz Xitla 2 (GU-SS2)	54.6 c	31.1 b	13.0 de	274.4 b	442.2 c
Santa Cruz Xitla 3 (GU-SS2)	56.2 bc	30.4 bc	15.0 c	252.2 de	458.2 bc
San Felipe Zapotitlan	39.7 ef	18.8 h	11.4 f	185.7 h	290.4 f
Santa Lucia Miahuatlan	47.3 d	27.0 e	12.5 e	266.3 bc	408.1 d
San Pedro El Alto	41.1 e	21.9 g	11.2 f	233.9 f	358.1 e

[1] CE and QE indicate catechin and quercetin equivalents, respectively; [2] within the columns, means with the same letter do not differ significantly (Tukey's test, $p \leq 0.05$).

According to the results of Pearson's correlation analysis, significant and positive correlations were detected between polyphenol and flavonoid contents and antioxidant activity according to the DPPH ($0.36 \leq r \leq 0.84$; $p < 0.01$) and FRAP ($0.44 \leq r \leq 0.94$; $p < 0.01$) methods. In these cases, the contents of polyphenol and flavonoid equivalents of catechin showed the highest correlation values.

3.4. Phenolic Compounds and Antioxidant Activity in the Inflorescences of *C. tepejilote*

In terms of polyphenol and flavonoid contents and antioxidant activity, the samples of tepejilote inflorescences exhibited different patterns depending on their geographical origin. For example, among the samples from Ayotzintepec, Jalapa de Diaz, and Santa Maria Jacatepec, significant differences were observed among the compounds evaluated and their antioxidant activity. Significant differences were also observed among sample origins. The samples from Jalapa de Diaz 1, 2, and 3 and Santa Maria Jacatepec 3 had the lowest polyphenol and flavonoid contents and antioxidant activity, and they differed significantly from the samples from Ayotzintepec 1 and 2, Santiago Jocotepec, and Santa Maria Jacatepec 1 and 2, which had the highest polyphenol and flavonoid contents. That is, there were

significant differences between and within sampled populations or sample origins in terms of polyphenol and flavonoid contents and antioxidant activity. The variation in total polyphenols ranged from 1.86 to 3.64 mg GAE g^{-1}; for catechin-equivalent flavonoids, it ranged from 1.91 to 2.61 mg CE g^{-1}; and for quercetin-equivalent flavonoids, it ranged from 0.96–1.72 mg QE g^{-1}. The antioxidant activity evaluated using the DPPH method ranged from 10.1 to 17.0 µmol TE g^{-1}, while that evaluated using the FRAP method ranged from 5.7 to 17.4 µmol TE g^{-1} (Table 6).

Table 6. Average total polyphenol and flavonoid contents and antioxidant activity in young inflorescences of *C. tepejilote* collected from different communities in Oaxaca, Mexico.

Communities of Origin of Samples Evaluated	Total Polyphenols (mg GAE g^{-1})	Flavonoids (mg g^{-1})		Antiox. Activity (µmol TE g^{-1})	
		CE [1]	QE [1]	DPPH	FRAP
Ayotzintepec 1 (TE-PA5)	3.30 c [2]	2.36 bc	1.32 c–e	14.5 c	13.9 b
Ayotzintepec 2 (TE-PA6)	3.23 c	2. 46 b	1.72 a	15.1 b	14.4 b
Ayotzintepec 3 (TE-PA7)	2.96 d	2.20 d	1.27 c–f	13.1 d	11.7 d
Jalapa de Diaz 1 (TE-PA2)	2.14 g	2.29 cd	1.04 d–f	12.2 e	5.9 g
Jalapa de Diaz 2 (TE-PA3)	2.42 f	2.30 cd	1.24 c–f	13.5 d	7.7 e
Jalapa de Diaz 3 (TE-PA4)	2.07 g	1.91 e	0.96 f	10.1 f	5.7 g
Santiago Jocotepec	3.36 bc	2.19 d	1.52 a–c	14.9 bc	12.56 c
San J. Bautista V. Nacional	2.59 e	2.46 b	1.36 b–d	13.2 d	8.3 e
Santa Maria Jacatepec 1 (TE-PA8)	3.45 b	2.38 bc	1.54 a–c	14.7 bc	14.5 b
Santa Ma. Jacatepec 2 (TE-PA9)	3.64 a	2.61 a	1.69 ab	17.0 a	17. 4 a
Santa Ma, Jacatepec 3 (TE-PA10)	1.86 h	2.39 bc	1.03 ef	12.3 e	6.8 f

[1] CE and QE, catechin and quercetin equivalents, respectively; [2] within the columns, means with the same letter do not differ significantly (Tukey's test, $p \leq 0.05$).

According to the results of Pearson's correlation analysis, significant and positive correlations were estimated between polyphenol and flavonoid contents with respect to antioxidant activity in extracts of tepejilote inflorescences evaluated using the DPPH ($0.70 \leq r \leq 0.86$; $p \leq 0.01$) and FRAP ($0.51 \leq r \leq 0.96$; $p \leq 0.01$) methods. Notably, the polyphenol content presented the highest correlation values, indicating that the antioxidant activity in the extract is strongly influenced by the variation in total polyphenols.

4. Discussion

Traditional edible flowers are food resources and provide nutrients and functional compounds that are beneficial for human health. However, the identification of species or types of edible flowers and forms of consumption processing are based on local gastronomic knowledge and culture. For example, a large number of species of 'quelites' (edible leafy plants and flowers) are found in gardens, backyards, and cultivation plots; however, the culture or habit of local consumption does not exist elsewhere. For the edible flowers studied in the present work, there was broad cultural support for consumption among different native groups of Oaxaca. For example, the consumption of inflorescences of maguey and izote has increased among the indigenous groups Mixtecos, Zapotecos, Triquis, Cuicatecos, Mazatecos, etc. The consumption of the tender inflorescences of tepejilote is common among Chinantecos, and the consumption of flowers and inflorescences of cuachepil is common among the Chatinos and Zapotecos groups. The consumption of flowers is not exclusive to Mexican gastronomic culture [6]; rather, it is common in several countries, such as Portugal and Mediterranean countries [8,34].

4.1. Composition of Inflorescences of Izote (Y. filifera)

The analysis of polyphenol and flavonoid concentrations and antioxidant activity in izote inflorescences revealed significant differences between population samples from different geographical origins, indicating that the environmental conditions of the growth site influence the contents of phenolic compounds and their antioxidant actions. The variation

in the contents of polyphenols in this work ranged from 10.1 to 14.6 mg GAE g^{-1} (Table 3), while the values estimated by Li et al. [35] in 51 species of edible wildflowers ranged from 0.50 to 24.36 mg GAE g^{-1}, suggesting that a part of this variation is due to genetics and possibly a genotype–environment interaction. For example, in *Y. elephantipes*, Cáceres et al. [36] estimated a variation of 30.02 mg GAE g^{-1}, while, in *Y. gloriosa*, Nicknezhad et al. [37] estimated an average of 6.63 mg GAE g^{-1}, where part of the difference is due to species and/or genotypes and environmental conditions.

In terms of flavonoid concentration, the variation recorded in catechin equivalents ranged from 2.45 to 4.65 mg g^{-1}, and that in quercetin equivalents ranged from 1.34 to 3.33 mg g^{-1} (Table 3). These values differ from the estimates reported by Nicknezhad et al. [37] for *Y. gloriosa* (12.28 mg CE g^{-1} fresh weight). Although comparisons between the results of this study and those of other studies involving different species are not reliable, the phytochemical variation in *Y. filifera* described here suggests that the ecological conditions at a growing site, genetic differences, and genetic–environmental interactions result in differences in the chemical composition of inflorescences. Additionally, a significant correlation was detected between higher contents of polyphenols and flavonoids and greater antioxidant activity. The results showed that the antioxidant activity of the evaluated populations was strongly influenced by the contents of polyphenols and flavonoids.

Juárez-Trujillo et al. [16] performed phytochemical analyses of specific compounds in *Y. elephantipes*. They detected 20 phenolic compounds and noted that this composition indicates high bioactive functional potential in addition to the general composition of this species. A similar potential has been recognized for *Y. filifera* since Mulík and Ozuna [6] estimated that this species contributes up to 25.9 mg of protein per 100 g^{-1}, including all of the essential amino acids and a high concentration of minerals; this finding was corroborated by Sotelo et al. [15] for *Y. filifera* collected in Hidalgo, Mexico. The findings presented here for this species are complementary to those of previous works, and there are no other comparative references from similar populations where, in addition to the contribution to phytochemical composition, the effects of geographical–environmental factors on the samples have been quantified.

4.2. Composition of Inflorescences of Maguey Pulquero (*A. salmiana*)

The inflorescences and flowers of maguey are commonly known as 'cacayas', 'gualumbos', 'hualumbos', or 'patas de gallina de cerro' (hen's feet). They are purple–green–yellowish when they open and are widely consumed in all regions of Oaxaca, where several species of maguey or agave are distributed, from mezcaleros to pulqueros. The traditional preparation of these inflorescences is 'desflemar' (immersion in salt water), namely, boiling with salt or frying them with or without eggs; sometimes, the pistil and part of the style of the individual flowers are removed, although this practice varies regionally. However, the local forms of consumption are not exclusive to Oaxaca but are common in other states, such as Puebla or Hidalgo, Mexico, and include other species of agave such as mezcaleros, pulqueros (fermented agave drink), and 'ixtle' (fibers for ropes) [14,38,39].

Significant differences were recorded among the samples of different geographical origins. This pattern was expected because *A. salmiana* plants can grow in patches or in a solitary habit, and the plants regularly experience restrictions in water, nutrients, and, in some cases, light. It is important to note that *A. salmiana* are CAM plants. The inflorescence samples from Santa Lucia Monte Verde, San Esteban Atatlahuca, Santo Tomas Ocotepec, and San Jose Monte Verde presented the lowest concentrations of polyphenols (12.1 to 13.3 mg GAE g^{-1}), while the samples collected from Santa Cruz Nundaco and Chalcatongo de Hidalgo had relatively high concentrations (15.6 to 16.6 mg GAE g^{-1}) (Table 4). Pinedo-Espinoza et al. [18] reported an average concentration of 4.63 mg GAE g^{-1} in the inflorescences of *A. salmiana* collected in Tantempango, Hidalgo, which was slightly lower than that obtained in the present study. This limited comparison also indicated the presence of high variability between populations and plant growth conditions.

In terms of the flavonoid equivalents of catechin (CE) and quercetin (QE), the inflorescences and flowers sampled in San Juan Teposcolula, San Pedro Molinos, Santo Tomas Ocotepec, and San Esteban Atlatlahuca of the Mixteca region presented the lowest values, from 3.18 to 3.44 mg CE g^{-1} and from 2.73 to 3.57 mg QE g^{-1}, respectively. The highest concentrations of CEs were detected in the samples from Chalcatongo Hidalgo and Santa Cruz Nundaco (3.95 and 4.73 mg CE g^{-1}, respectively), while the highest QE concentrations were detected in the samples from San Jose Monte Verde and Santa Cruz Itundujia (from 4.26 to 4.32 mg QE g^{-1}). In all of these regions, the drought or dry period is prolonged because it does not rain from November to May or June, resulting in seven to nine months without rain. Pinedo-Espinoza et al. [18] recorded an average of 4.58 mg QE g^{-1} for *A. salmiana* from Hidalgo, a value within the range of high values recorded in this study. Barriada-Bernal et al. [40] reported an average value of 1.21 mg QE g^{-1} for *A. durangensis*. These results show that not only environmental factors but also genetic factors can influence flavonoid contents.

The populations or samples with the highest contents of polyphenols and flavonoids were consistent with those with high antioxidant activity, and a significant and positive correlation was observed between these measures. The lowest antioxidant activity at the population level according to the DPPH method ranged from 34.4 to 36.8, while the highest activity level ranged from 45.4 to 47.5 µmol TE g^{-1}; the same pattern was recorded when activity levels were measured using the FRAP method—from 47.7 to 48.1 and from 56.8 to 68.0 µmol TE g^{-1} at lower and higher concentrations, respectively. Pinedo-Espinoza et al. [18] estimated averages of 24.64 and 25.21 µmol TE g^{-1} using the DPPH and FRAP methods, respectively, for extracts of flowers of *A. salmiana*. Although the values reported in this work are slightly greater than those reported by Pinedo-Espinoza et al. [18], these differences suggest high variability and differences between samples in terms of their functional effects to prevent nontransmissible food-related diseases.

4.3. Composition of Inflorescences of Cuachepil (D. americana)

Guachepil, cuachepil, gallito, chipilin, and guachipelin trees are distributed from Mexico to Panama, with inflorescences and yellow flowers distributed in racemes that are frequently visited by bees [24]. In Oaxaca, plants regularly bloom after the rainy season, and the flowers cover nearly the entire tree. In addition to their ornamental appearance, the flowers are sold in traditional markets for consumption as 'quelite' (edible flower) in the Valles Centrales and Sierra Sur regions of Oaxaca; these flowers have a high local demand as part of the local gastronomy.

In terms of the phenolic compound contents and antioxidant activity in cuachepil inflorescences, there were frequently significant differences between and within localities or geographical origins of the samples evaluated. This pattern was observed within the samples collected in Agua Fria and Santos Reyes in the municipality of Villa Sola de Vega and among samples from the municipality of Santa Cruz Xitla. The samples from Santos Reyes Sola de Vega-2 and Santa Cruz Xitla 1 and 3 had the highest polyphenol concentrations (56.2 to 59.6 mg GAE g^{-1}); the samples from Santos Reyes Sola de Vega-1, San Felipe Zapotitlan, and San Pedro El Alto had the lowest polyphenol concentrations (38.7 to 41.1 mg GAE g^{-1}) (Table 5). In samples of guachepil from Valles Centrales of Oaxaca, Manzanero-Medina et al. [19] estimated an average of 26.4 mg GAE g^{-1}, which is slightly lower than that reported in this study. However, these results suggest differences and high variability among the populations and plants sampled.

In terms of flavonoid contents, the populations or samples with low values were the same as those identified for equivalents of catechin (CE) and quercetin (QE): Santos Reyes Sola de Vega-1, San Felipe Zapotitlan, and San Pedro El Alto (18.8 to 21.9 mg CE g^{-1} and 11.2 to 11.4 mg QE g^{-1}); in contrast, the populations or samples with high values were Santa Cruz Xitla 1, 2, and 3 (30.4 to 38.1 mg CE g^{-1}) and Santos Reyes Sola de Vega-2 and Agua Fria Sola de Vega-2 (17.3 to 24.9 mg QE g^{-1}). In contrast, Manzanero-Medina et al. [19] estimated an average value of 47.1 $\pm$ 1.6 mg QE g^{-1}; these differences are due, in part, to

differences in the analytical approach and in the growth conditions and genetic conditions of the plants from which samples were collected.

These results showed a significant and positive correlation between the contents of polyphenols and flavonoids and the antioxidant activity evaluated using the DPPH and FRAP methods, indicating the strong influence of phenolic compounds on the antioxidant activity. These results suggest that samples with higher contents of polyphenols and/or flavonoids also have greater antioxidant activity (e.g., samples from Santos Reyes Sola de Vega-2 and Santa Cruz Xitla-1). In contrast, the samples with lower concentrations of phenolic compounds and antioxidant activity were from Santos Reyes Sola de Vega-1, San Felipe Zapotitlan, and San Pedro El Alto. These relationships show that the growth conditions of cuachepil plants significantly influence the concentration of phenolic compounds and, consequently, their antioxidant activity. Manzanero-Medina et al. [19] estimated mean values of 181.6 ± 5.9 μmol TE mg^{-1} in cuachepil samples via the DPPH method, and, in this work, the variations ranged from 185.7 to 299.6 μmol TE g^{-1} and from 290.4 to 508.7 μmol TE g^{-1} according to the DPPH and FRAP methods, respectively. Notably, antioxidant activity is related not only to the concentration of phenolic compounds but also to the concentrations of other compounds, such as terpenes, pigments, and other compounds generated via secondary metabolism.

The composition and antioxidant activity of *D. americana* (synonyms: *D. robinioides* or *D. carthagenensis*) are related to its high potential to be beneficial to human health. The characteristics of this species are associated with the prevention or treatment of gastrointestinal disorders generated by bacteria [41]; furthermore, the species has antifungal activity for treating dermatophytosis [42] and antivirulence properties that can be applied to agricultural crops [43]. These potential applications are also due to the set of compounds that have been identified in the species as isoflavones [44]. However, the phytochemistry of this species has rarely been studied, although its biological characteristics have the potential to support human health.

4.4. Composition of Tepejilote Inflorescences

The immature inflorescences of tepejilote, also known as 'Pacaya', are consumed in the Papaloapan region of Oaxaca, Mexico, commonly from tropical and subtropical climates and elevations from 100 to 1500 m, where this species is cultivated for sale in regional markets. According to Castillo-Mont et al. [45], *C. tepejilote* is distributed from Mexico to Colombia, and its consumption provides fiber, minerals, protein, vitamin A, and vitamin C. The composition reported in this work agrees with the evaluations of Centurión-Hidalgo et al. [20] in tepejilote inflorescences collected in Tabasco. The evaluation of samples from different communities of Oaxaca revealed that the contents of polyphenols and flavonoids and the antioxidant activity differed significantly between and within localities of origin. For example, this pattern was observed in samples collected in Ayotzintepec, Jalapa de Diaz, and Santa Maria Jacatepec, where it is commonly traded and consumed.

The samples with the lowest polyphenol contents were those collected in Jalapa 1 and 2 and in Santa Maria Jacatepec 3 (1.86 to 2.14 mg GAE g^{-1}), and the highest values were detected in the samples collected in Santa Maria Jacatepec 1 and 2 (3.45 to 3.64 mg GAE g^{-1}) (Table 6). These values were significantly greater than those reported by Cáceres et al. [35] (30.02 μg GAE mg^{-1}) in samples from Guatemala and the estimates of Mancera-Castro et al. [46] (from 0.36 to 3.96 μg GAE g^{-1}) for inflorescences of *C. tepejilote* with and without thermal cooking treatments collected from Tapachula, Chiapas. These results suggest that the polyphenol content differs with geographical origin and that the concentration is modified by environmental and genetic factors; however, variation due to the ontogeny of the inflorescences is also intrinsic because the flowers are cut and consumed in the immature state before emerging from the enveloping leaves. The contents of CEs and QEs were significantly different among the different collection sites. For example, samples of inflorescences from Ayotzintepec 3, Jalapa de Diaz 1 and 3, and Santa Maria Jacatepec 3 presented low values of 1.91 to 2.20 mg CE g^{-1} and 0.96 to 1.04 mg QE g^{-1}, respectively. In

contrast, high values were observed in the samples from Ayotzintepec 1 and 2, San J.B. Valle Nacional, and Santa Maria Jacatepec 1 and 2, with values of 2.36 to 2.61 mg CE g^{-1} and 1.54 to 1.72 mg QE g^{-1}, respectively. In addition, the samples had high and low flavonoid contents that were positively and significantly correlated with high and low antioxidant activity levels. The low values of antioxidant activity determined using the DPPH and FRAP methods ranged from 10.1 to 12.3 and from 5.7 to 6.8 µmol TE g^{-1}, respectively, and the high values ranged from 14.7 to 17.0 and from 13.9 to 17.4 µmol TE g^{-1}, respectively. These results suggest that variations in flavonoid contents significantly influence antioxidant activity in tepejilote inflorescences.

The consumption of the immature inflorescences of *C. tepejilote* has been a part of local culture since pre-Columbian times, as reported by Cáceres and Cruz [47], in the region dominated by the Mayan culture and linguistic family. Phytochemical food studies remain limited; although, these flowers can contribute to the Mexican diet by helping to prevent nontransmissible food-related diseases (e.g., diabetes, obesity, and metabolic syndrome), as suggested by the results reported here in terms of phenolic compounds and antioxidant activity. Centurión-Hidalgo et al. [48] demonstrated the high antibacterial potential of *C. tepejilote* inflorescence extracts, and Montejos-Ramos and Márquez-Montes [49] proposed using tepejilote as a food supplement or breakfast cereal to take advantage of its nutritional properties and dietary fiber content.

In all of the species evaluated (*C. tepejilote*, *Y. filifera*, *A. salmiana*, and *D. americana*), the contents of phenolic compounds and antioxidant activity in the flowers and inflorescences were consistently influenced by the locality of origin and the edaphic environmental conditions in which the samples were collected. Notably, in this work, genetic effects could not be separated from environmental effects. However, the results show that this group of edible flowers is an important source of phenolic compounds, although the specific phenolic compounds require further study; for example, Li et at. [50] identified up to 18 phenolic compounds in 73 species of edible flowers from China. The indigenous communities of Mexico regularly consume the four species evaluated, and the results presented here suggest that these edible flowers have high nutritional and nutraceutical value and can be incorporated into the diet of consumers, improving family- and community-level health, as evidenced by previous evaluations and reviews of edible flowers with similar characteristics [51–53].

5. Conclusions

The evaluation of phenolic compounds in the inflorescence samples of *Yucca filifera*, *Agave salmiana*, *Diphysa americana*, and *Chamaedorea tepejilote* revealed significant variations within and between sample origins. These variations correlated positively with antioxidant activity (DPPH and FRAP), indicating the potential health benefits of these species.

The samples with the highest contents of polyphenols and flavonoids and antioxidant activity were more common in the inflorescences of *Y. filifera* from Magdalena Jaltepec; those of *A. salmiana* from Chalcatongo de Hidalgo and Santa Cruz Nundaco of the Mixteca region; those of *D. americana* collected from Santos Reyes, Villa Sola de Vega, and Santa Cruz Xitla of the Sierra Sur; and those of *C. tepejilote* collected from the municipality of Santa Maria Jacatepec and Ayotzintepec of the Chinantla baja, Oaxaca.

The concentrations of phenolic compounds and their antioxidant activities are indicators of the high potential of these species to serve as functional foods for the prevention of cardiovascular diseases caused by dietary disorders; these effects should be explored in future studies. Furthermore, these results support the incorporation of these foods into diets to promote their consumption and improve the nutrition of Oaxacan residents.

Author Contributions: Conceptualization and methodology, R.M.-G., A.M.V.-G., J.L.C.-S., M.L.P.-O., L.M.-M., S.H.-D. and D.M.-S.; investigation and writing, R.M.-G., A.M.V.-G., J.L.C.-S., M.L.P.-O. and S.H.-D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Instituto Politecnico Nacional-Mexico through project Nos. SIP-20231194 and SIP-20230580.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

Acknowledgments: The authors acknowledge Prisciliano Diego Flores for his support in the collection of the samples.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Rzedowski, J. *Vegetación de México*, 1st ed.; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Ciudad de México, Mexico, 2006; p. 504.
2. Mapes, C.; Basurto, F. Biodiversity and edible plants of Mexico. In *Ethnobotany of Mexico*; Lira, R., Casas, A., Blancas, J., Eds.; Springer: New York, NY, USA, 2016.
3. Mlcek, J.; Rop, O. Fresh edible flowers of ornamental plants—A new sources of nutraceutical foods. *Trends Food Sci. Technol.* **2011**, *22*, 561–569. [CrossRef]
4. Fernandes, L.; Casal, S.; Pereira, J.A.; Saraiva, J.A.; Ramalhosa, E. Edible flowers: A review of the nutritional, antioxidant, antimicrobial properties and effects on human health. *J. Food Compost. Anal.* **2017**, *60*, 38–50. [CrossRef]
5. Pires, T.C.S.P.; Dias, M.I.; Barros, L.; Calhelha, R.C.; Alves, M.J.; Oliveira, M.B.P.P.; Santos-Buelga, C.; Ferreira, I.C.F.R. Edible flowers as sources of phenolic compounds with bioactive potential. *Food Res. Int.* **2018**, *105*, 580–588. [CrossRef]
6. Mulík, S.; Ozuna, C. Mexican edible flowers: Cultural background, traditional culinary uses, and potential health benefits. *Int. J. Gastron. Food Sci.* **2020**, *21*, 100235. [CrossRef]
7. Janarny, G.; Gunathilake, K.D.P.P.; Ranaweera, K.K.D.S. Nutraceutical potential of dietary phytochemicals in edible flowers—A review. *J. Food Biochem.* **2021**, *45*, e13642. [CrossRef]
8. Prabawati, N.B.; Oktavirina, V.; Palma, M.; Setyaningsih, W. Edible flowers: Antioxidant compounds and their functional properties. *Horticulturae* **2021**, *7*, 66. [CrossRef]
9. Nieto-Ramírez, M.I.; García-Trejo, J.F.; Caltzontzin-Rabell, V.; Chávez-Jaime, R.; Estrada-Sánchez, M.L. Efecto de las condiciones de cultivo en la producción de fenoles, flavonoides totales y su capacidad antioxidante en el árnica (*Heterotheca inuloides*). *Rev. Mex. Cienc. Agríc.* **2018**, *21*, 4296–4305. [CrossRef]
10. Pacheco-Coello, F.; Ramírez-Azuaje, D.; Pinto-Catari, I.; Peraza-Marrero, M.; Orosco-Vargas, C. Comparación de compuestos fenólicos totales en *Hibiscus sabdariffa* L. Venezuela. *Rev. Colomb. Cienc. Quím.-Farm.* **2019**, *48*, 521–527. [CrossRef]
11. Benvenuti, S.; Mazzoncini, M. The biodiversity of edible flowers: Discovering new tastes and new health benefits. *Front. Plant Sci.* **2021**, *11*, 569499. [CrossRef]
12. Bautista, I.; Boscaiu, M.; Lidón, A.; Llinares, J.V.; Lull, C.; Donat, M.P.; Mayoral, O.; Vicente, O. Environmentally induced changes in antioxidant phenolic compounds levels in wild plants. *Acta Physiol. Plant* **2016**, *38*, 9. [CrossRef]
13. Moore, B.D.; Andrew, R.L.; Külheim, C.; Foley, W.J. Explaining intraspecific diversity in plant secondary metabolites in an ecological context. *New Phytol.* **2014**, *201*, 733–750. [CrossRef] [PubMed]
14. Mulík, S.; Hernández-Carrión, M.; Pacheco-Pantoja, S.E.; Aguilar-Ruiz, N.; Ozuna, C. Culinary uses of Mexican edible flowers: Recipe analysis. *Int. J. Gastron. Food Sci.* **2022**, *28*, 100539. [CrossRef]
15. Sotelo, A.; López-García, S.; Basurto-Peña, F. Content of nutrient and antinutrient in edible flowers of wild plants in Mexico. *Plant Foods Hum. Nutr.* **2007**, *62*, 133–138. [CrossRef]
16. Juárez-Trujillo, N.; Monribot-Villanueva, J.L.; Jiménez-Fernández, V.M.; Suárez-Montaño, R.; Aguilar-Colorado, Á.S.; Guerrero-Analco, J.A.; Jiménez, M. Phytochemical characterization of izote (*Yucca elephantipes*) flowers. *J. App. Bot. Food Qual.* **2018**, *91*, 202–210.
17. Arellanes-Cancino, Y.; Casas-Fernández, A. Los mercados tradicionales del Valle de Tehuacán-Cuicatlán: Antecedentes y situación actual. *Nueva Antropología* **2011**, *24*, 93–123.
18. Pinedo-Espinoza, J.M.; Gutiérrez-Tlahque, J.; Santiago-Saenz, Y.O.; Aguirre-Mancilla, C.L.; Reyes-Fuentes, M.; López-Palestina, C.U. Nutritional composition, bioactive compounds and antioxidant activity of wild edible flowers consumed in semiarid regions of Mexico. *Plant Foods Hum. Nutr.* **2020**, *75*, 413–419. [CrossRef]
19. Manzanero-Medina, G.I.; Pérez-Herrera, A.; Lustre-Sánchez, H.; Vásquez-Dávila, M.A.; Santos-Sánchez, N.F.; Sánchez-Medina, M.A. Ethnobotanical and nutritional study of quelites sold in two traditional markets of Oaxaca, Mexico. *bioRxiv* **2018**. [CrossRef]
20. Centurión-Hidalgo, D.; Alor-Chávez, M.J.; Espinosa-Moreno, J.; Gómez-García, E.; Solano, M.L.; Poot-Matu, J.E. Contenido nutricional de inflorescencias de palmas en la sierra del estado de Tabasco. *Univ. Cienc.* **2009**, *25*, 193–199.
21. Guillot-Ortiz, D.; Van der Meer, P. El género Yucca L. en España. In *Monografías de la Revista Bouteloua*; Benito-Alonso, J.L., Ed.; Jolube: Valencia, Spain, 2009; Volume 2, p. 55.

22. Granados-Sánchez, D.; López-Ríos, G.F. Yucca "izote" del desierto. *Rev. Chapingo Ser. Cienc. For. Ambiente* **1998**, *4*, 179–192.
23. Reynoso-Santos, R.; García-Mendoza, A.J.; López-Báez, W.; López-Luna, A.; Cadena Iñiguez, P.; Pérez-Farrera, M.A.; Domínguez-Gutiérrez, M.H. Identificación taxonómica de agaves (*Agave* spp.) utilizados para la elaboración de licor comiteco en Chiapas, México. *Agro Product.* **2018**, *5*, 9–17.
24. Rojas-Rodríguez, F.; Torres-Córdoba, G. Árboles del Valle Central de Costa Rica: Reproducción guachipelín (*Diphysa americana* (Mill.) M. Sousa). *Rev. For. Mesoam. Kurú* **2019**, *16*, 69–71. [CrossRef]
25. Barney-Guillermo, H.; Vázquez-Torres, M.; Alejandre-Rosas, J.A.; Martinez Gándara, J. Usos de cuatro especies de palmas silvestres por los habitantes de la Sierra de Santa Marta, Veracruz. *Cienc. Hombre* **1996**, *23*, 68–82.
26. Molinari, M.S.; Aguilar Medina, J.I. Cosmovisión de la vida cotidiana en Chiltepec, Oaxaca. *Diario Campo* **2013**, *12*, 19–56.
27. Instituto Nacional de Estadística y Geografía (INEGI). *Compendio de Información Geográfica Municipal de los Estados Unidos Mexicanos 2010*; INEGI: Aguascalientes, Mexico, 2010. Available online: https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825293093 (accessed on 27 March 2024).
28. Singleton, V.L.; Rossi, J.A. Colorimetry of total phenolics with phosphomolybdic phosphotungstic acid reagents. *Am. J. Enol. Vit.* **1965**, *16*, 144–158. [CrossRef]
29. Zhishen, J.; Mengcheng, T.; Jianming, W. The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chem.* **1999**, *64*, 555–559. [CrossRef]
30. Lin, J.-Y.; Tang, C.-Y. Determination of total phenolic and flavonoid contents in selected fruits and vegetables, as well as their stimulatory effects on mouse splenocyte proliferation. *Food Chem.* **2007**, *101*, 140–147. [CrossRef]
31. Brand-Williams, W.; Cuvelier, M.E.; Berset, C. Use of a free radical method to evaluate antioxidant activity. *LWT -Food Sci. Technol.* **1995**, *28*, 25–30. [CrossRef]
32. Benzie, I.F.F.; Strain, J.J. Ferric reducing/antioxidant power assay: Direct measure of total antioxidant activity of biological fluids and modified version for simultaneous measurement of total antioxidant power and ascorbic acid concentration. *Methods Enzymol.* **1999**, *299*, 15–27.
33. SAS Institute Inc. *Base SAS®9.1.3 Procedures Guide*, 2nd ed.; SAS Institute Inc.: Cary, NC, USA, 2006.
34. Guiné, R.P.F.; Florença, S.G.; Ferrão, A.C.; Correia, P.M.R. Investigation about the consumption of edible flowers in Portugal. *Indian J. Tradit. Knowl.* **2019**, *18*, 579–588.
35. Li, A.-N.; Li, S.; Li, H.-B.; Xu, D.-P.; Xu, X.-R.; Chen, F. Total phenolic contents and antioxidant capacities of 51 edible and wild flowers. *J. Funct. Foods* **2014**, *6*, 319–330. [CrossRef]
36. Cáceres, A.; Lange, K.; Cruz, S.M.; Velásquez, R.; Lima, S.; Menéndez, M.C.; Dardón, R.; Córdova, D.; González, J. Assessment of antioxidant activity of 24 native plants used in Guatemala for their potential application in natural product industry. *Acta Hortic.* **2012**, *964*, 85–92. [CrossRef]
37. Nicknezhad, S.; Hashemabadi, D.; Allahyari, M.S. Nutritional value of some flowers found in green spaces as new food sources. *J. Ornam. Plants* **2022**, *12*, 143–155.
38. Blancas, J.; Casas, A.; Rangel-Landa, S.; Moreno-Calles, A.; Torres, I.; Pérez-Negrón, E.; Solís, L.; Delgado-Lemus, A.; Parra, F.; Arellanes, Y.; et al. Plant management in the Tehuacán-Cuicatlán Valley, México. *Econ. Bot.* **2010**, *64*, 287–302. [CrossRef]
39. Brena-Bustamante, P.; Lira-Saade, R.; García-Moya, E.; Romero-Manzanares, A.; Cervantes-Maya, H.; López-Carrera, M.; Chávez-Herrera, S. Aprovechamiento del escapo y botones florales de *Agave kerchovei* en el Valle de Tehuacán-Cuicatlán, México. *Bot. Sci.* **2013**, *91*, 181–186. [CrossRef]
40. Barriada-Bernal, L.G.; Almaraz-Abarca, N.; Delgado-Alvarado, E.A.; Gallardo-Velázquez, T.; Ávila-Reyes, J.A.; Torres-Morán, M.I.; González-Elizondo, M.D.S.; Herrera-Arrieta, Y. Flavonoid composition and antioxidant capacity of the edible flowers of *Agave durangensis* (Agavaceae). *CyTA J. Food* **2014**, *12*, 105–114. [CrossRef]
41. Cáceres, A.; Cano, O.; Samayoa, B.; Aguilar, L. Plants used in Guatemala for the treatment of gastrointestinal disorders. 1. Screening of 84 plants against enterobacteria. *J. Ethnopharmacol.* **1990**, *30*, 55–73. [CrossRef]
42. Cáceres, A.; López, B.R.; Girón, M.A.; Logemann, H. Actividad antimicótica de plantas usadas en Guatemala para el tratamiento de dermatofitosis. *Rev. Mex. Mic.* **1991**, *7*, 21–38.
43. Díaz-Núñez, J.L.; Pérez-López, M.; Espinosa, N.; Campos-Hernández, N.; García-Contreras, R.; Díaz-Guerrero, M.; Cortes-López, H.; Vázquez-Sánchez, M.; Quezada, H.; Martínez-Vázquez, M.; et al. Anti-virulence properties of plant species: Correlation between in vitro activity and efficacy in a murine model of bacterial infection. *Microorganisms* **2021**, *9*, 2424. [CrossRef] [PubMed]
44. Ingham, J.L.; Tahara, S. Isolation and identification of isoflavanone phytoalexins from leaflets of *Diphysa robinioides*. *Z. Naturforschung C* **1983**, *38*, 899–904. [CrossRef]
45. Castillo-Mont, J.J.; Gallardo, N.R.; Johnson, D.V. The pacaya palm (*Chamaedorea tepejilote*; Arecaceae) and its food use in Guatemala. *Econ. Bot.* **1994**, *48*, 68–75. [CrossRef]
46. Mancera-Castro, P.; Bernardino-Nicanor, A.; Juárez-Goiz, J.M.S.; Teniente-Martínez, G.; González-Cruz, L. Effect of the type of thermal treatment on the nutritional and nutraceutical characteristics of pacaya inflorescences (*Chamaedorea tepejilote* Liebm). *Biol. Life Sci. Forum* **2022**, *18*, 36. [CrossRef]
47. Cáceres, A.; Cruz, S.M. Edible seeds, leaves and flowers as Maya super foods: Function and composition. *Int. J. Phytocosmet. Nat. Ingred.* **2019**, *6*, 2. [CrossRef]

48. Centurión-Hidalgo, D.; Espinosa-Moreno, J.; Mayo-Mosqueda, A.; Frías-Jiménez, A.; Velázquez-Martínez, J.R. Evaluación de la actividad antibacteriana de los extractos hexánicos de las inflorescencias de palmas comestibles de la sierra de Tabasco, México. *Polibotánica* **2013**, *35*, 133–142.
49. Montejos-Ramos, O.; Márquez-Montes, R. Incorporación de la inflorescencia comestible de palma (Arecaceae: *Chamaedorea tepejilote* Liebm.) en un cereal para el desayuno. *Lacandonia* **2012**, *6*, 111–121.
50. Li, Z.; Zhang, J.; Meng, Q.; Yang, L.; Qiu, M.; Li, Y.; Yao, S.; Wei, W.; Yao, C.; Bi, Q.; et al. The content and distribution of 18 phenolic compounds in 462 batches of edible flowers from 73 species commercially available in China. *Food Res. Int.* **2023**, *166*, 112590. [CrossRef]
51. Kandylis, P. Phytochemicals and antioxidant properties of edible flowers. *Appl. Sci.* **2022**, *12*, 9937. [CrossRef]
52. Rao, V.; Poonia, A. Bioactive compounds, nanoparticles synthesis, health benefits and potential utilization of edible flowers for the development of functional dairy products: A review. *J. Food Sci. Technol.* **2023**, *61*, 1053–1068. [CrossRef]
53. Pensamiento-Niño, C.A.; Castañeda-Ovando, A.; Añorve-Morga, J.; Hernández-Fuentes, A.D.; Aguilar-Arteaga, K.; Ojeda-Ramírez, D. Edible flowers and their relationships with human health: Biological activities. *Food Rev. Int.* **2024**, *40*, 620–639. [CrossRef]