Research article

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Nutritional and nutraceutical components of four *Cantharellus* species (Cantharellaceae, Cantharellales) from the Mountain Region, Veracruz, Mexico

Componentes nutrimentales y nutraceúticos de cuatro especies de *Cantharellus* (Cantharellaceae, Cantharellales) de La Región de Las Montañas, Veracruz, México

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Abstract:

Background and Aims: *Cantharellus* species are traded in agricultural markets of the Mountain Region, Veracruz, Mexico, as an appreciated mushroom. The objective of this study was to analyze nutrients and nutraceutical properties in four *Cantharellus* species from Veracruz: antioxidant activity, total phenols, flavonoids, ascorbic acid, lycopene, and β-carotene; as well as the nutritional properties: dry matter, total ashes, crude protein, crude fat, crude fiber, moisture, carbohydrates and energy value of four wild edible mushrooms (*Cantharellus violaceovinosus*, *C. veraecrucis*, *C. roseocanus* and *Cantharellus* sp.).

Methods: Basidiomas of *Cantharellus* spp. were collected in the Mountain Region, Veracruz, Mexico. The ITS and tef-1α regions were amplified and sequenced. Species were identified molecularly based on the BLAST results. Samples were lyophilized and stored at 4 °C in vacuum bags for the preservation of nutraceutical and nutritional compounds. A methanol-water mixture (80:20 v/v) was used to extract the nutraceutical compounds and to analyze them by spectrophotometric techniques.

Key results: In general, outstanding values were found in *C. violaceovinosus* both in crude protein content (8.04 g/100 g-1) and in antioxidant capacity 2.28 mg TE/g extract. For flavonoids, *C. roseocanus* showed 2.98 mg QE/g extract and 6.23±0.68 mg/g of carotene. In addition, a high energy value was found in *C. violaceovinosus* (266.53 Kcal/100g) and *C. roseocanus* (222.73±15.43 Kcal/100 g). The nutritional and nutraceutical content of *C. violaceovinosus*, *C. veraecrucis* and *C. roseocanus* is presented for the first time.

Conclusions: The results show these species from nutritional and nutraceutical perspectives. *Cantharellus violaceovinosus* showed the highest values of the parameters evaluated. The consumption of these species constitutes an alternative source of protein and nutraceutical components that contribute to food security.

Key words: antioxidant capacity, nutraceutical compounds, nutritional content, wild mushrooms.

Resumen:

Antecedentes y Objetivos: Las especies de *Cantharellus* se comercializan en los mercados agrícolas de la Región de Las Montañas, Veracruz, México, como un hongo apreciado. El objetivo de este estudio fue analizar los nutrientes y propiedades nutracéuticas en cuatro especies de *Cantharellus* de Veracruz: capacidad antioxidante, fenoles totales, flavonoides, ácido ascórbico, licopeno y caroteno; así como las propiedades nutricionales: materia seca, cenizas totales, proteína bruta, grasa, fibra bruta, humedad, carbohidratos y valor energético de cuatro hongos silvestres comestibles (*Cantharellus violaceovinosus*, *C. veraecrucis*, *C. roseocanus* y *Cantharellus* sp.).

Métodos: Se colectaron basidiomas de *Cantharellus* spp. en la Región de la Montaña, Veracruz, México. Se amplificaron las regiones ITS y tef-1α y secuenciaron. Las especies se identificaron molecularmente en base en los resultados de BLAST. Las muestras fueron liofilizadas y almacenadas a 4°C en bolsas al vacío para la conservación de compuestos nutracéuticos y nutricionales. Se utilizó una mezcla metanol-agua (80:20 v/v) para extraer los compuestos nutracéuticos y analizarlos por técnicas espectrofotométricas.

Resultados clave: En general, se encontraron valores sobresalientes en *C. violaceovinosus*, tanto en contenido de proteína cruda (8.04 g/100 g-1) como en capacidad antioxidante (2.28 mg TE/g extracto). Para los flavonoides, *C. roseocanus* mostró 2.98 mg QE/g de extracto y 6.23±0.68 mg de caroteno/g de extracto. Además, se encontró un alto valor energético en *C. violaceovinosus* (266.53 Kcal/100g) y *C. roseocanus* (222.73±15.43 Kcal/100g) (266.53±14.64 Kcal/100g). Se presenta por primera vez el contenido nutricional y nutracéutico de *C. violaceovinosus*, *C. veraecrucis* y *C. roseocanus.*

Conclusiones: Los resultados muestran estas especies desde las perspectivas nutricional y nutracéutica. *Cantharellus violaceovinosus* mostró los valores más altos de los parámetros evaluados. El consumo de estas especies constituye una alternativa como fuentes de proteínas y componentes nutracéuticos que contribuyen a la seguridad alimentaria.

Palabras clave: capacidad antioxidante, compuestos nutraceúticos, contenido nutrimental, hongos silvestres.

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Introduction

Edible mushrooms are an alternative that contributes to satisfy the nutritional needs of the population, mainly in developing countries, due to the low production costs, high protein content and large harvest volumes in little space and time, with a precious flavor and highly desirable aromas (Wang et al., 2014; Kalač, 2016; Guerin-Laguette et al., 2020). The nutritional value of edible mushrooms is due to their high content of crude proteins, crude fibers, vitamins, minerals, and low-fat content (Assemie and Abaya, 2022). Indeed, mushrooms are rich sources of nutraceuticals, for example, several species of *Cantharellus* Adans. ex Fr. In Mexico, *Cantharellus cibarius* Fr., collected in the state of Hidalgo, reported important components (López-Vázquez et al., 2017), whiles in other countries it has been reported to have antioxidant, antigenotoxic, anti-inflammatory and antimicrobial properties (Barros et al., 2008a; Kumari et al., 2011; Ebrahimzadeh et al., 2015; Kozarski et al., 2015). The trace elements, nutrients and bioactive components of the species, as well as their apricot aroma, make these species popular among consumers worldwide (Ayaz et al., 2011; Politowicz et al., 2017). However, most of the studies of this genus refer to the physiology, taxonomy and ecology of its species (Barros et al., 2008a; Kumari et al., 2011; Ebrahimzadeh et al., 2015; Kozarski et al., 2015).

In the Mountain Region, Veracruz, Mexico, the climatic conditions, and its enormous biodiversity originate unique characteristics that are conducive to the growth of a huge amount of edible wild ectomycorrhizal mushrooms. In Mexico an important mycological richness is measured, positioning itself worldwide as the second reservoir of edible species, only behind China (Wu et al., 2019; Pérez-Moreno et al., 2020). Some of these species have a high gastronomic value. In recent years, new *Cantharellus* species have been reported in this region and are locally appreciated as choice wild edible mushrooms (Herrera et al., 2018; Montoya et al., 2021). Despite the popularity of edible species of the genus *Cantharellus* in agricultural markets in the region, there are no data on their nutritional and nutraceutical values. Therefore, it is essential to realize such investigations, to improve the conservation and valuation of these natural resources and their habitats (Barros et al., 2008b).

The aim of this study was to analyze the nutritional and nutraceutical composition of four species of wild ectomycorrhizal fungi of the genus Cantharellus from the mountain region, Veracruz, Mexico.

Materials and Methods

Sampling

Basidiomas of *Cantharellus* spp. were collected in different locations in the Mountain Region, Veracruz, Mexico, during June-October in the period 2019-2021 (Fig. 1). Fresh samples were dried using a freeze dry system (Labconco 4.5 Plus, Kansas, USA) and stored in vacuum sealed bags in complete darkness at 4 °C to preserve their bioactive components for further nutritional analysis. Specimens were deposited in the Herbarium CORU "Jerzy Rzedowski Rotter" of Faculty of Biological and Agricultural Sciences of the Universidad Veracruzana, Campus Córdoba, Mexico.

DNA isolation, PCR amplification and sequencing

DNA was isolated from dried specimens using a commercial DNA extraction kit (Plant/Fungi DNA Isolation Kit, Norgen Biotek Corp, Ontario, Canada). The internal transcribed spacer (ITS) region was amplified following the protocol of White et al. (1990), by using primers ITS3 and ITS4. The transcription elongation factor 1-alpha (tef-1α) was amplified using the primers tef1F and tef1R (Morehouse et al., 2003). The PCR products were purified and sequenced (Macrogen, 2023). Forward and reverse reads were assembled and edited with SeqMan Pro v. 7.1.0 (DNASTAR, 2023).

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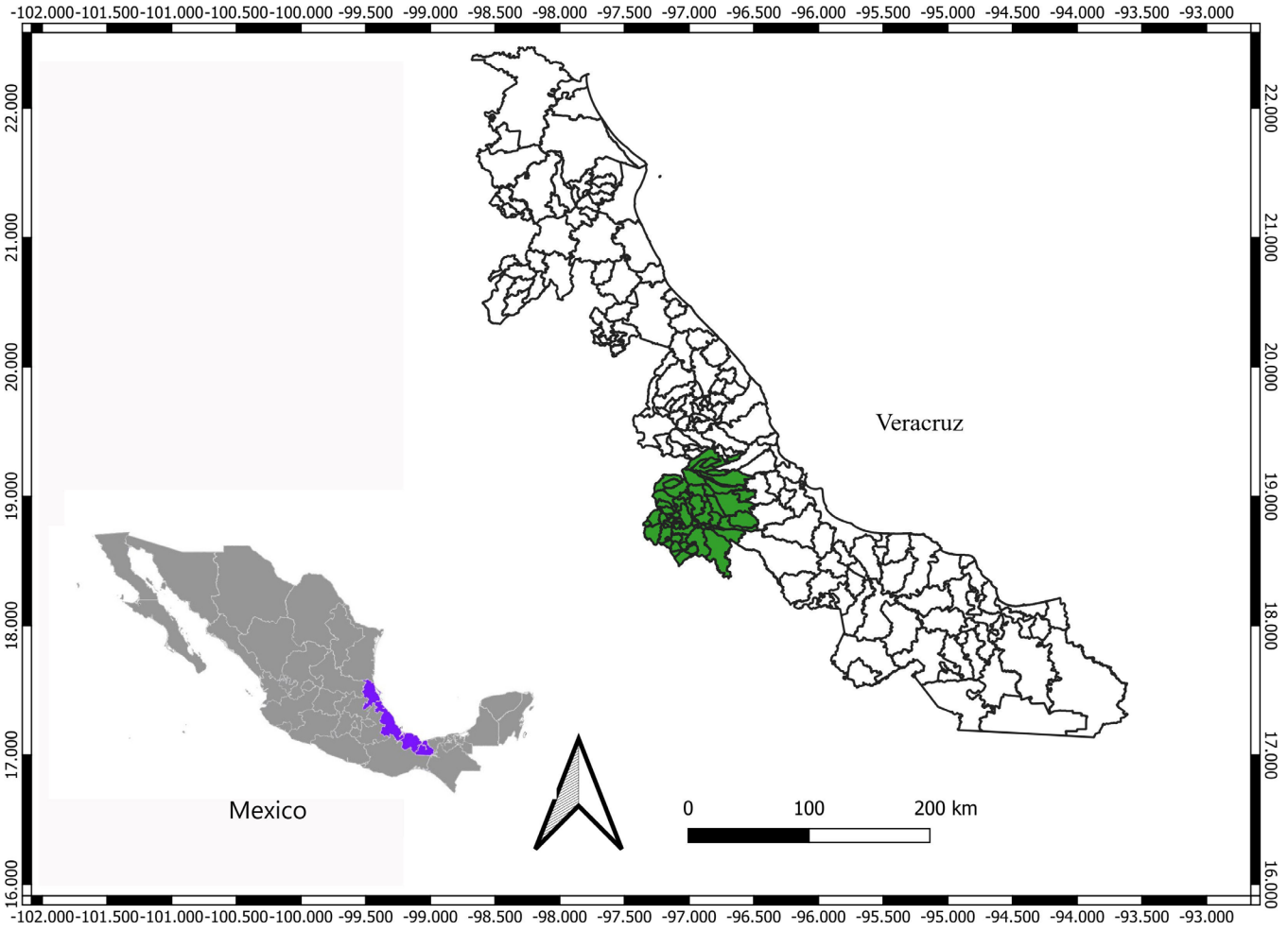

Figure 1: Map of the Mountain Region, Veracruz, Mexico. Elaborated with QGIS v. 3.18.3 (QGIS Development Team, 2023).

DNA sequence assembly and species identification

New sequences generated from this study were deposited in GenBank (Clark et al., 2016). Initial BLAST® (Altschul et al., 1990) searches of both ITS and tef-1α sequences were performed to estimate similarity with *Cantharellus* sequences in GenBank (GenBank, 2023). Species were identified molecularly based on the BLAST® results.

Standards and reagents

The reagents used in this study such as Folin-Ciocalteu phenol, gallic acid, aluminium chloride, sodium hydroxide, 1,4-dichlorobenzene, chloroform, ethyl acetate, acetic anhydride, sulfuric acid, acetone, petroleum ether, and methanol, Sodium Carbonate, Quercetin, were all purchased through Sigma-Aldrich (Sigma-Aldrich St. Louis, MO, USA).

Preparation of samples

A stock solution was prepared for nutraceutical analyses. One gram of lyophilized mushroom sample was extracted with 20 ml of 80:20 methanol-water. The extract was allowed to settle for 60 min and was subsequently subjected to three cycles of 5 min each, in an ultrasound (CIVEQ 8892, Mexico City, Mexico) and finally filtered through Whatman No. 4 paper. The extracts were stored at 4 °C for the analysis of bioactive compounds (Barros et al., 2008a; Ferreira et al., 2009).

Nutritional value analysis

The chemical composition (dry matter, moisture, crude protein, crude fat, crude fiber, carbohydrates, energetic value, and ashes) of the fungal samples were analyzed using the Association of Official Analytical Chemists procedures (AOAC, 1995).

The moisture content was determined by the loss of mass weight that occurs when the material is heated (AOAC, 1995). The crude protein content (N 4.38) of the samples was estimated by the Kjeldahl method (Micro Kjeldahl Digestor, Labconco, Kansas, USA). Crude fat was determined by extracting 2 g of pulverized mushrooms with petroleum ether, using a Soxhlet apparatus (PYREX, Mexico City, Mexico); the ash content was determined by incineration at 600±15 °C (Felisa® Zapopan, Jalisco, Mexico); the method for Crude fiber is determined gravimetrically after chemical digestion and solubilization of other materials in present.

$$Total\ carbohydrates = 100 - (g\ moisture + g\ protein + g\ fat + g\ ash)$$

Total energy was calculated according to the following equation (AOAC, 1995):

$$Energy\ (kJ) = 17 \times (g\ protein + g\ carbohydrate) + 37 \times (g\ lipid)$$

using the following formula:

$$Total\ Carbohidrates = 100 - [humidity\ (g) + protein\ (g) + fat\ (g) + ash\ (g)]$$

Determination of total bioactive compounds

Bioactive compounds were determined after 80% methanolic extraction. Phenols, flavonoids, ascorbic acid and carotenoids were determined according to the methodology described by Barros et al. (2008a). The antioxidant activity was carried out according to the protocol of Barros et al. (2007a), with some modifications.

Total phenol content

For the determination of phenolic compounds in the fungal extracts, 1 ml sample was mixed with 1 ml of Folin and Ciocalteu phenol reagent. After 3 min, 1 ml of a saturated sodium carbonate solution was added to the mixture and adjusted to 10 ml with distilled water. The reaction was kept in the dark for 90 min, and then the absorbance at 725 nm was measured (Spectrophotometer, Thermo Scientific™ Evolution™ 260, Waltham, Massachusetts, USA). Gallic acid was used to prepare the standard curve (0.01-0.1 mg/ml) (Y = 0.091848 + 0.057127x; R2 = 0.9997). The results were expressed as mg of gallic acid equivalents (GAE) per g of extract.

Total flavonoid content

Zero point five ml of the methanolic extract was mixed with 0.1 ml of 10% aluminum nitrate and 0.1 ml of 1 M potassium acetate. Subsequently, 4.3 ml of 80% methanol was added, leaving it to stand for 40 min, then absorbance was read at 415 nm. Quercetin (0-100 mg/l) was used to prepare the standard curve (Y = 0.010852 + 0.091128x; R2 = 0.9997). The results were expressed in mg of Quercetin Equivalent (QE) per g of extract.

Ascorbic acid content

Five ml of ascorbic acid standard solution was mixed with 5 ml of HPO_3. The mixture was titrated with 2.6 dichlorophenolindophenol until it presented a pink color that was maintained for 15 seconds. The ascorbic acid staining factor was determined using the following formula:

$$dilution\ factor = \frac{0.5}{Titration\ value}$$

Subsequently, 2 ml of the sample was mixed to 10 ml with HPO_3, filtered through Whatman No. 4 filter paper. A 0.5 ml aliquot of the extract was taken and titrated with the dye (Barros et al., 2008a).

β-carotene and lycopene content

For β-carotene and lycopene determination, 100 mg of dry methanolic extract were mixed vigorously with 10 ml of acetone-hexane (4:6) for 1 min and filtered through Whatmann nº 4. The absorbance of the filtrate was read at 453, 505, and 663 nm. The β-carotene and lycopene content were calculated by applying the following equations:

$$\beta - carotene\ (mg/100ml) = 0.216 \times A663 - 0.304 \times A505 + 0.452 \times A453$$

$$Lycopene\ (mg/100ml) = -0.0458 \times A663 + 0.372 \times A505 - 0.0806 \times A453$$

The results were expressed as mg of carotenoid and lycopene per g of extract.

Antioxidant activity

The antioxidant capacity was determined based on the method described by Brand-Williams et al. (1995). Zero point threeml of the previously prepared methanolic extract was taken (stored at 4 °C). A 0.1 ml sample was obtained from the

supernatant, which was placed in amber flasks and mixed with 3.9 ml of DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) methanolic solution with a concentration of 6 × 10-5 mol/l. Then the mixture was left to settle protected from light at room temperature for 70 min. Afterwards, the absorbance of the samples was measured in the spectrophotometer (Thermo Scientific™ Evolution™ 260, Waltham, Massachusetts, USA) at 517 nm; the control sample consisted of 0.1 ml of methanol and 3.9 ml of DPPH solution. Results were expressed as mg of Trolox Equivalent (TE) per g extract solution, using a trolox calibration curve as standard (Y = 0.58509 - 0.0214x; R2 = 0.9992).

Statistical analysis

For each of the fungal species, all the assays were carried out in triplicate. Results were expressed as mean values and standard deviation (SD). Results were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's HSD test with α = 0.05, using the program R software v. 4.3.0 (R Core Team, 2020).

Results

Species identification

Seven sequences were newly generated in this study. The four *Cantharellus* specimens were molecularly identified based on the blast results of ITS and tef-1α sequence data. The results are shown in Table 1.

Nutritional and nutraceutical value analysis

In general, *Cantharellus violaceovinosus* M. Herrera, V.M. Bandala & L. Montoya showed the highest values of the parameters evaluated (expressed on dry weight basis) (Table 2). Crude protein values between 5.60 g/100 g (*Cantharellus* sp.) and 8.04 g/100 g (*C. violaceovinosus*) were found. Crude fat ranged from 4.55 g/100 g (*Cantharellus* sp.) to 9.67 g/100 g (*C. violaceovinosus*). Carbohydrates were an abundant macronutrient ranging from 4.28 g/100 g (*C. veraecrucis* Bandala, Montoya & M. Herrera) to 24.50 g/100 g (*C. violaceovinosus*). The ash content was between 3.93 g/100 g (*C. roseocanus* Redhead, Norvell & Danell) Redhead, Norvell & Moncalvo) and 9.22 g/100 g

Table 1: Results of GenBank BLAST® searches for ITS and tef-1α sequences of four *Cantharellus* Adans. ex Fr. species from Mexico. S = Similarity, QC = Query Cover, "-" = sequence data is not available. The sequences here generated are in bold.

Species	GenBank accession no.			
	Collection	ITS	tef-1α	References
Cantharellus veraecrucis Bandala, Montoya & M. Herrera	Bandala 4505 Type	-	MT449712	Montoya et al., 2021
	EJHM20220813	-	OQ876854 S=100%, QC=79%	
Cantharellus violaceovinosus M. Herrera, V.M. Bandala & L. Montoya	-	-	MF616521	Herrera et al., 2018
	EJHM20220814	OQ875961	OQ876855 S=99.87%, QC=84%	
Cantharellus roseocanus Redhead, Norvell & Danell) Redhead, Norvell & Moncalvo	UBC F23802	KX592760	-	Thorn et al., 2017
	EJHM20220922	OQ875962 S=99.42%, QC=99%	OQ876856 S=99.77%, QC=95%	
	T. Volk CC29		JX030415	Foltz et al., 2013
Cantharellus sp.	**EJHM20220923**	OQ875963 S=98.46%, QC=100%	OQ876857 S=97.86%, QC=100%	
	C-2	LC085373	LC085470, 1	Ogawa et al., 2018

(*C. violaceovinosus*). Based on the proximal analysis, it was determined that a 100 g portion of edible ectomycorrhizal fungi can ensure an intake of 266.53 Kcal in the case of *C. violaceovinosus*, while the lowest caloric intake with 91.32 Kcal was recorded for *C. veraecrucis.*

The main antioxidant component found (1.91-6.23 mg/g) was β-carotene extract (Table 3), followed by flavonoids 0.43-2.98 mg QE/g extract. Ascorbic acid was found in small amounts 0.16-0.17 mg/g extract. Lycopene was found in amounts ranging from 1.18 to 2.52 mg/g extract. Lower ranges were observed in total polyphenols 0.34-0.82 mg GAE/g extract. Regarding the total antioxidant activity, a range of 1.74-2.44 mg TE/g extract was detected. There were differences between the species studied in terms of the concentrations of bioactive compounds. The exception was registered for the case of lycopene where no species presented statistical differences. *Cantharellus roseocanus* presented the highest amount of β-carotenes and flavonoids, compared to the other three species evaluated. In contrast, *C. roseocanus* recorded the highest amount of polyphenols.

Table 2: Approximate chemical composition (g/100 g) and energetic value (Kj/100 g) of four species of the genus *Cantharellus* Adans. ex Fr. Results are expressed in a dry weight basis. Values represent average values (±standard deviation) n = 3. In each column different letters mean significant differences ($p<0.05$) according to Tukey's comparison of means test ($\alpha = 0.05$).

Parameter\Species	*Cantharellus violaceovinosus* M. Herrera, V.M. Bandala & L. Montoya	*Cantharellus roseocanus* Redhead, Norvell & Danell) Redhead, Norvell & Moncalvo	*Cantharellus* sp.	*Cantharellus veraecrucis* Bandala, Montoya & M. Herrera
Dry material	7.81±1.15^{b}	6.55±0.68^{b}	8.37±0.54^{b}	17.05±2.49^{a}
Crude protein	8.04±0.78^{b}	7.74±1.06^{b}	5.60±0.83^{a}	7.86±0.85^{b}
Crude fat	9.67±0.95^{a}	9.62±0.88^{a}	4.55±0.63^{b}	5.8±0.42^{b}
Crude fiber	20.98±0.91^{a}	2.67±.05^{b}	1.64±0.8^{b}	2.50±.05^{b}
Ash	9.22±1.55^{a}	3.93±0.64^{b}	6.49±0.73^{b}	8.22±1.05^{a}
Moisture	92.69±1.19^{a}	94.45±1.32^{a}	92.66±1.01^{a}	84.56±1.07^{b}
Carbohydrates	24.50±5.78^{a}	15.25±4.34^{b}	12.81±1.90^{b}	4.28±1.61^{c}
Energetic value	266.53±14.64^{a}	222.73±15.43^{b}	166.78±6.69^{c}	91.32±6.46^{d}

Table 3: Total bioactive compounds of four species of wild ectomycorrhizal fungi of the genus *Cantharellus* Adans. ex Fr. values represent average values (± standard deviation) n = 3. Different letters in the same row indicate significant differences ($p<0.05$) according to Tukey's comparison of means test ($\alpha = 0.05$).

Compounds	*Cantharellus violaceovinosus* M. Herrera, V.M. Bandala & L. Montoya	*Cantharellus roseocanus* Redhead, Norvell & Danell) Redhead, Norvell & Moncalvo	*Cantharellus* sp.	*Cantharellus veraecrucis* Bandala, Montoya & M. Herrera
Antioxidants (mg TE/g extract)	2.28±0.04^{ab}	1.74±0.04^{c}	2.44±0.06^{a}	2.22±0.10^{b}
Polyphenols (mg GAE/g extract)	0.34±0.02^{c}	0.82±0.02^{c}	0.39±0.01^{b}	0.62±0.07^{a}
Flavonoids (mg QE/g extract)	0.43±0.12^{c}	2.98±0.26^{a}	0.43±0.01^{c}	0.51±0.0^{3b}
Ascorbic acid (mg/g extract)	0.16±0.01^{ab}	0.17±0.01^{a}	0.18±0.01^{a}	0.12±0.01^{b}
Lycopene (mg/g extract)	2.52±0.38^{a}	2.55±1.23^{a}	2.14±0.38^{a}	1.18±0.11^{a}
β-Carotene (mg/g extract)	3.97±0.95^{b}	6.23±0.68^{a}	3.67±0.62^{b}	1.91±0.15^{c}

Cantharellus sp. and *C. violaceovinosus* registered the highest total antioxidant activity.

Discussion

To the best of our knowledge, this is the first nutritional and nutraceutical report of *C. violaceovinosus*, *C. veraecrucis* and *C. roseocanus* in Mexico. The analyzed mushrooms contain valuable nutraceuticals such as phenols, ascorbic acid and β-carotenoids that could be extracted to be used as functional ingredients, specifically against microbial infections, food safety through food diversification, and soil restoration using mycorrhizal plants (Pérez-Moreno et al., 2021).

Edible ectomycorrhizal mushrooms are rich sources of protein with low amounts of fat with almost 400 species of edible mushrooms in Mexico second only to China (Garibay-Orijel and Ruan-Soto, 2014; Aguilar-Romero et al., 2016). Their conservation is associated with its hosts in Mexico, the genera *Pinus* L. and *Quercus* L., stand out, as it is one of their diversification centers (Romero-Sánchez et al., 2018; Castillo-Mendoza et al., 2022). Therefore, understanding the sustainable management of edible ectomycorrhizal fungi is important, since they support the production of fruiting bodies (Gernandt and Pérez-de la Rosa, 2014; Aguilar-Romero et al., 2016).

In this study, six antioxidant activities are reported: total phenols, total flavonoids, ascorbic acid, lycopene and β-carotene, as well as its total antioxidant activity. A report of species of the genus *Cantharellus* shows similar levels of flavonoids and β-carotene (Kumari et al., 2011). On the other hand, the same authors report a higher level of polyphenol (7.67-12.46 mg GAE/g extract) than this study. Compared to other edible species, Vega et al. (2022) reported a total polyphenols level from 1.87 to 3.03 mg GAE/g extract in *Pleurotus djamor* (Rumph. ex Fr.) Boedijn. In Latin America, commercial *Pleurotus* (Fr.) P. Kumm. production is mainly generated in Brazil, Mexico, Colombia, Argentina and Guatemala. It is known that the characteristics of the fungi are affected by different factors such as the species, strain, host, harvest time, management techniques, edaphoclimatic conditions and ecosystem conditions, among others (Manzi et al., 2004; Agrahar-Murugkar and Subbulakshmi, 2005).

Total antioxidant values in edible mushrooms of regional importance are diverse, such as *Pleurotus ostreatus* (Jacq.) P. Kumm, which could present values of 4.3 to 9.0 mg of TE/g extract (Stastny et al., 2022), while in this study *C. violaceovinosus* showed 2.28 mg of TE/g extract. This characteristic is important since according to the health authorities, it is considered that prevention and treatment with nutraceuticals is a powerful instrument to maintain and promote health, longevity, and life quality of the population (Barros et al., 2008a).

It should be noted that the species *Cantharellus cibarius* is the one with the largest number of reports on its chemical and nutraceutical composition (Barros, et al., 2007b; Ferreira et al., 2009). The chemical composition of *Cantharellus cibarius* in other countries was previously described from India, and contains protein as the main macronutrient (Agrahar-Murugkar and Subbulakshmi, 2005; Kumari et al., 2011), while in the Mexican samples of the species investigated here, the main component is carbohydrates, representing a source of nutrients and nutraceuticals. Therefore, these fungal species represent a source of nutrients and nutraceuticals as an alternative in the diet of the inhabitants of the municipalities of the Mountain Region where there are indices of marginalization and, both, poverty and extreme poverty (CONEVAL, 2020).

These mushrooms represent a growing segment of the current food industry (Willis, 2018). In the species studied *C. violaceovinosus* showed the highest values of the parameters evaluated. For this reason, the *Cantharellus* species reported in this study can be used directly in the diet and to promote health, taking advantage of the antioxidant molecules, and additive and synergistic effects tthat is bioactive components could have (Barros et al., 2008a).

Author contributions

EJHM, AHM and RNP collected and processed samples for chemical analysis. JC and RCLH contributed to DNA extraction and molecular analysis. JPM and AAT performed the data integration, analysis and interpretation of the results. All authors contributed to the writing, discussion, review, and approval of the final manuscript.

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Literature cited

Agrahar-Murugkar, D. and G. Subbulakshmi. 2005. Nutritional value of edible wild mushrooms collected from the Khasi hills of Meghalaya. Food Chemistry 89(4): 599-603. DOI: https://doi.org/10.1016/j.foodchem.2004.03.042

Aguilar-Romero, R., F. García-Oliva, F. Pineda-Garcia, I. Torres, E. Peña-Vega, A. Ghilardi and K. Oyama. 2016. Patterns of distribution of nine *Quercus* species along an environmental gradient in a fragmented landscape in central Mexico. Botanical Sciences 94(3): 471-482. DOI: https://doi.org/10.17129/botsci.620

Altschul, S. F., W. Gish, W. Miller, E. W. Myers and D. J. Lipman. 1990. Basic local alignment search tool. Journal of Molecular Biology 215(3): 403-410. DOI: https://doi.org/https://doi.org/10.1016/S0022-2836(05)80360-2

AOAC. 1995. Official methods of analysis. 16th ed. Association of Official Analytical Chemists. Washington, DC., USA. 771 Pp.

Assemie, A. and G. Abaya. 2022. The effect of edible mushroom on health and their biochemistry. International Journal of Microbiology 2022: 8744788. DOI: https://doi.org/10.1155/2022/8744788

Ayaz, F., A. Chuang, L. T. Torun, H. Colak, A. Sesli, E. Presley, J. Smith and R. H. Glew. 2011. Fatty acid and amino acid compositions of selected wild-edible mushrooms consumed in Turkey. International Journal of Food Sciences and Nutrition 62(4): 328-335. DOI: https://doi.org/10.3109/09637486.2010.533160

Barros, L., P. Baptista and I. C. F. R. Ferreira. 2007a. Effect of *Lactarius piperatus* fruiting body maturity stage on antioxidant activity measured by several biochemical assays. Food and Chemical Toxicology 45(9): 1731-1737. DOI: https://doi.org/10.1016/j.fct.2007.03.006

Barros, L., R. C. Calhelha, J. A. Vaz, I. C. F. R., Ferreira, P. Baptista and L. M. Estevinho. 2007b. Antimicrobial activity and bioactive compounds of Portuguese wild edible mushrooms methanolic extracts. European Food Research and Technology 225(2): 151-156. DOI: https://doi.org/10.1007/s00217-006-0394-x

Barros, L., T. Cruz, P. Baptista, L. M. Estevinho and I. C. F. R. Ferreira, 2008a. Wild and commercial mushrooms as source of nutrients and nutraceuticals. Food and Chemical Toxicology 46(8): 2742-2747. DOI: https://doi.org/10.1016/j.fct.2008.04.030

Barros, L., B. A. Venturini, P. Baptista, L. M. Estevinho and I. C. F. R. Ferreira. 2008b. Chemical composition and biological properties of Portuguese wild mushrooms: A comprehensive study. Journal of Agricultural and Food Chemistry 56(10): 3856-3862. DOI: https://doi.org/10.1021/jf8003114

Brand-Williams, W., M. E. Cuvelier and C. Berset. 1995. Use of a free radical method to evaluate antioxidant activity. LWT-Food Science and Technology 28(1): 25-30. DOI: https://doi.org/https://doi.org/10.1016/S0023-6438(95)80008-5

Castillo-Mendoza, E., A. Zamilpa, M. González-Cortázar, E. A. González and E. Tovar-Sánchez. 2022. Chemical constituents and their production in Mexican oaks (*Q. rugosa*, *Q. glabrescens* and *Q. obtusata*). Plants 11(19): 2610. DOI: https://doi.org/10.3390/plants11192610

Clark, K., I. Karsch-Mizrachi, D. J. Lipman, J. Ostell and E. W. Sayers. 2016. GenBank. Nucleic Acids Research 44(D1): D67-D72. DOI: https://doi.org/10.1093/nar/gkv1276

CONEVAL. 2020. Informe de Pobreza y Evaluación 2020.Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL). Cd. Mx., México. https://www.coneval.org.mx/coordinacion/entidades/Documents/ Informes_de_pobreza_y_evaluacion_2020_Documentos/Informe_Veracruz_2020.pdf (consultado noviembre de 2022).

DNASTAR. 2023. SeqMan Pro ver. 7.1.0. DNASTAR, Inc. Wisconsin, USA. https://www.dnastar.com/software (consulted March, 2023).

Ebrahimzadeh, M., Y. Safdari and M. Khalili. 2015. Antioxidant activity of different fractions of methanolic extract of the golden chanterelle mushroom *Cantharellus cibarius* (Higher Basidiomycetes) from Iran. International Journal of Medicinal Mushrooms 17(6): 557-565. DOI: https://doi.org/10.1615/IntJMedMushrooms.v17.i6.60

Ferreira, I., L. Barros and R. Abreu. 2009. Antioxidants in Wild Mushrooms. Current Medicinal Chemistry 16(12): 1543-1560. DOI: https://doi.org/10.2174/092986709787909587

Foltz, M. J., K. E. Perez and T. J. Volk. 2013. Molecular phylogeny and morphology reveal three new species of *Cantharellus* within

20 m of one another in western Wisconsin, USA. Mycologia 105(2): 447-461. DOI: https://doi.org/10.3852/12-181

GenBank. 2023. National Library of Medicine, National Center for Biotechnology Information. Rockville Pike, USA. http://www.ncbi.nlm.nih.gov/genbank/ (consulted March, 2023).

Garibay-Orijel, R. and F. Ruan-Soto. 2014. Listado de los hongos silvestres consumidos como alimento tradicional en México. In: Moreno-Fuentes, A. and R. Garibay-Orijel (eds.). La Etnomicología en México, Estado del Arte. Red de Etnoecología y Patrimonio Biocultural (CONACYT) - Universidad Autónoma del Estado de Hidalgo - Instituto de Biología (UNAM) - Sociedad Mexicana de Micología - Asociación Etnobiológica Mexicana, A.C. - Grupo Interdisciplinario para el Desarrollo de la Etnomicología en México - Sociedad Latinoamericana de Etnobiología. México, D.F., Mexico. Pp. 91-112.

Gernandt, D. S. and J. A. Pérez-de la Rosa. 2014. Biodiversidad de Pinophyta (coníferas) en México. Revista Mexicana de Biodiversidad 85(S1): S126-S133. DOI: https://doi.org/10.7550/rmb.32195

Guerin-Laguette, A., R. Butler and Y. Wang. 2020. Advances in the cultivation of *Lactarius deliciosus* (Saffron Milk Cap) in New Zealand. In: Pérez-Moreno, J., A. Guerin-Laguette, R. Flores Arzú and F. Q. Yu (eds.). Mushrooms, humans and nature in a changing world. Springer. Cham, Germany. DOI: https://doi.org/10.1007/978-3-030-37378-8_5

Herrera, M., V. M. Bandala and L. Montoya. 2018. *Cantharellus violaceovinosus*, a new species from tropical *Quercus* forests in eastern Mexico. MycoKeys 32: 91-109. DOI: https://doi.org/10.3897/mycokeys.32.22838

Kalač, P. 2016. Proximate composition and nutrients. In: Kalač, P. (ed.). Edible Mushrooms. Academic Press. New York, USA. Pp. 7-69. DOI: https://doi.org/10.1016/B978-0-12-804455-1.00002-3

Kozarski, M., A. Klaus, D. Jakovljevic, N. Todorovic, J. Vunduk, P. Petrović, M. Niksic, M. M. Vrvic and L. Van Griensven. 2015a. Antioxidants of edible mushrooms. Molecules 20(10): 19489-19525. DOI: https://doi.org/10.3390/molecules201019489

Kozarski, M., A. Klaus, J. Vunduk, Z. Zizak, M. Niksic, M. D. Jakovljevic, M. M. Vrvic. and L. J. L. D Van Griensven. 2015b. Nutraceutical properties of the methanolic extract of edible mushroom *Cantharellus cibarius* (Fries): primary mechanisms. Food Function 6(6): 1875-1886. DOI: https://doi.org/10.1039/C5FO00312A

Kumari, D., M. S. Reddy and R. C. Upadhyay. 2011. Nutritional composition and antioxidant activities of 18 different wild *Cantharellus* mushrooms of Northwestern Himalayas. Food Science and Technology International 17(6): 557-567. DOI: https://doi.org/10.1177/1082013211427620

López-Vázquez, E., F. Prieto-García, M. Gayosso-Canales, E. M. Otazo Sánchez and J. R. Villagómez Ibarra. 2017. Phenolic acids, flavonoids, ascorbic acid, β-glucans and antioxidant activity in Mexican wild edible mushrooms. Italian Journal of Food Science 29(4): 766-774. DOI: https://doi.org/10.14674/IJFS-838

Magrogen. 2023. Macrogen Humanizing Genomas. Seoul, South Korea. https://dna.macrogen.com (consulted March, 2023).

Manzi, P., S. Marconi, A. Aguzzi and L. Pizzoferrato. 2004. Commercial mushrooms: nutritional quality and effect of cooking. Food Chemistry 84(2): 201-206. DOI: https://doi.org/https://doi.org/10.1016/S0308-8146(03)00202-4

Montoya, L., M. Herrera, V. M. Bandala and A. Ramos. 2021. Two new species and a new record of yellow *Cantharellus* from tropical *Quercus* forests in eastern Mexico with the proposal of a new name for the replacement of *Craterellus confluens*. MycoKeys 80: 91-114. DOI: https://doi.org/10.3897/mycokeys.80.61443

Morehouse, E. A., T. Y. James, A. R. D. Ganley, R. Vilgalys, L. Berger, P. J. Murphy and J. E. Longcore. 2003. Multilocus sequence typing suggests the chytrid pathogen of amphibians is a recently emerged clone. Molecular Ecology 12(2): 395-403. DOI: https://doi.org/10.1046/j.1365-294X.2003.01732.x

Ogawa, W., N. Endo, M. Fukuda and A. Yamada. 2018. Phylogenetic analyses of Japanese golden chanterelles and a new species description, *Cantharellus anzutake* sp. nov. Mycoscience 59(2): 153-165. DOI: https://doi.org/10.1016/j.myc.2017.08.014

Pérez-Moreno, J., M. Martínez-Reyes and F. Hernández-Santiago. 2020. Biotecnología de inoculación de árboles de importancia forestal con hongos ectomicorrízicos comestibles. Agro Productividad 13(5): 91-92. https://doi.org/10.32854/agrop.vi.1540

Pérez-Moreno, J., A. Guerin-Laguette, A. C. Rinaldi, F. Yu, A. Verbeken, F. Hernández-Santiago and M. Martínez-Reyes. 2021. Edible mycorrhizal fungi of the world: What is their role in forest sustainability, food security, biocultural conservation and climate change? Plants, People, Planet 3(5): 471-490. DOI: https://doi.org/10.1002/ppp3.10199

Politowicz, J., K. Lech, L. Sánchez-Rodríguez, A. Szumny and Á. A. Carbonell-Barrachina. 2017. Volatile composition and sensory profile of *Cantharellus cibarius* Fr. as affected by drying method. Journal of the Science of Food and Agriculture 97(15): 5223-5232. DOI: https://doi.org/10.1002/jsfa.8406

QGIS Development Team. 2023. QGIS Geographic Information System v. 3.18.3. Open Source Geospatial Foundation. http://qgis.org (consulted May, 2023).

R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. https://www.r-project.org/ (consulted November, 2022).

Romero-Sánchez, M. E., R. Pérez-Miranda, A. González-Hernández, M. V. Velasco-García, E. Velasco-Bautista and A. Flores. 2018. Current and potential spatial distribution of six endangered pine species of Mexico: Towards a Conservation Strategy. Forests 9(12): 767. DOI: https://doi.org/10.3390/f9120767

Stastny, J., P. Marsik, J. Tauchen, M. Bozik, A. Mascellani, J. Havlik, P. Landa, I. Jablonsky, J. Treml, P. Herczogova, R. Bleha, A. Synytsya and P. Kloucek. 2022. Antioxidant and anti-inflammatory activity of five medicinal mushrooms of the Genus *Pleurotus*. Antioxidants 11(8): 1569. DOI: https://doi.org/10.3390/antiox11081569

Thorn, R. G., J. I. Kim, R. Lebeuf and A. Voitk. 2017. The golden chanterelles of Newfoundland and Labrador: A new species, a new record for North America, and a lost species rediscovered. Botany 95(6): 547-560. DOI: https://doi.org/10.1139/cjb-2016-0213

Vega, A., J. A. De León, S. Miranda and S. M. Reyes. 2022. Agroindustrial waste improves the nutritional and antioxidant profile of *Pleurotus djamor*. Cleaner Waste Systems 2: 100018. DOI: https://doi.org/10.1016/j.clwas.2022.100018

Wang, X. M., J. Zhang, L. H. Wu, Y. L. Zhao, T. Li, J. Q. Li, Y. Z. Wang and H. G. Liu. 2014. A mini-review of chemical composition and nutritional value of edible wild-grown mushroom from China. Food Chemistry 151: 279-285. DOI: https://doi.org/10.1016/j.foodchem.2013.11.062

White, T. J., T. Bruns, S. Lee and J. Taylor. 1990. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Inns, M. A., D. H. Gelfand, J. J. Sninsky and T. J. White (eds.). PCR protocols: a guide to methods and applications. Academic Press. London, UK. Pp. 315-322. DOI: https://doi.org/10.1016/B978-0-12-372180-8.50042-1

Willis, K. J. 2018. State of the World's Fungi 2018. Report. Royal Botanic Gardens. Kew Publishing. London, UK. Pp. 92.

Wu, F., L. W. Zhou, Z. L. Yang, T. Bau, T. H. Li and Y. C. Dai. 2019. Resource diversity of Chinese macrofungi: edible, medicinal and poisonous species. Fungal Diversity 98(1): 1-76. DOI: https://doi.org/10.1007/s13225-019-00432-7