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Characterization of microcapsules from capulín pulp extracts obtained by ultrasound and microwave-assisted extraction

Caracterización de microcápsulas a partir de extractos de pulpa de capulín obtenidos por ultrasonido y microondas

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ABSTRACT

Capulin fruits are a potential bioactive compounds source that can be used mainly in the pharmaceutical, cosmetic, and food industries. This study aimed to characterize the physicochemical properties of microcapsules made with calcium alginate and gum arabic as encapsulating agents, using capulin pulp extracts obtained through ultrasound-assisted and microwave extraction. The microcapsules produced were categorized into three groups: fresh, freeze-dried, and rehydrated. Each group was characterized by assessing dimensions, shape, texture, color, phenolic content, and antioxidant activity. The results showed that the microcapsules ranged in length from 1.25 ± 0.35 to 3.05 ± 0.78 mm and in width from 1.15 ± 0.07 to 2.40 ± 0.14 mm; with spherical or irregular shapes; rough or smooth textures; and colors ranging from yellow-orange-pink to green. The average phenolic content was 0.79 ± 0.22 and 1.23 ± 0.35 mg GAE g^{-1} dw, and the antioxidant activity was 5.47 ± 0.29 and 6.23 ± 0.74 mg TE g^{-1} dw. Microencapsulation using calcium alginate and gum arabic helped preserve the bioactive compounds of the capulin fruit. Morphologically, the fresh microcapsules showed more defined shapes, smoother textures, and more vibrant, saturated colors.

KEYWORDS: *Prunus serotina*, antioxidant activity, phenolic content.

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RESUMEN

Los frutos de capulín son una fuente potencial de compuestos bioactivos, los cuales pueden ser empleados principalmente en la industria farmacéutica, cosmética y alimentaria, la presente investigación tuvo como objetivo la caracterización fisicoquímica de microcápsulas elaboradas con alginato de calcio y goma arábiga como agentes encapsulantes, utilizando extractos de pulpa de capulín obtenidos mediante tecnologías de extracción asistida por ultrasonido y microondas. Las microcápsulas obtenidas se clasificaron en tres grupos: frescas, liofilizadas y rehidratadas, cada grupo se sometió a una caracterización donde se evaluaron las dimensiones, forma, textura, color, contenido fenólico y actividad antioxidante. En los resultados, las microcápsulas presentaron dimensiones de 1.25 ± 0.35 a 3.05 ± 0.78 mm de largo y 1.15 ± 0.07 a 2.40 ± 0.14 mm de ancho; formas esféricas e irregulares; texturas rugosas y lisas; colores entre rosa-amarillo-naranja y verde; contenido fenólico promedio de 0.79 ± 0.22 y de 1.23 ± 0.35 mg GAE g^{-1} dw y una actividad antioxidante de 5.47 ± 0.29 y 6.23 ± 0.74 mg TE g^{-1} dw. La microencapsulación con alginato de calcio y goma arábiga permitió preservar compuestos bioactivos del capulín, desde el punto de vista morfológico, las microcápsulas frescas presentaron formas más definidas, texturas lisas, colores más agradables y saturados.

PALABRAS CLAVE: *Prunus serotina*, actividad antioxidante, contenido fenólico.

Introduction

In 2023, the Agri-Food and Fisheries Information Service (SIAP, 2023) reported a production of 114.28 tons of capulín in the states of Estado de México, Puebla, Mexico City, and Jalisco. In the municipalities of Santa María Citendeje and Jocotitlán (Estado de México), capulín is used for medicinal purposes, as fuel, forage, and in cabinetmaking (López et al., 2024).

The fruits of capulín, Prunus serotina subsp. capuli (Cav.) McVaugh, are valued for their pleasant flavor and are consumed fresh or used in the preparation of conserves, tamales, fermented beverages, and traditional products like medicinal tea (Jiménez et al., 2011; Guzmán et al., 2020). The pulp, fruit peel, and by-products derived from the kernel (shell, paste, and oil) contain bioactive compounds, especially polyphenols, which provide notable antioxidant and antimicrobial properties (Jiménez et al., 2011; Luna-Vázquez et al., 2013; Gallardo et al., 2021).

Bioactive compounds are extracted using methods such as microwave-assisted extraction

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(MAE) and ultrasound-assisted extraction (UAE). The former is one of the most popular and cost-effective techniques (Delazar et al., 2012), as it uses energy to heat the moisture in plant material or in the solvents in contact with it. It is completed within a few minutes, yields higher extraction efficiency, and requires less solvent, making it environmentally friendly (Desai et al., 2010). Conversely, the latter method (UAE) depends on the ultrasonic power applied to the medium and the extraction time (Corona et al., 2016). UAE offers an ecological and economically viable alternative for foods and natural products; its benefits include shorter extraction and processing times, as well as lower energy and solvent use (Chemat et al., 2017). The highest extraction rate is usually achieved during the first few minutes, representing the most cost-effective period (Esclapez et al., 2011).

Polyphenols are considered among the most powerful bioactive compounds synthesized by plants due to their ability to directly scavenge reactive oxygen species and their capacity to donate hydrogen atoms or electrons. Additionally, they show a unique combination of chemical, biological, and physiological effects; however, they lack long-term stability, making these natural compounds highly sensitive to light and heat. They often have poor bioavailability, mainly due to their low water solubility (Munin & Edwards-Lévy, 2011).

Encapsulation is a promising and innovative technique that protects bioactive compounds, improves their oxidative stability, and regulates the release of specific compounds (Di et al., 2022). Different encapsulation methods, whether physical or chemical, can be used, and their selection is closely related to their intended application (Assis et al., 2023). Among various options are micro- and nanoencapsulation techniques (Alu'datt et al., 2022). Key quality parameters in encapsulation methods include moisture and ash content, yield, morphology, microcapsule size, and color (Parra, 2010).

The development of micro- or nanocapsules loaded with polyphenols, carotenoids, fatty acids, phytosterols, probiotics, vitamins, minerals, and bioactive peptides from natural sources enhances stability, solubility, bioavailability, sensory properties, retention of bioactive compounds, and microstructure. It also reduces hygroscopicity and extends shelf life (Zabot et al., 2022). In the food industry, microencapsulated polyphenols are used as ingredients in functional products, beverages, dairy items, and baked goods. Due to their natural preservative properties, they serve both to enrich and protect, effectively inhibiting the growth of bacteria, molds, and yeasts (Bińkowska et al., 2024).

In the cosmetic and pharmaceutical industries, encapsulating polyphenols has emerged as an innovative strategy, particularly in the cosmetics and nutraceutical sectors. When used with polyphenols, this method can reduce their sensory impact, address instability, enhance skin penetration, and increase flexibility in cosmetic product formulation (Rispo et al., 2024).

Given this context, this study aimed to characterize the physicochemical properties of microcapsules prepared with calcium alginate and gum arabic as encapsulating agents, using capulín pulp extracts obtained through ultrasound- and microwave-assisted extraction.

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Materials and Methods

Plant material

Fruits of *Prunus serotina* subsp. capuli (Cav.) McVaugh were harvested in Barrio Tungareo, San Felipe del Progreso, Estado de México (19° 39′ 41.57″ N, 19° 53′ 55.21″ W). Once collected, they were transported to the Food Industries Engineering Laboratory at the Tecnológico de Estudios Superiores de San Felipe del Progreso, where fruits with a reddish-black color, soft texture, and no physical damage were selected. The seeds or kernels were removed, and the fruits were washed with distilled water. A portion of the fruits was reserved for subsequent evaluation, while another portion was dehydrated at 52 °C for 20 hours in a dehydrator (CHEFMAN RJ43-ROB-5, 110 V).

Ultrasound- and microwave-assisted extraction

Separately, 10 g of fresh pulp and 10 g of dehydrated pulp were each mixed with 100 mL of distilled water and then subjected to ultrasound- and microwave-assisted extraction.

For UAE and MAE, the method described by Pinzón & Gómez (2020) was used with slight modifications. In the first case, the samples were placed in an ultrasonic bath (110 V) for 20-second intervals, with 40-second pauses in between, until a total extraction time of 1 h was reached. Afterward, the aqueous extracts were centrifuged for 15 min at 400 rpm, and the supernatants were collected. In the second extraction method, the samples were placed in a microwave oven (700 W) for 2 min; the extracts were then centrifuged for 15 min at 400 rpm, and the supernatants were collected.

Microencapsulation of extracts

The method of Calero *et al.* (2008) was used with some modifications. To the supernatants obtained from the aqueous extracts: fresh pulp ultrasound extract (EFU), dehydrated pulp ultrasound extract (EDU), fresh pulp microwave extract (EFM), and dehydrated pulp microwave extract (EDM), 2 g of a calcium alginate-gum arabic mixture (3:1) was added. The mixture was homogenized and transferred to a disposable syringe (3 mL x 32 mm) to produce droplets, which were allowed to fall into a calcium chloride solution (14.60%). Once the microcapsules formed, they were removed from the solution; some were kept in their original (fresh) state, others were freeze-dried (Freeze Dryer, EGO-FD10PT, 110/60 V) for 24 h at -37.60 °C, and part of the freeze-dried samples were rehydrated. Only fresh microcapsules were used to measure moisture content, ash content, and yield.

Determination of moisture content, ash content, and yield

Moisture content (%) was determined according to NOM-116-SSA1-1994, with some modifications. Portions of 3.00 g, 1.00 g, 0.80 g, 0.70 g, and 0.50 g of microcapsules for each treatment were placed in an oven (Marla, Mod. J-01, 220 V) at 110 °C for 2 h. Afterward, the

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capsules were cooled in a glass desiccator, and the weight of each capsule was measured using an analytical balance (Electronic Compact Scale, Mod. SF-400 C). Moisture percentage was calculated using Equation 1.

Equation 1. $$Moisture\ (\%) = \frac{(P_1 - P_2)}{m}\ x\ 100$$

Where:

P_1 = weight of the sample.

P_2 = weight of the watch glass plus the dried sample.

m = weight of the sample.

Ash content (%) was determined following NMX-Y-362-SCFI-2019. A 0.50 g sample of microcapsules from each treatment was placed in an oven (Marla, Mod. J-01, 220 V) at 550 °C for 2 h. The calculation was done using Equation 2.

Equation 2. $$Ash\ (\%) = \frac{P_2 - P_0}{P_1 - P_0} x100$$

Where:

P_2 = weight of the crucible with ash.

P_1 = weight of the crucible with sample.

P_0 = weight of the empty crucible.

Yield (%) was calculated according to Dincer & Temiz (2023), considering the weight of fresh microcapsules and freeze-dried microcapsules. Results were reported as percentages using Equation 3.

Equation 3. $$Yield\ (\%) = \frac{Pmf}{Pml}\ x\ 100$$

P_{mf} = weight of fresh microcapsules.

P_{ml} = weight of freeze-dried microcapsules.

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Characterization of fresh, freeze-dried, and rehydrated microcapsules

Size was determined using ImageJ software v1.53 (National Institutes of Health, Bethesda, MD, USA, https://imagej.nih.gov/ij/). The microcapsules were measured for length and width, and the results were reported in millimeters (mm).

Shape was described using an optical microscope (Velab, stereo ves-Ia), and results were reported as spherical or irregular.

Texture was characterized based on the external structure observed in the microcapsules and classified as smooth or rough.

Color was measured at the center of each microcapsule using the ImageJ Software. Reported values included lightness (L), hue angle (°Hue; Equation 4), and chroma (Equation 5), according to Lancaster *et al.* (1997).

Equation 4. $^{\circ}Hue = tan^{-1}\frac{b}{a}$

Equation 5. $Chroma = \sqrt{a^2 + b^2}$

Phenolic content and antioxidant activity

These parameters were determined in freeze-dried microcapsules using the methodology described by Borrás *et al.* (2021). Phenolic content results were expressed as milligrams of gallic acid equivalents per gram of sample on a dry weight basis (mg GAE g^{-1} dw), while antioxidant activity, determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method, was reported as milligrams of Trolox equivalents per gram of dry weight (mg TE g^{-1} dw).

Statistical analysis

An ANOVA was used to analyze moisture content, ash content, and microcapsule size. In the last case, mean comparisons were performed using Tukey's test ($p \leq 0.05$) with the statistical software Statistica v.7.1, USA.

Results and Discussion

Moisture content

The average moisture content of the microcapsules was 21.00%. The highest values were observed in those formulated with UAE extracts (23.00 ± 6.9%), while the lowest were in those

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formulated with MAE extracts (19.00 ± 4.83%). However, the analysis of variance applied to the moisture data, considering the extraction method, showed no significant difference between the two ($\alpha = 0.05$, $p = 0.2907$), indicating that the observed variation is not due to the extraction process. In contrast, Ramos et al. (2024) reported moisture values ranging from 7.19% to 8.17%, which support storage stability and extend the shelf life of microcapsules. It should be noted that moisture content may be affected by the chemical makeup of the wall material and the preconditioning of the encapsulated material (Carrillo-Navas *et al.,* 2011; Liau *et al.,* 2025). In this study, using a desiccator to reduce ambient humidity effects during preconditioning was not considered, which may have influenced the results.

Ash content

A high ash content was observed in the microcapsules (UAE = 39.25 ± 5.34%, MAE = 38.00 ± 4.46%), attributed to the presence of 15.00% calcium alginate. This differs from other encapsulated systems using the same formulation, which used a 2.00% solution (Viveros-Contreras *et al.,* 2012; Sukanya *et al.,* 2022). Likewise, Gómez (2018) reported that capsules containing gum arabic have higher ash contents because of inorganic material components retained within the polymer grid. Similarly, using calcium alginate-gum arabic produces a comparable effect, as both are biopolymers. The analysis of variance of ash content data based on the extraction method showed no significant differences ($\alpha = 0.05$, $p = 0.1478$).

Yield

On average, the yield of the microcapsules was 76.00%. The lowest percentage was observed in the UAE (EFU = 48.50%), while the highest was observed in MAE (EDM= 91.25 %). In this regard, Paini *et al.* (2015) reported a high yield (94.00%) in the microencapsulation of phenolic compounds, whereas Enascuta *et al.* (2025) obtained 87.11% when encapsulating bioactive compounds. These authors indicated that variations in yield may be attributed to the concentration ratio of the encapsulating agent to the compound of interest, as an increase in this ratio results in greater microcapsule mass. Additionally, dripping time is a key factor, as longer periods (30 min) tend to decrease yield to the likelihood of droplet fusion within the solution. The microcapsule formation process is also important, as larger droplets form non-homogeneous encapsulates with possible coating defects, making them more susceptible to partial loss of the compound of interest.

Regarding the influence of the extraction method (UAE and MAE) on microcapsule yield, it has been shown that MAE induces alterations in the surface structure of the material and produces smaller particles compared to UAE (Hamamouche *et al.,* 2024), which improves their incorporation into the encapsulating matrix and thereby increases yield. In the case of EDM, which showed the highest yield, this was attributed to the combination of MAE with dehydration, as dehydration significantly reduces moisture content and enhances porosity (Ali *et al.,* 2025), allowing for greater interaction with the encapsulating agents.

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Characterization of fresh, freeze-dried, and rehydrated microcapsules

Table 1 shows the characteristics of size (mm), shape (spherical-irregular), and texture (rough-smooth) of the three groups of microcapsules (fresh, freeze-dried, and rehydrated) obtained from UAE and MAE extracts. The analysis of variance performed to compare microcapsule size among the groups revealed significant differences; therefore, a mean-comparison test was conducted, which indicated that freeze-dried microcapsules generally had the smallest size values.

Microcapsules obtained through ultrasound-assisted extraction had an average width of 1.15 ± 0.07 mm in freeze-dried microcapsules (EDU), while in fresh microcapsules, the average was 2.40 ± 0.14 mm (EFU).

Microcapsules obtained through microwave-assisted extraction had lengths of 1.25 ± 0.35 mm in freeze-dried microcapsules (EDM) and 3.05 ± 0.78 mm in rehydrated microcapsules (EFM). The results of this study align with those reported by Singh *et al.* (2010), who indicated that microcapsule sizes range from 50.00 µm to 2.00 mm. Conversely, Sánchez-Molina *et al.* (2018) reported that dimensional variations depend on the ratio of liquid extract to encapsulating material.

Fresh microcapsules formed from ultrasound extracts showed a well-defined appearance (EFU and EDU = spherical and smooth texture), compared to fresh microcapsules from microwave extracts (EFM and EDM = irregular shapes and rough textures). Freeze-dried microcapsules from both extraction methods, UAE and MAE, displayed irregular shapes and rough textures. This aligns with the findings of Trujano & Lozano (2020), who reported that microcapsules subjected to freeze-drying exhibit irregular morphology due to water sublimation during the drying process, resulting in a porous texture. Consequently, freeze-dried microcapsules exhibited irregular shapes and smaller sizes, which facilitate the release of active substances and enhance absorption and bioadhesion, making them advantageous in fields like medicine.

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Table 1. Characterization of fresh, lyophilized, and rehydrated microcapsules.

	Fresh		Lyophilized		Rehydrated		Fresh	Liophilized	Rehydrated	Fresh	Liophilized	Rehydrated
	Length (mm)	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Form (Spherical- Irregular)**			**Texture (Rough- Smooth)**		
EFU	2.50 ± 0.28 [a]	2.40 ± 0.14 [a]	1.60 ± 0.14 b	1.50 ± 0.42 [b]	2.25 ± 0.07 [a]	2.25 ± 0.35 [ab]	Spherical	Irregular	Irregular	Smooth	Rough	Smooth
EDU	2.70 ± 0.42 a	2.35 ± 0.49 [a]	1.66 ± 0.07 [b]	1.15 ± 0.07 [b]	2.45 ± 0.21 a	1.90 ± 0.28 [a]	Spherical	Irregular	Irregular	Smooth	Rough	Smooth
EFM	2.20 ± 0.42 [b]	2.05 ± 0.35 [a]	1.90 ± 0.14 [b]	1.50 ± 0.00 [b]	3.05 ± 0.78 [a]	2.10 ± 0.28 [a]	Irregular	Irregular	Irregular	Rough	Rough	Smooth
EDM	2.65 ± 0.50 [a]	2.20 ± 0.28 [a]	1.25 ± 0.35 [b]	1.30 ± 0.14 [b]	2.30 ± 0.42 [a]	2.05 ± 0.21 [a]	Irregular	Irregular	Irregular	Smooth and Rough	Rough	Smooth

EFU = fresh pulp ultrasound extract, EDU = dehydrated pulp ultrasound extract, EFM = fresh pulp microwave extract, and EDM = dehydrated pulp microwave extract. Values with different letters in length and width of each row (comparing microcapsules fresh, freeze-dried, and rehydrated) are statistically different, Tukey; $p \leq 0.05$.
Source: Own elaboration based on the size, form, and texture data of the microcapsules.

Regarding color, fresh UAE microcapsules showed hues ranging from pink to red (EFU and EDU = 19.04°Hue and 22.35°Hue), while those obtained by MAE displayed hues from orange to yellow (EFM and EDM = 51.15°Hue and 55.26°Hue). Chroma values ranged between 32.00 and 39.00 for both UAE and MAE microcapsules, whereas lightness values were below 32.00, with EDM showing the lowest value (19.90) and EFU the highest (31.80) (Figure 1). Freeze-dried UAE microcapsules displayed green coloration (EFU and EDU = 162.44°Hue and 175.40°Hue), while MAE microcapsules ranged from orange to green (EFM and EDM = 112.14°Hue and 43.79°Hue). Chroma values ranged from 21.00 to 37.00, with MAE microcapsules showing values below 23.00. Lightness values stayed between 26.00 and 32.00, with EDU presenting the lowest value (26.96) and EFM the highest (31.75) (Figure 2). Rehydrated UAE microcapsules exhibited hues from pink to red (EFU and EDU = 15.87°Hue and 20.56°Hue), while MAE microcapsules leaned toward green coloration (EFM and EDM = 177.71°Hue and 164.89°Hue). Chroma values ranged from 12.00 to 19.00 for MAE microcapsules and from 31.00 to 33.00 for UAE microcapsules. Lightness values ranged from 26 to 39, with EFU showing the lowest value (26.13) and EDM the highest (38.34) (Figure 3).

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Regarding the above, fresh microcapsules showed colors ranging from pink to yellow; after freeze-drying, hues shifted from orange to green, and upon rehydration, UAE microcapsules returned to pinkish-red shades, while MAE microcapsules displayed green hues. Chroma values were highest in fresh microcapsules and gradually decreased during freeze-drying and rehydration, whereas the highest lightness values were found in rehydrated microcapsules, likely due to water content. Based on the evaluated color parameters, the microcapsules with the most visually appealing appearance were the fresh EFU microcapsules, as they exhibited a more reddish tint (typical of capulín pulp), higher color saturation (Chroma value), and greater lightness.

A study conducted by Dincer & Temiz (2023) on freeze-dried microcapsules of *Pyracantha coccinea* var. *lalandi* reported values of °Hue = 65.85, Chroma = 17.23, and L = 77.54. Compared to the values reported herein, the °Hue values were similar, color saturation was higher, and lightness was lower, which may be attributed to the concentration of the calcium chloride solution used.

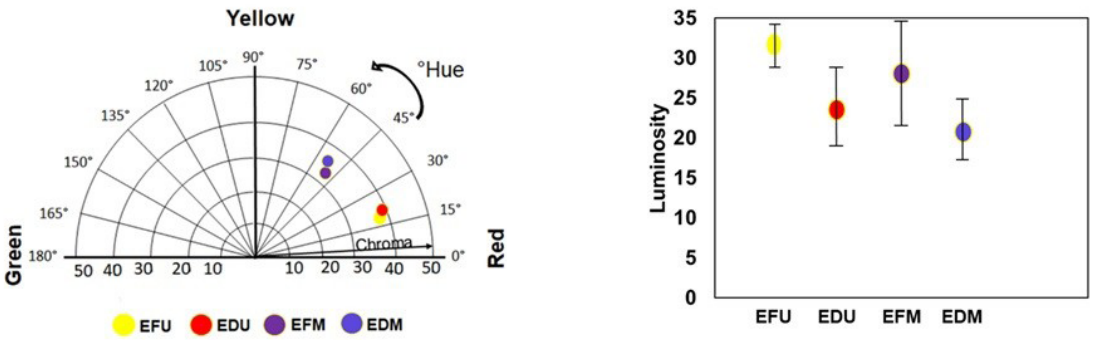

Figure 1. Distribution of Luminosity, °Hue, and Chroma of fresh microcapsules, obtained from EFU = fresh pulp extract by ultrasound, EDU = dehydrated pulp extract by ultrasound, EFM = fresh pulp extract by microwave, and EDM = dehydrated pulp extract by microwave.

Source: Own elaboration based on color data from fresh microcapsules.

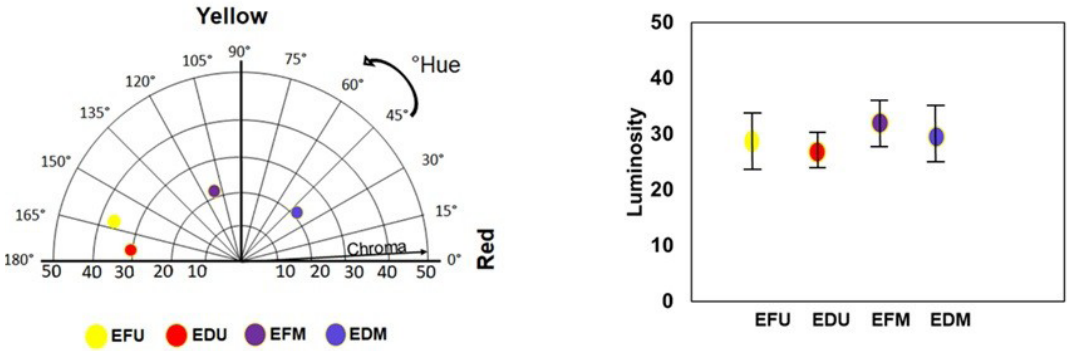

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Figure 2. Distribution of Luminosity, °Hue, and Chroma of lyophilized microcapsules, obtained from EFU = fresh pulp extract by ultrasound, EDU = dehydrated pulp extract by ultrasound, EFM = fresh pulp extract by microwave, and EDM = dehydrated pulp extract by microwave.

Source: Own elaboration based on color data from lyophilized microcapsules.

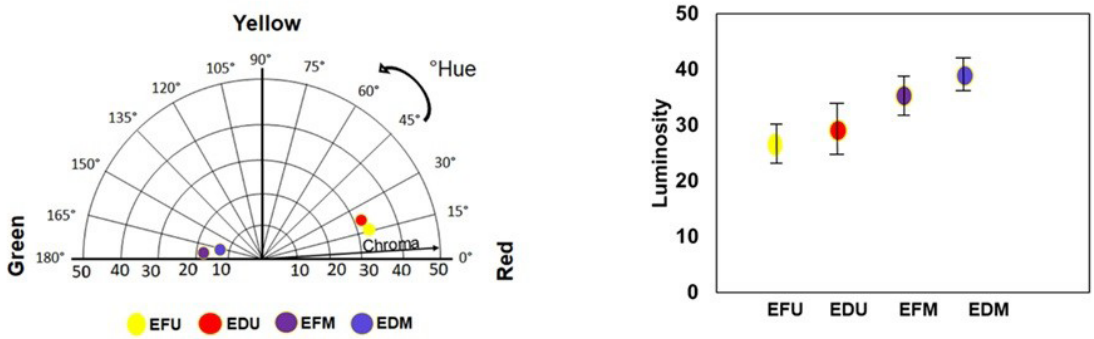

Figure 3. Distribution of Luminosity, °Hue, and Chroma of rehydrated microcapsules, obtained from EFU = fresh pulp extract by ultrasound, EDU = dehydrated pulp extract by ultrasound, EFM = fresh pulp extract by microwave, and EDM = dehydrated pulp extract by microwave.

Source: Own elaboration based on color data from rehydrated microcapsules.

Phenolic content and antioxidant activity

The phenolic content in UAE microcapsules was 0.79 ± 0.22 mg GAE g^{-1} dw, while microcapsules obtained by MAE showed a value of 1.23 ± 0.35 mg GAE g^{-1} dw. Regarding antioxidant activity, UAE microcapsules exhibited 5.47 ± 0.29 mg TE g^{-1} dw, whereas MAE microcapsules reached 6.23 ± 0.74 mg TE g^{-1} dw. The antioxidant activity of phenolic compounds reflects their ability to stabilize free radicals, with activity related to the number of hydroxyl groups present. The higher phenolic content and antioxidant activity in MAE microcapsules can be attributed to the extraction conditions, as rapid heat generation promotes cell matrix disruption and enhances phenolic release (Weremfo *et al.,* 2020). Dincer & Temiz (2023), who evaluated gallic acid in freeze-dried microcapsules of fruits similar to capulín, reported a higher content (8.34 mg GAE g^{-1} dw) than in the present study. This difference may mainly result from the use of different plant species, variations in phenolic extraction methods, the encapsulating agents used (maltodextrin/gum arabic), and the freeze-drying conditions applied to the microcapsules.

The evaluation and characterization of the obtained microcapsules revealed differences in appearance, phenolic content, and antioxidant activity. Visually, microcapsules that were not freeze-dried kept their reddish color with higher saturation and lightness.

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Regarding the extraction method of bioactive compounds, microwave-assisted extraction proved to be more effective in this study. The calcium alginate-gum arabic polymers enabled the encapsulation of bioactive compounds; however, it is important to consider the concentration of the solution used, which in this case was relatively high and may have negatively affected microcapsule lightness.

Sánchez-Molina et al. (2018) reported that developing microencapsulated systems with antioxidant activity provides alternatives for the cosmetic and food industries to create high-value-added products. In the food sector, capulín pulp-based microcapsules could be a suitable option for dairy products, baked goods, and nutraceuticals, as they not only extend shelf life, reduce lipid oxidation, and act as natural preservatives, but also enable the incorporation of antioxidants. In the nutraceutical field, microcapsules help improve the stability, bioavailability, and controlled release of bioactive ingredients, thereby enhancing their physiological effectiveness. In the cosmetic industry, they facilitate the formulation of skincare and makeup products enriched with antioxidants.

Conclusions

The microencapsulation process using calcium alginate and gum arabic proved to be an effective technological method for preserving bioactive compounds. Physicochemical characterization of the microcapsules confirmed the presence of phenolic compounds and antioxidant activity, with those formulated through microwave-assisted extraction showing better performance. Morphologically, fresh microcapsules had more defined shapes, smooth textures, and more vibrant, saturated colors. After freeze-drying and rehydration, the microcapsules that best restored their original color were those produced from ultrasound-assisted extracts, indicating a more favorable interaction between the encapsulating matrix and the bioactive compounds during freeze-drying and reconstitution.

The spherical, smooth shape observed in some microcapsules provides important technological benefits, including increased stability, reduced permeability, controlled release of active ingredients, and improved flowability. These features are ideal for developing sustained-release pharmaceuticals, long-lasting cosmetics, functional food products, and various industrial additives. Conversely, microcapsules with rough, porous surfaces enable faster release of compounds and exhibit greater adhesion. These qualities are useful in immediate-release pharmaceuticals, skincare products, and functional coatings.

Finally, further research is recommended to identify the bioactive compounds in capulín pulp and to assess the performance of microcapsules in food, cosmetic, and pharmaceutical applications, to validate their industrial use.

Author contributions

V.G.D.A., T.M.A., S.B.M., B.E.A.J., and T.M.G.A.: organization and development of the

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Conflicts of interest

The authors declare no conflicts of interest.

References

Ali, M. A., Haque, A. R., Hossain, M. A., & Hasan, S. M. K. (2025). Effect of freeze drying on selective bioactive compounds and physicochemical characteristics of papaya puree. *Heliyon*, 11, e43626. https://doi.org/10.1016/j.heliyon.2025.e43626

Alu'datt, M. H., Alrosan, M., Gammoh, S., Tranchant, C. C., Alhamad, M. N., Rababah, T., Zghoul, R., Alzoubi, H., Ghatasheh, S., Ghozlan. K. & Tan, T. C. (2022). Encapsulation-based technologies for bioactive compounds and their application in the food industry: A roadmap for food-derived functional and health-promoting ingredients. *Food Bioscience*, 50(101971). https://doi.org/10.1016/j.fbio.2022.101971

Assis, M., Gonçalves, M. O., de Foggi, C. C., Burck, M., dos Passos Ramos, S., Libero, L. O., & Braga, A. R. C. (2023). Applications of (Nano) encapsulated natural products by physical and chemical methods. InCruz, J.N. Drug Discovery and Design Using Natural Products. (pp. 323-374). Ed. Springer. https://doi.org/10.1007/978-3-031-35205-8_11

Borrás, E. A. J., Reyes, V. E., Villanueva, R. S. J., & Moreno, V. L. (2021). Effect of Ultrasound-Assisted Extraction Parameters on Total Polyphenols and Its Antioxidant Activity from Mango Residues (*Mangifera indica* L. var. *Manililla*). *Separations*, 8(7), 94. https://doi.org/10.3390/separations8070094

Bińkowska, W., Szpicer, A., Stelmasiak, A., Wojtasik-Kalinowska, I., & Półtorak, A. (2024). Microencapsulation of Polyphenols and Their Application in Food Technology. *Applied Sciences*, 14(24), 11954. https://doi.org/10.3390/app142411954

Revista Bio ciencias
ISSN 2007-3380

Carrillo-Navas, H., González-Rodea, D. A., Cruz-Olivares, J., Barrera-Pichardo, J.F., Román-Guerrero, A., & Pérez-Alonso, C. (2011). Storage stability and physcochemical properties of passion fruit juice microcapsules by spray-drying. *Revista mexicana de ingeniería química*, 10(3), 421-430.

Calero, H. J. A., Sánchez, Y. F., Tórrez, B. R. J., Hernann, E., & López, K. (2008). Elaboración y Caracterización de microcápsulas gastrorresistentes de Diclofenac obtenidas por Gelificación Iónica. *Universitas (León)*, 2(1), 27–30. https://doi.org/10.5377/universitas.v2i1.1640

Chemat, F., Rombaut, N., Sicaire, A. G., Meullemiestre, A., Fabiano-Tixier, A. S., & Abert-Vian, M. (2017). Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. *Ultrasonics sonochemistry*, 34, 540–560. https://doi.org/10.1016/j.ultsonch.2016.06.035

Corona, J. E., Martínez, N. N., Ruiz, E. H., & Carranza, C. J. (2016). Extracción asistida por ultrasonido de compuestos fenólicos de semillas de chia (*Salvia hispanica* L.) y su actividad antioxidante. *Agrociencia*, 50(4), 403-412.

Delazar, A., Nahar, L., Hamedeyazdan, S., & Sarker, S. D. (2012). Microwave-assisted extraction in natural products isolation. En Sarker, S.D. & Nahar, L. *Natural products isolation* (pp. 89-115). Ed. Humana Press. https://doi.org/10.1007/978-1-61779-624-1_5

Desai, M., Parikh, J., & Parikh, P. A. (2010). Extraction of Natural Products Using Microwaves as a Heat Source. *Separation & Purification Reviews*, 39(1), 1-32. https://doi.org/10.1080/15422111003662320

Di, Z., Ngouana, M. A. I., Suleiman, A. H., Marcillinus, Z., Fopa, K. R. E., Haroon, E. T., Guicai, W., Chengtao, W., & Xiaobo, Z. (2022). Recent trends in the micro-encapsulation of plant-derived compounds and their specific application in meat as antioxidants and antimicrobials. *Meat Science*, 191, 108842. https://doi.org/10.1016/j.meatsci.2022.108842

Dincer, E. İ., & Temiz, H. (2023). Investigation of physicochemical, microstructure and antioxidant properties of firethorn (*Pyracantha coccinea* var. *lalandi*) microcapsules produced by spray-dried and freeze-dried methods. *South African Journal of Botany*, 155, 340-354. https://doi.org/10.1016/j.sajb.2023.02.024

Enascuta, C. E., Sirbu, E. E., Pasarin, D., Ghizdareanu, A. I., Senin, R., Hosu, I. S., Gavrilă, A. M., Burdusel, B. A. M., & Lavric, V. (2025). Enhancement of Microencapsulation of Rapeseed Oil Bioactive Compounds in Alginate Through Sonication. *Foods*, 14(10), 1692. https://doi.org/10.3390/foods14101692

Esclapez, M. D., García, P. J. V., Mulet, A., & Cárcel, J. A. (2011). Ultrasound-Assisted Extraction of Natural Products. *Food Engineering Reviews*, 3, 108-120. https://doi.org/10.1007/s12393-011-9036-6

Gallardo, R. C. T., Lu, A., Treviño, G. M. Z., García, M. E., Amaya, G. C., Aguilera, C., & Báez, G. J. G. (2021). Valorization of Almond (*Prunus serotina*) by Obtaining Bioactive Compounds. *Frontiers in Nutrition*, 8, 663953. https://doi.org/10.3389/fnut.2021.663953

Gómez, V. H. D. de J. (2018). Microencapsulación por secado por aspersión y evaluación de estabilidad en almacén de compuestos fenólicos extraídos de frutos de *Morus nigra* L. [Tesis de Maestría, Universidad de Guadalajara, Biomédica]. https://hdl.handle.net/20.500.12104/81801

Guzmán, F. A., Segura., L. S. D., & Almaguer, V. G. (2020). El capulín (*Prunus serotina* Ehrh.): árbol multipropósito con potencial forestal en México. *Madera y Bosques*, 26(1). https://doi.

org/10.21829/myb.2020.2611866

Hamamouche, K., Elhadj, Z., Khattabi, L., Zahnit, W., Djemoui, B., Kharoubi, O., Boussebaa, W., Bouderballa, M., EL Moustapha Kallouche, M., Attia, S. M., Ahmad, S. F., Atanassova, M., & Messaoudi, M. (2024). Impact of Ultrasound- and Microwave-Assisted Extraction on Bioactive Compounds and Biological Activities of *Jania rubens* and *Sargassum muticum*. *Marine Drugs*, 22(12), 530. https://doi.org/10.3390/md22120530

Jiménez, M., Castillo, I., Azuara, E., & Beristain, C. I. (2011). Antioxidant and antimicrobial activity of capulin (*Prunus serotina subsp capuli*) extracts. *Revista mexicana de ingeniería química*, 10(1), 29-37.

Lancaster, J. E., Lister, C. E., Reay, P. F., & Triggs, C. M. (1997). Influence of Pigment Composition on Skin Color in a Wide Range of Fruit and Vegetables. *Journal of the American Society for Horticultural Science*, 122(4), 594-598. https://doi.org/10.21273/JASHS.122.4.594

Liau, K. Y., Liu, Y., & Zhao, Y. (2025). Comparative Evaluation of Palm-Based Carotene Microcapsules Produced via Spray Drying and Supercritical Fluid Drying and Their Application as a Non-Dairy Creamer. *Food and Bioprocess Technology*, 18, 9912- 9926. https://doi.org/10.1007/s11947-025-04008-z

López, H. E. F., Gómez, O. Y., & Santiago, M. H. (2024). Conocimiento etnobotánico asociado al árbol de capulín (*Prunus serótina* Ehrh.) en comunidades mazahua de Jocotitlán estado de México, México. *Revista Etnobiología*, 22(1), 19-35. https://revistaetnobiologia.mx/index.php/etno/article/view/566/527

Luna-Vázquez, F. J., Ibarra-Alvarado, C., Rojas-Molina, A., Rojas-Molina, J. I., Yahia, E. M., Rivera-Pastrana, D. M., Rojas-Molina, A., & Zavala-Sánchez, Á. M. (2013). Nutraceutical value of black cherry *Prunus serotina* Ehrh. Fruits: antioxidant and antihypertensive properties. *Molecules*, 18(12), 14597-14612. https://doi.org/10.3390/molecules181214597

Munin, A., & Edwards-Lévy, L. F. (2011). Encapsulation of Natural Polyphenolic Compounds; a review. *Pharmaceutics*, 3 (4), 793-829. https://doi.org/10.3390/pharmaceutics3040793

Norma Oficial Mexicana. Bienes y servicios. (1994). Determinación de humedad en alimentos por tratamiento térmico. método por arena o gasa (NOM-116-SSA1-1994). https://salud.gob.mx/unidades/cdi/nom/116ssa14.html

Norma Mexicana. (2019). Alimentos para animales determinación de cenizas en alimentos terminados e ingredientes para consumo animal- método de prueba (NMX-Y-362-SCFI-2019). https://es.scribd.com/document/865244848/NMX-Y-362-SCF-2019-Determinacion-de-Cenizas

Paini, M., Aliakbarian, B., Casazza, A. A., Lagazzo, A., Botter, R., & Perego, P. (2015). Microencapsulation of phenolic compounds from olive pomace using spray drying: A study of operative parameters. *LWT-Food Science and Technology*, 62(1), 177-186. https://doi.org/10.1016/j.lwt.2015.01.022

Parra, R. A. (2010). Revisión: Microencapsulación de Alimentos. Revista Facultad Nacional de Agronomía. *Revista Facultad Nacional de Agronomía- Medellín*, 63(2), 5669-5684.

Pinzón, R. J., & Gómez, H. J. (2020). Methods for the extraction and characterization of bioactive compounds in orange fruit waste [Thesis Bachelor´s degree, Universidad de los Andes, B.SC. Chemical Engineering]. https://hdl.handle.net/1992/49084

Ramos, I., Ligarda, C. A., Ramos, D. J., Moscoso, E., Choque, D., Palomino, H., Ramos, B. S., & Buleje, D. (2024). Evaluación de la Microencapsulación de compuestos bioactivos extraídos

Revista Bio ciencias
ISSN 2007-3380

de coronta de maíz morado (*Zea mays* L.) en matrices de maltodextrina y goma de tara. InMedina, D., França, L., & De Oliveira, V.C. Avances científicos y tecnológicos en ciencias agrícolas 4. (pp. 74-88). Ed. Atena. https://doi.org/10.22533/at.ed.6172402028

Rispo, F., De Negri Atanasio, G., Demori, I., Costa, G., Marchese, E., Perera-del-Rosario, S., Serrano-Candelas, E., Palomino-Schätzlein, M., Perata, E., Robino, F., Ferrari, P. F., Ferrando, S., Letasiova, S., Markus, J., Zanotti-Russo, M., & Grasselli, E. (2024). An extensive review on phenolic compounds and their potential estrogenic properties on skin physiology. Frontiers in Cell and Developmental Biology, 11, 1305835. https://doi.org/10.3389/fcell.2023.1305835

Sánchez-Molina, D., Vargas-Porra, M., Ortega-Toro, R., & Piñeros-Castro, Y. (2018). Extracción y encapsulación de compuestos fenólicos provenientes de cascarilla de arroz. *Revista Colombiana de Ciencias Químico - Farmacéuticas*, 47(3), 410-423. https://doi.org/10.15446/rcciquifa.v47n3.77373

Singh, M. N., Hemant, K. S., Ram, M., & Shivakumar, H.G. (2010). Microencapsulation: A promising technique for controlled drug delivery. *Research in pharmaceutical science*, 5(2), 65-77. https://pubmed.ncbi.nlm.nih.gov/21589795/

Servicio de Información Agroalimentaria y Pesquera [SIAP]. (2023, mayo 09). Capulín, Cierre de la producción agrícola, Acciones y Programas. https://nube.agricultura.gob.mx/cierre_agricola/

Sukanya, D., Mitra, L., Govindarajan, S., Spoorthy, N. B., & Ayesha, N. (2022). Effect of Microencapsulation by Calcium Alginate on the Anti-Oxidant Properties of *Swietenia macrophylla*. *Current Trends in Biotechnology and Pharmacy*, 16, 123-132.

Trujano, F. A., & Lozano, J. M. (2020). Efecto de la gelificación iónica de alginato de sodio y gelana de alto acilo en microcápsulas adicionadas de iones calcio [Tesis de licenciatura, Universidad Nacional Autónoma de México, Ingeniería en Alimentos]. https://repositorio.unam.mx/contenidos/3624332

Viveros-Contreras, R., Téllez-Medina, D. I., Perea-Flores, M.J., Alamilla-Beltrán, L., Cornejo-Mazón, M., Beristain-Guevara, C.I., Azuara-Nieto, E., & Gutiérrez-López, G. F. (2012). Encapsulation of ascorbic acid into calcium alginate matrices through coacervation coupled to freeze-drying. *Revista Mexicana de Ingeniería Química*, 12 (1), 29-39.

Weremfo, A., Adulley, F., & Adarkwah-Yiadom, M. (2020). Simultaneous Optimization of Microwave-Assisted Extraction of Phenolic Compounds and Antioxidant Activity of Avocado (*Persea americana* Mill.) Seeds Using Response Surface Methodology. *Journal of analytical methods in chemistry*, 7541927. https://doi.org/10.1155/2020/7541927

Zabot, G. L., Schaefer, F., Polano, L., Vinícius, M., Herrera, E., Palacin, H., Córdova, J. S., Best, I., & Olivera, L. (2022). Encapsulation of Bioactive Compounds for Food and Agricultural Applications. *Polymers*, 14(19), 4194. https://doi.org/10.3390/polym14194194