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Antioxidant Capacity and Physicochemical Characterization of Microencapsulated Aqueous Extracts of Cinnamon (*Cinnamon zeylanicum*) by Spray-Dryer

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Abstract: Cinnamon has a significant content of bioactive compounds, mainly flavonoids, that have biological activities that promote anti-inflammatory, lipid-lowering, antidiabetic, and cardioprotective effects, which are susceptible to oxidative degradation in the presence of external factors. Therefore, it is required to use a technique that improves its storage, chemical stability, and bioavailability, with microencapsulation by spray as one of the best protection options. Therefore, this research proposes the following objective: aqueous microencapsulated extract of cinnamon (*Cinnamomum zeylanicum*) by spray dryer to determine the antioxidant capacity and its physicochemical characteristics. The conditions for obtaining an aqueous extract of cinnamon by ABTS were determined; the extract was microencapsulated with maltodextrin and acacia gum in four different proportions: 12.5% maltodextrin (M) + 12.5% acacia gum (GA), 5 % M + 15% GA, 10% M + 10% GA and 5% M + 5% GA. Physicochemical characterization was performed on the microencapsulates with the highest content and antioxidant capacity. Obtaining microencapsulated aqueous extract of cinnamon with (498.14 µg AG phenols, 85.03 µg catechin flavonoids, and 76.33% DPPH inhibition) $p<0.05$ and suitable physicochemical characteristics for its improvement in a food matrix, emphasizing its potential use as a natural antioxidant ingredient.

Keywords: *Cinnamon zeylanicum*; antioxidants; microencapsulated.

1. Introduction

Cinnamon is a spice traded as a stick or powder [1] and is obtained from the dried bark of trees from the genus Cinnamomum [2]. It is used to improve the flavor of foods and beverages [3]. It provides protein, fiber, volatile components, vitamins (A, B, K, and C), and minerals such as potassium, calcium, sodium, magnesium, manganese, phosphorus, choline, nitrogen, copper, iron, and zinc [4]. It also contains antioxidants that eliminate reactive oxygen

species such as superoxide anions, hydroxyl radicals, and other free radicals [3,5]. Furthermore, cinnamon has bioactive compounds with proven effects on human health, including increased blood flow, anticancer properties such as antimutagenic and antitumor, hypoglycemic, antilipidemic, antimicrobial (microbes, bacteria, and fungi), digestive disorders (diarrhea and flatulence), respiratory problems (asthma and bronchitis), infections, tissue regeneration, anti-inflammatory action, hepatoprotective and weight loss [6–9]. However, these bioactive compounds are chemically unstable. They undergo oxidative degradation reactions in the presence of external factors such as heat, light, oxygen, and humidity [10], deteriorating phenolic compounds, generating free radicals, giving a bitter taste and sensation of astringency, affecting the acceptability of the product among consumers [3,10,11]. Microencapsulation is a technique in which bioactive compounds are encapsulated with a continuous film coating to form microparticles [12]. Once encapsulated within a polymer, the microparticles are protected against the action of atmospheric agents such as light, humidity, heat, pH, and oxygen, thereby maintaining their stability and increasing their bioavailability and shelf life. During this technique's processing and storage phases, degradation by oxidation or hydrolysis is reduced, which masks the flavors or odors and allows a controlled and directed release [3,11,13–17]. This technique consists of spray drying by spray dryer through the atomization of a liquid combined with wall materials such as acacia gum, cyclodextrins, and maltodextrin in a hot gas stream to obtain a powder by means of an injector that includes a stream of hot drying gas [12]. This approach is the most widely used microencapsulation technique in the food industry due to the simplicity of the process [15], low cost, the flexibility of continuous operation, high stability of the final product, volume reduction, ease of handling, transport, and storage of the particles [13]. Due to the aforementioned reasons, this paper aims to microencapsulate the aqueous extracts of cinnamon (*Cinnamomum zeylanicum*) by spray dryer to determine antioxidant capacity and physicochemical characteristics.

2. Materials and Methods

2.1. Raw material and aqueous extract obtention.

The bark of *Cinnamomum zeylanicum* blume was obtained from a local distributor in Mexico City. To obtain aqueous extract, three different methods were used. Decoction extraction consists of putting 10 g of cinnamon bark in a flask cut into pieces of 1 cm with 100 mL of distilled water on a hot plate until reaching 92°C following the indications of [18]. For the infusion method, hot water (70 and 90°C) was placed in a beaker with one g of cinnamon for 60 minutes [19]. The water bath approach was carried out by adding 0.1 g of cinnamon to 10 mL of distilled water in falcon tubes which were then placed in a water bath at 70 and 90 ºC [20]. During the process of obtaining aqueous extract, samples were acquired at 5, 10, 20, 30, 40, 50, and 60 min. Then samples were filtered through the Whatman no. 2 paper once samples were measured for antioxidant capacity using ABTS radical (2,2'-azino-bis acid (3-ethylbenzothiazoline-6- sulfonic)) according to Zehiroglu *et al*., [21].

2.2. Characterization of aqueous extract.

Total phenols were determined using the Folin-Ciocalteau reagent following the method described by Mohamed *et al*. [22]. Read the samples at 750 nm with a spectrophotometer Shimadzu model UV-1280 (SHIMADZU Corporation, Kioto, Japón). Results were expressed as mg of gallic acid equivalents (mg GAE). Flavonoids were measured

using the aluminum chloride colorimetric method, as indicated by Mohamad *et al*. [23]. Read was made at 415 nm of absorbance using the spectrophotometer mentioned above. Results were expressed as mg of catechin equivalents per 100 mL of extract. Quantification of antioxidant activity was performed with the DPPH radical (2,2-diphenyl-1-picrylhydrazyl) using a spectrophotometer described above. The results were expressed in g of sample per g of DPPH [24]. Also, ABTS, according to Zehiroglu *et al*. [21]. Titratable acidity was measured according to Goeltz and Cuevas [25], and moisture was determined in an oven TERLAB model T-H-45DM (TERLAB, Guadalajara, México) at 37°C as 925.10 methods from AOAC [26]. The soluble solids were determined using a refractometer Atago model Smart-1 (Atago, Bellevue, Washington, U.S.A.) following the indications of Cassol *et al*. [27]. Also, the solubility of the microencapsulate was determined using the gravimetric method based on the weight percentage of the waste that did not pass through the filter paper [24]. Apparent density was measured according to Boyano-Orozco *et al*. [24]. The pH value was measured using a pHmeter Hanna model HI 2211 (HANNA instruments, Monterrey, México) following the 939.05 methods from AOAC [26]. Color determination was performed using the Minolta CM-508d colorimeter (KONICA MINOLTA, New Jersey, U.S.A.). The data obtained were interpreted under the CIELab international system, which estimates the deviations between L* (Lightness), a*(redness), and b*(yellowness) parameters. All the samples were performed in triplicate [28]. In order to identify the chemical compounds present in the extract, the following phytochemical tests of colorimetric reactions were carried out: alkaloids by a Mayer test, sterols from a Liebermann-Burchard reaction [29], unsaturations, sesquiterpene lactones by a Baljet test, flavonoids by a sulfuric acid test, saponins through Salkowski and Shinoda tests [30], coumarins with a sodium hydroxide test, phenolic hydroxyls through an iron chloride test, anthraquinone glycosides by a Borntrager test, cardiac glycoside by a Keller-Killiani test, as well as determining quinones, oxalates, tannins and anthocyanins [22].

2.3. Aqueous extract microencapsulation.

To microencapsulate the aqueous extract, four different mixes of maltodextrin (M) and acacia gum (E414, AG) were used to optimize the cinnamon extract. The mixes were T1 (M:12.5%, AG:12.5%), T2 (M:5%, AG: 15%), T3 (M:10%, AG: 10%, T4 (M:5%, AG: 5%). The aqueous cinnamon extract was mixed and homogenized using a homogenizer IKA model T25 (IKA Works, Inc., Wilmington, U.S.A.) setup at 9000 rpm for 30 minutes. Then, the mixtures were stirred for 24 h at room temperature, as indicated by Cenobio-Galindo *et al*. [31]. After that, samples were dried using a mini spray dryer Büchi model B-290 (BÜCHI Labortechnik AG, Meierseggstrasse, Suiza). The equipment was configured to maintain an inlet temperature of 160 °C, ais pressure of 4 bar, and flow at 10 mL.min-1 as indicated by Martínez *et al*. [32]. The microencapsulated obtained was stored under airtight bags until use.

2.4. Physicochemical determinations in the microencapsulation.

Moisture and solubility were determined according to Cassol *et al*. [27], pH was followed by 939.05 methods from AOAC [26], apparent density was measured according to Boyano-Orozco *et al*. [24], and data color was determined according to El-Messery *et al*. [28]. All the samples were performed in triplicate.

2.5. Statistical analysis.

A completely randomized design was used to analyze data. A repeated time one-way design was used to analyze methods to obtain the extract. An analysis of variance was then carried out following the general linear model procedure and a Tukey test to determine significant differences ($p<0.05$). All analyses were determined using SPSS software ver. 25.

3. Results and Discussion

3.1. Aqueous extract of Cinnamon zeylanicum.

The aqueous extract contains bioactive compounds through a safe extraction [18]. Table 1 shows the percentage of inhibition of the ABTS radical obtained from the techniques and preparation times of the aqueous extracts evaluated. It can be observed that the decoction technique contains the highest inhibition activity of ABTS from 5 to 20 min and from 92.96 to 95.89%. This is in comparison with the infusion technique at 70-90 ºC and the bath technique at 70 ºC, which report their highest activity at 20 and 30 min, respectively, and the infusion technique at 90 ºC, which shows the highest activity at 50 min. This could be due to the fact that the raw material consists of tree bark with a hard and semi-porous texture, meaning that it could require greater heat exposure to release these compounds [14]. After this time, a percentage decrease is observed in all techniques, which indicates the loss of antioxidants due to exposure to heat.

Table 1. Effect of extraction method and time on antioxidant activity of the aqueous cinnamon extract.

Time	Extraction method[1]				
	B70	**B90**	**Dec**	**Inf70**	**Inf90**
5	59.18^{bB}	54.61^{bB}	92.96^{aA}	43.75^{bB}	34.69^{bB}
10	62.78^{bB}	67.12^{aB}	93.73^{aA}	47.06^{aC}	39.84^{bC}
20	53.47^{bB}	61.79^{bB}	95.89^{aA}	56.12^{aB}	41.01^{bB}
30	70.63^{aB}	71.09^{aB}	94.63^{aA}	65.90^{aB}	40.84^{bB}
40	73.43^{aB}	71.67^{aB}	94.47^{aA}	66.53^{aB}	39.70^{bC}
50	54.06^{bC}	66.83^{aB}	94.99^{aA}	49.31^{bC}	49.04^{aC}
60	43.97^{cC}	72.94^{aB}	94.07^{aA}	56.67^{aC}	45.75^{aB}

abc Superscript different indicates significative differences among rows ($p<0.05$). ABC Superscript difference indicates significative differences among columns ($p<0.05$). 1B70= Water bath at 70°C, B90= Water bath at 90 °C, Dec= decoction, Inf70= infusion at 70 °C, Inf90= Infusion at 90 °C.

3.2. Characteristics of aqueous extract to Cinnamon zeylanicum.

Extract characteristics are important to explain beneficial properties for a healthy relationship with their bioactive compounds [33]. In Table 2, was observed the phenolic content of the *Cinnamomum zeylanicum* extract for the 1:100 concentration was 304.62 mg/ g AG ± 12.6, and for flavonoid content, it was 18.36 µg catechin / mL extract ± 0.57. The phenolic content for the 10:100 concentration was 356 mg / g AG ± 27.2, while the flavonoid content was measured at 23.2 ± 0.89 µg catechin / mL extract. The antioxidant capacity for DPPH was 57.23% for the 1:100 concentration, while for the 10:100 concentration, the value was 71.55%. Regarding the percentage of inhibition for ABTS, in the 1:100 concentration, an inhibition of 73.42% was obtained, while for the 10:100 concentration, it was approximately 92.98%. The phenolic content for the aqueous extracts reported in both concentrations (1:100 and 10:100) is within the range indicated by Dudonné *et al*. [34], which was stated as 300-400 mg / g AG,

Jayaprakasha *et al*. [35] confirmed that extracts with water contained the highest phenolic content compared to the extraction techniques with methanol, acetone. Ethyl acetate Dudonné *et al*. [34] stated that phenolic compounds are the main contributor of the antioxidant properties in aqueous cinnamon extracts and identified compounds derived from flavan-3-ols such as catechin, epicatechin, procyanidins, and phenolic acids. The flavonoids contained in the aqueous extract at a concentration of 1:100 mL are slightly higher than that obtained by Muhammad *et al*. [14], who reported content of 17 mg of quercetin equivalents per gram of *Cinnamon burmannii* aqueous extract (1:100). In contrast, the concentration of 10:100 presented a much higher value with 23.2 µg catechin / mL extract. Ali *et al*. [36] reported total flavonoid content in the range of 2.03–3.3 g QE/100 g DW in the phenolic compound extraction from cinnamon. These values are within the range obtained for both concentrations of extract evaluated in this investigation. The antioxidant capacity of the evaluated aqueous extracts at concentrations of 1:100 and 10:100 is slightly lower than the percentage of inhibition by DPPH (84.43%) obtained by Dudonné *et al*., [34] and slightly higher for the percentage of inhibition obtained by ABTS (64.88%) from the same investigation. In the paper by Dudonné *et al*., [34] extracts of the same evaluated species were made by grinding the stick while the concentration was created with an evaporator, demonstrating that the processing technique influences the antioxidant activity contained within the extracts. The positive relationship between the concentration of phenolic substances and the shown antioxidant activity suggests the potential of using cinnamon as a natural source of antioxidants, which can be beneficial for human health [37]. The values obtained for phenols in the microencapsulates are similar to those reported by Ismail *et al*. [38] (269.9 mg GAE/100 g sample) for the first three formulations, while the formulation with the lowest content of wall material obtained almost twice this value (498.14 µg AG / mL). The flavonoid content reported by Ismail *et al*. [38] was 62.1 mg catechin equivalents CE/100 g of the sample, which, when compared to what was reported in this research, is slightly lower than the value obtained in the last formulation and higher than that obtained in the first three formulations evaluated. These differences could be due to the occupied wall material and the concentration of the microencapsulated emulsion by Ismail *et al*., [38] which facilitated successful microencapsulation and release of the flavonoids contained in the aqueous extracts compared to the first three formulations tested in this investigation.

For the physicochemical characterization of the aqueous cinnamon extract at a concentration of 1:100, pH was 6.37 ± 0.14, cinnamic acid was 0.03%. In comparison, the percentage of dry matter found was 92.57% ± 2.46 along with solubility of 0.07 ± 0.01 g/mL. In contrast, the concentration of 10:100 presented a pH of 6.82 ± 0.12, cinnamic acid of 0.04%, dry matter of 95.17% ± 2.24, and solubility of 0.11 ± 0.02 g/mL. The color was measured with a colorimeter on the extracts obtained from two concentrations (1:100 and 10:100) by decoction for 5 min. Greater luminosity and a tendency towards red and yellow tones were observed on the outer part of the cinnamon stick compared to its inner part, which showed less luminosity, thereby making it darker. The extract at a concentration of 1:100 presented a luminosity of 37.19 ± 5.38, with a tendency towards a red coloration of 2.62 ± 0.18 and a yellow coloration of 22.09 ± 1.55. It was less luminous than the concentrated extract at 10:100, which presented a luminosity of 51.29 ± 0.42 and had an increased tendency towards a red coloration of 3.29 ± 0.55 and yellow coloration of 29.21 ± 2.98. The chemical compounds identified in the 1:100 concentration, the presence of sesquiterpene lactones, flavonoids (flavones), coumarin, and anthraquinone glycoside can be observed. In contrast, for the 10:100 concentration, the

abovementioned chemical compounds were found as well as unsaturations, saponins, phenolic hydroxyls, tannins, and anthocyanins. For the physicochemical characterization of the aqueous cinnamon extract, the pH value obtained in the two evaluated concentrations (1:10 and 10:100) was higher than that reported by Kirana and Sunartharum [39] for *Cinnamon burmannii* infusion at 100 ºC (4.87). This may be due to the fact that the infusion technique decreases the pH value, thereby making the extract more acidic, as this value for the *Cinnamon zeylanicum* infusion was lower than the one obtained by decoction (5.96). The percentage of cinnamic acid contained in the aqueous cinnamon extract is 0.04%; cinnamon oil contains 3 to 4% cinnamic acid [40]., while cinnamon oil requires 1-1.42 mL for its neutralization [41], meaning that it is more acidic than the aqueous extract [42]. The percentages of dry matter for both concentrations are higher than those reported after 5 hours of drying (90.61 %) for the zeylanicum species, showing constant values after 24 hours of drying [43]. This difference can be related to the elaboration process of grinding, which results in increased surface-heat contact due to the smaller particle size, thereby achieving better moisture extraction than the whole cinnamon stick [44]. The values for soluble solids obtained in both concentrations are higher than those reported by Alsaud *et al*. [45] (0.02 g/mL) for *Cinnamon cassia*. This difference could be due to the elaboration technique of the extract, meaning that the heat could extract a higher bioactive compound content compared to the elaboration of crude extracts, leading to higher temperatures caused by the solid soluble content in the extracts. The values for luminosity and the tendency towards red and yellow colorations of the cinnamon stick and extracts differ from the values reported for the *Cinnamon burmannii* species [39]. This variety has higher luminosity as well as higher a* and b* values, which could be due to the variation between species. The *Cinnamon burmanni* variety has a more intense color with a brown coloration compared to *Cinnamon zeylanicum*, which has a more subdued tone [46], meaning its extracts vary in luminosity with a yellow-red coloration. The differences observed could also be due to the concentration of certain bioactive compounds with properties of natural pigments, such as anthocyanins and coumarins contained in the *Cinnamon burmannii* species, that affect the color change mentioned [47]. The presence of sesquiterpene lactones was observed in the aqueous extract with a concentration of 1:100 and comprised of a terpenoid compound with anti-inflammatory activity. Sesquiterpene lactones are found in low quantities in the *Lauraceae* family to which cinnamon belongs [48] and in which the following volatile sesquiterpenes have been identified: β-caryophyllene, α-humulene, α-copaene, δ- and γ -cadinene, germacrencia-B, τ- and α-cadinol, α-bergamotene, α-copaene, α-humulene, and δ-cadinene) [35]. There is also a presence of flavonoids of the flavone type, among which the catechin and quercetin contained in cinnamon are noteworthy [49], and coumarin at trace levels of approximately 0.004% [3], in addition to anthraquinone glycoside, which can reduce the proliferation of cancer cells which is found in the bark and root of cinnamon [50]. Regarding the concentration of 10:100 along with the previous chemical compounds, unsaturations were observed, which are present in the cinnamaldehyde, a compound that is chemically composed of an unsaturated aldehyde linked to a phenyl group, thereby giving it its characteristic aroma and low solubility in water. Also present are methoxycinnamaldehyde and coumarin, which have properties in reducing edema and anticoagulant precursor [51], and saponins that produce foam when shaken in aqueous solutions that have anti-inflammatory, anticancer, biological, cholesterol-lowering, antibacterial, antifungal, antiviral and insecticidal properties. This means that they could be responsible for the antimicrobial effect in cinnamon [52], phenolic hydroxyls, tannins, and anthocyanins that comprise phenolic compounds with significant

antioxidant activity [53]. According to the phytochemical analysis of *Cinnamomum verum* aqueous extract by Vakilwala *et al*. [54] and the study by Mohamed *et al*. [22] on the extracts of acetone, methanol and water, a high presence of alkaloids, flavonoids, tannins, saponins, anthraquinone glycosides were found in both analyses, with a particularly high presence of phenols and coumarin. In contrast, a low presence of anthocyanins in all extracts was identified. These results differ from what was found in this investigation regarding the presence of alkaloids, which could be due to the cinnamon that caused the extracts to contain and then release this chemical compound, which acts as an analgesic, anesthetic, or psychotropic on the central nervous system. With the use of a phytochemical sieve, Adarsh *et al*. [55] identified the presence of alkaloids in *Cinnamon zeylanicum*, and highlighted the presence of a reddish-brown precipitate was obtained through a Wagner test instead of a creamy white coloration. This coincided with what was obtained in this investigation when performing the same test and could be due to the type of species that reacts differently to the same chemical agents (Wagner's reagent), meaning that the aqueous extracts evaluated could also contain alkaloids. However, Sonu Garg and Gaurav report the same absence of alkaloids in their water extract of the verum species at a concentration of 10:100 [56], which suggests that Adarsh *et al*. could have reported a false positive in this chemical compound.

Table 2. Antioxidant properties and phytochemical screening of microencapsulated obtained with decoction method at 5 min.

Chemical compound	**Cinnamon extract dilution**	
	1:100	**10:100**
Total phenols, mg/ g GA	304.62 ± 12.6^{a}	356.00 ± 27.2^{a}
Flavonoids, µg catechin / mL extract	18.36 ± 0.57^{b}	23.2 ± 0.89^{a}
DPPH, % of inhibition	57.23 ± 5.14^{b}	71.55 ± 8.52^{a}
ABTS, % of inhibition	73.42 ± 0.29^{b}	92.98 ± 1.77^{a}
pH	6.37± 0.14^{b}	6.82 ± 0.12^{a}
Cinnamic acid, %	0.03 ± 0.00^{b}	0.04 ± 0.00^{a}
Dry matter, %	92.57 ± 2.46^{a}	95.17 ± 2.24^{a}
Solubility, g/mL	0.07 ± 0.01^{b}	0.11 ± 0.02^{a}
L*	37.19 ± 5.38^{b}	51.29 ± 0.42^{a}
a*	2.62 ± 0.18^{a}	3.29 ± 0.55^{a}
b*	22.09 ± 1.55^{a}	29.21 ± 2.98^{b}
Alkaloids	-	-
Sterols	-	-
Instaurations	-	+
Sesquiterpene lactones	+	+
Flavonoids (flavones)	+	+
Saponins Shinoda Test	-	+
Saponins Sodium Hydroxide Test	-	+
Coumarin	+	+
Phenolic hydroxyls	-	+
Anthraquinone glycoside	+	+
Cardiac Glycoside	-	-
Quinones	-	-
Oxalates	-	-
Tannins	-	+
Anthocyanins	-	+

1Qualitative test - indicates absence, and + indicates the presence of the chemical compound in the extract. ab Superscript difference indicates significative differences among columns ($p<0.05$).

3.3. Aqueous extract microencapsulation.

Based on the results obtained for the evaluation sections of cinnamon concentration, the quantity of phenols and flavonoids, as well as antioxidant capacity and phytochemical sieve, the concentration of 10:100 was chosen because it has a higher bioactive compound

content for microencapsulation. In order to determine the best combination of coating material used, four emulsions made with maltodextrin (M), acacia gum (GA), and *Cinnamomum zeylanicum* extract were evaluated. The antioxidant capacity of the microencapsulates obtained through the combination of four formulations (Table 3) was assessed with wall material emulsions of 25% (12.5% M + 12.5% GA), 20% (5% M + 15% GA), 20% (10% M + 10% GA) and 10% (5 % M + 5 % GA), obtaining values for phenols of between 212.07 and 498.14 µg AG / mL and flavonoids of between 33.65 and 85.03 µg catechin / mL extract, and percentages of inhibition for DPPH radicals of between 76.33 and 83.26%. A pattern can be observed where lower concentrations of coating material result in higher quantities of phenols and flavonoids for the concentrated extract of cinnamon. The formulation of 10% of encapsulating matter had the highest encapsulation of antioxidant compounds (498.14 µg AG / mL of phenols, 85.03 µg catechin / mL of flavonoids, and 76.33% of DPPH inhibition), which corresponds to the formulation elaborated with 5 % maltodextrin + 5% acacia gum. Considering this result, it was decided to undertake a physicochemical characterization of this microencapsulation formulation. In addition, the absence of flavonoids, glycosides, tannins, and phenolic compounds was also reported, which could be due to the elaboration of the extract undertaken by dilution with chemical agents [55]. These compounds may have been collected when recovered, leading to their absence. Therefore, with these results, it can be observed that although the same species of plant was evaluated in lower concentrations, unsaturations and compounds such as saponins, phenols, tannins, and anthocyanins may not be present in this determination, or that depending on the production method these compounds are lost from the extract. Therefore, it is suggested to undertake this test with at least two different concentrations and methods of elaboration to observe these divergences and to be able to choose the concentration and elaboration method for the extract that is most suitable for what is required.

Table 3. Bioactive compounds and antioxidant activity of extract of cinnamon microencapsulated with a different matrix.

Treatment[1]	Total phenols, mg/ g GA	Flavonoids, µg catechin / mL microencapculate	DPPH inhibition %
T1	212.07 ± 18.34^{b}	33.65 ± 1.40^{d}	83.26 ± 1.45^{a}
T2	226.45 ± 13.16^{b}	61.40 ± 0.38^{b}	78.80 ± 1.11^{ab}
T3	208.7 ± 22.45^{b}	38.69 ± 2.35^{c}	80.61 ± 2.92^{ab}
T4	498.14 ± 30.23^{a}	85.03 ± 1.85^{a}	76.33 ± 0.79^{b}

[1]T1=Maltodextrin 12.5%:Acacia gum 12.5%, T2=Maltodextrin 5%:Acacia gum 15%, T3= Maltodextrin 10%: Acacia gum 10%, T4=Maltodextrin 5%:Acacia gum 5%. ^{ab}Superscript different indicates significative differences among rows ($p<0.05$).

3.4. Characteristics of Cinnamomum zeylanicum microencapsulate.

The physicochemical characterization of the microencapsulated formulations with the highest antioxidant activity and capacity is shown in Table 4, where a moisture percentage of 1.47 ± 0.05, a solubility of 86.83 ± 4.33 g/L, pH of 5.01 ± 0.1, and an apparent density of 0.38 ± 0.01g/L can be observed. Regarding the microencapsulation's color, a luminosity of 90.01 ± 1.28, a* value of 1.72 ± 0.31, and a b* value of 11.24 ± 0.70 were presented. The moisture percentage obtained in this research is within the range reported by Santiago *et al*. [57] (1.34-1.89%), who microencapsulated *Cinnamomum zeylanicum* infusion with maltodextrin. The percentage of solubility obtained in this research (86.83%) is much higher than the value obtained in the microencapsulation of cinnamon oil with acacia gum, whey protein, and maltodextrin carried out by Felix *et al*. [58] (33.04-49.57%). This may be due to the relationship between the microencapsulates and the diluent used, meaning that when water is

used, a hydrophilic microencapsulate similar to the one obtained in this aqueous extraction research dissolves better, compared to a lipophilic variant such as essential oil of cinnamon. Low pH values (acidity) in the microencapsulates affect the polysaccharides of the wall material, modifying their permeability, encapsulation, and retention efficiency (59), leading to higher acidity values, thereby preventing the encapsulation of bioactive compounds. This was shown in the investigation by Matiacevich *et al*. [60] on the effect of the type of emulsifier and pH on carvacrol microencapsulated with alginate, where stability at pH 4 was achieved. The bulk density obtained in this investigation (0.38 g/L) is lower than that reported by Santiago *et al*. [73] (0.55-0.55 g/L), which could be mainly due to the fact that a higher proportion of wall material of 100 g/L was used, which is a larger quantity to what was used in this study, resulting in a lower density value compared to the one in this investigation. Regarding the color obtained in the microencapsulates, the luminosity value (L* 90.01) is within the range indicated by the *Cinnamomun verum* oleoresin microencapsulates elaborated by Procopio *et al*., [51] (L*88.37-91.87), this same study also reported a* values in the range of (-0.57-0.18) which is lower than what was obtained in this investigation (1.72), which was also the case with b* values (11.24) which was in the range of (6.01-7.65). These differences could be attributed to the fact that cinnamon oleoresin has a darker coloration than the aqueous extract, with a lower tendency to red and yellow coloration, which is derived from the concentration of bioactive compounds with natural pigment properties such as anthocyanins and coumarins [47].

Table 4. Physicochemical characteristics of *Cinnamomum zeylanicum* microencapsulate.

Parameter	**Microencapsulate**
Moisture, %	1.47 ± 0.05
Solubility, %	86.83 ± 4.33
pH	5.01 ± 0.1
Apparent density, g/L	0.38 ± 0.01
L*	90.01 ± 1.28
a*	1.72 ± 0.31
b*	11.24 ± 0.70

performed in triplicate

4. Conclusions

This research recommends that the preparation of cinnamon aqueous extract with high antioxidant activity and capacity should be elaborated with the decoction technique. The presence of bioactive compounds depends on the concentration of the aqueous extract, as the higher the concentration, the higher the presence of bioactive compounds and antioxidant activity. Microencapsulation by spray dryer with 5% maltodextrin and acacia gum conserved the significant antioxidant activity and capacity. The physicochemical characteristics found in the microencapsulated aqueous extract of cinnamon *Cinnamon zeylanicum* highlight its potential for use as a natural antioxidant ingredient when added to foods and derivatives to enhance nutritional content.

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Conflict of interests

The authors declare no conflict of interest.

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