DISCIPLINARUM SCIENTIA *Disciplinarum Scientia.* **Série: Naturais e Tecnológicas**
Santa Maria, v. 27, n. 1, p. 23-35, 2026
Recebido em: 24.09.2025. Aprovado em: 23.10.2025.
ISSN 2176-462X | DOI: doi.org/10.37779/nt.v27i1.5553

DEVELOPMENT, CHARACTERIZATION, AND STABILITY OF LIPOSOMES CONTAINING RED PITAYA (*Hylocereus lemairei*) PEEL AQUEOUS EXTRACT[1]

DESENVOLVIMENTO, CARACTERIZAÇÃO E ESTABILIDADE DE LIPOSSOMAS CONTENDO EXTRATO AQUOSO DE CASCA DE PITAYA DE POLPA VERMELHA (Hylocereus lemairei)

Jéssica Teixeira[1], Karina Zanella Lodi[2], Carina Cassini[3], Valéria Weiss Angeli[4] e Cátia Santos Branco[5]

ABSTRACT

The demand for natural-based technological products is a global trend, driven by factors such as sustainability and minimal environmental impact. Botanical extracts are often incorporated into nanotechnological systems, which can circumvent the chemical instability of some compounds with antioxidant action. Pitaya (*Hylocereus lemairei*) is a highly popular fruit, and its production generates a substantial amount of waste. This study aimed to associate pitaya peel aqueous extract with liposomes to protect its phenolic composition. Liposomes were produced by the lipid film hydration method, and particle size, zeta potential, polydispersity index, and encapsulation efficiency were evaluated. The pH, antioxidant activity, and lipid peroxidation index of nanosuspensions were evaluated at time zero and after 30 days in different temperatures (21 - 25°C and 2 - 8ºC). No statistical differences were found in the particle size of liposomes in the presence or absence of pitaya extract (287.46 *versus* 275.91 ± 44.06). The same was noted in polydispersity index (0.53 *versus* 0.50) and the zeta potential (-37.99 *versus* -36.10). The recovery rate of phenolic compounds was greater than 90%, indicating that there was no loss in the process. However, the encapsulation efficiency reduced from 44% to 27% at 30 days of monitoring. The pH and antioxidant activity of the liposome containing the extract remained stable. The peroxidation index in the suspension containing the extract was reduced, demonstrating that the extract's actives can prevent the peroxidation of lipids. Data can contribute to defining the ideal nanocarrier for future pitaya-based applications, a significant advancement for natural and technological applications.

Keywords: Nanotechnology; phospholipids; antioxidants; botanical extracts.

RESUMO

A demanda por produtos tecnológicos de base natural é uma tendência global, impulsionada por fatores como sustentabilidade e impacto ambiental mínimo. Extratos botânicos são frequentemente incorporados em sistemas nanotecnológicos, o que pode contornar a instabilidade química de alguns compostos com ação antioxidante. A pitaya (Hylocereus lemairei) é uma fruta muito popular e sua produção gera uma quantidade substancial de resíduos. Este estudo teve como objetivo associar o extrato aquoso da casca da pitaya com lipossomas para proteger sua composição fenólica. Os lipossomas foram produzidos pelo método de hidratação de filme lipídico e o tamanho de partícula, o potencial zeta, o índice de polidispersão e a

1 E-mail: jteixeira6@ucs.br. ORCID: https://orcid.org/0009-0007-4830-7043
2 E-mail: kzanella@ucs.br. ORCID: http://orcid.org/0009-0008-7770-5099
3 E-mail: ccassini@ucs.br. ORCID: https://orcid.org/0000-0002-8294-267X
4 E-mail: vwangeli@ucs.br. ORCID: https://orcid.org/0000-0002-1019-7949
5 E-mail: csbranc1@ucs.br. ORCID: http://orcid.org/0000-0003-3709-3004

eficiência de encapsulamento foram avaliados. O pH, a atividade antioxidante e o índice de peroxidação lipídica das nanosuspensões foram avaliados no tempo zero e após 30 dias em diferentes temperaturas (21 - 25 °C e 2 - 8 ºC).Não foram encontradas diferenças estatísticas no tamanho de partícula dos lipossomas na presença ou ausência do extrato de pitaya (287,46 versus 275,91 ± 44,06). O mesmo foi observado no índice de polidispersão (0,53 versus 0,50) e no potencial zeta (-37,99 versus -36,10). A taxa de recuperação de compostos fenólicos foi superior a 90%, indicando que não houve perda no processo. Entretanto, a eficiência de encapsulamento reduziu de 44% para 27% em 30 dias de monitoramento. O pH e a atividade antioxidante do lipossomo contendo o extrato permaneceram estáveis. O índice de peroxidação na suspensão contendo o extrato foi reduzido, demonstrando que os ativos do extrato podem prevenir a peroxidação de lipídios. Os dados podem contribuir para definir o nanocarreador ideal para futuras aplicações à base de pitaya, um avanço significativo para aplicações naturais e tecnológicas.

Palavras-chave: *Nanotecnologia; fosfolipídios; antioxidantes; extratos botânicos.*

INTRODUCTION

Exotic fruits, originating from tropical and subtropical regions, have been the focus of scientific studies due to their biological potential in promoting and protecting human health (Kanlayavattanakul *et al*., 2013). Pitaya, an exotic fruit native to the tropical forests of Mexico and Central America, is a good example. Known as Dragon Fruit due to its scaly skin, it belongs to the genus Hylocereus and the family Cactaceae (Joshi; Prabhakar, 2020) and is considered a superfood due to its antioxidant properties.

In Brazil, red-fleshed pitaya is one of the most found varieties. Studies have shown that it is rich in bioactive phenolic compounds, particularly flavonoids, which are present in both the peel and the pulp. In the peel of the red-fleshed pitaya, betalains, anthocyanins, 3-glucoside, and pelargonidin have been detected (Saenjum; Pattananandecha; Nakagawa, 2021). In the same study, using the fruit's seed, other compounds were detected, such as epigallocatechin, caffeine, and gallic acid. These metabolites contribute to the pitaya's antioxidant, antimicrobial, and anti-inflammatory properties (Joshi; Prabhakar, 2020). Another study evaluated the phenolic compound content in pitaya peel extract, and the results showed that the antioxidant activity of the extract is higher than the antioxidant capacity of ascorbic acid (Lodi *et al*., 2022). Therefore, peels contain a rich antioxidant composition; however, they are often discarded. One proposed use for pitaya peel extract is its incorporation into nanotechnology-based formulations, which would expand its potential applications in the pharmaceutical, nutraceutical, and cosmetic industries.

Nanotechnology represents a valuable strategy to overcome the chemical instability of phenolic compounds found in botanical extracts. Incorporating these compounds into nanosystems allows for the gradual release of actives without altering their mechanism of action, modulating the rate at which these substances cross biological barriers, reaching the target cells (Cassini *et al*., 2021). With the advent of nanotechnology, lipid-based nanocarriers, such as liposomes, have been widely

valued for their use in biomedical applications, as they can transport both hydrophobic and hydrophilic active compounds. Several plant-derived active compounds have already been studied to evaluate their antioxidant potential when associated with liposomes as carriers of these actives (Lin *et al.*, 2022). A study was conducted with *Rosa canina* extract (Krajewska; Dziki, 2023) comparing the antioxidant activity of the free extract (15.50 ± 2.18 %), showing a significant increase in the antioxidant potential of the extract when associated with liposomes (80.70 ± 2.61%). On the other hand, a study involving the ethanolic extract of red pitaya pulp associated with liposomes reported no significant difference in DPPH free radical scavenging capacity compared to the free extract, indicating that encapsulation was not able to enhance the extract's antioxidant activity (Lin *et al.*, 2021). These results suggest that there is no consensus regarding the increase in antioxidant activity of plant-based actives when delivered in liposomal form.

The present study aimed to develop a liposome formulation to deliver an aqueous extract of the red-fleshed pitaya peel, characterizing it in terms of its chemical properties and stability. The results obtained may serve as a basis for future studies aimed at the development of anti-aging nutraceuticals and cosmetics.

MATERIALS AND METHODS

PREPARATION OF THE EXTRACTS

Red-fleshed pitayas (2020 harvest) were purchased from commercial establishments in Caxias do Sul, RS, Brazil. The pulp was carefully separated from the peel and frozen (-20°C). The obtained peels were dried in a forced-air circulation oven at 45 ± 5°C until constant weight, then ground in a knife mill. Analyses were performed using aqueous extracts of the dried, ground pitaya peels at different concentrations (0.5 to 5% w/v) under reflux conditions, aiming to determine the best extraction condition. The optimal plant-to-solvent ratio was selected for lyophilization. The lyophilized extract powder was stored in a freezer until further analysis.

LIPOSOME DEVELOPMENT

Liposomes were prepared by the lipid film hydration method using phosphatidylcholine and cholesterol (7:3 molar ratio), dissolved in chloroform. The solvent was then evaporated on a rotary evaporator at 42°C with stirring at 25 rpm to form a phospholipid film. Lip film hydration was achieved by incorporating aqueous pitaya peel extract or sodium chloride under the following conditions: a) to prepare plain liposomes (without the addition of pitaya extract), three samples were solubilized with 60 ml of water and 0.89 grams of sodium chloride; b) to prepare liposomes containing pitaya peel

extract, a 2.5 mg/mL solution was prepared in triplicate from a lyophilized aqueous extract at 1% w/v. The suspensions containing liposomes were sonicated for 5 minutes (Sonics Vibra-Cell) to homogenize and reduce particle size. The samples were then filtered through a 0.45 µm membrane.

DETERMINING ENCAPSULATION EFFICIENCY

To evaluate encapsulation efficiency, the Folin Ciocalteu colorimetric method (Singleton; Rossi, 1965) was used. Initially, 1.000 µL of liposome suspension was centrifuged at 14,000 rpm for 15 min. The supernatant was filtered (0.22 µm), and the phenolic compound content was determined spectrophotometrically at a wavelength of 765 nm. The supernatant fraction corresponded to the unencapsulated phenolic compounds. The recovered phenolic compounds were measured by mixing one part of the liposome suspension with two parts of methanol: water (9:1). The phenolic compound content was determined after filtration through a 0.22 µm membrane, and the encapsulation efficiency was calculated using the formula below:

EE (%) = [(TPC - TPCne) / TPC x 100
EE = encapsulation efficiency; TPC = total phenolic compounds recovered; TPCne = total phenolic compounds in the supernatant (not encapsulated)

PARTICLE SIZE AND POLYDISPERSITY INDEX, ZETA POTENTIAL, AND PH

Particle diameter and polydispersity index (PdI) were measured by dynamic light scattering using Zetasizer ZS (Zetasizer Nano, Malvern, UK) using 2 mL of the liposome suspension resuspended in 1 mL of purified water. Zeta potential was measured by electrophoretic mobility shift using Zetasizer ZS (Zetasizer Nano, Malvern, UK). For zeta potential reading, 10 mL of the liposome suspension was resuspended in 5 mL of 10 mM NaCl.

STABILITY EVALUATION

To monitor stability, the pH and lipid peroxidation of the formulations were evaluated at time zero and after 30 days, stored at 21 - 25 °C and 2 - 8 ºC. The pH was measured using a properly calibrated pH meter (Digimed). The results are expressed as the average of three determinations. The average pH variation was obtained by the observed amplitude and is expressed as Δ_{pH}.

To evaluate the lipid peroxidation index of the formulations, the TBARS assay (Wills, 1965) was performed. This experiment is based on a colorimetric reaction that detects the levels of malondialdehyde (MDA), a product of the oxidative action of free radicals on lipids. An aliquot of the liposomal formulations (400 µL) was added to 0.67% w/v thiobarbituric acid and heated in a boiling water bath for 1 h. Absorbances were read at 532 nm, and the results were expressed in nmol MDA/mL.

ANTIOXIDANT ACTIVITY ASSESSMENT - DPPH SCAVENGING CAPACITY

This method consists of the antioxidant capacity of the sample to donate hydrogen to the 2,2-diphenyl, 1-picrylhydrazyl (DPPH) radical (Yamaguchi *et al.*, 1998). The solution presents a purple to yellow coloration, indicating its antioxidant potential. Tris-HCl buffer (100 µM, pH 7.0) and DPPH radical (250 µM) were added. The mixture was left to stand for 20 minutes in the dark at room temperature, and then the absorbance was measured at 517 nm in a spectrophotometer. The results are represented as a percentage (%) radical scan.

STATISTICAL ANALYSIS

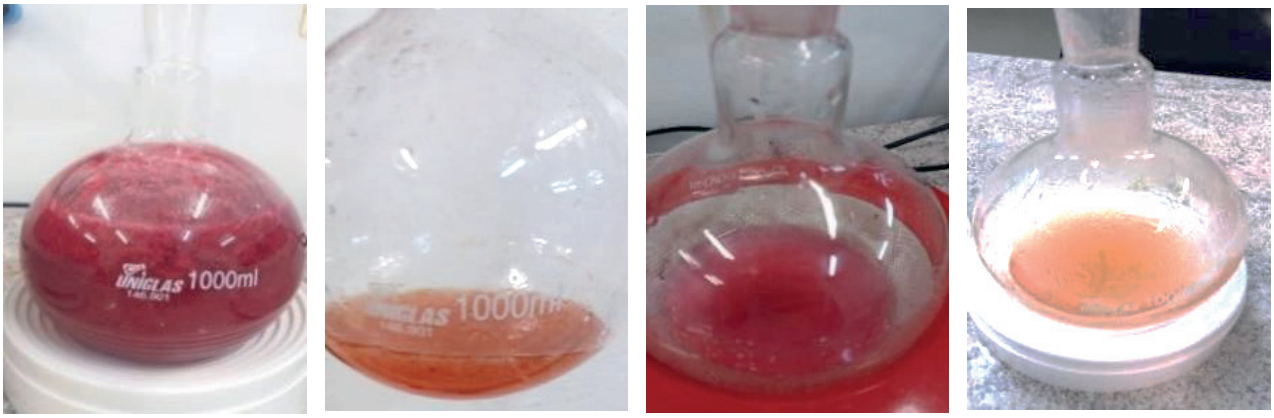
Results were tabulated in Excel, with tests performed in triplicate, and analyzed using SPSS 22.0 software. Results were expressed as mean ± standard deviation. Analysis of variance (ANOVA) and Tukey's post-test and Student t-test were performed, with statistical significance set at $p \leq 0.05$.

RESULTS AND DISCUSSION

EXTRACT OBTAINING

Increasing concentrations of pitaya peel were tested under hot water extraction using a reflux system. As shown in Figure 1, the extracts at 5% and 2.5% (w/v) were very concentrated and pasty, making filtration impossible. The 0.5% concentration, on the other hand, was very dilute. Therefore, the 1% w/v concentration was freeze-dried and used for liposome development.

Figure 1 - Extraction process with different proportions of pitaya peel powder and water at (A) 5%, (B) 2.5%, (C) 1% and (D) 0.5% (w/v).



A B C D

LIPOSOMES CHARACTERIZATION

Lipid vesicles can exhibit different behaviors *in vitro* and *in vivo*, and their characterization is a relevant step for their application in the therapeutic, cosmetic, and/or food industries. Table 1 presents the characterization data of liposomes in the presence or absence of aqueous extract of pitaya peel.

Table 1 - Evaluation of particle size, polydispersity index, and zeta potential of the prepared liposomes.

	Particle size (nm)	Polydispersity index (PdI)	Zeta potential (mV)
		Initial time	
Pitaya liposome	287.46 ± 54.38	0.53 ± 0.10	-37.99 ± 4.18
Plain liposome	275.91 ± 44.06	0.50 ± 0.10	-36.10 ± 7.45
		30 days (21 - 25°C)	
Pitaya liposome	279.60 ± 22.58	0.45 ± 0.01	-39.49 ± 2.59
Plain liposome	577.30 ± 46.31#	0.49 ± 0.06*	-45.03 ± 3,11#
		30 days (2 - 8°C)	
Pitaya liposome	287.33 ± 27.79	0.56 ± 0.13	-42.03 ± 9.15
Plain liposome	562.85 ± 9.73#	0.42 ± 0.28*	-48.80 ± 4.16#

Results are expressed as MD ± standard deviation. * Indicates statistical difference between liposomes by Student's t-test ($p \leq 0.05$). # indicates statistical difference by paired t-test concerning initial time.

Initially, the particle size obtained for liposomes containing pitaya peel extract was 287.46 ± 54.38, and for plain liposomes it was 275.91 ± 44.06 immediately after preparation. There was no significant difference between the groups, and this parameter did not change significantly in liposomes containing pitaya extract. On the other hand, plain liposomes increased in size under both storage conditions, indicating instability over time. Previously, a significant increase in liposome size over time was reported for plain liposomes compared to those containing a phenolic-rich extract. The researchers suggested that this increase could be due to system instability, such as particle agglomeration (Cassini *et al.*, 2025) In fact, the interaction of phenolic compounds with the lipid bilayer

may contribute to the stabilization of the liposomal system, as previously reported in phenolic-containing liposome models (Malekar *et al.*, 2016) Moreover, the particle size values obtained corroborate the literature, where liposome sizes have been reported to be greater than 200 nm (Machado *et al.*, 2019; Manconi *et al.*, 2016). The technique used in the present study was sonication, which serves to remove possible lamellar particles from the liposomes and homogenize the size of the vesicles. Therefore, it can be inferred that the preparation method was adequate.

In the present study, the results seem to indicate that the liposomes obtained are unilamellar. As observed by Wang *et al.*(2022)its application is restricted because of its characteristics, such as extremely low water solubility, bioavailability, and easy degradation. Currently, flexible nanoliposomes have gained increasing interest as a biocompatible polymer for applications such as transdermal drug delivery. We prepare amphiphilic hyaluronic acid (HA in the study carried out with moringa seeds, the liposomes had an average size of 193 nm. Sklenarova *et al.* (2023) in turn, obtained oleuropein liposomes with an average size of 137 nm. On the other hand, (Hosseini *et al.*, 2023) a study with *Salvia hispanica*, found that the liposomes formed had an average size of 59.23 nm. These differences in size can be attributed to the type of lipid composition of the liposomes, as previously discussed by (De Luca *et al.*, 2023).

The PdI represents the homogeneity of the particle size distribution. When values are less than 0.1, they indicate low dispersion, i.e., homogeneity (Păvăloiu *et al.*, 2020). In the present study, the PdI found was 0.45, indicating heterogeneity, and, like the particle size, the PdI did not change significantly, indicating stability. However, after 30 days, at 21-25 °C, the PdI of liposomes containing pitaya extract was lower than that in plain liposomes, while in the same period at 2-8 °C, it was higher in liposomes containing pitaya extract. (Lin *et al.*, 2021) finding a PdI of 0.26 in liposomes containing red pitaya betacyanins extracted with acidified ethanol, lower than that found in the present study.

Zeta potential reflects the surface charge of particles, which is influenced by changes in the interface with the dispersing medium due to the dissociation of functional groups on the particle surface or the adsorption of ionic species present in the aqueous dispersion medium. High zeta potential values with the same sign provide repulsion between molecules, preventing them from aggregating and contributing to stability over time (Schaffazick *et al.*, 2003). Therefore, zeta potential is an important indicator of liposomal suspension stability. In the present study, a strongly negative zeta potential was obtained, and there were no significant changes after 30 days of storage in liposomes containing pitaya extract. It is important to highlight that none of the formulations presented a zeta potential close to zero, indicating stability during the study period (Table 1).

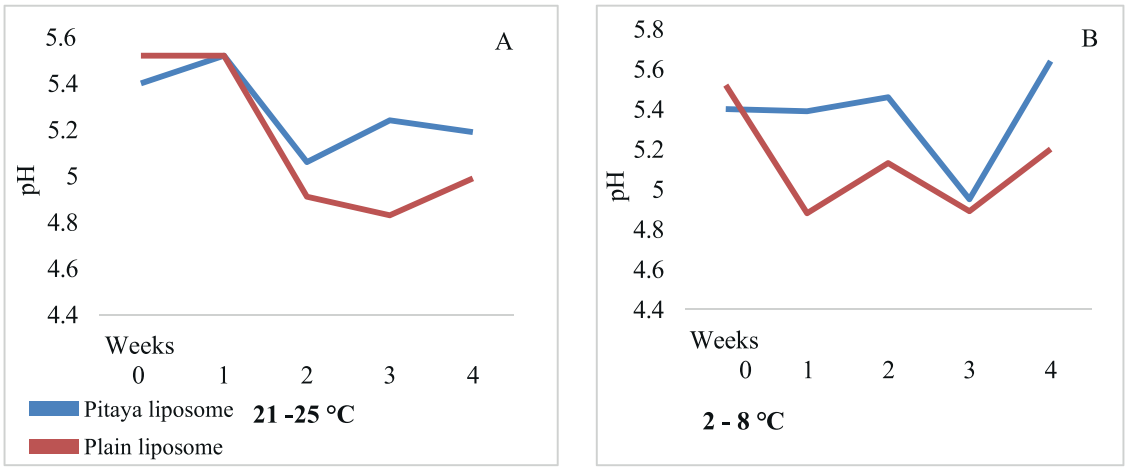
Previous studies with plant active ingredients found zeta potentials similar to those of the present study. The hydroethanolic extract of *Prunus spinosa* in liposomes, for example, presented a zeta potential of -47 (De Luca *et al.*, 2023), and the study by (Hosseini *et al.*, 2023) with ethanolic extract of *Salvia hispanica* in liposomes, which presented a zeta potential of -44.47.

STABILITY ASSESSMENT - PH EVALUATION

The pH was evaluated during 30 days under two temperature conditions: 21 -25 °C and 2 - 8 °C, and the samples were evaluated over a 7-day interval (Figure 2 A-B).

For the liposome containing pitaya extract, the pH did not undergo significant changes (Δ_{pH} = 0.21 and Δ_{pH} = 0.24; Figure 2 A-B, respectively). Plain liposome suspension, however, was more unstable, exhibiting a variation of Δ_{pH} = 0.53 (Figure 2A) and Δ_{pH} = 0.32 (Figure 2B) from the beginning to the end of the experiment, a variation of 1.7-fold.

Figure 2 - pH monitoring in liposome suspensions over storage time.



The evaluation of pH over time in liposomes is little discussed in the literature. This is an important parameter, since the lipid composition of liposomes can predict phospholipid oxidation and, therefore, alter pH values. In this sense, a previous study found that betacyanins, phenolic compounds found in pitaya extract, were retained for longer within the vesicles at pH close to 7.0 and for less time at pH close to 3.0 (Lin *et al.*, 2021). Changes in pH over time may indicate sample degradation. Thus, it is possible to verify that liposomes containing pitaya extract were stable in this parameter.

STABILITY ASSESSMENT - ENCAPSULATION EFFICIENCY (EE)

EE, a parameter that demonstrates how much of the active is associated with the system, was evaluated from time zero, at 21 to 25°C, and at 2 to 8°C. This parameter is important because it determines the amount of lyophilized pitaya peel extract that was successfully encapsulated.

The recovery of phenolic compounds in the pitaya liposome decreased by 17% after 30 days when stored at 2 to 8°C (Table 2). This was not observed in the same period between 21 to 25°C. In parallel, an EE of 44% was found in the pitaya liposome. Other authors have found different association rates in nanosystems containing plant extracts. A study using aqueous extract of

Hibiscus sabdariffa associated with multilamellar liposomes reported encapsulation efficiency of approximately 70% (Gibis; Zeeb; Weiss, 2014). Similar results were described by Manconi (2016) in liposomes prepared with ethanolic extract of *Citrus limon* (EE of 59%) and by (Oskoueian *et al.*, 2020), who obtained EE of 38% of methanolic extract of *Pistacia vera* in liposomes. Therefore, the encapsulation efficiency of the lyophilized pitaya peel extract would be in line with data already found in other similar studies. Further optimization is needed to address the loss of efficacy observed in the pitaya liposome after 30 days.

Table 2 - Recovery of total phenolic compounds and encapsulation efficiency of liposomes containing lyophilized pitaya extract.

	PC recovery (%)			Encapsulation efficiency (%)		
		30 days			30 days	
	Initial time	21 - 25°C	2 - 8ºC	Initial time	21 - 25°C	2 - 8ºC
Pitaya liposome	108.80 ± 1.91	111.40 ± 3.20	91.27 ± 3.34#	44.27 ± 2.24	29.73 ± 1.47#	27.52 ± 1.86#

PC: phenolic compounds. Results are expressed as MD ± standard deviation.
#indicates statistical difference by paired t-test comparing time.

LIPID PEROXIDATION

Oxidative damage to lipids was monitored using the TBARS assay, which was evaluated at time zero and after 30 days (Table 3). Initially (time zero), lipid peroxidation of pitaya peel extract, when associated with liposomes, was 4.62 ± 1.04, and after 30 days, there was a 24% reduction when stored at 21-25°C and a 43% reduction at 2-8 °C. This reduction in lipid peroxidation did not occur in the plain liposomes and is likely due to the antioxidant action of the phenolic compound, which protects vesicle lipids against oxidation. The presence of polyphenols in pitaya extract may aid in the stabilization of liposomes, possibly through interactions with the lipid bilayer that promote greater phospholipid packing, less aggregation, and protection against oxidation, as demonstrated byMalekar *et al.* (2016) , in liposomes containing phenolic compounds.

Table 3. Lipid peroxidation of liposomes immediately after preparation and after 30 days of storage at different temperatures.

	TBARS (nmol/mL)		
		30 days	
	Initial time	21 - 25°C	2 - 8ºC
Pitaya liposome	4.62 ± 1.04	3.51 ± 0.79	2.60 ± 0.76#
Plain liposome	2.67 ± 1.33*	3.36 ± 0.55#	2.57 ± 0.76

Results are expressed as MD ± standard deviation. * Indicates statistical difference between pitaya liposomes and plain liposomes by Student's t-test ($p \leq 0.05$). # indicates statistical difference by paired t-test concerning time zero.

A previous study also demonstrated that a liposome containing phenolic-rich extract from *Thymus serpyllum* possesses efficacy in mitigating lipid peroxidation by TBARS assay (Jovanović

et al., 2025). Similarly, Cassini *et al.* (2025) reported that liposomes containing phenolic-rich extract from *Araucaria angustifolia* bracts showed a decay in lipid peroxidation along the storage period compared to plain liposomes, thus corroborating our results. The control/reduction of lipid peroxidation in liposomes may be associated with the antioxidant activity of the associated active ingredients. Therefore, to better understand this result, the antioxidant activity of liposomes containing pitaya extract was monitored.

ANTIOXIDANT ACTIVITY

The ability of a substance to donate electrons to the free radical DPPH explains its antioxidant activity. In the present study, this parameter was evaluated (Table 4).

Table 4 - Evaluation of the antioxidant activity of liposomes containing lyophilized extract of pitaya peel.

	DPPH (%)		
		30 days	
	Initial time	**21 - 25°C**	**2 - 8ºC**
Pitaya liposomes	12.06 ± 1.61	12.05 ± 0.60	10.73 ± 2.51

Results are expressed as MD ± standard deviation.

The antioxidant activity of the liposome containing the extract remained stable throughout the storage period under both tested temperature conditions. This indicates that the suspension maintained its antioxidant capacity effectively over time. However, despite its stability, the formulation did not show strong antioxidant activity. This may be attributed to the relatively low concentration used (2.5 mg/mL) of extract. Therefore, increasing the extract concentration may enhance its antioxidant potential, warranting further studies with higher doses.

CONCLUSIONS

In this study, liposomes containing aqueous pitaya extract were produced to protect its phenolic compounds. The preparation method was found to be suitable for combining the lyophilized pitaya peel extract. However, improvements to the suspension are needed, as, despite its stability, the results showed low encapsulation efficiency, resulting in low antioxidant activity.

Further research, altering the extract: solvent and extract: lipid ratios, is needed to increase encapsulation efficiency and the suspension's antioxidant performance.

REFERENCES

CASSINI, Carina *et al.* Liposome-Based Delivery of Araucaria angustifolia Aqueous Extract Phenolic Compounds. **Waste and Biomass Valorization**, [*s. l.*], v. 16, n. 6, p. 3011-3027, 2025.

CASSINI, Carina *et al.* Mutual Effects of Free and Nanoencapsulated Phenolic Compounds on Human Microbiota. **Current Medicinal Chemistry**, [*s. l.*], v. 29, n. 18, p. 3160-3178, 2021.

DE LUCA, Maria *et al.* Phenolic Fingerprint, Bioactivity and Nanoformulation of Prunus spinosa L. Fruit Extract for Skin Delivery. **Pharmaceutics**, [*s. l.*], v. 15, n. 4, p. 1-18, 2023.

GIBIS, Monika; ZEEB, Benjamin; WEISS, Jochen. Formation, characterization, and stability of encapsulated hibiscus extract in multilayered liposomes. **Food Hydrocolloids**, [*s. l.*], v. 38, p. 28-39, 2014. Disponível em: http://dx.doi.org/10.1016/j.foodhyd.2013.11.014.

HOSSEINI, Farinaz *et al.* Antioxidant activity of nanoencapsulated chia (Salvia hispanica L.) seed extract and its application to manufacture a functional cheese. **Food Science and Nutrition**, [*s. l.*], v. 11, n. 3, p. 1328-1341, 2023.

JOSHI, Monica; PRABHAKAR, Bala. Phytoconstituents and pharmaco-therapeutic benefits of pitaya: A wonder fruit. **Journal of Food Biochemistry**, [*s. l.*], v. 44, n. 7, 2020.

JOVANOVIĆ, Aleksandra A. *et al.* Liposome-Based Encapsulation of Extract from Wild Thyme (Thymus serpyllum L.) Tea Processing Residues for Delivery of Polyphenols. **Foods**, [*s. l.*], v. 14, n. 15, 2025.

KANLAYAVATTANAKUL, Mayuree *et al.* Salak plum peel extract as a safe and efficient antioxidant appraisal for cosmetics. **Bioscience, Biotechnology and Biochemistry**, [*s. l.*], v. 77, n. 5, p. 1068-1074, 2013.

KRAJEWSKA A.; DZIKI D. Enrichment of Cookies with Fruits and Their By-Products: Chemical Composition, Antioxidant Properties, and Sensory Changes. **Molecules**, [*s. l.*], 2023. Disponível em: https://pubmed.ncbi.nlm.nih.gov/37241744/.

LIN, Xing'E *et al.* Comparative Metabolic Profiling in Pulp and Peel of Green and Red Pitayas (Hylocereus polyrhizus and Hylocereus undatus) Reveals Potential Valorization in the Pharmaceutical and Food Industries. **BioMed Research International**, [*s. l.*], v. 2021, 2021.

LIN, Xian *et al.* Storage Stability and In Vitro Bioaccessibility of Liposomal Betacyanins from Red Pitaya (Hylocereus polyrhizus). **Molecules**, [*s. l.*], v. 27, n. 4, 2022.

LODI, K *et al.* Pre-clinical evidence for the therapeutic effect of Pitaya (Hylocereus lemairei) on diabetic intestinal microenvironment. **Natural Product Research**, [*s. l.*], v. 0, n. 0, p. 1-7, 2022. Disponível em: https://doi.org/10.1080/14786419.2022.2110091.

MACHADO, Adriana R. *et al.* Liposomes loaded with phenolic extracts of Spirulina LEB-18: Physicochemical characterization and behavior under simulated gastrointestinal conditions. **Food Research International**, [*s. l.*], v. 120, p. 656-667, 2019. Disponível em: https://doi.org/10.1016/j.foodres.2018.11.023.

MALEKAR, Swapnil A. *et al.* The Localization of Phenolic Compounds in Liposomal Bilayers and Their Effects on Surface Characteristics and Colloidal Stability. **AAPS PharmSciTech**, [*s. l.*], v. 17, n. 6, p. 1468-1476, 2016.

MANCONI, Maria *et al.* Polymer-associated liposomes for the oral delivery of grape pomace extract. **Colloids and Surfaces B: Biointerfaces**, [*s. l.*], v. 146, p. 910-917, 2016. Disponível em: http://dx.doi.org/10.1016/j.colsurfb.2016.07.043.

OSKOUEIAN, Ehsan *et al.* Nanoliposomes encapsulation of enriched phenolic fraction from pistachio hulls and its antioxidant, anti-inflammatory, and anti-melanogenic activities. **Journal of Microencapsulation**, [*s. l.*], v. 37, n. 1, p. 1-13, 2020. Disponível em: http://dx.doi.org/10.1080/02652048.2019.1692941.

PĂVĂLOIU, Ramona Daniela *et al.* Polyphenolic extract from sambucus ebulus L. Leaves free and loaded into lipid vesicles. **Nanomaterials**, [*s. l.*], v. 10, n. 1, p. 1-17, 2020.

SAENJUM, Chalermpong; PATTANANANDECHA, Thanawat; NAKAGAWA, Kouichi. Antioxidative and anti-inflammatory phytochemicals and related stable paramagnetic species in different parts of dragon fruit. **Molecules**, [*s. l.*], v. 26, n. 12, 2021.

SCHAFFAZICK, Scheila Rezende *et al.* Caracterização e estabilidade físico-química de sistemas poliméricos nanoparticulados para administração de fármacos. **Química Nova**, [*s. l.*], v. 26, n. 5, p. 726-737, 2003.

SINGLETON, V L; ROSSI, J A Jr. Colorimetry to total phenolics with phosphomolybdic acid reagents. **American Journal of Enology and Viticulture**, [*s. l.*], v. 16, n. 48, p. 144-58, 1965. Disponível em: http://garfield.library.upenn.edu/classics1985/A1985AUG6900001.pdf.

SKLENAROVA, Renata *et al.* Co-delivering of oleuropein and lentisk oil in phospholipid vesicles as an effective approach to modulate oxidative stress, cytokine secretion and promote skin regeneration. **European Journal of Pharmaceutics and Biopharmaceutics**, [*s. l.*], v. 185, n. August 2022, p. 126-136, 2023.

WANG, Yijin *et al.* Anti-photoaging effects of flexible nanoliposomes encapsulated Moringa oleifera Lam. isothiocyanate in UVB-induced cell damage in HaCaT cells. **Drug Delivery**, [*s. l.*], v. 29, n. 1, p. 871-881, 2022. Disponível em: https://doi.org/10.1080/10717544.2022.2039802.

WILLS, B Y E D. Mechanisms of Lipid Peroxide Formation in Animal Tissues. **Biochemistry Journal**, [*s. l.*], p. 667-676, 1965.

YAMAGUCHI, Tomoko *et al.* Hplc method for evaluation of the free radical-scavenging activity of foods by using 1,1-diphenyl-2-picrylhydrazyl. **Bioscience, Biotechnology and Biochemistry**, [*s. l.*], v. 62, n. 6, p. 1201-1204, 1998.