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Effect of emulsifier type and dispersed phase on the synthesis of curcumin nanoemulsions and their in vitro release

Efecto del tipo de emulsificante y la fase dispersa en la síntesis de nanoemulsiones de curcumina y su liberación in vitro

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ABSTRACT: Curcumin is a polyphenol recognised for its beneficial effects; however, it has low solubility, which limits its bioavailability and effectiveness. Its application in nanoscale delivery systems allows these limitations to be overcome. The **objective** of this study was to evaluate the effect of composition variables on the formation of curcumin nanoemulsions and their in vitro release. The **methodology** used consisted of evaluating the effect of pre-emulsification conditions, type of emulsifier (Tween 40, Tween 80, and phosphatidylcholine), dispersed phase (coconut oil and omega 5), and pH on globule size and nanoemulsion stability. The trapping efficiency and in vitro release of curcumin were determined. Among the **results**, it was found that curcumin nanoemulsions with medium-chain oil and pomegranate seed oil stabilised with Tween 40 showed the smallest particle size (23 and 33.4 nm, respectively) and were stable for 7 weeks. When phosphatidylcholine was evaluated as an emulsifier, the globule sizes were 90.7 and 126.2 nm, respectively. The curcumin entrapment efficiency was 93%. Factors such as pH show a change in globule size, however, the type of emulsifier used influences stability. it is **concluded** that the release of curcumin shows different behaviour at the nanometric scale compared to the coarse form. Composition variables significantly affect the characteristics of nanoemulsions, their stability during storage, and influence the release of curcumin and, therefore, its bioavailability.

Keywords: Coconut oil, pomegranate seed oil, curcumin, entrapment efficiency, in vitro release.

RESUMEN: La curcumina es un polifenol reconocido por sus efectos benéficos; sin embargo, posee una baja solubilidad lo que limita su biodisponibilidad y efectividad. Su aplicación en sistemas de vehiculización a nanoescala permite superar estas limitantes. El **objetivo** de este trabajo fue evaluar el efecto de variables de composición en la formación de nanoemulsiones de curcumina y en su liberación in vitro. La **metodología** empleada consistió en evaluar el efecto de condiciones de pre-emulsificación, tipo de emulsificante (tween 40, tween 80 y fosfatidilcolina), fase dispersa (aceite de coco y omega 5) y el pH sobre el tamaño de glóbulo y la estabilidad de las nanoemulsione. Se determinó la eficiencia de atrapamiento y la liberación in vitro de la curcumina. Entre los **resultados**, se encontró que las nanoemulsiones de curcumina con aceite de cadena media y aceite de semilla de granada estabilizadas con tween 40 mostraron el menor tamaño de partícula (23 y 33.4 nm, respectivamente) y fueron estables durante 7 semanas. Al evaluar la fosfatidilcolina como emulsificante, se obtuvo que los tamaños de glóbulo fueron de 90.7 y 126.2nm, respectivamente. La eficiencia de atrapamiento de curcumina fue del 93 %. Factores como el pH muestran un cambio en el tamaño del glóbulo, sin embargo, el tipo de emulsificante empleado influye en la estabilidad. Se **concluye** que la liberación de la curcumina muestra un diferente comportamiento al encontrarse a escala nanométrica en comparación con la forma gruesa. Las variables de composición afectan significativamente las características de las nanoemulsiones, su estabilidad durante el almacenamiento, así como influenciar la liberación de curcumina y por ende su biodisponibilidad.

Palabras clave: Coconut oil, pomegranate seed oil, curcumin, entrapment efficiency, in vitro release.

1. INTRODUCTION

Curcumin is the main polyphenol present in turmeric (Curcuma longa) and has attracted growing interest due to its many beneficial properties, including anti-inflammatory, antioxidant, antimicrobial, and anticancer activity [1]-[3]. However, due to its low solubility in water, absorption is reduced, as is its bioavailability, and it is rapidly eliminated from the body, limiting its use in clinical applications [4].

To overcome these limitations, various delivery systems have been developed, including liposomes, micelles, solid lipid nanoparticles, inclusion complexes, and emulsions, with nanoscale emulsions being an alternative for applications in the pharmaceutical and food industries [5]. In the food industry, the development of emulsions of hydrophobic compounds improves their solubility and allows them to be integrated into food formulations such as beverages, dressings, soups, desserts, sauces, yoghurt, etc., thus taking advantage of their properties [6]. Nanoemulsions are colloidal dispersions composed of nanometric globules stabilised by emulsifiers, which offer improved solubility of lipophilic compounds, physicochemical stability to external factors and allow controlled release [7], [8]. In the specific case of curcumin, nanoemulsion formulations have been shown to significantly improve protection against light, pH and temperature, thereby increasing its bioavailability and therapeutic efficacy [9]-[11]. The development of nanoemulsions is influenced by numerous factors, from the formation method, the emulsifiers that allow the formation of systems at the nanometric scale and which in turn promote stability during storage, to the characteristics of the dispersed phase that allow the formation of a system that provides the bioactive compound to be encapsulated with benefits such as protection, stability, and bioavailability, among others [12], [13].

This study investigated the formation and characterisation of curcumin nanoemulsions under different composition conditions, evaluating the role of emulsifiers and the dispersed phase in improving the stability of curcumin nanoemulsions and the release of curcumin in these developed systems.

2. MATERIALS AND METHODS

2.1 Formation of nanoemulsions

For the formation of nanoemulsions, coconut oil (Now Foods) as a precursor of medium-chain fatty acids and pomegranate seed oil (Etja Olej) as a precursor of omega-5 fatty acids were evaluated as dispersed phases at a concentration of 5% (w/w). The emulsifiers used were Tween 40, Tween 80 (Merck, KGaA) and phosphatidylcholine (Avanti) in a proportion of 15% (w/w). The dispersing phase consisted of 80% (w/w) Milli-Q water in which the emulsifier had been previously dissolved. To prepare the nanoemulsions with curcumin (Sigma, C1386), curcumin was mixed into the dispersed phase at a concentration of 0.05 mg/g emulsion. The dispersed phase was added to the continuous phase, pre-emulsification was carried out using rotor-stator equipment (Ultra turrax T25 digital, IKA) at 10,000 rpm for 25 minutes, and then processed in ultrasound equipment at 40% amplitude for 20 minutes. The emulsions formed were stored in glass vials at room temperature and protected from light until analysis.

2.2 Characterisation of the nanoemulsions

To characterise the nanoemulsions formed, the globule size, globule size distribution and surface charge were analysed. For this purpose, after the emulsification process and during storage, the globule size and globule size distribution were analysed using a Zetasizer Nano-ZS90 device (Malvern Instruments Inc). The reported globule size is that provided by the equipment as the average diameter (Z-Average), and the globule size distribution was determined by the polydispersity index (PdI). For sample analysis, the methodology reported by [14] was followed. For globule size, the nanoemulsion (5 µL) was diluted in 1 mL of Milli Q water and placed in a cell; the measurement was carried out at a temperature of 25 °C, and each sample was read in triplicate. Surface charge analysis was performed by measuring the zeta potential of the nanoemulsions using a Zetasizer Nano-ZS90 (Malvern Instruments Inc). The nanoemulsion (25 µL) was diluted in 2 mL of Milli Q water, the determination was carried out at a temperature of 25 °C, and each sample was read in triplicate.

2.3 Study of the stability of nanoemulsions during storage

The treatments under the best conditions were stored at room temperature and the stability of the nanoemulsions was determined by measuring the change in globule size and distribution. The nanoemulsions selected as stable showed no phase separation and had globule sizes of less than 100 nm.

2.4 Curcumin trapping efficiency

For trapping efficiency (EE%), the nanoemulsions with curcumin were centrifuged at 10,000 rpm for 15 minutes in order to separate the phases within the nanoemulsion. The amount of curcumin remaining in the nanoemulsion residue was quantified spectrophotometrically. The trapping efficiency was calculated according to equation 1:

$$(\text{EE}\%)=\frac{Cantidad\ inicial\ de\ curcumina\ en\ el\ sobrenandante}{cantidad\ de\ curmina\ inicial\ en\ la\ nanoemulción}\ \text{X}100 \qquad (1)$$

2.5 Evaluation of the effect of pH on the stability of nanoemulsions

The effect of pH was studied in the treatments under the best conditions obtained. The pH values in nanoemulsions were adjusted using a pH meter (Thermo Orion 5-Star) to pH 3, 4 and 5, using NaOH or HCl (1M). The globule size, PDI and surface charge of the nanoemulsions adjusted to different pH values were measured.

2.6 In vitro release of curcumin in nanoemulsion

Curcumin release kinetics were performed by dialysis, using a nanoemulsion and a coarse emulsion at the same concentration of curcumin and the same concentrations of the other components (emulsifier, water, and oil). The methodology reported by [9] was followed with some modifications. Cellulose tubes with a molecular weight of 12,000-14,000 KDa (Spectrapor, Spectrum) were used and loaded with 5 mL of the nanoemulsion or emulsion. The membranes were placed in containers with 200 mL of phosphate buffer containing 40% ethanol, maintained at 37°C ± 0.5°C in an orbital shaker at 70 rpm for 96 h. At different time intervals, 20 mL of sample was taken and the same volume of buffer was added to the system. The experiment was performed in duplicate and the curcumin concentration was analysed spectrophotometrically.

2.7 Quantification of curcumin

The quantification of curcumin allowed the determination of the amount present in the nanoemulsions, as well as the filtrates during the in vitro release methodology. Curcumin (SIGMA, C7727) with a purity of ≥94% curcuminoids was used as the standard for preparing a stock solution, from which dilutions were made to construct the calibration curve in a concentration range of 0.0008-0.0125 mg curcumin/mL solution. The quantification of curcumin in nanoemulsions and in membrane release was performed according to the methodology reported by [15], with the modification of dissolving the curcumin in ethanol. All samples were protected from light at all times and subsequently read spectrophotometrically at a wavelength of 421 nm.

2.8 Statistical analysis

All results are presented as reported as the mean ± standard deviation (n = 3). Simple analysis of variance was performed using Fisher's test (α=0.05) for comparisons between means using the MINITAB 19® statistical package.

3. RESULTS

3.1 Formation of nanoemulsions

Preliminary comparisons were made during pre-emulsification of emulsions containing coconut oil as the dispersed phase and stabilised by the emulsifiers Tween 40 and Tween 80. The emulsions with the smallest particle size will be used to encapsulate curcumin and subsequently compared with the nanoemulsions stabilised with phosphatidylcholine. During the formation of thick emulsions (Figure 1), larger globule sizes were observed when Tween 80 was used. a maximum emulsification time of 25 minutes was evaluated, and the emulsifier concentration was varied. In all cases, the globule sizes of the emulsions stabilised by Tween 80 were larger than those stabilised by Tween 40. The thick emulsions stabilised by Tween 40 under all the conditions evaluated in terms of time and emulsifier concentration showed globule sizes close to or less than 100 nm, which ensures that globule sizes smaller than 100 nm can be achieved during the formation of nanoemulsions. The selected pre-emulsification conditions were 25 minutes of homogenisation and 15% (w/w) emulsifier, which allowed globule sizes of 77 nm and were the conditions selected for subsequent emulsification by ultrasound.

During the formation of emulsions using the ultrasound equipment, the particle size obtained in the nanoemulsions stabilised by Tween 40 or phosphatidylcholine was compared, in addition to the use of different oils in the dispersed phase, where coconut oil and pomegranate seed oil (omega 5) were compared. The emulsions formed with Tween 40 had globule sizes smaller than 100 nm (Figure 2). at time zero, the sizes were 22 nm for nanoemulsions with the dispersed phase of coconut oil and 35.7 nm for nanoemulsions with the dispersed phase of omega 5. In terms of PDI, the values were 0.22 and 0.17, respectively. It has been reported that PDI values below 0.3 are an indicator of good stability [12], which shows that the globule sizes obtained were uniform. Furthermore, during 12 weeks of storage, the nanoemulsions containing omega 5 as the dispersed phase continued to have globule sizes of less than 100 nm (41.35 nm). However, the nanoemulsions containing coconut oil as the dispersed phase were not stable after 9 weeks. Therefore, the use of Tween 40 and coconut oil allowed the formation of nanoemulsions with the smallest globule sizes (23 nm) and stable for 6 weeks.

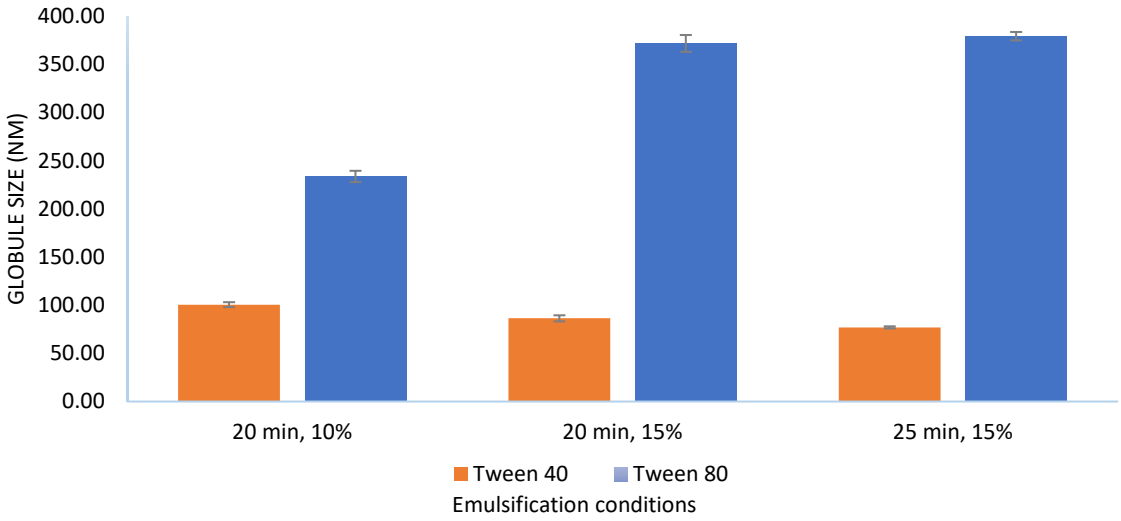

Figure 1. Globule size obtained during pre-emulsification for emulsions stabilised by Tween 40 and Tween 80. The values for emulsions with Tween 40 with different lowercase letters are significantly different ($p < 0.05$), while the values for nanoemulsions with Tween 80 with different uppercase letters are significantly different ($p < 0.05$). Source: own elaboration.

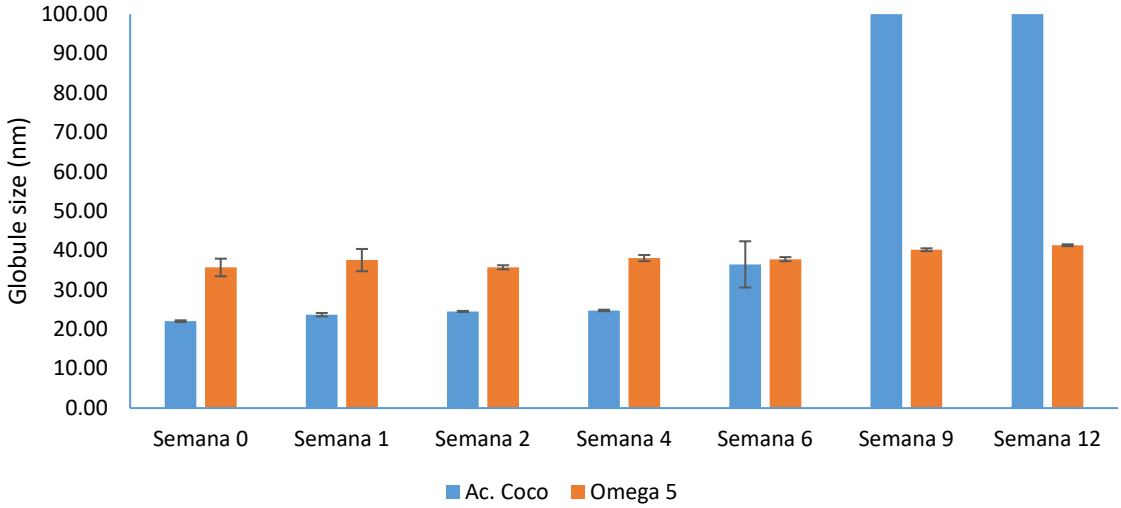

Figure 2. Initial globule size and during storage of emulsions stabilised by Tween 40. Source: own elaboration.

Emulsions stabilised by phosphatidylcholine with coconut oil and omega 5 as the dispersed phase showed larger globule sizes than those stabilised with Tween 40 (Figure 3). The smallest globule size obtained with phosphatidylcholine as an emulsifier was 90.7 nm using coconut oil as the dispersed phase. In terms of PDI, the emulsions showed values of 0.15 when either of the two oils was used as the dispersed phase (omega 5 or coconut oil), indicating that despite showing a larger globule size, they were distributed homogeneously. In the study of stability during storage, the treatments containing coconut oil showed an increase in globule size to values greater than 100 nm from the second week onwards. All treatments containing omega 5 as the dispersed phase from the outset showed sizes greater than 100 nm, and during the first week of storage, the growth in globule size was 47%. This increase was higher compared to treatments where coconut oil was used as the dispersed phase. All treatments stabilised by phosphatidylcholine are not considered suitable conditions for the production of nanoemulsions due to the globule sizes obtained.

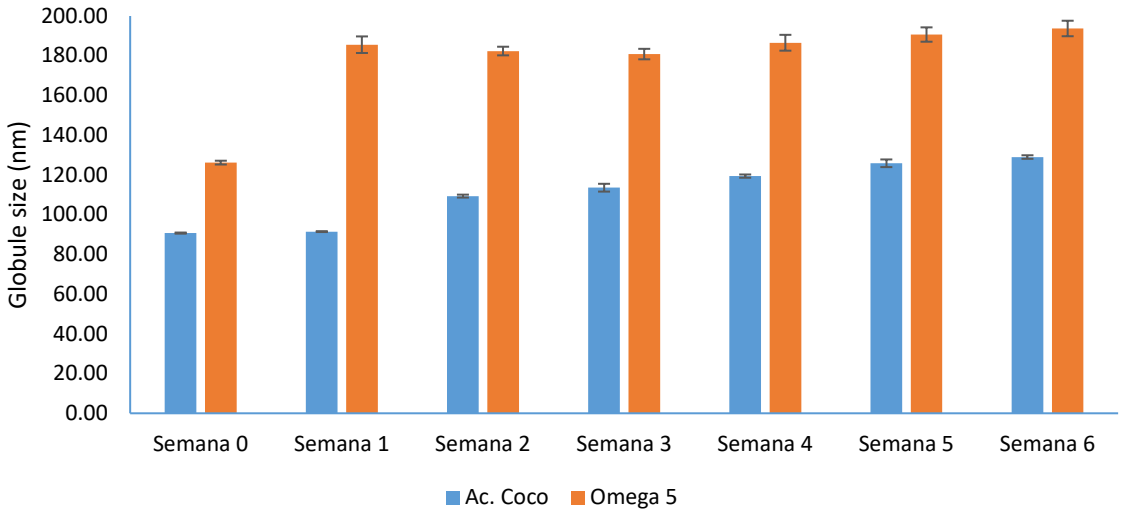

Figure 3. Initial globule size and during storage of emulsions stabilised with phosphatidylcholine. Source: own elaboration.

These tests made it possible to evaluate the effect of the emulsifier on the stabilisation of a nanoemulsion and the effect of the dispersed phase on globule size and stability during storage. Nanoemulsions stabilised using 15% (w/w) Tween 40 and having medium-chain oil (coconut oil) as the dispersed phase allowed emulsions to be obtained at the nanometric scale even during storage, so these were the conditions for the preparation of curcumin nanoemulsions in this study. Figure 4 shows the globule size obtained in the nanoemulsions once curcumin was incorporated. The curcumin nanoemulsions using omega 5 as the dispersed phase showed no significant difference in globule size compared to the nanoemulsions without curcumin. The PDI values for the nanoemulsions where coconut oil and omega 5 were used as the dispersed phase were 0.21 and 0.14, respectively, showing a homogeneous distribution. During storage, it can be observed that emulsions where the dispersed phase was omega 5 increased by around 14% after 7 weeks compared to their initial size. This behaviour is similar to that observed in nanoemulsions without curcumin. For nanoemulsions with curcumin where the dispersed phase was coconut oil, the largest increase in globule size (25%) was observed after 7 weeks of storage. Although nanoemulsions using coconut oil as the dispersed phase show a smaller initial size than those with omega 5 as the dispersed phase, due to their stability during storage, it might be better to use those with omega 5, in addition to the beneficial effects associated with their lipid profile.

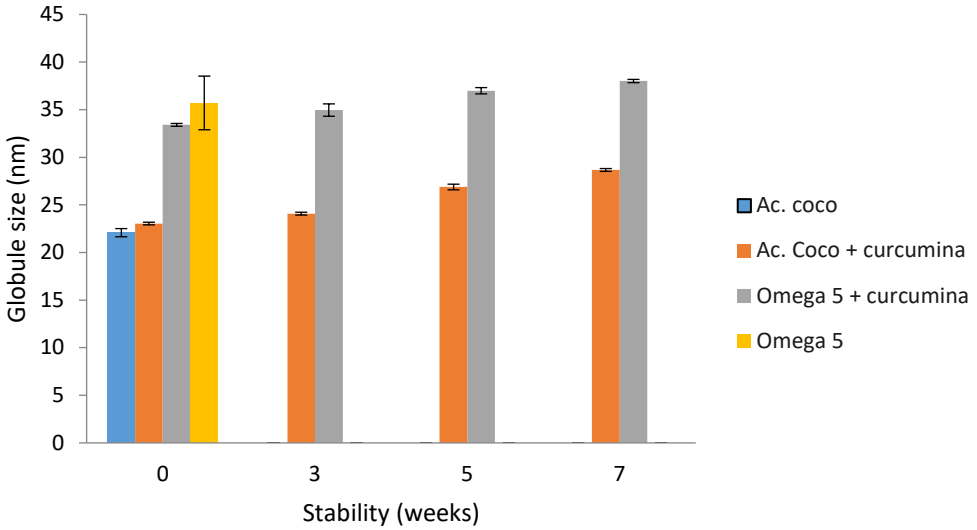

Figure 4. Initial globule size and size during storage of emulsions with curcumin stabilised by Tween 40.
Source: own elaboration.
Note: At time zero, the values of the coconut oil nanoemulsions with different lowercase letters are significantly different ($p < 0.05$), while the values of the omega 5 nanoemulsions with different uppercase letters are significantly different.

3.2 Curcumin trapping efficiency

The entrapment efficiency (EE%) of the curcumin nanoemulsion was analysed immediately after preparation in order to separate the phases within the nanoemulsion and analyse the unencapsulated curcumin after the ultrasound treatment. Using the equation for calculating the trapping efficiency, it was found that the nanoemulsions stabilised by Tween 40 and with a dispersed phase of coconut oil and omega 5 resulted in trapping of 93.11% and 93%, respectively.

3.3 Evaluation of the effect of pH on the stability of nanoemulsions

The effect of pH on nanoemulsions was studied in order to evaluate their behaviour when external charges in the dispersing phase were changed. Tween 40-stabilised nanoemulsions with a dispersed phase of coconut oil and omega 5 were adjusted to different pH values, and their surface charge (Figure 5), globule size (Figure 6) and PDI were measured. It was observed that for nanoemulsions with a coconut oil dispersed phase, the surface charge decreased as the pH increased, and for nanoemulsions with an omega 5 dispersed phase, the opposite occurred. The maximum zeta potential values were 0.2 mV, very close to zero charge.

It has been considered that to promote globule stability, the surface charge must be greater than 35 mV, and the values found in this study showed variations of less than 1 mV, so this charge cannot influence the aggregation or repulsion of the globules. Therefore, the effect of pH variation on globule size due to charge is also not significant (maximum variation of 8 nm). In the case of PDI, in all treatments using coconut oil as the dispersed phase, the PDI values ranged from 0.17 to 0.32, from which it can be deduced that they have better stability in acidic conditions (pH 3). For nanoemulsions with omega 5, values of 0.5 were obtained, demonstrating that there was a change in globule size distribution when the pH was changed.

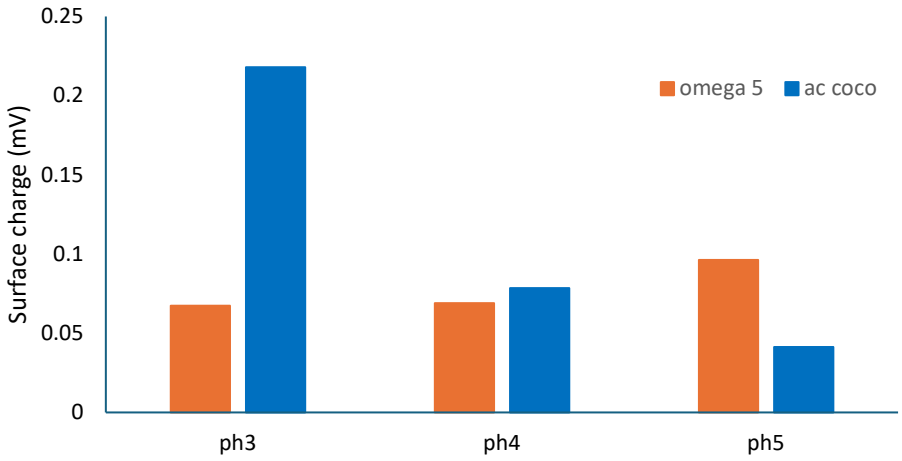

Figure 5. Effect of pH on the surface charge value of nanoemulsions with curcumin. Source: own elaboration.

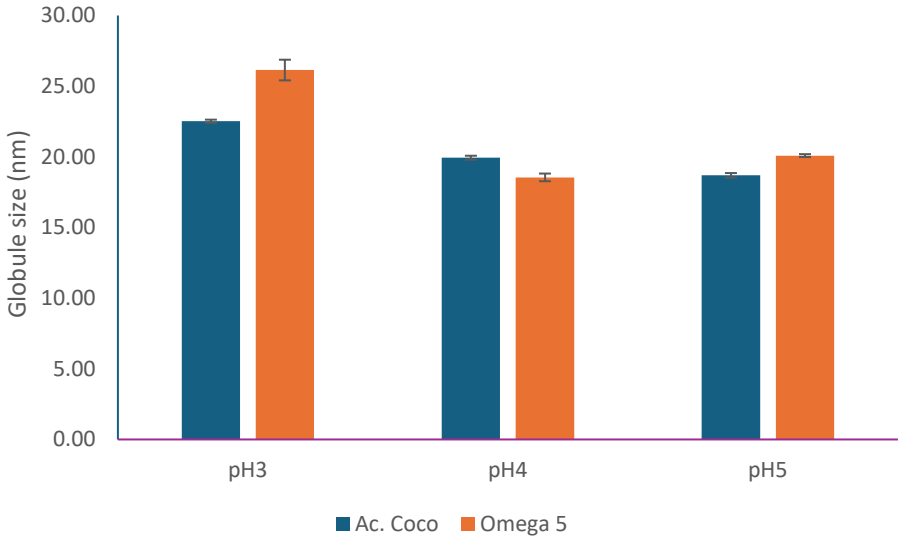

Figure 6. Effect of pH on the globule size value of nanoemulsions with curcumin. Source: own elaboration.

3.4 In vitro release of curcumin in nanoemulsion

The methodology was used to evaluate the release of curcumin in emulsion, either in the form of a thick emulsion or a nanoemulsion, to see if the reduction in globule size would influence the release. Figure 7 shows the in vitro release kinetics of curcumin encapsulated in the form of a nanoemulsion (dispersed phase of coconut oil and omega 5) and in a thick emulsion (dispersed phase of coconut oil), both at the same curcumin concentration. The release experiment was carried out at pH 5.0, due to the low stability of curcumin at alkaline pH values. In vitro release allowed the behaviour to be elucidated by reducing the globule size. The thick emulsion showed greater release of curcumin, with more than 50% of the concentration released after 24 hours and 80% of the total curcumin released after 96 hours, while the maximum release of the nanoemulsions with omega 5 dispersed phase was 50%.

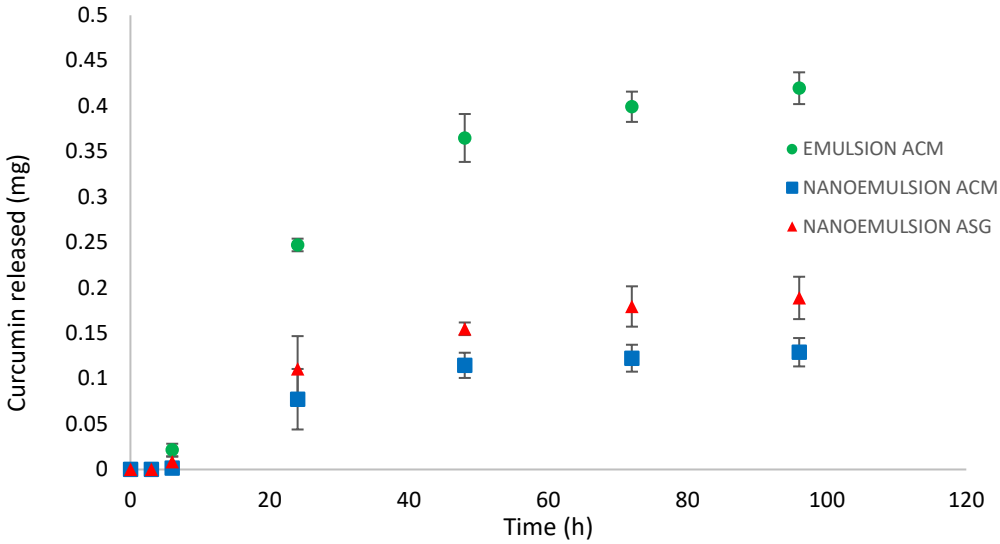

Figure 7. Evaluation of in vitro curcumin release. Source: own elaboration.

In nanoemulsions with a dispersed phase of coconut oil and omega 5, the release at the end of the kinetics was 0.12 and 0.18 mg/mL, respectively. For the thick emulsion, the final concentration was 0.42 mg/mL, more than double. Even visually, the increase in the concentration of curcumin released in this treatment could be seen compared to the nanoscale treatments (Figure 8).

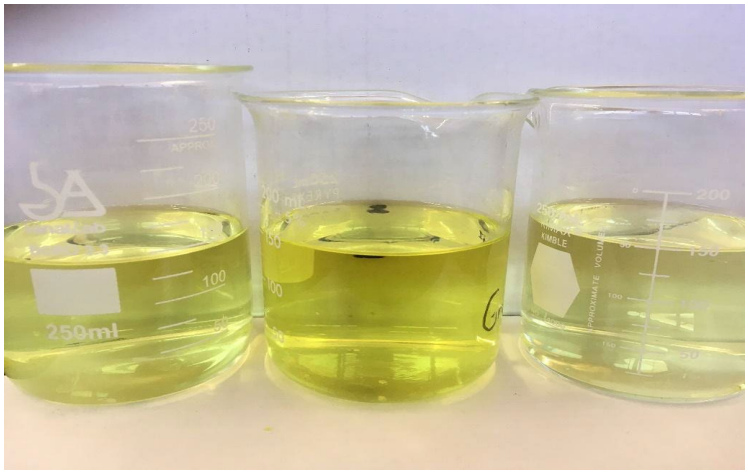

Figure 8. Visual appearance of the in vitro release of the emulsion (B) and nanoemulsions with omega 5 (A) and coconut oil (C). Source: own elaboration.

In the treatments evaluated, a lower intensity of yellow colouring can be observed as a result of a lower release of curcumin in the nanoscale treatments with omega 5 and coconut oil. The thick emulsion had the highest release in the dialysate, showing that the amount of curcumin released may be associated with the size of the globule.

4. DISCUSSION

Pre-emulsification has an important effect on the formation of nanoemulsions. If thick emulsions have large globule sizes, this hinders the subsequent reduction of globule size to the nanometric scale during ultrasonic emulsification. The variation in the type of emulsifier influences the reduction in globule size. When comparing two emulsifiers that differ in

aliphatic chain length, it is expected that the one with a longer chain will have larger globule sizes due to an increase in hydrophobic chains, causing greater resistance to globule size reduction due to higher internal pressure. This is why the emulsifier Tween 40, having shorter and less lipophilic chains compared to Tween 80, presented smaller globule sizes under all emulsification conditions evaluated.

The high-energy method used for the preparation of nanoemulsions by ultrasound allows the size of the globule to be reduced to the nanometric scale. It has been reported that the size of the globule and the PDV are defined by the configuration of the equipment used. Various authors have demonstrated that the size of the globule is affected by ultrasound conditions, mainly the amplitude in values from 20 to 40% [16] - [19]. However, it is also necessary to evaluate the composition variables. For the formation of nanoemulsions, sonication at 40% amplitude allowed the formation of nanoemulsions with sizes close to 20 nm. The globule size was observed to be influenced by the internal phase and the emulsifier used. Nanoemulsions stabilised by Tween 40 showed smaller globule sizes than those using phosphatidylcholine. These results may be due to the molecular size of the emulsifiers and the ratio of hydrophilic and hydrophobic areas in each. In the case of phosphatidylcholine, the hydrophobic zone has two fatty acid chains ranging from 16 to 18 carbon atoms, while Tween 40 has a chain with 16 carbons, making it less hydrophobic compared to phosphatidylcholine. The formation of phospholipid-stabilised curcumin nanoemulsions has been reported, with sizes of 176 nm. Therefore, although phosphatidylcholine in this study did not allow the formation of nanoemulsions with the smallest globule sizes, these were still smaller than those reported by other authors [12].

The stability during storage of the emulsions stabilised by phosphatidylcholine and omega-5 oil showed a significant increase in globule size from the first week onwards. This behaviour may be due to the long-chain polyunsaturated fatty acids in the oil and, in conjunction with the fatty acids in the lecithin, which, when surrounding the dispersed phase, cannot be arranged molecularly in a more compact form. The nanoemulsions formed with Tween 40 and coconut oil were smaller in size compared to those with omega-5. This is due to differences in the composition of fatty acids that influence the hydrophobicity of oils. Oils with a higher composition of long-chain fatty acids will have greater repulsion upon contact with the aqueous phase. and a higher amount of unsaturation in the fatty acids could influence a larger area arrangement and, therefore, a larger globule size in the emulsion. Regarding the globule sizes obtained, in [12] the effect of using different emulsifiers on the globule size of curcumin nanoemulsions prepared by high-pressure homogenisation was evaluated. They obtained globule sizes ranging from 144 nm to 176 nm when using rhamnolipids, phosphatidylcholine, and Tween 80, and stable PDI values (around 0.22). In this study, the emulsions stabilised by Tween 80 were the largest, and the PDI values were close to 0.22 in all treatments, showing a uniform globule size distribution. When the nanoemulsions were prepared with curcumin, it was observed that the sizes were very close to those obtained in the treatments without curcumin. Similar results have been reported by other authors in terms of globule size. [6] reported globule sizes of 17 nm using medium-chain oil as the dispersed phase, Tween 80 as a 15% emulsifier, and two co-surfactants. However, the emulsification method was carried out by developing ternary diagrams and vigorous stirring.

The trapping efficiency has been reported to be related to the lipophilic characteristics of the encapsulated compounds [20]. The results obtained are close to or higher than those reported by other authors, such as in [21], where they report EE% of 100 in phospholipid-stabilised nanoemulsions obtained by the thin-layer hydration and ultrasound method. while in [5] they report EE% of 64.3 to 93.6% for nanoemulsions stabilised with Tween 20 and obtained by ultrasound, results similar to those obtained in this study. Therefore, the results of this study show that a considerable amount can be encapsulated using this emulsification method and under these experimental conditions.

The effect on pH variation was done in order to evaluate the behaviour if this formulation were used in any food. The variation in surface charge was minimal, close to zero, due to the

emulsifier, which, being non-ionic, has no effect on the surface charge of the surrounding globule. The changes in zeta potential could be attributed to the fatty acid composition of both oils; however, this change is not as significant in magnitude as has been reported in other studies. The globule size changed minimally, however, the PDI showed a significant change. These changes may be due to the flocculation of the globules as a destabilisation mechanism, demonstrating lower stability at certain pH values.

There are reports in which nanoemulsions have been considered as controlled release systems that gradually dispense the active compounds encapsulated in them, and this behaviour was observed in the present study. The size of the globule and the composition of the dispersed phase influence the release of curcumin. Nanoemulsions with coconut oil showed lower release due to the fatty acid composition, which influences the hydrophobicity, intramolecular ordering, and behaviour of fatty acids within the system [22], [23].

5. CONCLUSIONS

The type of emulsifier significantly influences the characteristics of emulsions and the achievement of nanoscale systems. The internal phase used modifies the properties of nanoemulsions in terms of stability and surface charge. The in vitro release of curcumin was prolonged and constant, suggesting that this and other compounds will remain present for longer periods at low concentrations that do not cause toxicity. This study provides information on the importance of composition variables in the development of nanoemulsions and their delivery.

6. ABOUT THE ARTICLE

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Researcher's declaration: I hereby declare that the results presented in this study are original, have not been previously published, and comply with the principles of scientific rigour and academic ethics. I also assume full responsibility for any claims related to intellectual property rights.

Author contributions:

All authors contributed equally to the conceptualisation of the study; methodology; supervision, research, data analysis, as well as the writing, review and editing of the manuscript.

Conflicts of Interest: The authors declare that they have no financial, academic or personal conflicts of interest that could have influenced the development or results of this manuscript.

REFERENCES

[1] X. Du *et al.,* "pH-shifting formation of goat milk casein nanoparticles from insoluble peptide aggregates and encapsulation of curcumin for enhanced dispersibility and bioactivity," *Lwt*, vol. 154, p. 112753, Jan. 2022. https://doi.org/10.1016/j.lwt.2021.112753

[2] B. B. Aggarwal, Y.-J. Surh, and S. Shishodia, Eds., *The molecular targets and therapeutic uses of curcumin in health and disease*, 2007a ed. New York, NY, United States of America: Springer, 2007. https://doi.org/10.1007/978-0-387-46401-5

[3] Z. Stanić, "Curcumin, a compound from natural sources, a true scientific challenge–a review," *Plant Foods for Human Nutrition*, vol. 72, pp. 1–12, Mar. 2017. https://doi.org/10.1007/s11130-016-0590-1

[4] A. Siviero *et al.,* "Curcumin, a golden spice with a low bioavailability," *J. Herb. Med.*, vol. 5, pp. 57–70, Jun. 2015. https://doi.org/10.1016/j.hermed.2015.03.001

[5] N. Sharma, G. Kaur, and S. K. Khatkar, "Optimization of emulsification conditions for designing ultrasound assisted curcumin loaded nanoemulsion: Characterization, antioxidant assay and release kinetics," *Lebenson. Wiss. Technol.,* vol. 141, p. 110962, Apr. 2021. https://www.sciencedirect.com/science/article/abs/pii/S0023643821001158

[6] M. Kharat, Z. Du, G. Zhang, and D. J. McClements, "Physical and chemical stability of curcumin in aqueous solutions and emulsions: Impact of pH, temperature, and molecular environment," *J. Agric. Food Chem.*, vol. 65, pp. 1525–1532, Dec. 2016. https://pubs.acs.org/doi/10.1021/acs.jafc.6b04815

[7] M. T. Bazana, C. F. Codevilla, and C. R. de Menezes, "Nanoencapsulation of bioactive compounds: Challenges and perspectives," *Current opinion in food science*, vol. 26, pp. 47–56, Apr. 2019. https://doi.org/10.1016/j.cofs.2019.03.005

[8] R. Jamwal, "Bioavailable curcumin formulations: A review of pharmacokinetic studies in healthy volunteers," *Journal of integrative medicine*, vol. 16, no. 6, pp. 367–374, Nov. 2018. https://doi.org/10.1016/j.joim.2018.07.001

[9] Y. Xu *et al.,* "Curcumin-carrying nanoparticles prevent ischemia-reperfusion injury in human renal cells," *Oncotarget*, vol. 7, no. 52, pp. 87390–87401, Nov. 2016. https://doi.org/10.18632/oncotarget.13626

[10] R. Chávez-Zamudio *et al.,* "Preparation, characterization and bioavailability by oral administration of O/W curcumin nanoemulsions stabilized with lysophosphatidylcholine," *Food & function*, vol. 8, no. 9, pp. 3346–3354, Sep. 2017. https://doi.org/10.1039/c7fo00933j

[11] A. A. Ochoa, J. A. Hernández-Becerra, A. Cavazos-Garduño, H. S. García, and E. J. Vernon-Carter, "Phosphatidylcholine enrichment with medium chain fatty acids by immobilized phospholipase A1-catalyzed acidolysis," *Biotechnology Progress*, vol. 29, no. 1, pp. 230–236, Jan.-Feb. 2013. https://doi.org/10.1002/btpr.1648

[12] R. F. Gonçalves, J. T. Martins, L. Abrunhosa, A. A. Vicente, and A. C. Pinheiro, "Nanoemulsions for enhancement of curcumin bioavailability and their safety evaluation: Effect of emulsifier type," *Nanomaterials*, vol. 11, no. 3, p. 815, Mar. 2021. https://doi.org/10.3390/nano11030815

[13] A. Araiza-Calahorra, M. Akhtar, and A. Sarkar, "Recent advances in emulsion-based delivery approaches for curcumin: From encapsulation to bioaccessibility," *Trends Food Sci. Technol.*, vol. 71, pp. 155–169, Jan. 2018. https://doi.org/10.1016/j.tifs.2017.11.009

[14] J. C. Serrano-Niño *et al.,* "Optimization of the byosynthesis of gold nanoparticles using Hypericum perforatum and evaluation of their antimicrobial activity," *Revista Mexicana de Ingeniería Química*, vol. 19, no. 2, pp. 889–902, 2020. URL

[15] K. Hazra, R. Kumar, B. K. Sarkar, Y. A. Chowdary, M. Devgan, and M. Ramaiah, "UV-visible spectrophotometric estimation of curcumin in nanoformulation," *International journal of pharmacognosy*, vol. 2, no. 3, pp. 127–130, Mar. 2015. https://doi.org/10.13040/IJPSR.0975-8232.IJP.2(3).127-30

[16] G. Cardoso-Ugarte, and M. Jiménez-Munguía, "Nanoemulsiones en alimentos: preparación y aplicaciones," *Temas Selectos de Ingeniería de Alimentos*, vol. 9, pp. 15–24, 2015. https://www.udlap.mx/TSIA/assets/files/volumen9/TSIA-Vol9-Cardoso-Ugarte-et-al-2015.pdf

[17] T. Tadros, P. Izquierdo, J. Esquena, and C. Solans, "Formation and stability of nano-emulsions," *Advances in Colloid and Interface Science*, vols. 108–109, pp. 303–318, May. 2004. https://doi.org/10.1016/j.cis.2003.10.023

[18] J. Rao, and D. J. McClements, "Formation of flavor oil microemulsions, nanoemulsions and emulsions: Influence of composition and preparation method," *Journal of Agricultural and Food Chemistry*, vol. 59, no. 9, pp. 5026–5035, Mar. 2011. https://pubs.acs.org/doi/10.1021/jf200094m

[19] A. Cavazos-Garduño, A. O. Flores, J. C. Serrano-Niño, C. E. Martínez-Sánchez, C. I. Beristain, and H. S. García, "Preparation of betulinic acid nanoemulsions stabilized by ω-3 enriched phosphatidylcholine," *Ultrasonics Sonochemistry*, vol. 24, pp. 204–213, May. 2015. https://pubmed.ncbi.nlm.nih.gov/25572417/

[20] T. Baccarin, and E. Lemos-Senna, "Potential application of nanoemulsions for skin delivery of pomegranate peel polyphenols," *AAPS PharmSciTech*, vol. 18, no. 8, pp. 3307–3314, Jun. 2017. URL

[21] A. A. Ochoa *et al.,* "Preparation and characterization of curcumin nanoemulsions obtained by thin-film hydration emulsification and ultrasonication methods," *Revista mexicana de ingeniería química*, vol. 15, no. 1, pp. 79–90, 2016.

https://www.scielo.org.mx/scielo.php?script=sci_arttext_plus&pid=S1665-27382016000100079&lng=es&tlng=en&nrm=iso

[22] M. Fang *et al.,* "In vitro characterization and in vivo evaluation of nanostructured lipid curcumin carriers for intragastric administration," *Int J Nanomedicine*, vol. 7, pp. 5395–5404, 2012. https://www.dovepress.com/article/download/11219

[23] X. Chen *et al.,* "Curcumin-Loaded Nanoparticles Protect Against Rhabdomyolysis-Induced Acute Kidney Injury," *Cell Physiol Biochem*, vol. 43, no. 5, pp. 2143–2154, Oct. 2017. https://d-nb.info/1149952512/34