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Stabilization of a Pickering Emulsion by Nanoparticles of Eudragit RSPO and Pol-epsilon Caprolactone: Contact Angle Measurement and Surface Tension Studies

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The use of colloidal particles to prepare and stabilize emulsions, known as "Pickering emulsions ", has aroused growing interest in recent years. Pickering and Ramsden demonstrated at the beginning of the last century the feasibility of surfactant-free emulsions, in presence of these emulsions is called "Pickering Emulsions". This concept of emulsions stabilized by solid particles is experiencing renewed interest nowadays given the many advantages it offers good stability, environmental protection, user safety, and particle varieties.
The first part is devoted to the synthesis of Eudragit RSPO and pol epsilon-caprolactone nanoparticles and their characterization. The characterization of the nanoparticles is performed by dynamic light scattering and geometry. The understanding of the interfacial behavior of these nanoparticles and their associated stabilization mechanisms for emulsions was carried out. The second part of the study investigated the formulation and stabilization of the emulsion using the washed suspension containing the nanoparticles as the only stabilizer. The objective of this part is to stabilize and characterize the formulated emulsions. Droplet size determination and microscopy were performed using a Zeiss optical microscope. The direction of the formulated emulsions was determined by conductimetry. In conclusion, Pickering emulsions stabilized solely by Eudragit RSPO and Poly-epsilon Caprolactone nanoparticles appear to be highly effective innovative drug carriers, opening new doors as potential drug delivery systems.

Keywords: Pickering emulsion; polymer; contact angle; eudragit RSPO; poly-epsilon caprolactone.

1. INTRODUCTION

The term emulsion has a very wide application and is usually difficult to identify with a particular product. Emulsions are metastable mixtures of two immiscible liquids and an amphiphilic agent. One of the liquids is dispersed in the other in the form of small spherical drops whose size varies according to the conditions from 0.1 to a few tens of micrometers. There are different types of emulsions: Water-in-oil emulsions where the dispersing phase, also called the external phase or continuous phase, is constituted by the oil, and the internal phase or discontinuous phase or dispersed phase is represented by the water; Oil-in-water emulsions with the aqueous dispersing phase and the dispersed oily phase; Mixed emulsions or multiple emulsions (W/O or O/W/O). The system thus created does not correspond to a thermodynamically stable state, the most stable state would be the macroscopic separation of the two fluids. Kinetic stability is ensured by the presence of amphiphilic molecules, called emulsifiers, adsorbed at the interface between the two phases [1].

These emulsifiers are most often surfactants. These are molecules with an affinity for both water and oil. They are made up of a polar hydrophilic head and an apolar hydrophobic tail. However, because they are harmful to the environment and the body, their use is not without risk.

The use of colloidal particles to prepare and stabilize emulsions, known as 'Pickering emulsions', has attracted increasing interest in recent years [2]. These emulsions are called "Pickering emulsions". These emulsions are known in the petroleum industry, food industry, and the design of inks, paints, roaand d surfaces. Recently, the possibilities of applications of particle-stabilized emulsions have been considered in the pharmaceutical industry. This type of formulation can be a potential encapsulation system for active ingredients, allowing the controlled and targeted release of the active from the internal phase [3-7]. However, this type of emulsion is not yet commercially available. There are many studies on the formulation and physicochemical properties of emulsions stabilized by solid particles, but to date studies in a biological environment have not been described in the literature.

The control of the adsorption of colloidal particles at the liquid/ liquid interface leads to the development of new functionalized. However, the

study of the adsorption of colloidal particles is very important to better understand their properties, materials such as colloidosomes [8,9] as it can be, for instance, strong and irreversible at the oil/water interface. The irreversible adsorption of the particles allows one to obtain very stable emulsions [10,11]. This leads to the formation of a dense film, thus creating a barrier around the droplets, giving them high resistance to coalescence. The particle adsorption or desorption energy DE is mainly related to their ability to be partially wetted by the two phases of the emulsion [9,12-14]. The particle wetting is characterized by the contact angle between the aqueous phase, the oil phase, and the solid particles, measured on the aqueous phase side, making the contact angle and the particle diameter two crucial parameters to determine the interfacial adsorption forces. The well-documented literature in this research area concerns, in most cases, the development of Pickering emulsions and foams, and their potential use [15-20].

The direct effect of the nanoparticles on the interfacial tension, which, is still in discussion, is the ‘‘macroscopic’’; the result of their impact on the formulation lies in their capabilities of Pickering emulsion stabilization. The stabilization is generally higher when they form a dense ‘‘monolayer’’ around the droplets, while partial coverage does not stabilize the emulsion effectively because the ‘‘bald’’ plates favor the drainage of the film and flocculation/coalescence. For this reason, it is acknowledged that better coverage is generally obtained with smaller particles [21].

This work is devoted to the preparation and study of Pickering emulsions stabilized by a polymer such as poly epsilon-caprolactone and eudragit RSPO. The work is divided into three parts: first, the synthesis and characterization of nanoparticles for emulsion stabilization. Then we carried out a formulation study including the determination of the contact angle and the interfacial tension to better understand the stabilization mechanisms, and finally, the preparation and characterization of the emulsions obtained.

2. MATERIALS AND METHODS

2.1 Materials

The equipment used for the synthesis and characterization of the nanoparticles is a Malvern Zetasizer and a rotary evaporator. To measure the contact angle, we have developed an experimental device. This device consists of an Optical bench, a light source, a thermostatic tank filled with oil and a needle with a rising drop, a syringe filled with the aqueous phase, a calibrated telecentric lens, a CCD camera, and a video monitor and a computer. A Wilhelmy blade tensiometer (Dogno Abribat tensiometer) was used in the tensiometry study.

2.2 Regents

The polymers used for the synthesis of the nanoparticles are poly epsilon-caprolactone (Sigma Aldrich) and Eudragit RSPO (Rohm Germany), and the surfactant used is sodium dodecyl sulfate (SDS) (LABOSI). As an aqueous phase, we used MilliQ water (Millipore). The organic solvent used for the synthesis was acetone, Sigma Aldrich). Various other chemicals were used.

2.3 Methods

Synthesis and characterizations of nanoparticles:

Synthesis of poly epsilon-caprolactone and eudragit RSPO nanoparticles: The nanoprecipitation technique, sometimes described as "solvent displacement", allows the production of nanospheres or nanocapsules. It consists of dissolving the polymer in the organic solution. The solvent chosen is generally a semi-polar solvent such as acetone or ethanol, which must be miscible with water in all proportions. This solution is injected, with moderate stirring, into an aqueous phase, possibly including sodium dodecyl sulphate, in which the polymer is not soluble. The nanoparticles are then formed instantaneously under the effect of the diffusion of the acetone toward the aqueous phase. The polymer, insoluble in the water-solvent mixture, precipitates in the form of nanospheres. The organic solvent is then removed by evaporation under reduced pressure.

Dynamic light scattering. Size distributions and poly- dispersity indices (PDI) were measured by dynamic light scattering (DLS) with a NanoZS Malvern apparatus (Malvern, Orsay, France). The helium/neon laser, 4 mW, was operated at 633 nm, with the scattering angle fixed at 1731 and the temperature maintained at 25 1C. DLS data were analyzed using a cumulant-based method, and experiments were performed in triplicate.

ζ Potential Measurements ζ were measured, with a NanoZS Malvern apparatus (Malvern, Orsay, France). ζ potentials measurements were performed 1 h after formulation. The NanoZS used in this study determined the electrophoretic mobility of the particle and then calculated the values of ζ potential using teary's equation under the Smoluchowski approximation. All experiments were performed in triplicate.

Contact angle measurement:

The contact angle measurement reports the ability of a liquid to spread on a surface by wettability. The method consists of measuring the angle of the tangent of the profile of a drop deposited on the substrate, with the surface of the substrate. It allows the surface energy of the liquid or solid to be measured. The measurement of the contact angle gives access to the free energy of a surface. It also allows the discrimination of the polar or apolar nature of the interactions at the liquid-solid, liquid-liquid, and liquid-gas interface. The hydrophilic or hydrophobic nature of a surface can thus be deduced.

To measure the contact angle we have developed an experimental device. This device consists of an optical bench, light sources, thermostatic tanks filled with oil and needle with raising drop, a syringe filled with the aqueous phase, calibrated telecentric lenses, CCD cameras, a video monitor, and a computer. For drop formation, we have a system consisting of a micrometric syringe with a volume of 1 ml, a silicone tube, and a stainless steel flat-tip needle with an external diameter of 0.8 mm and an internal diameter of 0.5 mm. The drop images are acquired by a CCD camera. They are then transmitted to a computer equipped with a graphics card and Studio acquisition software. The images are then processed with Image J image processing software. To obtain good image contrast, diffuse lighting is used. The intensity of the lamp is set to its minimum. The optimal objective-drop distance x is about 13 cm; the best compromise between magnification and image quality is then obtained. The camera-drop distance x' is 30 cm, and the optical fiber-diffuser distance x' is 22 cm. The diffuser-drop distance affects the contrast of the image obtained. The height of the millimetric syringe does not influence the results but must be fixed during handling to avoid any instability.

The equipment used must be as clean as possible. The acquisition of the image of a drop is done using the Studio software and the processing of this image to obtain the contact angle using the ImageJ software. Before starting the measurements, it must be ensured that the lamp, the camera, and the control screen are switched on. To obtain a sharp image of the drop, it is advisable to place the camera lens approximately 13 cm from the drop.

Determination of the contact angle; Using Image J software.

We use the Image J software to open the images and to measure a length or an angle. Opening an image: File/Open and choose your image in the appropriate directory.

Measurement of a length: To measure the length of an image, you need a standard. So, on the same image as what you want to measure, you must have a millimeter ruler or an object whose size you know. In the rising drop experiment, a good standard is a syringe. To measure the diameter of the drop, use the same method and note the length in pixels. Then, draw a vertical line of the same length in pixels which will allow you to measure the diameter in the right place. You can permanently draw this line by right-clicking/drawing or clearing.

Measuring an angle: To measure an angle, you must use the "Angle tool". To measure the angle between two lines, first, click on the two lines then at the intersection, hold the mouse click and position it on the other line. The angle ("angle") is then displayed in the main Image J window.

Tensiometer:

Interfacial tension is the free energy per unit area between two liquids [1]. It is called surface tension when one of the two liquids is gaseous. This interfacial tension is measured using a tensiometer. Therefore, the main technique used in our study is the Wilhelmy blade method.

In the case of the blade method, the liquid is brought into contact with a platinum blade (Pt), itself connected to a precision balance. The force (F) necessary to tear the blade is measured to determine the interfacial tension (according to the equation).

$$\gamma = \frac{F}{L\cos\theta}$$

γ: surface tension, F: surface tension force, L: length of the platinum plate, θ: contact angle A

Wilhelmy plate tensiometer (Dogno Abribat tensiometer) was used during this work. For interfacial tension measurements, oil was gently added to the surface of the aqueous phase to completely immerse the slide. The zero was performed before the measurement by immersing the Wilhelmy blade in oil.

Formulation and characterizations of emulsion:

Macroscopic Examination: The emulsions are left to stand in the dark and at room temperature in 15 ml conical tubes fitted with lids. This visual inspection highlights certain phenomena of instability such as sedimentation, flocculation, and coalescence.

pH Determination: The determination of the pH of the solutions is based on the measurement of the potential between two electrodes immersed in a solution rich in H + ions After calibrating the pH meter with solutions of known pH, the electrode is dipped into a 15 ml conical tube containing the preparation to be studied. Like conductivity, care should be taken to immerse the electrodes to the level of the emulsified phase for tubes with sedimentation. The reading is made a few minutes after the insertion of the electrode.

Conductivity Measurement: It is based on the measurement of the electrical resistance of a solution located between 2 plates covered with platinum black. Depending on the concentration of ions present, the solution will have a greater or lesser conductivity. The conductimetry cell is introduced into a 15 ml tube fitted with a screw-on lid containing the preparation to be studied. In the presence of a conductive preparation, the conductivity meter displays a value corresponding to the conductivity expressed in Siemens per meter (S. m-1). In the case of tubes with sedimentation, immerse the conductive cell to the level of the emulsified fraction.

Droplet Size of Pickering Emulsion: a droplet of emulsion is placed on a slide and then covered with a coverslip. The slide is placed on the stage of the microscope and the observation is carried out with the 40X objective. The device is equipped with software that allows direct photography of the observed image. The image of the droplets obtained thereafter is correlated by the software which makes it possible to determine the size of the droplets by delimiting the diameter of each droplet.

3. RESULTS

3.1 Synthesis and Characterization of Nanoparticles

3.1.1 Synthesis of poly epsilon-caprolactone and eudragit RSPO nanoparticles

Dynamic light scattering. Size distributions and poly- dispersity indices (PDI): We have developed nanoparticles by nanoprecipitation at different concentrations of polymers 0.5%, 1%, 2%, 3%, and 4% for eudragid RSPO and Poly epsilon-caprolactone. Fig. 1 shows the size distribution of the nanoparticles. The size of the nanoparticles obtained varies from 90 to 300 nanometers with polydispersity indices from 0.1 to 0.3.

Potential Measurements ζ : Le Potentiel Zeta déterminé pour le poly epsilon caprolactone nous donne des valeurs comprises entre -25 et -30 Mv et pour ceux de l'eudragit RSPO on a des valeurs comprises entre +20 et +40Mv.

3.2 Contact Angle Mesurement

The following figures show the transformations of the image obtained with the assembly and the determination of the liquid-liquid contact angle by the Image J software. The results obtained are presented in Figs. 2a and 2b.

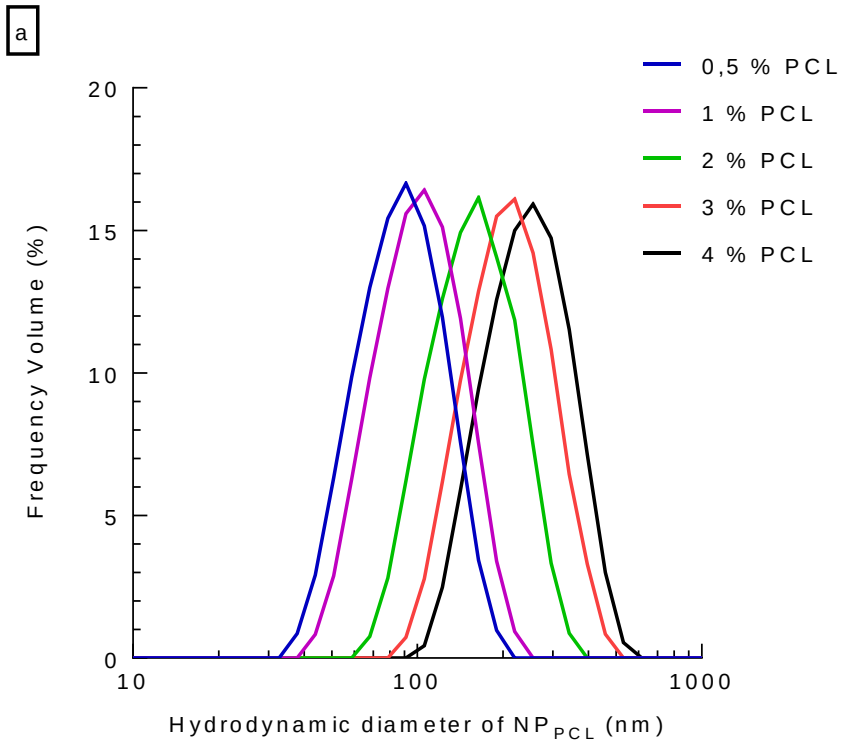
3.3 Tensiometer Studies

The surface tension measurements carried out show a lowering of the tension which is conferred on the activity of the polymers at the water/oil interface. The reference voltage without the nanoparticles being higher than that with the nanoparticles, Fig. 3 shows the results of the tensiometric studies.

3.4 Formulation and Characterization of Pickering Emulsion

3.4.1 Macroscopic examination

In this part, the study consisted in preparing a series of emulsions with the suspensions of nanoparticles prepared (Eudragit RSPO and Poly Epsilon Caprolactone), to study their stability. Except for the T1 tube, which has become destabilized since the first day after preparation, and the T'1 tube, which has a dispersible cream by simple shaking, the emulsions obtained have


a
0,5 % PCL
1 % PCL
2 % PCL
3 % PCL
4 % PCL
Frequency Volume (%)
20
15
10
5
0
10
100
1000
Hydrodynamic diameter of NP PCL (nm)

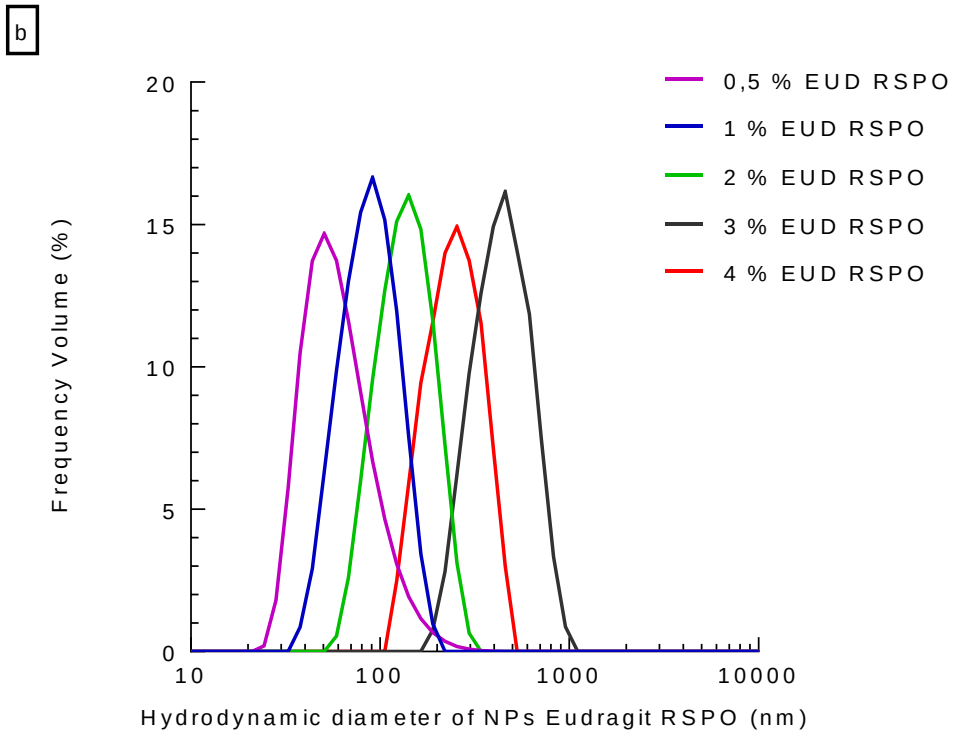
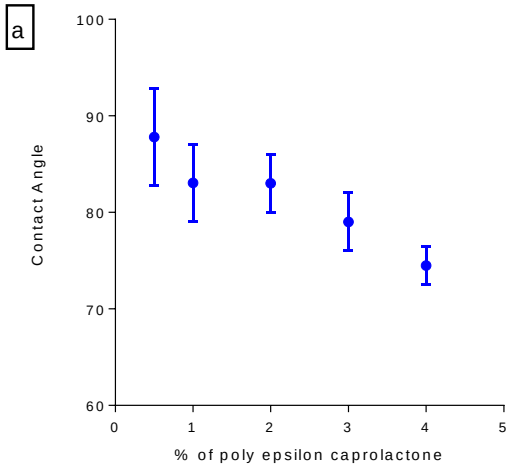
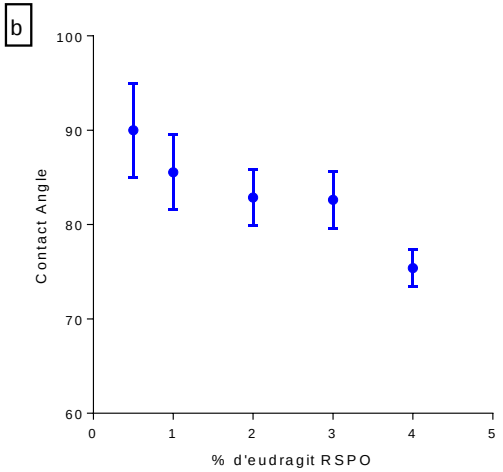


Fig. 1. Hydrodynamic diameter of nanoparticles (a) pol epsilon-caprolactone (b) Eudragit RSPO



Tubes	T1	T2	T3	T4	T5
% PCL	0,5	1	2	3	4
Contact Angle	87,8	83,05	83,01	79,01	74,48



Tubes	T'1	T'2	T'3	T'4	T'5
% Eud RSPO	0,5	1	2	3	4
Contact Angle	90	85,55	82,87	82,63	75,38

Fig. 2. Contact angle (°) (a) Polyepsilon Caprolactone, (b) Eudragit RSPO.

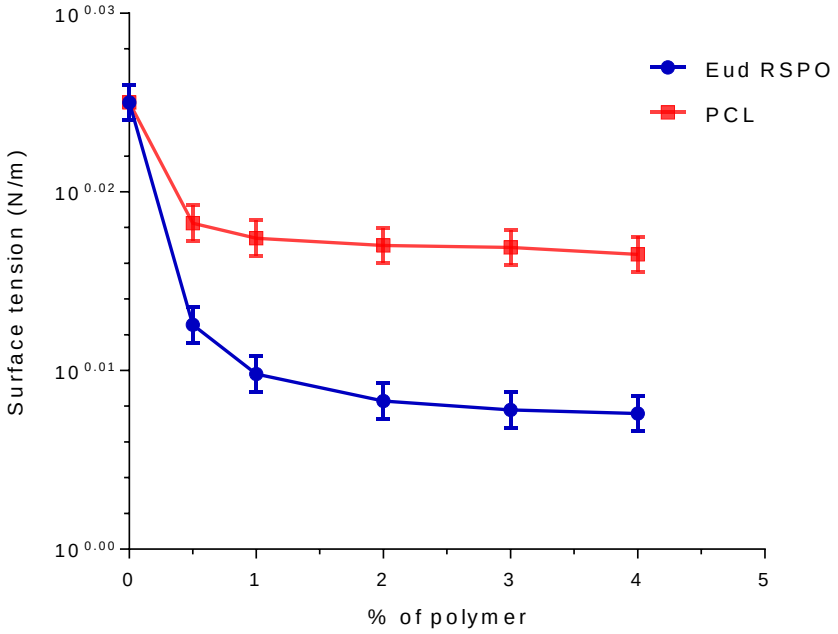


Fig. 3. Surface tension as a function of polymer percentage

a white color and are stable. All the preparations (except tube 1 which is not stable and tube 1' which presents a re-dispersible creaming by simple shaking), appear macroscopically stable. That is to say that they do not show any destabilization phenomenon visible to the naked eye at the end of the 28 days of storage.

3.4.2 Examen microscope

The microscopic examination with a ZEISS microscope shows us that these synthesized particles are active at the water/oil interface and capable of stabilizing emulsions. The size and density of the droplets depend on the quantity of polymer used for the synthesis of the nanoparticles. Figs. 4(a) and (b) show us the microscopic appearance of emulsion droplets.

3.4.3 pH determination

Les mesures de pH ont été réalisées à J1, J7, J14, J21. Les résultats sont représentés dans les Figs. 5a et 5b ci-dessous.

The pH measurements were carried out on D1, D7, D14, and D21. The results are shown in Figs. 5a and 5b below.

Conductivity Measurement: The conductivity measurements were taken on D1, D7, D14, and D21. The results give conductivity values of less than 0.02 mS/cm for all the preparations. The emulsions being conductive, then we can confirm the direct direction of the emulsions obtained.

Droplet Size of Pickering Emulsion: The measurement of the size of the droplets carried out on D15 after preparation shows the results indicated in Fig. 6 As the T1 tube was not stable, we did not consider it necessary to study the size of its droplets.

4. DISCUSSION

The main results obtained show that polymeric nanoparticles are potential candidates for emulsion stabilization. Indeed, the replacement of solid particles with biodegradable organic particles is an interesting prospect. This would make it possible to consider other routes of application, for example, local injection (oral, subcutaneous, intramuscular). The absorption of nanoparticles by intestinal cells is well known (Borm et al. 2006), so choosing a type of particle without any possible toxicity is necessary.

In our context, which was emulsion stabilization by polymer nanoparticles, we demonstrated the possibility of using poly epsilon-caprolactone and eudragit RSPO nanoparticles of size between 90 and 300 nm and having stable emulsions. We prepared the emulsions by varying the percentage of polymers to obtain suspensions of particles obtained by nanoprecipitation.

The study of the mechanisms of stabilization of emulsions by nanoparticles has become essential. There are many studies on the mechanism of stabilization of Pickering emulsions by ideally spherical particles and stabilization theories have been developed. In this study, we studied the contact angle at the oil-water interface and the influence of nanoparticles on the contact angle but also the surface tension between water and oil to see the influence of nanoparticles. The drop in surface tension as a function of the percentage of nanoparticles indicates an increase in the stability of the formulated emulsions.

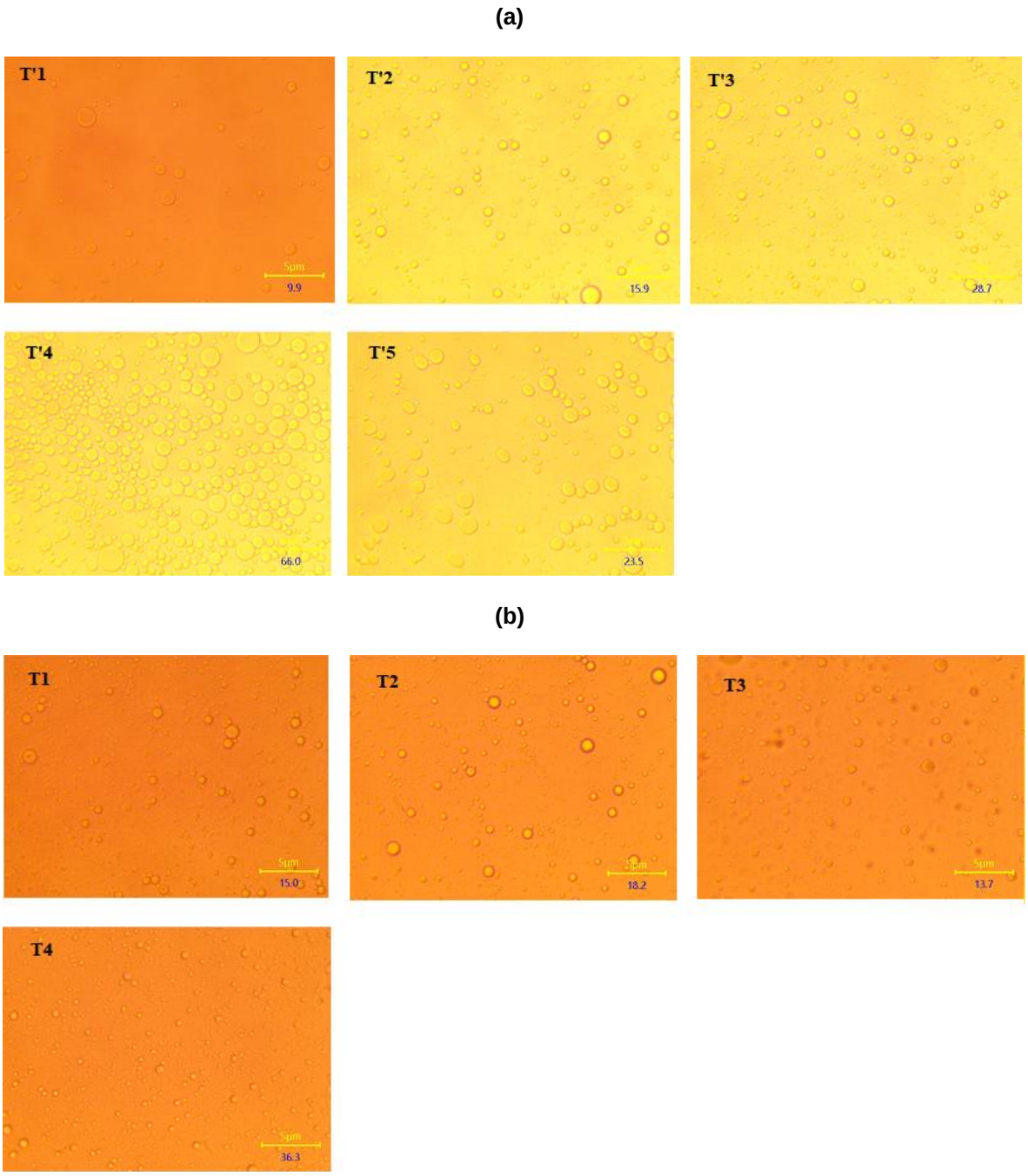


Fig. 4. Optical microscopy (a) emulsion stabilized by nanoparticles of Eudragit RSPO, (b) emulsion stabilized by nanoparticles of pol epsilon-caprolactone

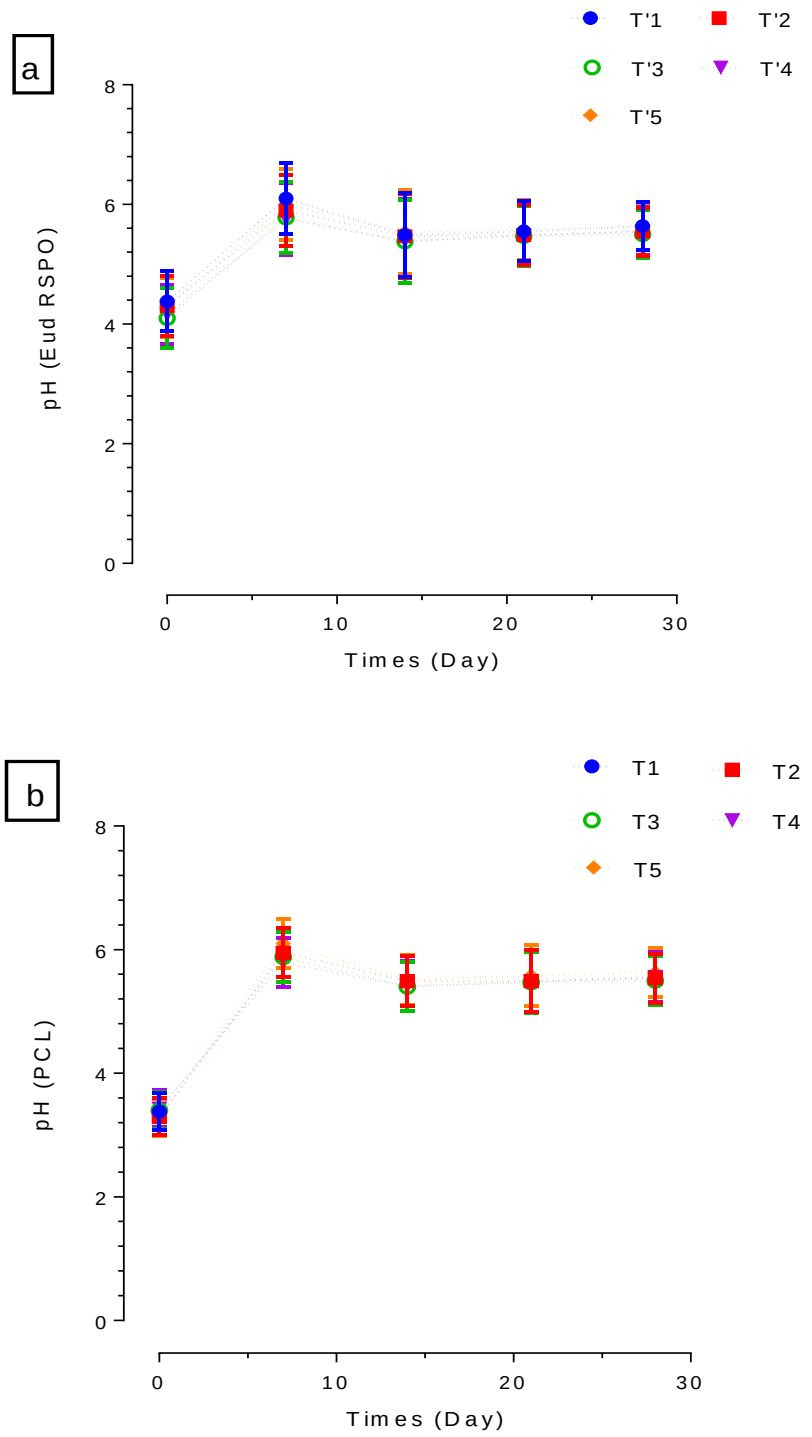


Fig. 5. pH of emulsions, (a) with Eudragit RSPO, (b) with pol epsilon-caprolactone

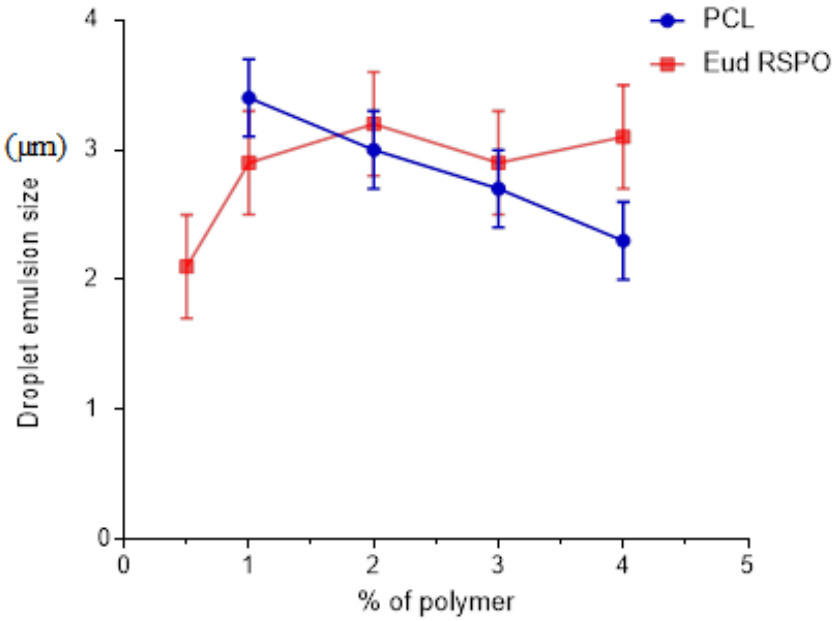


Fig. 6. Droplet size as a function of polymer percentage

The main results obtained about the physical properties showed that macroscopically, all the formulations were stable during the first hours. Immediately afterward, the T1 tube destabilized. For the T'1 tube, a re-dispersible cream was observed by simple agitation.

However, it should be kept in mind that these physical characteristics perceived with the naked eye do not prejudge the stability of the emulsions obtained. Indeed, macroscopic observation does not allow to see droplets smaller than 50 µm.

The determination of the direction of the emulsion was established thanks to the measurement of the conductivity. The conductivity of the emulsions (all <0.02mS/cm) therefore confirms their O/W nature. Indeed, the value of the conductivity of an emulsion depends on its external phase [22]. The results thus obtained throughout the observation period show that the emulsions did not undergo any phase inversion phenomenon.

Regarding the pH measurements, the results obtained indicated an acid character for all the tubes. This acidity is unfavorable to the stability and preservation of the emulsions. The basic nature gives the emulsions better stability. Yang and his collaborators showed that the adjustment due to high values (9-12) allows a good stabilization of the emulsion by favouring better adsorption of the particles at the interfaces [23]. In addition, the pH value of the emulsions influences its conservation and determines the incompatibilities that there could be with the other components possibly present [24]

For all the preparations we used a fixed quantity of oil, the variable parameter being the percentage of polymer used for the synthesis of the nanoparticles. We find that the size of the droplets depends on the percentage of polymer used for the synthesis of the nanoparticles. As for the size of the droplets, it plays an important role in the stability of emulsions and it is one of the parameters that can modify the sedimentation rate described by Stokes' law [25-28], thus a 100-micrometer globule rises 10 cm in water in only 3 minutes, while it takes 5 hours and 20 days for globules respectively of 10 micrometers and 1 micrometer.

We observed that for all the tubes the average diameters are between 20 and 35 micrometers.

For the tubes with the poly epsilon-caprolactone nanoparticles, a reduction in the average size of the droplets is observed as a function of the percentage of polymer used for the synthesis of the nanoparticles. Indeed, the most probable hypothesis would be, the increase in the number

of particles which would reduce the size of the droplets thus leading to an increase in the interfacial zone [28-30].

The relationship between the diameter and the number of particles is illustrated by the following formula.

$$D=(6Øv\ V)/A$$

D is the diameter of the droplets
A/V is the interfacial area per unit volume
Øv is the fraction of the dispersed phase

However, for emulsions stabilized by eudragit RSPO, this logic is not verified, we have average sizes ranging from 2.1 to 3.2 nm (T1 (2.1 µm) T2 (2.9 µm) T3 (3.2 µm) T4(2.9µm) T5(3.1µm)).

The results made it possible to obtain Pickering emulsions stabilized by nanoparticles of poly epsilon-caprolactone and eudragit RSPO.

5. CONCLUSION

Unlike surfactant molecules which adsorb and desorb continuously, the particles adsorb at the interfaces under the effect of agitation and irreversibly (the desorption energy of a particle is of the order of 1500KBT where KB is the Boltzmann constant). We set ourselves the objective of producing Pickering emulsions stabilized by polymeric nanoparticles of poly epsilon-caprolactone and eudragit RSPO.

Of all the preparations, only T1 shows a phenomenon of instability and creaming for T'1. Conductive made-up emulsions are therefore of the O/W type. We had to note an acidity for all the emulsions which is unfavorable for the stability of the latter. Compared to the two batches, we observed that the size of the droplets is controlled by the number of nanoparticles. Indeed, a high percentage of poly epsilon-caprolactone decreases the size of the emulsion droplets. Also, the increase in the percentage of eudragit RSPO leads to a reduction in the size of the droplets from 2%.

We also found that the amount of polymer used influences the value of the contact angle. Indeed, the increase in the percentage of the polymer decreases the contact angle of the emulsions. Better stability is noted with low surface tension values. The lower the surface tension, the more stable the emulsion. This is why emulsions with eudragit RSPO are more stable than those with poly epsilon-caprolactone. We can retain that the respect for various physicochemical parameters makes it possible to guarantee better stability of the emulsions.

During this work all the emulsions prepared except for T1 are stable and those with eudragit RSPO had better stability than emulsions with poly epsilon-caprolactone. The stability can be improved by using a very high-speed stirrer for further work. The prospect of a double encapsulation allowing a release in two stages, from nanoparticles and droplets, opens up the prospects for significant therapeutic modulation. It would also be interesting to study the incorporation of hydrophilic molecules in this type of formulation to determine their mode of encapsulation in these particles and their release mechanisms.

CONSENT AND ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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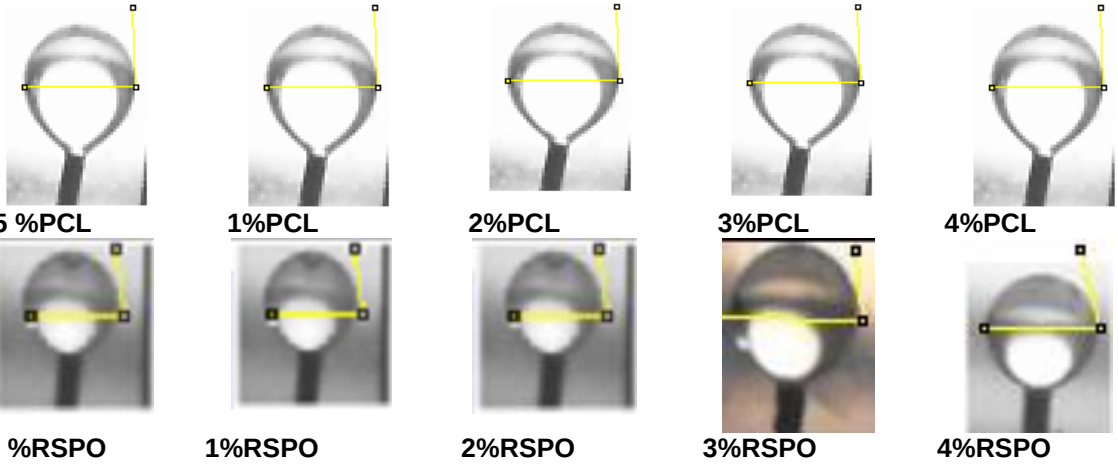
ANNEXES



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