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Evaluation of the rheological properties of pluronic blends for the incorporation of *Cymbopogon citratus* essential oil

Avaliação das propriedades reológicas de blendas pluronic para a incorporação do óleo essencial de *Cymbopogon citratus*

M. G. S. Carvalho[1]; B. J. de C. Alves[2]; S. S. Simplicio[3]; G. R. S. de Araujo[4]; J. K. M. C. Gonsalves[1,2,3*]

[1]*Graduate Program in Biosciences, Federal University of Vale do São Francisco, Petrolina-PE, Brazil*
[2]*College of Pharmacy, Federal University of Vale do São Francisco, Petrolina-PE, Brazil*
[3]*Graduate Program in Materials Science, Federal University of Vale do São Francisco, Juazeiro-BA, Brazil*
[4]*Department of Pharmacy, Federal University of Sergipe, São Cristóvão-SE, Brazil*

** joyce.gonsalves@univasf.edu.br*
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In this work, systems of polymeric blends of Pluronic with hydrophilic polymers (chitosan, guar gum, polyvinyl pyrrolidone, polyvinyl alcohol) were developed to convey the essential oil of *Cymbopogon citratus* (OECC) as a model of healing material. An experimental design was carried out based on the influence of these hydrophilic polymers on the gel formation characteristics, evaluating the gelation time at 37 °C as a response. After selecting the formulation with the required characteristics, OECC was added and the blend was characterized by pH, spreadability, viscosity, rheology, and chemical analysis. Chitosan, a polymer defined by the design, provided the formation of the gelled blend in a shorter time and the absence of precipitates. The presence of OECC allows for discreet changes in chemical properties (in the infrared spectrum, displacement of the C=C peak of the oil in the blend; in pH, a slight increase to 4.6); but not in the rheological ones, only a reduction in spreadability and maintenance of the pseudoplastic behavior of the blend without the OECC. Therefore, no significant modifications would make applying the blend as an auxiliary material impossible in the cutaneous tissue healing process.
Keywords: hydrophilic polymer, thermoresponsive polymer, healing.

Neste trabalho, foram desenvolvidos sistemas de blendas poliméricas de Pluronic com polímeros hidrofílicos (quitosana, goma guar, polivinil pirrolidona, álcool polivinílico) com o objetivo de veicular o óleo essencial de *Cymbopogon citratus* (OECC) como modelo de material cicatrizante. Um planejamento experimental partindo da influência destes polímeros hidrofílicos nas características de formação de gel foi executado, avaliando-se como resposta o tempo de gelificação a 37 °C. Após selecionar a formulação com as características exigidas, foi adicionado OECC e a blenda foi caracterizada através do pH, espalhabilidade, viscosidade, reologia e análise química. A quitosana, polímero definido pelo planejamento, proporcionou a formação da blenda geleificada em menor tempo e na ausência de precipitados. A presença do OECC, além das características visuais, possibilitou modificações discretas nas propriedades químicas (no espectro de infravermelho, deslocamento do pico C=C do óleo na blenda; no pH, discreto aumento para 4,6); mas não nas reológicas, apenas uma redução de espalhabilidade e manutenção do comportamento pseudoplástico da blenda sem o OECC. Portanto, nenhuma modificação significativa impossibilitaria a aplicação da blenda como material auxiliar na condução do processo cicatricial de tecidos cutâneos.
Palavras-chave: polímero hidrofílico, polímero termorresponsivo, cicatrização.

1. INTRODUCTION

Post-injury tissue repair occurs naturally, via an inflammatory process, in the sense of remodeling and sealing the exposed wound [1]. However, depending on the physiological and local conditions of the tissue, this process may last for months, leaving the local environment conducive to the action of external agents, such as pathogenic microorganisms [2]. Using a biomaterial that leads to rapid tissue sealing, while releasing active microbial action, is desired.

Hydrophilic polymers that form hydrogels have gained space in developing technological frameworks for obtaining biomaterials applied in wound healing [3]. Its chemical structure, rich in hydroxyl groups, promotes interaction with the exudate, absorbing it during the swelling

process [4, 5]; in addition, most of them are biocompatible, a primordial requirement for application as a biomaterial, nontoxic, biodegradable, and may even act together with bioactive molecules in the healing process [3]. Among the most popular are those of natural origin, such as chitosan and guar gum, and synthetic ones, such as polyvinyl pyrrolidone and polyvinyl alcohol.

Those of natural origin have the main advantages of being eco-friendly and low-cost. The low cytotoxicity and good biodegradability of guar gum (GG), a polymer extracted from *Cyamopsis tetragonolobus*, makes it widely applied as an emulsifier, suspending agent, and adhesive [6]. Chitosan (CH), also non-toxic, biocompatible, and biodegradable, is among the most recruited in the development of biomaterials [3, 7]. Among her abilities, she can form an intermolecular network capable of absorbing aqueous fluids and remaining insoluble [8].

Although natural ones are the most studied, synthetic ones are also studied for this purpose. Polyvinyl alcohol (PVA) is of synthetic origin, hydrophilic, biocompatible, and biodegradable. Its chemical backbone formed by hydroxyls allows for unique crosslinks in the polymer backbone [9], causing it to be found in dressings, wound care, drug delivery systems, and biomaterials [10]. Polyvinylpyrrolidone (PVP), an inert synthetic polymer, temperature resistant, pH stable, biocompatible, biodegradable, and with low cytotoxicity [11], has been used in pharmaceutical preparations due to its similarity to proteins, which increases its compatibility, but also in delivery systems [12].

Associating these polymers with other polymeric agents in the making of blends guarantees greater resistance of the material, increases compatibility, and allows it to carry bioactive for local release, in addition to providing changes in the physical-chemical characteristics of the new material, such as the rheological ones. Combinations of these with polymers such as Pluronic®, a temperature-responsive triblock copolymer (polyoxypropylene-polyoxyethylene) [13, 14], provide a moldable and responsive environment to changes in electrolytes (exudate), pH (intact and injured skin) and temperature (body). The formation of the blend conditioned to the alternation of the environmental conditions of an application under the wound would imply the gel transition in situ, leaving the system more structured, favoring its permanence, and being an excellent ally in the release of bioactive.

Therefore, this work aimed to analyze the chemical and rheological behavior of polymeric blends of pluronic with hydrophilic polymer in the presence of a natural agent of biological activity, C*ymbopogon citratus*, as a model of the bioactive agent.

2. MATERIALS AND METHODS

2.1 Materials

Pluronic® F-127 (PLU), powder, molecular weight 12,600 g mol^{-1}; chitosan (CH, 79% GD, experimentally confirmed) as a powder, medium molecular weight; guar gum (GG), high molecular weight powder; polyvinyl alcohol (PVA), 99% hydrolyzed, molecular weight 85,000-124,000 g mol^{-1}, polyvinylpyrrolidone (PVP), in powder form, molecular weight 111.4 g mol^{-1}; all purchased from Sigma Aldrich® (United States); P.A. glacial acetic acid, purchased from SYNTH® (Brazil); and distilled water.

The essential oil of *Cymbopogon citratus* (OECC) (viscous, pale yellow, density of 0.92 g mL^{-1}, and extractive yield of 1.18%) was obtained through hydrodistillation in the laboratory by the researchers themselves (S*upplementary material*).

2.2 Experimental planning

Following the experimental design outlined in Table 1, polymeric dispersions were prepared to compose the *PLU: hydrophilic polymer blend*. CH, PVA, and PVP dispersions were prepared, respectively, separately: dispersing them in acetic acid solution (1%, v/v) at 25 ºC, for 24 h; in water, at 70 ºC, for 30 min; and in water at 25 °C for 30 min. The PLU dispersion, 20% (w/v), was prepared under constant magnetic stirring in distilled water cooled at 4 °C for 30 min.

Table 1: Experimental design to obtain a polymeric blend containing PLU.

Trial number	**PLU % (p/v)**	**PVA % (p/v)**	**PVP % (p/v)**	**GG % (p/v)**	**CH % (p/v)**
1	20	-	-	-	-
2	20	1	-	-	-
3	20	-	1	-	-
4	20	-	-	1	-
5	20	-	-	-	1
6	20	1	1	-	-
7	20	1	-	1	-
8	20	1	-	-	1
9	20	-	1	1	-
10	20	-	1	-	1
11	20	-	-	1	1
12	20	1	1	1	-
13	20	1	1	-	1
14	20	-	1	1	1
15	20	1	1	1	1

Legend: **(PLU)** Pluronic dispersion; **(PVA)** Polyvinyl alcohol dispersion; **(PVP)** polyvinylpyrrolidone dispersion; **(GG)** guar gum dispersion; **(CH)** chitosan dispersion.

On the PLU dispersion, each supporting polymeric dispersion was dripped separately and as indicated in Table 1; an alternating agitation program was promoted: under mechanical agitation using the portable mix (Original Line, Premium model), the system remained in dispersion for 10 min, followed by magnetic agitation for 50 min, at a temperature of 25 ºC.

As a response variable of the experimental design, the shortest gelation time was fixed, at 37 ºC, *'sol-gel transition time'*. Using a body temperature of 37 ºC as a basis, the samples were submitted to Bain Maria SL - 150, with a timer, until the formation of the gel was observed and, later, with the aid of a thermometer, the temperature was measured to check the gelation temperature.

The formulations were analyzed regarding the characteristics of coloration and formation of precipitate demonstrated after the interaction between the polymers, being analyzed visually and through photographs (Cellular device, model Mi 9 lite). Samples with precipitates, color changes, and no gel formation were discarded. For reproducibility purposes, each experimental design point was performed in triplicate.

After defining the formulation following the parameters established in the sample selection, 20 µL of OECC was added under mechanical agitation for 30 min.

2.3 Experimental planning

2.3.1 Formulation pH

To determine the pH of the formulations, a digital benchtop pH meter (Lab1000® brand, model mPA 210) with a glass electrode and temperature sensor, previously calibrated with pH 4 and 7 buffer solutions, at a temperature of 25 ± 0.5 °C.

2.3.2 Viscosity

A device of the Microprocessed Rotary Viscometer type (Quimis® brand, model Q860M) was used, operating at an initial ascending speed of 10 to 60 r.p.m., subsequently operated at a

descending speed of 60 to 10 r.p.m., at a temperature of 25 and 37 °C, in the evaluation of the viscosity of the formulations.

2.3.3 Spreadability

The diameters covered by the samples were read in a system formed by a mold plate. About 0.3 g of the sample was placed between two 20 cm^2 glass plates, one of which was placed on graph paper. The addition of masses of 303.4 g, 306.1 g, 304.1 g, and 378.8 g every 3 min to the top plate promoted the spreading of the product, which was measured as extensibility in millimeters. The results were expressed in sample spreadability as a function of the applied mass, according to the equation below, and they correspond to the average of the triplicates.

Equation 01 $$Ei = d^2\pi 4$$

Where:
Ei = spreadability of the sample for weight i (mm^2); d = average diameter (mm); and π = 3.14.

2.3.4 Rheology

Data on the rheological behavior were acquired in a Compact Modular Rheometer (MCR 302, Anton Paar, Austria), coupled to a cone-plate geometry with a 20 mm diameter, 1° angle, and 52 μm gap. The linear viscoelastic region was initially determined, sweeping the strain amplitude between 0.1 and 100%, with a fixed frequency of 1 Hz. Subsequently, after determining the linearity region common to all samples, the behavior of the storage and loss modules were observed as a function of frequency, which ranged from 0.1 to 100 Hz, with a fixed strain amplitude. The samples were deposited in the center of the bottom plate of the rheometer, with minimal shear, waiting for 2 min. of rest to stabilize the system before the beginning of the experiment, which was performed at temperatures of 25 and 37 °C.

2.3.5 Fourier Transform Infrared Spectroscopy (FTIR)

Using the ATR module, analyzed in the IRTracer-100-Shimadzu® spectrometer in the region between 4000 and 600 cm^{-1}, scans with 45 scans and 8 cm^{-1} resolution were performed on the raw materials, blends, and OECC.

3. RESULTS AND DISCUSSION

3.1 Blend selection

Experimental plans are based on the principle of the best selection of the sample in the face of variables that influence its process, optimizing time and resources allocated to its execution [4, 13, 15]. Knowing which factors influence the achievement of the desired result is extremely important in obtaining a precise material for the intended application. Therefore, the PLU thermoresponsive transition was determined, as a response variable of the experimental design (Table 1), as a function of time and temperature (Table 2) and only formulations n º 1, 2, 5, and 8 were able to gel.

No formulation composed of PVP and GG polymers gelled. A probable change in the thermosensitivity of the PLU may have led to gelation above the temperature of 37 ºC (object of observation since this is the body temperature under physiological conditions). Cationic polymers, gel when the environment is modified in the charge balance, probably induced by pH modification, promoting cross-linking in the polymeric chain and thus increasing the resistance of the dispersion to flow [14-16]. As the medium in which it was inserted did not promote this

cross-linking and the pH was not adjusted, the dispersions in which they were present did not form a gel, therefore, they were disregarded to find potentially adhesive hydrogels for skin sealants.

Table 2: Experimental planning for the production of PLU blends: Hydrophilic polymers.

TRIAL NUMBER	FORMULATIONS	PRECIPITATE FORMATION	GELLING TIME
1	PLU	-	10 min
2	PLU/PVA	+	30 min
3	PLU/PVP	-	-
4	PLU/GG	+	-
5	PLU/CH	-	20 min
6	PLU/PVA/PVP	+	-
7	PLU/PVA/GG	+	-
8	PLU/PVA/CH	+	20 min
9	PLU/PVP/GG	+	-
10	PLU/PVP/CH	-	-
11	PLU/GG/CH	+	-
12	PLU/PVA/PVP/GG	+	-
13	PLU/PVA/PVP/CH	+	-
14	PLU/PVP/GG/CH	+	-
15	PLU/PVA/PVP/GG/CH	+	-

Legend: **(PLU)** Pluronic dispersion; **(PVA)** Polyvinyl alcohol dispersion; **(PVP)** polyvinylpyrrolidone dispersion; **(GG)** guar gum dispersion; **(CH)** chitosan dispersion.

PVA is a polymer that forms soluble dispersions at warmer temperatures, precipitating when this is reduced [17-19]. Its solubility is dependent on the degree of hydrolysis, polymerization, and temperature. The high hydrolysis of PVA can promote the formation of hydrogen bonds between this polymer and water. With the sharp increase in hydroxyl groups resulting from the high degree of hydrolysis, PVA molecules tend to form intra- and intermolecular hydrogen bonds with each other. This impairs the interaction of PVA with water, thereby reducing its solubility [9, 20]. As a result, small agglomerates of polymeric aggregates, known as precipitates, are formed, which is exactly what was observed in formulations 2 and 8. The formation of precipitates is undesirable when formulating different dispersions, essentially those for application in health since it limits the interaction of the material with the environment.

The opposite was observed in dispersions containing CH. Also a cationic polymer, CH is soluble in acidified media, making its structure protonated and susceptible to the formation of bonds by ionic interactions, essentially through the protonated amino groups [7, 21, 22]. CH is a versatile polymer, being applied in different areas, in medicine for being biocompatible, biodegradable, antibacterial activity, hemostasis, and anesthetic effect, in addition to forming interactions very easily with other polymers in dispersions [1, 23, 24]. The alternation of charges stimulated by the pH reduction induced by the protonation of the amino groups of the CH promoted the propitious environment for modifying the thermosensitivity of the medium, promoting the gelation of the PLU at a temperature of 37 ºC. An increase in time was observed after the addition of the CH dispersion (20 min) to the PLU dispersion (10 min). The presence of another element dispersed in the solution can change the network mesh of the polymers and thus delay the interaction between them.

It is worth mentioning the non-observance of precipitates, thus indicating that there is miscibility and compatibility between these materials, allowing their analysis and further studies. Thus, on the formulation nº 5 (PLU/CH) there was the addition of OECC, which promoted changes to the dispersion, such as the non-formation of precipitates and increasing resistance to fluidity, without altering the gelling condition in a short time at 37 ºC.

3.1.1 Formulation pH

The determination of pH in polydisperse systems is extremely important in its development and application. Changes in the pH of the medium may promote precipitation, inactivation, or conformational changes in the dispersed elements, and thus negatively influence the development of new delivery systems [15]. Furthermore, in the case of a product to be applied to injured skin, the pH of recovery devices may cause problems in the healing context, since the pH of wounds is slightly altered, slightly higher than the pH of intact skin, and may provide a greater risk of infection.

Figure 1 shows the pH values of the hydrogel-type polymeric dispersions that make up the investigated blend (PLU/CH), in the presence and absence of the bioactive, the OECC (PLU/CH and PLU/CH/OECC). It is observed that the PLU/CH blend had a slightly lower pH (pH=4.3) than that of the isolated PLU (pH=6). The presence of dispersion of CH, soluble in an acid medium, is crucial for such a reduction, but it would probably not have significant deleterious effects, since the cutaneous pH in normal parameters is comprised of 4.5 to 6.5 [1, 25]. The presence of OECC, due to its chemical composition consisting of terpenes, did not induce significant changes, therefore, not influencing this property.

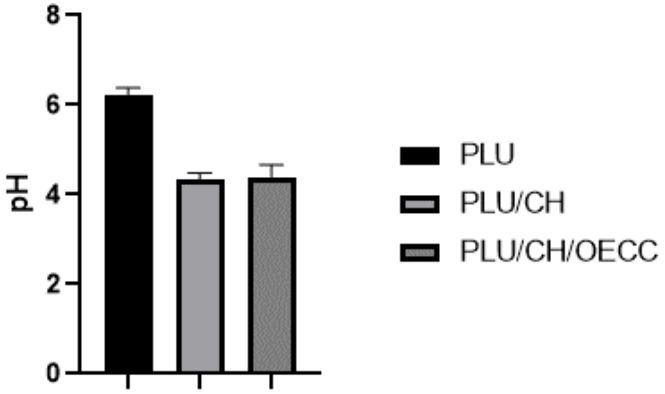

Figure 1: pH analysis of the samples. ***PLU:*** *Pluronic dispersion;* ***CH:*** *chitosan dispersion;* ***OECC:*** *essential oil of Cymbopogon citratus.*

3.1.2 Spreadability

Hydrogels have low flow characteristics; therefore, using them as a tool to transport actives and apply them under the skin proves to be an appropriate tool. In the case of skin lesions, healing materials need to remain in the lesion, spreading throughout the laceration, but not oozing. Therefore, it is necessary to evaluate the viscoelastic and spreadability properties of hydrogels as done and described in Figure 2.

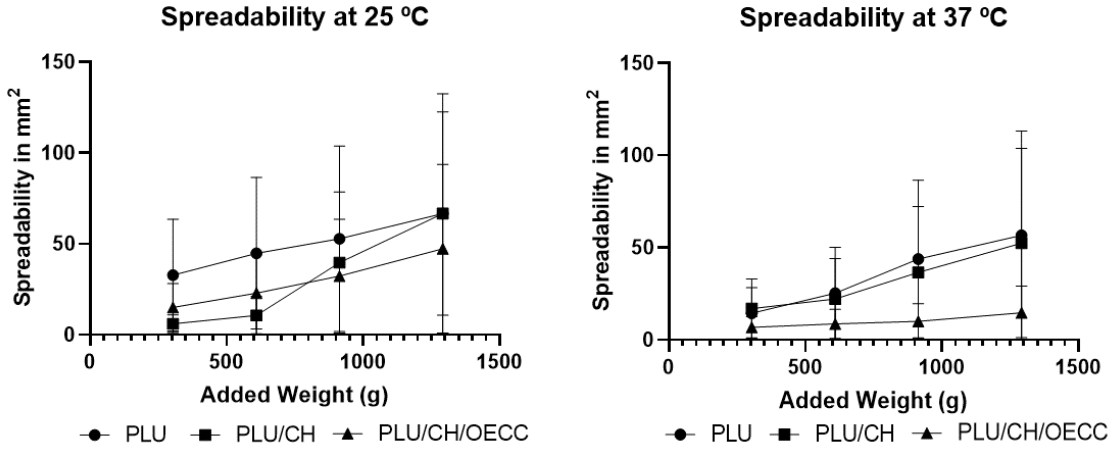

Figure 2: ***(A)*** *Demonstration of the results of the spreadability of solutions at 25 ºC.* ***(B)*** *Demonstration of the results of the spreadability of solutions at 37 ºC.* ***PLU:*** *Pluronic dispersion;* ***CH:*** *chitosan dispersion;* ***OECC:*** *essential oil of Cymbopogon citratus.*

For comparative purposes, the spreadability was observed at room temperature (25 ºC) and body temperature (37 ºC). Because it is thermoresponsive, forming a gel at temperatures above 30 ºC, the PLU hydrogel, as well as the blends, proved to be fluid, with a low resistance to spreading as the applied weight gradually increased. However, increasing the temperature to 37 ºC allowed the spreadability to be dependent on the applied weight, showing greater resistance to flow. Such motivation is related to the thermally induced sol-gel transition in the PLU, when reaching temperatures slightly higher than the ambient one, an alternation of the viscous state is perceived due to structural modifications in the polymeric mesh [10, 26].

It is noticeable that the presence of OECC was extremely important for increasing the hydrogel structuring and, consequently, the resistance to flow (Figure 2). Spread ability was significantly reduced ($p < 0.05$) on the PLU/CH/OECC hydrogel. A greater microstructural organization leads to the formation of uniform reticules, which add strength to resist spreadability, which proves to be interesting since the followability of formulations on wounds would limit the action of pharmacological agents and would require constant replacement.

3.1.3 Viscosity

Based on the viscosity measurements, it is possible to evaluate the hydrogel's resistance to flow, indicating the behavior of the fluid as a function of the applied shear rate, and classify them as Newtonian fluids and non-Newtonian fluids of the pseudoplastic type, as shown in Figure 3. An increase in intermolecular interactions governed by temperature resulted in the viscoelastic change of the PLU, comparing the graphs at temperatures of 25 ºC and 37 ºC. The molecular dispersion promoted by the PLU triblock when heated, or having its concentration increased, forms a gel *in situ*, reducing the resistance to flow with the increase of the shear force, but returning to its original state without elastic losses [27-29].

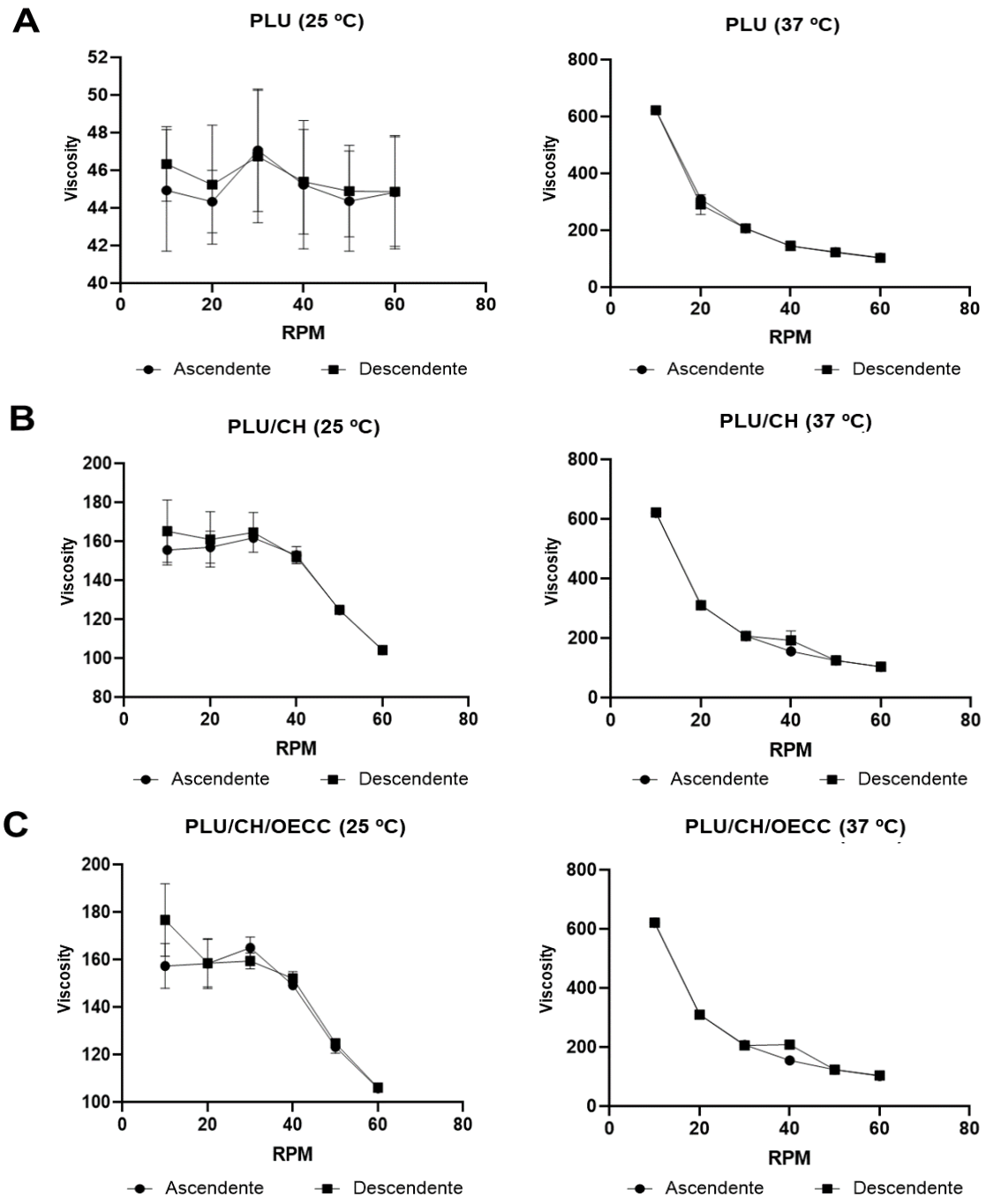

*Figure 3: Viscosity analysis (mpa.s) of **(A)** PLU dispersion; **(B)** blend PLU/CH; and **(C)** blend PLU/CH/OECC, at 25 ºC and 37 ºC. **PLU:** Pluronic dispersion; **CH:** chitosan dispersion; **OECC:** essential oil of Cymbopogon citratus.*

The addition of hydrophilic polymers to the PLU dispersion can result in conformational changes and therefore rheological changes. However, what was observed after the addition of the CH dispersion to the PLU dispersion did not allow the visualization of changes in its pseudoplastic behavior, but with viscosity variations for the blend at a temperature of 25 ºC. A slight increase in viscosity is observed at this temperature, but it remains practically unchanged at 37 ºC, observing the PLU hydrogels and the PLU/CH blend. The OECC also did not influence the alteration of the pseudoplastic profile or the relative viscosity, when compared to the blend without, guaranteeing the new blend's structural stability. This is guaranteed when, after changes in composition, the viscosity of the gel becomes constant as a function of time [4, 28, 30]. The

characterization of the viscosity provides a glimpse of the applicability of hydrogels, mainly for those used as delivery devices to be applied under the skin.

3.1.4 Rheology

The hydrophilic crosslinking in the polymeric mesh caused by the swelling of the colloidal dispersion in hydrogels generates a particular accommodation to this structure, which modifies its viscoelastic behavior depending on its composition [2, 30]. One way to evaluate such behavior is through rheology, observing the storage modules and elastic loss as a function of frequency, as illustrated in Figure 4.

The oscillatory frequency test of the PLU hydrogel at 25 °C (Figure 4A) showed the existence of storage (G') and loss (G") modules, indicating a viscoelastic behavior [27]. In addition, the values of G' and G" are similar and low, which justifies the Newtonian behavior of low viscosity and high spreadability obtained for this system when compared to other hydrogels. Furthermore, it is observed that G' is influenced by frequency, which reinforces the character of a hydrogel with the low organization. Furthermore, it is noted that these parameters change with the increase in temperature, which was expected since this polymer is formed with sequences of three copolymers that conform with an increase in temperature [31].

At 37 °C, the PLU hydrogel maintains the viscoelastic behavior, however, with a change in the values of G' and G", which showed a sharp increase, with G' becoming greater than G". This phenomenon indicates that there was a structuring of the system, reflecting on its viscosity, which increased and, consequently, reduced its spreadability. Finally, it is important to note that with increasing temperature, the G' modulus became independent of frequency, reinforcing the character of a structured gel [32].

The formation of the PLU/CH blend (Figure 4B) did little to modify the rheological profile, with the same behavior being observed for the PLU hydrogel, which is why only this polymer is thermosensitive in the blend's composition. However, the values found were lower than those of PLU, probably because the presence of a second polymer, less viscous such as CH, altered the structural organization in the blend, promoting this reduction in the mechanical strength of the material. The addition of OECC (Figure 4C) also did not influence changes in the rheological behavior, which had already been observed previously, corroborating the analysis of viscosity and spreadability (Figures 2 and 3).

Therefore, these hydrogels, when at room temperature, present G'~G", which shows the low viscosity for the system. The sol-gel transition of the hydrogel will occur at temperatures slightly elevated from room temperature, through the reordering of the polymeric chain, which results in a reticulated mesh resistant to the applied force [13, 33]. This characteristic is what makes it of interest for biomedical applications and its vast versatility, such as favoring the application on the skin and making a cohesive reticulum that provides the release of actives under a cutaneous lesion.

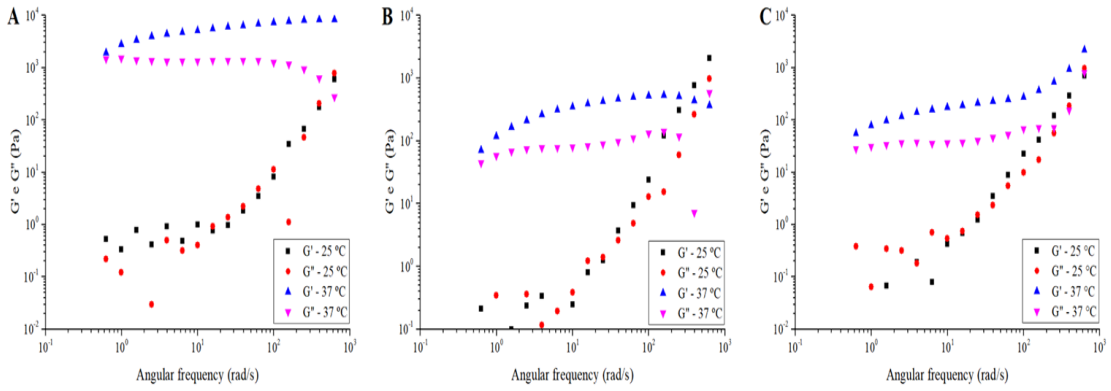

Figure 4: Viscoelastic properties of ***(A)*** *PLU hydrogels;* ***(B)*** *PLU/CH blend, and* ***(C)*** *PLU/CH/OECC blend at different temperatures. G': storage module; G'': loss modulus.* ***PLU:*** *Pluronic dispersion;* ***CH:*** *chitosan dispersion;* ***OECC:*** *essential oil of Cymbopogon citratus.*

3.1.5 Fourier Transform Infrared Spectroscopy (FTIR)

Within multiple systems, intermolecular interactions can be promoted by aiming at the structural organization of the system, identifying the functional groups is important in the elucidation of the possible interactions. Fourier Transform Infrared Spectroscopy (FTIR) was used to analyze the PLU. The absorption bands between 1200 and 1500 cm^{-1} indicate the C-H angular deformation; a band at 1097 cm^{-1} is attributed to the axial C-O-C deformation of the ethers present in the polymer chain. The rotation of the C-H bond can be observed at 700 and 950 cm^{-1}, while the C-H axial deformation can be observed at 2800 cm^{-1}. Finally, a weak band belonging to the hydroxyl group is observed at 3677 cm^{-1} [34, 35].

CH presents an absorption band from 3500 to 3300 cm^{-1} referring to N-H; a C=O stretch, approximately at 1700-1640 cm^{-1}, characteristics of the amide function, the absorptions shown with peaks at 1321 cm^{-1}, 1260 cm^{-1}, and 1379 cm^{-1} correspond to the folding vibrations of the amines. The vibrations of the C-H bond are related to the saccharide structure at 1154 cm^{-1} and 896 cm^{-1} and can also be found in this spectrum, it is also observed, absorptions from 1100 to 1500 cm^{-1}, which are much discussed in the literature and represent the C-N stretch present on carbon 2 of the glycopyranoside ring [36-38].

In the OECC spectrum, the functional groups of citral, which is the major substance, can be visualized. Vibrations at 2968 cm^{-1}, represent these groups. Symmetric and asymmetric CH_2 elongations are observed at 2915 and 2857 cm^{-1}, respectively. An intense peak at 1671 cm^{-1} is due to C=C vibrations present in acyclic monoterpenes like citral. A peak at 1632 cm^{-1} shows an elongation belonging to an aldehyde group C=O. At 1442 cm^{-1}, a peak is observed from the $-CH_2$ group. Additionally, the presence of -C-O elongation occurs in the range of 1194 to 1120 cm^{-1} [39-41].

The PLU/CH blend spectrum resembled the PLU spectrum, showing bands and peaks characteristic of this polymer, however with increased relative intensity for the band in the region of 3500 cm^{-1}. Justified by the addition of a new polymer, rich in hydroxyl groups, which absorbs radiation in this region. The addition of OECC caused subtle changes in the spectrum in the region between 1000 and 1800 cm^{-1}, indicating the presence of OECC.

Figure 5 shows the corresponding spectrum of the OECC incorporated into the polymeric blend (PLU/CH/OECC). From the analysis of the spectra, it was possible to verify a discrete peak in the region of 1689 cm^{-1} corresponding to C=C vibrations, present in the OECC spectrum at 1674 cm^{-1}, probably due to the low concentration of the oil about the amount of solution.

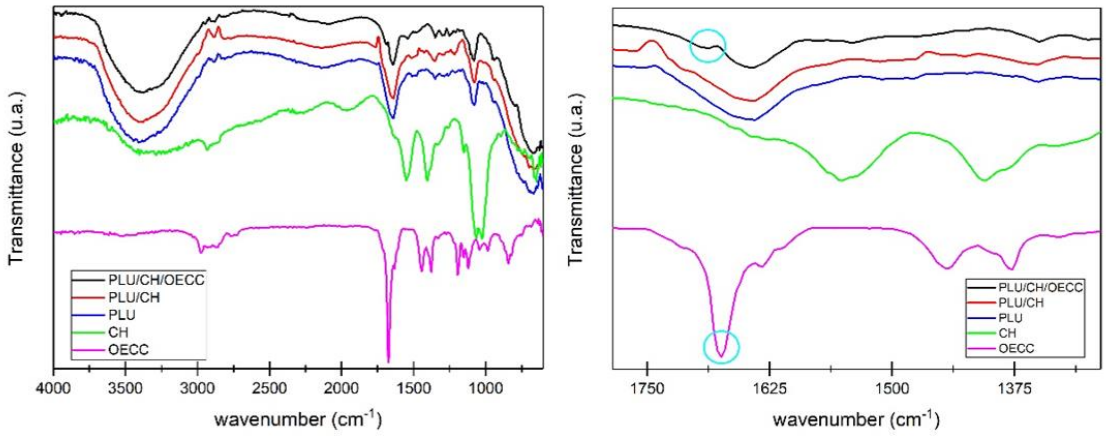

Figure 5: Infrared absorption spectra of CH, PLU, OECC, blend PLU/CH, and blend PLU/CH/OECC. ***PLU:*** *Pluronic dispersion;* ***CH:*** *chitosan dispersion;* ***OECC:*** *essential oil of Cymbopogon citratus.*

4. CONCLUSION

The development of a hydrophilic polymer system was achieved through experimental design to create a device that facilitates the release of bioactive substances (OECC, as a model) within

polymeric dispersions that are responsive to changes in temperature. OECC, a bioactive substance with microbial and healing properties, is a component of this blend. This system, consisting of a hydrophilic polymer, is thermally applied as a biomaterial for tissue repair and cutaneous healing. The choice of hydrophilic polymer (CH) was based on its gelation time at body temperature and its ability to avoid the formation of precipitates. It was important to ensure that the addition of bioactive substances or polymers to the composition did not alter the skin's pH, thus preventing hypersensitivity reactions during the healing process. Additionally, significant structural changes due to the formation of new groups were also avoided. Rheological characterization tests including rheology, spreadability, and viscosity confirmed previous findings that the properties of systems containing PLU, a thermoresponsive polymer, are influenced by temperature variations. This observation was particularly significant after blending and following the addition of OECC. Therefore, the polymeric blend of PLU, CH, and OECC shows promise for use in tissue repairs. Moreover, the polymers in the mixture can adapt to biological conditions such as body temperature, preventing them from dissipating too quickly from the application site. This provides an advantage over fluid devices typically used as curing agents. Consequently, this polymeric blend could serve as an alternative to traditional systems used in biomedical engineering for skin tissue sealants.

5. ACKNOWLEDGMENTS

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