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Thermal, Mechanical and Electrochemical Characterization of Gelatin-Based Physical Emulgels

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The present study reports the development of gelatin based physical emulgels (EHs). Emulgels were prepared using gelatin and mustard oil. The emulgels were characterized thoroughly by microscopy, FTIR (fourier transform infrared) spectroscopy, DSC (Differential scanning calorimetry), mechanical studies and impedance spectroscopy. The microscopic results suggested unimodal size distribution of the oil droplets. Thermal, mechanical and electrical properties of the emulgels showed composition dependent properties. Ciprofloxacin was used as the model drug. The release kinetics of the drug followed anomalous release behavior and showed good antimicrobial activity. The emulgels were hemocompatible and showed pHs within the physiological limits.

Keywords: Hydrogels, Emulsions, genipin, drug delivery

1. INTRODUCTION

Emulsion hydrogels, also known as emulgels, are biphasic hydrogel based formulations. Emulgels are usually formed either by dispersing an oil phase in a gel phase or by inducing gellation of the external phase of an oil-in-water emulsions. The concept of emulgels was conceived to eliminate the limitation of the hydrogels in delivering hydrophobic drugs. Even though the emulgels are biphasic in nature like emulsions, the stability of the emulgels are far superior to the emulsions [1]. In recent years, emulgels have emerged as novel topical formulations for dermatological applications, which has the capability to replace creams, emulsions and gels. The emulgels retain the advantage of the emulsions but the emulgels are thermodynamically more stable than the emulsions. The emulgels

possesses shear-thinning property, which makes them suitable for topical applications possess. The presence of water makes the formulations easily washable and non-staining. This improves the patient compliance. They also possess longer shelf-life, which may be explained by the higher viscosity at lower shear-rates. Shahin et al. (2011) developed jojoba oil based emulgels using hydroxypropyl methylcellulose (HPMC) and Carbopol 934 P for the delivery of clotrimazole release. The emulgels showed superior antimycotic activity against *Candida albicans* compared to the commercially available formulations [2]. Khullar et al. (2012) prepared mefenamic acid loaded emulgel using carbapol 940 as a gelling agent. Mentha oil and clove oil were used as the penetration enhancers in the study [3]. Akram *et al.* (2013) reported insulin loaded emulgels for transdermal delivery of insulin [4]. Rahmani-Neishaboor *et al.* (2013) prepared film-forming emulgel of stratifin and acetylsalicylic acid for wound healing applications [5]. Shen et al. (2014) reported emulgel formulation for the ocular delivery of Cyclosporin A [6]. Badilli et al. (2014) prepared emulgels of inclusion complex of calcipotriol and cyclodextrin for the topical applications [7].

Biopolymers, also known as natural polymers, are the polymers which are obtained from the biological sources. The biopolymers may either be from animal source (e.g. collagen, gelatin, bovine serum albumin, chitosan) or plant source (e.g. alginate, cellulose, xanthan gum). The biopolymers have been extensively explored for developing formulations or polymeric constructs of biomedical (pharmaceutical, tissue engineering), food and cosmetic applications. Amongst the various biopolymers, gelatin based formulations and constructs have been widely explored for biomedical applications. Gelatin is an animal protein biopolymer (derived from animal collagen) and is highly biocompatible.

Mustard oil is conventionally used in the southern Asian countries as edible oil and for body massages [8-10]. The production of mustard oil is in the third position in the world, after soya bean and palm oils. It has also been used for developing formulations for ocular delivery of diclofenac (an anti-inflammatory drug) and immunity modulating formulations [11-12]. Recently, mustard oil based microemulsions have been reported to have anti-bacterial activity against *E. coli* [13]. Hence, mustard oil was used as the representative oil.

In the current study, gelatin based EHs were developed. The EHs were thoroughly characterized using microscopic, FTIR, thermal, mechanical and electrical studies. Ciprofloxacin, model antimicrobial drug, was incorporated within the emulgels. The release of the drug was studied both quantitatively and qualitatively. Though, there are reports of gelatin based permanent emulgels, no reports were found to analyze the properties of physical. Hence, an attempt was made to prepare and thoroughly characterize the gelatin based physical emulgels.

2. MATERIALS AND METHODS

2.1. Materials

Tween 80 and gelatin were procured from Himedia, Mumbai, India. Ciprofloxacin was obtained from Fluka Biochemica, China. Edible grade refined mustard oil (Gokul House, Ahmedabad, Gujrat, India) was purchased from the local market. Distilled water was used throughout the study.

2.2. Preparation of EHs

Mustard oil is one of the coomonly used oil for cookingand pharmaceutical purposes. The major fatty acid component is erucic acid (40-55 %), a monounsaturated omega-9 fatty acid [14]. The other fatty acid components include linoleic acid (12-15 %), linolenic (10-12 %) and arachidic acid (4-5 %). Also, it contain about 15 % of saturated fatty acid content [15]. Gelatin is derived from the collagen present in animal's skin and bones. It possess high protein content (89.94 g/100 g) and low fat contents (0.28 g/100 g) [16].

Mustard oil, maintained at 50 °C, was added to 20 % (w/w) gelatin solution. Tween 80 (1 % w/w) was added as an emulsifier. The above mixture was homogenized at 800 rpm (50 °C, 15 min) to form an emulsion. The emulsion was poured into culture tubes and incubated at 4 ^{o}C for 30 min to promote gellation. Ciprofloxacin loaded emulgels were prepared in a similar manner. Ciprofloxacin was dissolved in mustard oil. Sufficient amount of the drug was dissolved so as to have a concentration of 1% (w/v) in the final formulations. The gels were stored under refrigerated conditions for further analysis.

The pH of the stable gels was measured using a digital pH meter (Model 132E, EI products, India) by dipping the probe into the freshly prepared gels. The measurements were carried out in triplicate. The effect of variation of the composition on the pH of the gels was studied [17].

2.3. Microscopic evaluation of the gels

The internal structures of the MO-in-gelatin emulgels were analyzed under bright-field microscope (Leica-DM750 equipped with ICC 50-HD camera, Germany). Thin smears of emulgels were made by placing a drop of the liquefied emulgels (50 ^{o}C) on microscopic slides and subsequently covering it using a cover-slip. The droplet size distribution of the mustard oil droplets in the emulgels was determined [18].

2.4. FTIR spectrophotometric analysis

Fourier transform infrared (FTIR; ATR mode, Alpha-E, Bruker, USA) spectroscopy was used to have an insight on the presence of various functional groups in the raw materials used and the interaction of the functional groups in emulgels. The analysis was done in the range of 4000 to 500 cm^{-1} [19].

2.5. Thermal studies

The melting points of the formulations were analyzed by falling ball method, as per the reported method [20]. The thermal property of the emulgels was studied using differential scanning calorimeter (DSC-200 F3 MAIA, Netzsch, Germany) in the temperature range of 20 °C - 150 °C at 2

°C /min scan rate. The analysis was done under N_2 environment in sealed aluminum pans (pierced lid) [21].

2.6. Mechanical properties

The mechanical properties of the gels were studied using static mechanical tester (Stable Microsystems, TA-HDplus, U.K.). Backward extrusion, compression, gel strength, spreadability and stress relaxation studies were carried out using the instrument. Table 1 summarizes the details of the studies. Backward extrusion study was conducted using molten emulgels. The emulgels were incubated at 40 ^{o}C for 30 min to form a sol. The other tests were conducted at 5 °C [22].

Table 1. Details of texture analysis studies

Type of study	Type of fixture	Testing conditions			Mode of study
		Pre test speed (mm/sec)	Test speed (mm/sec)	Post test speed (mm/sec)	
Backward extrusion	A/BE back extrusion rig	1.0	1.0	1.0	Button mode (Distance, 20 mm)
Stress relaxation	HDP/SR spreadability rig with 45° conical perspex probe	1.0	0.5	10.0	Auto force (5g, 5mm)
Spreadability	HDP/SR spreadability rig with 45° conical perspex probe	2.0	2.0	2.0	Auto force (5g, 20 mm)

2.7. Electrochemical impedance spectroscopy

The electrical properties of the emulgels were determined in an impedance analyzer (PSM 1735, Numetriq, UK) at room-temperature. An AC voltage of 100 mV was used for the analysis. The analysis was done in the frequency range of 0.1 Hz to 1.0 MHz [23].

2.9. In vitro drug release studies

In vitro drug delivery studies were performed in a modified Franz diffusion cell [24]. 1.5 g (approx) of the emulgels were weighed accurately and kept into the donor chamber of the diffusion cell. The donor and the receptor were separated by a dialysis membrane. The receptor volume was maintained at 50 ml throughout the study. During the study, sampling was done at every 15 min during first hour and subsequently at every 30 min in the next 7 h. The whole receptor medium was replaced with the fresh medium (water) during sampling. At the end of the study, the samples were analyzed for the presence of ciprofloxacin at 271 nm using UV-visible spectrophotometer (UV-3200, LABINDIA, Mumbai, India) [25].

The qualitative *in vitro* drug release study was conducted by determining the antimicrobial efficiency of the drug loaded formulations against Gram positive *Bacillus subtilis* (MTCC 121). The analysis was done by bore-well method. Bores of 9 mm diameter were made into the agar plates using a SS steel borer. Emulgels of 9 mm diameter were put into the bores of the agar plates. Ciprofloxacin powder served as the positive control whereas blank emulgels served as the negative control. The petri-plates were incubated at 37 ± 0.5 °C for 24 h to allow the growth of the bacteria. The zone of inhibition was measured by using a ruler at the end of 24h [26].

3. RESULTS AND DISCUSSION

3.1. Preparation of the emulgels

Table 2. Composition of the prepared gels

Samples	Volume of 20 % (w/v) gelatin solution (ml)	Volume of MO (ml)	Genipin (g)	Ciprofloxacin (g)	Result
uG1	20.0	0	--	--	Gel formed
uG2	17.5	2.5	--	--	Gel formed
uG3	15.0	5.0	--	--	Gel formed
uG4	12.5	7.5	--	--	Gel formed
uG5	10.0	10.0	--	--	Gel formed
uG1D	19.8	0	--	0.2	Gel formed
uG2D	17.3	2.5	--	0.2	Gel formed
uG3D	14.8	5.0	--	0.2	Gel formed
uG4D	12.3	7.5	--	0.2	Gel formed
uG5D	9.8	10.0	--	0.2	Gel formed

The emulgels were prepared by varying the proportions of the gelatin solution and oil. The compositions of the gels have been tabulated in Table 2. The blank gelatin gel was light brown in color and was translucent. The emulgels were yellowish in color due to the yellow color of the mustard oil. There was an increase in the yellowish tinge as the proportion of mustard oil was increased (Figure 1). The emulsion hydrogels had a smooth texture and were opaque. There were no changes in the texture properties of the emulsion hydrogels after the addition of the drug (ciprofloxacin). All the drug containing formulations were stable and did not show phase separation.

The study of the pH of the pharmaceutical formulation is an important parameter. Various pharmacopoeia have set standards for the pharmaceutical formulations [27]. This is due to the reason that the formulations are meant to be in contact with the cells and tissues. Higher or lower pH values may cause irritation and sometimes even chemical burns. The pH of the emulsion hydrogels was found to be in the range of 5.5 to 7.0 suggesting that the formulations may be non-irritant. Further, the hemocompatibility of the formulations were tested using citrated goat blood as per the reported literature (Figure 2h).

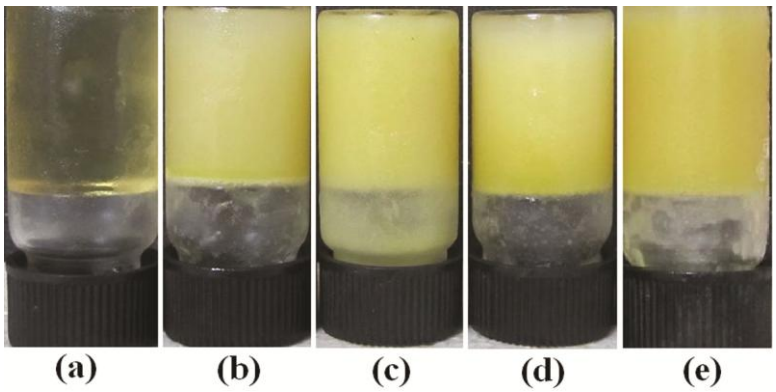

Figure 1. Pictographs of the emulgels. (a) uG1, (b) uG2, (c) uG3, (d) uG4 and (e) uG5

3.2. Microscopic evaluation of the emulsions

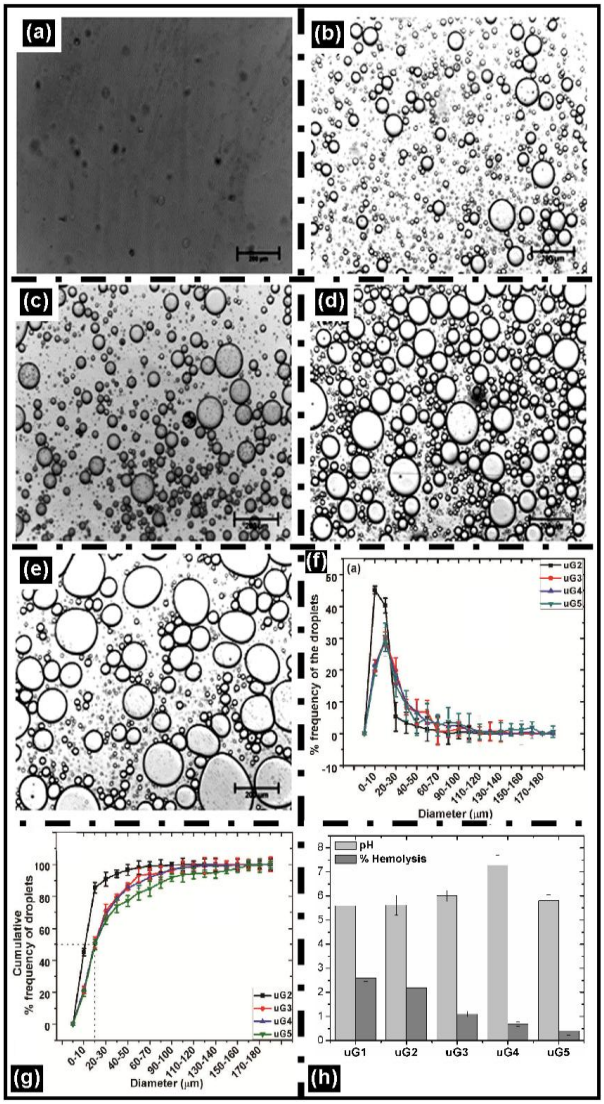

Figure 2. Light micrographs of MO-in-gelatin emulgels. (a) uG1, (b) uG2, (c) uG3, (d) uG4 and (e) uG5 gels; Droplets size distribution of uEHs, in terms of their (f) % frequency and (g) cumulative % frequency and (h) pH and hemocompatibility.

The micrographs of the emulsion hydrogels suggested the presence of dispersed circular mustard oil droplets within the gelatin continuum phase (Figure 2a-e). There was an increase in the size of the dispersed phase droplets with the increase in the mustard oil proportion. Unimodal droplet size distribution was observed (Figure 2f). This may be explained by the physical method of emulsion preparation employed [28-29]. In a similar study under high pressure homogenization, at high ratios of vegetable oil, bimodal size distribution was observed [30]. Although high pressure homogenization was employed, improper emulsification at high oil ratio leads to the bimodal size distribution. Improper emulsification was due to the presence of the surfactant at low concentrations. To circumvent this problem, 1 % (w/w) Tween 80 was used throughout the study. This lead to the proper emulsification in the formulations even under stirring conditions. The prevalence of good emulsification conditions resulted in the unimodal size distribution. The sizes of the droplets were in the range of 10-30 μm. 50 % of the droplet's population was having the size of 15 microns (approx) (Figure 2g). The presence of narrow size distribution gives an indication of a probable stable emulsion [31].

3.3 FTIR spectrophotometric analysis

The FTIR spectra of the raw materials and the emulsion hydrogels have been shown in figure 3a and 4b, respectively. The FTIR spectra of the raw materials were in exact match with the reported literature [32-33]. The characteristic peaks at 3,378 and 1,178 cm^{-1} were observed in the FTIR spectrum of ciprofloxacin. These peaks were due to–OH and C=O stretching vibration of the carboxylic acid groups present in ciprofloxacin. Apart from the above, peaks at 3528 and 1624 cm^{-1} were also observed. These peaks may be associated with the presence of amines [33]. The FTIR spectra of the emulgels showed the presence of gelatin (1,638 cm^{-1}, 1,558 cm^{-1} and 1,244 cm^{-1}) [34]. The bands at 1,638 cm^{-1} and 1,558 cm^{-1} were attributed to C=O and C-N stretching vibrations of amide I and amide II bonds. The peak at 1,244 cm^{-1} was mainly due to N-H bending vibrations coupled with C-N stretching vibrations of amide III bonds. The broad peak at 3,319 cm^{-1} was due to the hydroxyl and the primary amine groups intercalated with the intermolecular hydrogen bonds (due to interconnected triple helices of polypeptide chains in gelatin). The decrease in gelatin and water proportion might have lead to the decrease in the peak intensity of O-H and N-H bonds at ~ 3,300 cm^{-1}. The decrease in the peak intensity with the increase in the oil proportion was seen in the emulgels. The decrease in peak intensity was quantified by calculating the area under the peak (Table 3). The area under the peak was decreased with the increase in the oil proportion. The measured area provided an indication about the extent of the intermolecular hydrogen bonding. A decrease in peak area with the increase in the oil proportion suggested a reduction in the intermolecular hydrogen bonding [35].

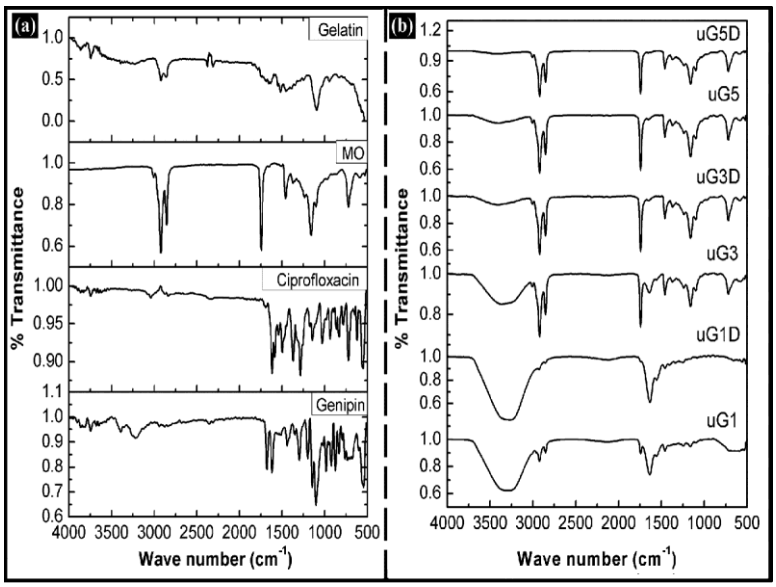

Figure 3. FTIR spectra of: (a) Raw materials and (b) Emulgels

Table 3. FTIR spectral peak area (3,714 – 3029 cm^{-1}) of the emulgels

Samples	Peak area (3,714 – 3029 cm^{-1})
uG1	124.91 ± 2.33
uG1D	140.65 ± 4.41
uG3	91.11 ± 3.26
uG3D	95.39 ± 2.41
uG5	25.04 ± 3.40
uG5D	23.22 ± 2.42

3.4 Thermal studies

The melting point (T_m) of the emulgels was determined by drop ball method as reported earlier (table 4) [20]. The T_m of the gels was found to be decreasing as the proportion of mustard oil was increased. Higher T_m of uG1 may be due to the formation of strong physical polymeric network when gelatin molecules were dissolved in water. Incorporation of mustard oil within the gel structure resulted in the reduction of the intensity of the intermolecular hydrogen bonding which, in turn, resulted in the reduction of the T_m.

Table 4. Melting point of the emulgels

Samples	T_m (°C)
uG1	32.10 ± 2.66
uG2	31.20 ± 1.92
uG3	30.90 ± 2.44
uG4	30.50 ± 3.32
uG5	30.00 ± 2.26

The thermal profiles of the emulgels were further evaluated using DSC (figure 4a). uG1 and uG3 were chosen as the representative samples for analysis. The emulgels showed a broad endothermic peak in the tested temperature range. Broad endothermic peak can be explained by the evaporation of water from the emulgels. The endothermic peak of uG1 was at a higher temperature (105 °C) than that of uG3 (90 °C). ΔH_m (change in enthalpy) and ΔS_m (change in entropy) during the endothermic transition were calculated (figure 4b). The ΔH_m and ΔS_m values were found to be higher in uG1 as compared to uG3. ΔH_m is an indicator of the cohesive energy whereas ΔS_m provides information about the thermal stability [36]. The results suggested higher cohesive energy and thermal stability of uG1 as compared to uG3.

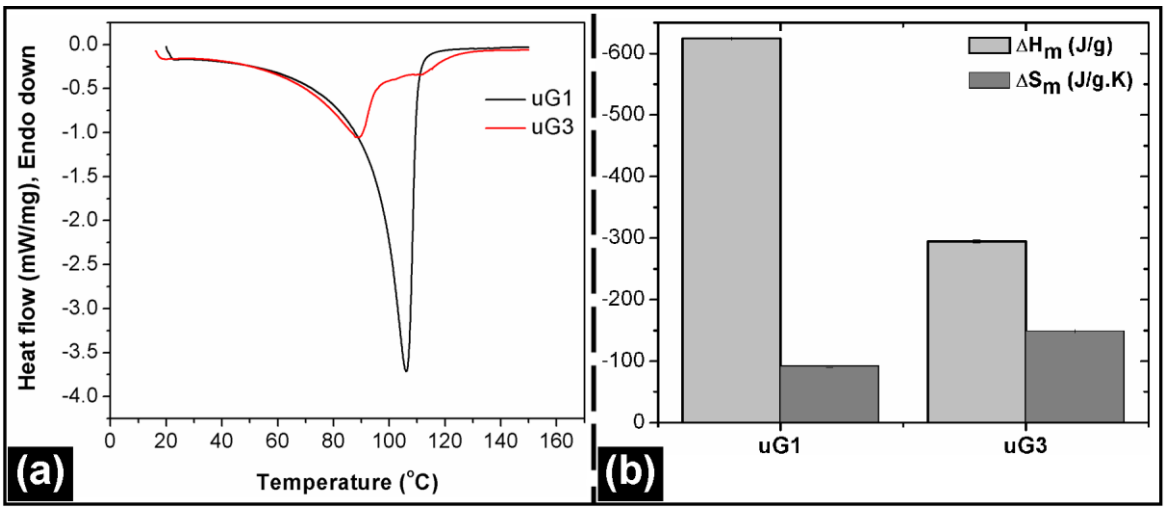

Figure 4. Thermal studies (a) The DSC curves of uEHs and (b) ΔH_m and ΔS_m values

3.5. Mechanical analysis

Stress relaxation provides information about the molecular rearrangements polymeric architecture when a stress is applied. A 45^o perpex conical probe (spreadability fixture) was used for the test. The emulgels were deformed by allowing the probe to move to a set distance (5 mm) after a trigger force of 3 g. The probe was kept at the position for a period of 60 sec and a corresponding reduction in the stress was recorded (Figure 5a). The stress relaxation parameters were calculated (Table 5). There was a decrease in the force sensed by the load cell when the probe moved to its target distance as the oil content was increased. This suggested that the order of the firmness was uG1 > uG2 > uG3 > uG4 ≈ uG5. The firmness of the emulgels was also confirmed by calculating D_{25}. D_{25} was found to be in the order of uG1 < uG2 < uG3 < uG4 < uG5. This also suggested that the emulgels with lower proportion of mustard oil was firmer than the others The F_0 and F_{60} forces were determined to calculate % relaxation of the emulgels. A decrease in the % relaxation with the increase in the proportion of the mustard oil suggested that the emulgels containing higher amount of mustard oil relaxed to a greater extent.

The stress relaxation data was fitted in the modified Peleg's equation [37].

$$\frac{(F_0 - F(t))t}{F_0} = k_1 + k_2 t \qquad (8)$$

where, F_0 is the maximum force attained after loading; k_1 and k_2 represent the initial rate and extent of the relaxation, respectively.

The normalized stress relaxation curve has been shown in Figure 5b. k_1 and k_2 were calculated from the normalized curve and have been tabulated in Table 5. The initial rate of relaxation (k_1) decreased with the increase in the proportion of the mustard oil. But, the extent of relaxation (k_2) over a period of time was almost uniform in all the emulgels. Since, k_2 represents the total relaxation behavior of the stress relaxation profiles, the analysis was further continued by calculating two more parameters. These parameters viz., normalized stress relaxation (F^*) and the area under the normalized stress relaxation curve (S^*) facilitate the quantification of the viscoelastic properties of the formulations [38]. F* values showed a decreasing trend as the proportion of the mustard oil was increased. S* values lies in the range of 0 and 1. A value closer to 1 suggests predominant elastic material-like behavior whereas a value closer to 0 indicates fluid-like behavior. There was a decrease in the S* values indicating an increase in the stress relaxation of the formulations with the increase in the proportion of the mustard oil.

$$F^* = \frac{F_r}{F_0} \qquad (9)$$

$$S = \int_a^b P(t).dt \qquad (10)$$

$$S_0 = \left(\frac{S}{b-a}\right)a \qquad (11)$$

$$S^* = \frac{S}{S_0} \qquad (12)$$

where, ‘a’ and ‘b’ are the lower and upper limits of the time, respectively.

Table 5. Mechanical parameters of the gels from stress relaxation studies

Samples	F_0 (g)	F_r (g)	k_1	k_2	S^*	F^*	% relaxation
uG1	45.78	63.82	0.091	0.016	0.8585	0.717	70.868
uG2	38.35	60.64	0.077	8E-05	0.8578	0.632	63.020
uG3	19.37	39.41	0.048	8E-05	0.8572	0.491	48.161
uG4	13.93	35.43	0.037	8E-05	0.8571	0.436	41.509
uG5	15.12	34.63	0.05	8E-05	0.8570	0.393	39.630

Spreadability of the emulgels was studied by allowing the perpex cone to move a distance of 23 mm into the samples kept in the female cone (Figure 5c, Table 6). The uG1 showed higher firmness and cohesiveness than the mustard oil containing emulgels. The firmness and cohesiveness of the emulgels showed a decreasing trend as the proportion of the mustard oil was increased. uG1 was brittle in nature whereas the emulgels were ductile in nature. Spreadability is inversely related to the firmness

of the formulations. The results indicated a higher spreadability of the emulgels with higher proportion of mustard oil. The study indicated that the emulgels had negligible stickiness and adhesive properties (towards perpex cone) as the negative peaks (obtained during retraction of the probe) were not significant in both types of the gels.

Table 6. Texture parameters from spreadability and backward extrusion studies

Samples	Firmness (kg)	Cohesiveness (kg.sec)	Stickiness (kg)	Adhesiveness (kg.sec)	Viscosity (Pa.s)
uG1	9.63 ± 2.21	15.52 ± 2.32	-1.02 ± 2.33	-0.30 ± 2.22	0.16 ± 2.12
uG2	9.60 ± 1.19	11.86 ± 1.92	-0.42 ± 3.21	-0.42 ± 4.41	0.19 ± 1.99
uG3	5.17 ± 3.21	6.54 ± 4.01	-0.15 ± 2.64	-0.27 ± 3.22	0.21 ± 1.38
uG4	3.95 ± 1.88	5.41 ± 3.37	-0.04 ± 1.12	-0.09 ± 2.28	0.25 ± 2.11
uG5	1. 04 ± 3.31	1.03 ± 2.46	-0.04 ± 1.19	-0.12 ± 3.12	0.24 ± 1.92

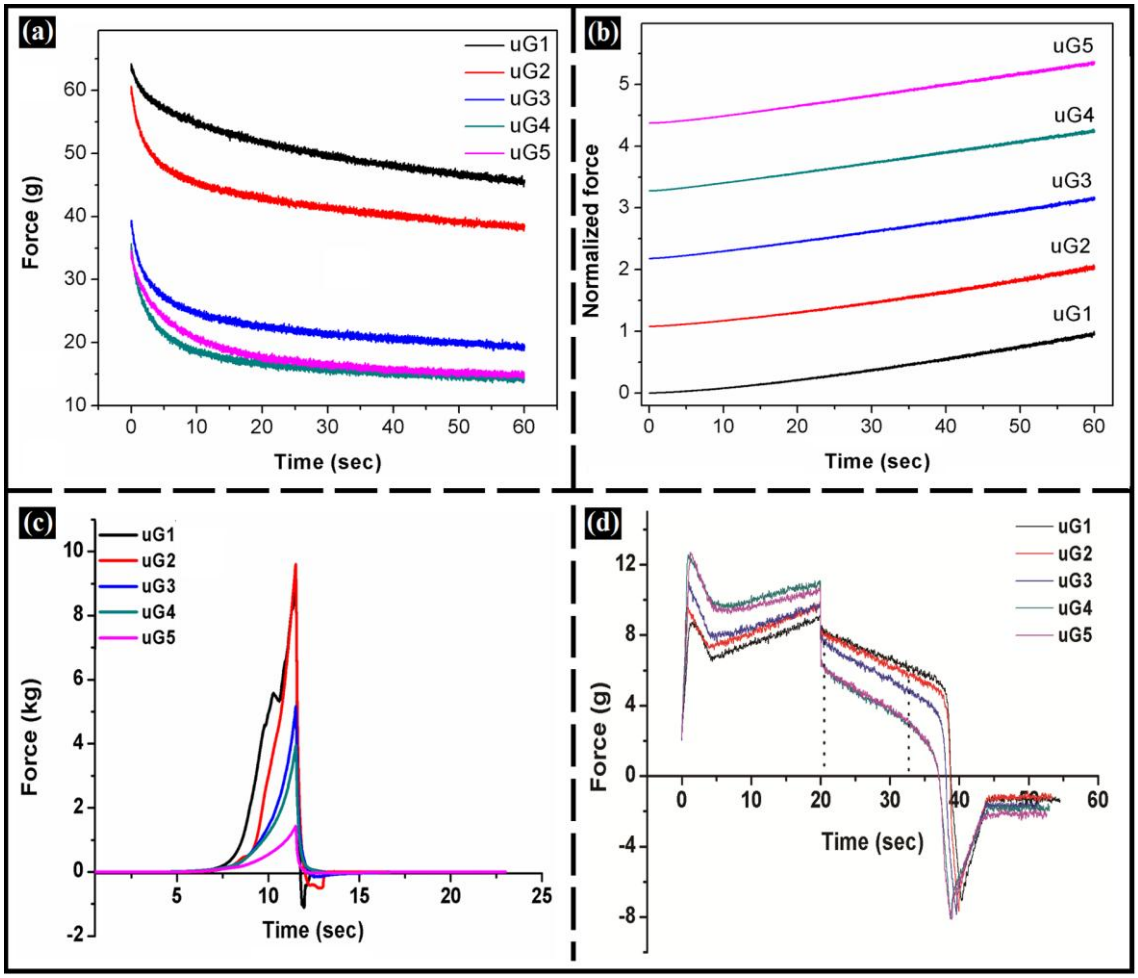

Figure 5. Texture analysis of the gels: Stress relaxation curves terms of (a) force vs time, (b) Fitting curves of stress relaxation in modified Peleg's equation, (c) spreadability studies and (d) backward extrusion studies

The backward extrusion of the molten emulgels (incubated at 40 °C) was carried out in 50 ml glass beakers. 40 ml of the molten uEHs were taken in the beakers. A flat probe (made of perpex) of 40 mm diameter was used for the study. The probe moved a target distance of 20 mm after a trigger force of 3g. The molten emulgels showed consistent fluid-like behavior. uG4 and uG5 showed least consistency and may be explained by the higher proportions of mustard oil (Figure 5d). The viscosity of the molten emulgels was calculated from the linear portion of the graph when the probe was retracting back (Table 6) [39]. As the proportion of the mustard oil was increased, there was a corresponding increase in the viscosity of the emulgels. This may be attributed to the incorporation of the additional frictional components in the system due to the presence of the dispersed phase.

3.8. Electrochemical Impedance Spectroscopy

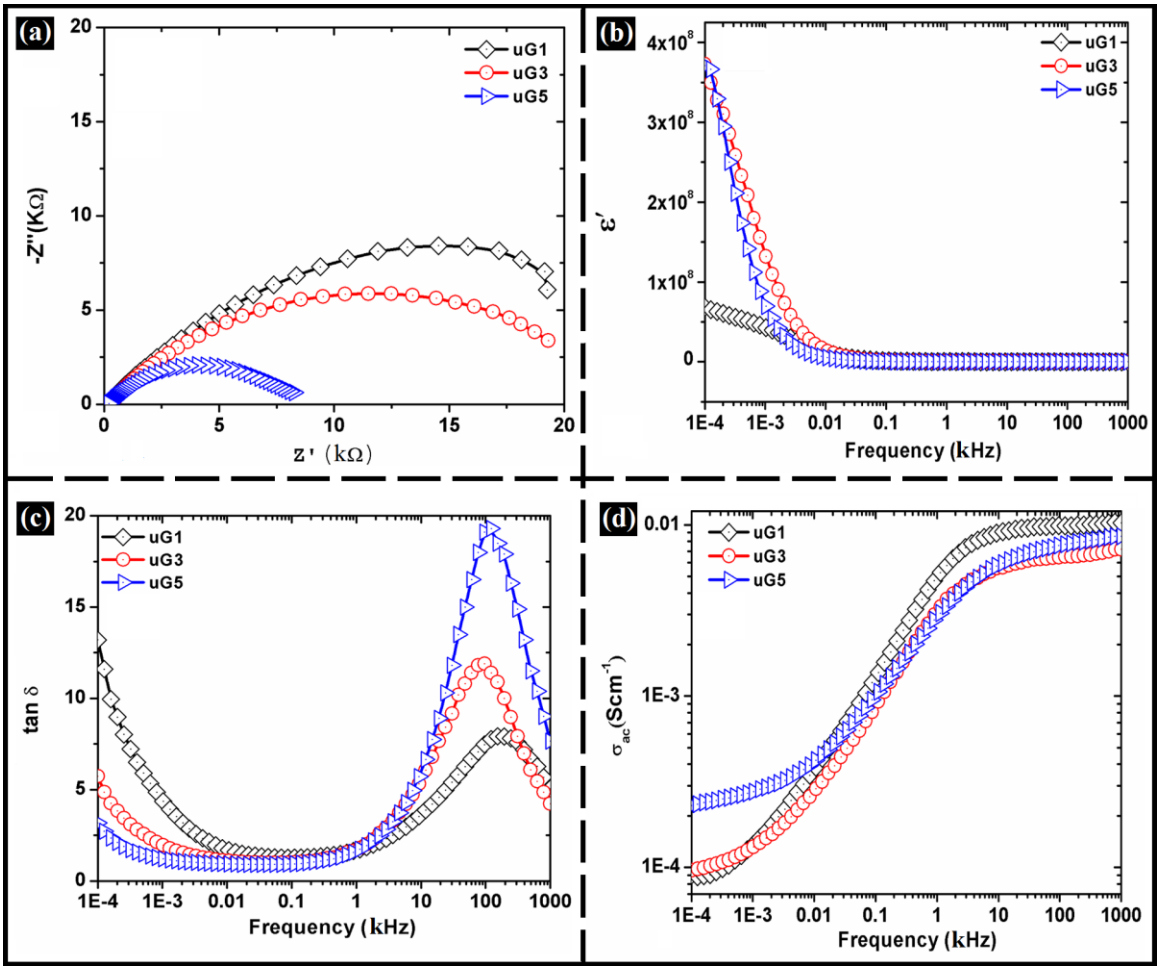

Figure 6. The impedance parameters of gels. Nyquist plot of (a) uEHs, Frequency dependent (b) ε' for uEHs, (c) tan δ for uEHs and (d) $б_{ac}$ of uEHs.

Nyquist plots (Z'' vs. Z') of the formulations showed the formation of a semicircle (Figure 6a). The bulk resistance of the sample was obtained from the intersection of the semicircle with the real axis [1]. uG1 has shown highest resistance followed by uG3 and uG5 indicating an increase in the bulk resistance with the increase in the gelatin content [40]. The increase in the dielectric constant (ε') at

lower frequencies can be attributed to the accumulation of the charges at the interface of the sample and the electrodes. This phenomenon resulted in the polarization of the electrodes with a corresponding increase in the ε' of the emulgels. At high frequencies, a rapid periodic reversal of the ac field resulted in the constant ε' value [41]. uG1 showed lowest ε' as compared to uG3 and uG5 (Figure 6b). This may be associated with the viscosity rendered by the presence of the gelatin which was responsible for the lower ε' in the emulgels with higher gelatin content. The tangent loss (tan δ) associated with the relaxation may be due to the mobility of the polymeric chains below the glass transition temperature of the polymeric formulation (Figure 6c) [40]. The tan δ was observed at similar locations for all the emulgels [42]. A higher tangent loss was observed in emulgels with higher mustard oil content. This indicating a more fluid-like behavior of the emulgels with higher oil fraction [40]. Similar results were also observed from the mechanical studies (stress relaxation). The conductivity profiles suggested frequency independent behavior of the emulgels at lower frequencies which got dispersed at higher frequencies (Figure 6d) [43].

3.11. In vitro drug release studies

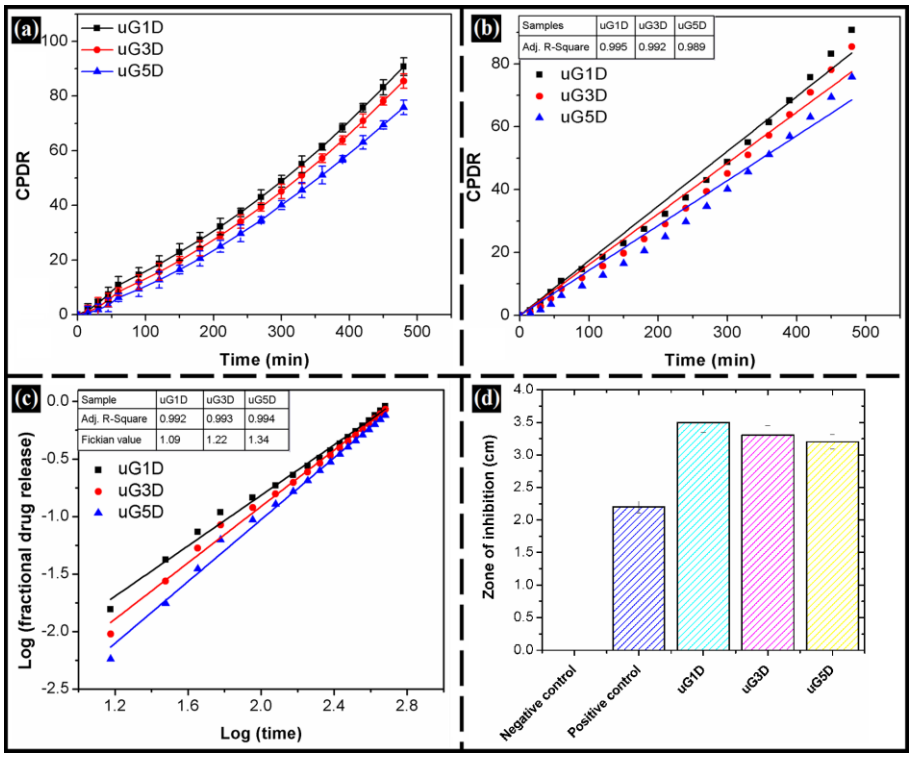

Figure 7. Drug release kinetics of the gels (a) CPDR vs time, (b) Zero order kinetics, (c) KP kinetics and (d) Antimicrobial efficiency

The rate of drug release was found to be dependent on the physicochemical properties of the emulgels. The higher amount of drug release was observed in uG1 followed by uG3 and uG5, respectively (Figure 7a). The results may be explained by the fact that an increase in the oil fraction in the emulgels resulted in the slower partitioning of the drug in the aqueous layer of the emulgels. This

resulted in the slower release of the drug from the emulgels with higher oil content. The release kinetics of ciprofloxacin from the EHs were analyzed using zero-order, Higuchian and Korsmeyer-Peppas (KP) models [44].

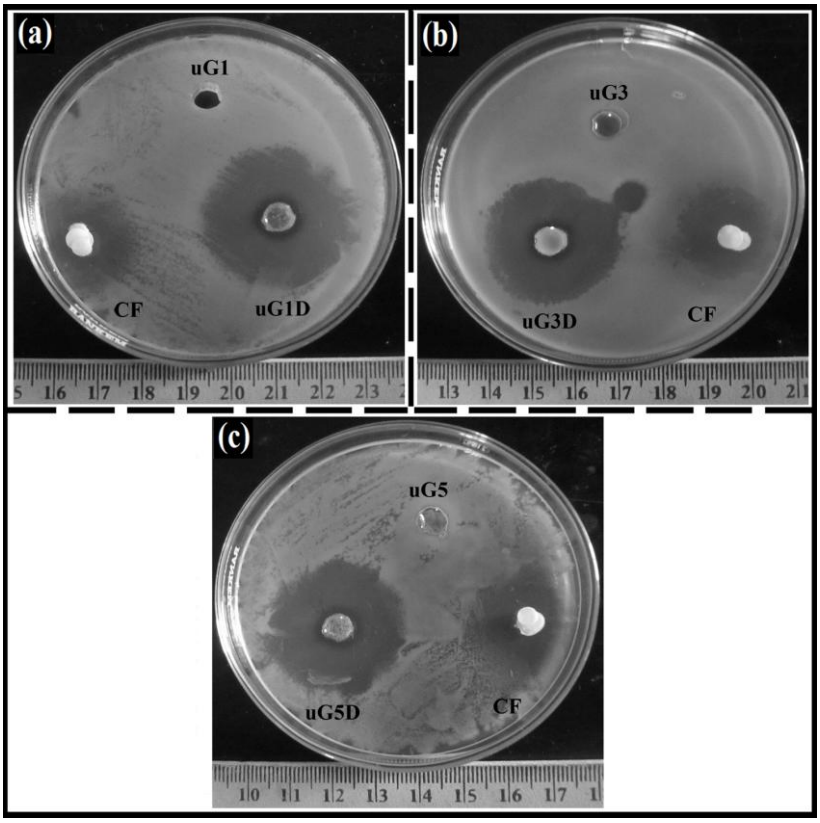

Figure 8. Antimicrobial activity of the gels against *B. subtilis*

The results indicated that the release of the drug followed zero-order release model (Figure 7b). The KP model indicated Super-case II release behavior (Figure 7c). This indicated that the release of the drug from the emulgels was a combination of diffusion and erosion of the emulgels matrices (Fickian value of > 1) [45-46].

The antimicrobial efficiency of the ciprofloxacin loaded emulgels was determined against *B. subtilis* (Figure 7d, Figure 8). The uG1D, uG3D and uG5D were chosen as the representative emulgels. Ciprofloxacin was taken as the positive control while the blank emulgels (emulgels without drug) were taken as the negative controls. Zone of inhibition was found to be highest in uG1 whereas uG3 and uG5 showed similar antimicrobial efficiency.

4. CONCLUSION

The study reports the successful development of gelatin based physical emulgels. The experimental conditions used in this study resulted in the formation of unimodal size distribution patterns of the emulsion droplets. The effect of oil content on the properties of the emulgels was

studied by various physical techniques. The amount of drug released was dependent on the oil content. The release study indicated erosion of the matrices during release studies. The study suggested that the rate of release of the drugs may be altered by altering the proportion of the oil. The emulgels were hemocompatible and may be explored as matrices for the topical drug delivery.

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