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Effect of Aqueous Extracts of *Quercus resinosa* on the Mechanical Behavior of Bigels

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Abstract: *Quercus resinosa* leaves are rich in polyphenol compounds, however, they are unstable to several chemical and physical factors that limit their activity. Several methods have been developed to solve such problems, among which bigels can be mentioned and obtained using hydrogels and oleogels. The mechanical characterization of this type of materials is by using rheological methods. Although the use of these methods is well documented, the Carreau-Yasuda model has been little used to evaluate the effect of polyphenols on the mechanical behavior of bigels. Therefore, bigels were obtained from hydrogels (guar gum/xanthan gum, 0.5/0.5% w/v) and oleogels (sesame oil/sorbitan monostearate 10% w/w). Micrographs, linear viscoelasticity range, frequency sweep, and single shear tests were performed. The data were analyzed using ANOVA and Tukey test ($p < 0.05$); micrographs showed linear relationship between polyphenols concentration and droplet size. Liquid fraction of bigels showed a pseudoplastic behavior, while the parameters of Carreau-Yasuda model showed that the highest value of the complex viscosity at zero shear was at the lowest concentration of extract; the relaxation time presented the lowest value at higher concentrations of extracts. These results indicate that the presence of polyphenols modifyes the mechanical behavior of bigels.

Keywords: drug delivery; bigels; polyphenols; rheology

1. Introduction

In recent years, scientific research has documented beneficial health effects of polyphenol compounds related with their antioxidant, anti-inflammatory, and antimicrobial activities. The presence of polyphenols in plants is common. Among them, it is possible to mention the presence of this type of compounds in oak leaves (*Quercus* spp.) Many oak species are endemic to Mexico. Particularly, Durango state is rich in diversity of oak species. Recent studies have shown that some compounds of phenolic nature, present in the oak leaves, can inhibit the growth of *Staphylococcus epidermidis* [1], a microorganism associated with acne of microbial origin. Acne is a skin condition, which has various causes. One of them is the presence of dysbiosis in the skin microbiota, which results in the appearance of acne. It usually appears in adolescence and youth of human beings, leaving behind scars and severe self-esteem problems [2].

Several treatments have been developed to control the bacterial infection caused by the microorganisms associated with the appearance of acne. However, it is complicated because the skin is a barrier that makes difficult the compounds passage through, limiting the topical treatment [3,4]. In this sense, in recent years, the use of new type of materials has been suggested to improve the load and transport of bioactive compounds across the skin; these materials are called bigels, which are semi-solid formulations made up of two gelled immiscible phases [5].

The advantages of using bigels have been documented, such as the ability to release hydrophilic and lipophilic compounds, enrichment of the stratum corneum, providing a

refreshing and moisturizing effect on the skin, ease of application on the skin, improvement on the permeability of active compounds through the skin, and good physicochemical stability [6]. It is important to mention, that bigels are non-thermoreversible systems. There are various types of bigels, being the most common the oleogel in hydrogels [7]. Once the bigel has been obtained, it is possible to add various elements that prolong its shelf life, such as parabens, as well as bioactive compounds; most of the studies have focused on evaluating the release mechanisms of such bioactives [8], or the mechanical stability of the bigels [9]. The use of bigels includes hydrogels, where several polysaccharides are used as gelators. Hydrogels have been reported showing interactions with polyphenols [10], however, little work has been reported on the influence that bioactive compounds might exert on the mechanical stability of the bigels. Several reports have described the effect of phenolic compounds on hydrogel mechanical stability [11]. In this sense, the development of soft dosage forms as vehicle to transport bioactives for topical use is important in pharmaceutical industry. They are dispersed systems with a distinctive viscoelastic behavior. Their viscous behavior at a given temperature and shear stress is non-linear, depending on the shear rate [12]. This complicates the mechanical analysis because during the developing of soft dosage vehicles (i.e., as bigels), the study of their mechanical properties is useful to determine their stability [13]. Also, it is a useful tool to obtain objective criteria for quality control, production, storage, release of bioactives, and consumer requirements [14]. Several models have been used as the Creep cycles [15], the Palierne model [16], the Krieger-Dougherty model [17] and the semi-empirical model proposed by Lupi et al. [13]. The complexity of the rheological behavior remains unknown.

A relatively simple alternative to study rheological behavior is the Carreau-Yasuda model [18]. Some authors [19,20] have used a Carreau-Yasuda model to evaluate the rheological behavior of bigels loaded with vitamin E and organogels loaded with vitamin E, respectively. They found that the use of the Carreau-Yasuda model and their parameters could help to identify changes in the mechanical properties of bigels and organogels. Generally, viscoelastic properties of materials obtained by rheological methods could deliver data about several properties as structure, phase behavior, and physical interactions [21,22]. The most known model for complex viscosity is the Carreau-Yasuda, which correlates complex viscosity to zero complex viscosity, relaxation time, power law index and width of the transition between Newtonian and Power law behavior [23]. The expression is shown next:

$$\eta * (w) = \eta_0^* = \eta_0^* \left[1 + \left(\frac{\eta_0^*}{\tau^*} * w \right)^a \right]^{\frac{n-1}{a}} \tag{1}$$

where,

$\eta^*(w)$ is complex viscosity

η_0^* is zero complex viscosity

λ is the relaxation time

n is the Power law index

τ^* is the shear stress at the transition zone

a indicates width of the transition between Newtonian to Power law behavior

And the relaxation time can be defined as:

$$\lambda = \frac{\eta_0^*}{\tau^*} \tag{2}$$

Usually, Equation (1) has been used by researchers in several areas of knowledge, focusing on fitting the model to experimental data and determine the parameters. However, more recently several groups have used this model to obtain more information about material properties [21]. Thus, the objective of this work is to evaluate the effect of the presence of phenolic compounds from oak leaf extracts on the rheological properties of bigels.

2. Materials and Methods

Guar gum and xanthan gum were purchased from Quimica Hércules (Toluca, Edo de México, México), methyl paraben (Sigma, Toluca México), sesame oil, purchased from a local store in Durango, Dgo., México. Sorbitan monostearate was acquired from (Sigma, Toluca, México), procyanidin-B2, (epi)-catechin gallate, (epi)-catechin, procyanidin-B1, catechin, quercetin, rutin, kampferol-3-O-glucoside, taxifolin, naringenin, eriodictyol, acacetin, neohespiridin, phlorizin, and mangiferin were obtained from Sigma-Aldrich (St Louis, MO, USA). *Staphylococcus epidermidis* (ATCC 14990) and *Cutibacterium acnes* (ATCC 6919) were obtained from ATCC, (Manassas, VA, USA).

2.1. Oak Leaves Collection and Infusion Preparation

Quercus resinosa leaves were collected in Durango, Dgo, México, characterized by botanist Dr. Socorro González-Elizondo and deposited in the CIIDIR-IPN herbarium. The leaves were dried in the shade, ground in an IKA blade mill, and separated in a 100 mesh sieve (0.147 mm). Infusions of oak leaves were prepared, according to Rocha-Guzmán et al. [24]. Briefly, 10 g of powder of *Quercus resinosa* leaves were placed in a beaker with 1 L of distilled water at 80 °C and stirring for 10 min. The infusion was lyophilized and stored until use.

2.2. Chemical Characterization of the Aqueous Extract of Oak Leaves

The determination of the phenolic profile was carried out according to reported methodology [25]. Briefly, an UPLC coupled to a photodiode array (PDA)-electrospray ionization (ESI)-triple quadrupole tandem (QqQ) (Waters, Milford, MA, USA) was used. An Acquity UPLC BEH C18 column of 2.1 μm × 50 mm × 1.7 μm at 35 °C. The elution gradient consisted of two solvents, phase A was MiliQ water acidified with 7.5 mM formic acid and acetonitrile (B) at a flow rate of 210 μL/min. The gradient applied was as follows, it started with 3% phase B, at 1.88 min; then, 9% B, at 5.66 min, up to 16%, at 16.9 min, up to 50% B, at 19.62 min, then, to 3% B, where it was maintained isocratically for 20 min. The ionization was performed in negative mode with a capillary voltage of 2500 V, the desolvation temperature was 400 °C, the source temperature was 150 °C, the collision gas flow was 800 L/h, the flow of the collision gas was 130 L/min, the collision energy values were 5 for MS and 20 for MS/MS. For the identification and quantification of phenolic compounds, a mixture of the following pure standards was used: Procyanidin-B2, (epi)-catechin gallate, (epi)-catechin, procyanidin-B1, catechin, quercetin, rutin, kampferol-3-O-glucoside, taxifolin, naringenin, eriodictyol, acacetin, neohespiridin, phlorizin, mangiferin (at a concentration of 20 μg/mL), which were used to obtain retention times and MS/MS transitions. The chromatographic and spectrometric systems were controlled using MassLinx software (Waters, Milford, MA, USA).

2.3. Microbiological Assay

The determination of the load of aqueous extracts of oak leaves into the bigels was made by the evaluation of growth inhibition of the two bacterial strains associated with skin diseases, i.e., *Staphylococcus epidermidis* (ATCC 14990) and *Cutibacterium acnes* (ATCC 6919). In the case of *Staphylococcus epidermidis*, nutrient broth was used, while in the case of *Cutibacterium acnes*, the BHI broth was used. A growth kinetic evaluation was carried out, incubating in a CO_2 chamber (5%) at 37 °C, taking readings at 630 nm in a UV/VIS spectrophotometer and seeding in a plate to count the colony-forming units, using the serial dilution method. Once the growth kinetics were determined, the minimum inhibitory concentration of the aqueous extracts of *Quercus resinosa* leaves on both microorganisms was evaluated according to the following methodology. Samples of 50 μL were taken from each microorganism in the exponential growth phase and their concentration was adjusted to 1×10^4 CFU. They were incubated in a CO_2 chamber (5%) at 37 °C for 20 h, when serial dilutions were made and different concentrations of aqueous extract of *Quercus resinosa* leaves were applied. Benzoyl peroxide and penicillin G were used as positive controls and

the concentrations evaluated were penicillin G 100 µg/mL, benzoyl peroxide 500 µg/mL, and concentrations of 500, 1000, 2000, 3000 and 4000 µg/mL of the aqueous extracts of *Quercus resinosa* leaves.

2.4. Bigels

To obtain the bigels, a hydrogel was prepared with 175 mg of guar gum and 175 mg of xanthan gum, methyl paraben was added as a preservative. Guar gum and xanthan gum were dissolved in water (34.64 mL at 50 °C), while the oleogels were prepared using 12.75 mL of sesame oil and 2.25 mg of sorbitan monostearate. For this purpose, the sesame oil was heated at 80 °C for 10 min, then the sorbitan monostearate was added and kept stirring for 30 min. The oleogel was softly added to the hydrogel at 60 °C under continuous stirring and the bigels were stored at 4 °C for 24 h until use.

2.5. Quercus Leaves Extract Load into the Bigels

Once the oak infusions were obtained [25], they were frozen and lyophilized. Subsequently, in the aqueous phase (hydrogel), different concentrations of the aqueous infusions (i.e., 500, 1000, 2000, 3000 and 4000 µg/mL of sample) were resuspended in the aqueous phase of hydrogel, until their complete dissolution. In the case of the rheological analyses, the control samples were the bigels without load. The higher concentrations 3000 and 4000 µg/mL were tried but presented solubility problems.

2.6. Microscopy Analysis

The samples were observed in a Carl Zeiss microscope (Carl Zeiss de México, México City, México), equipped with a camera. The images were processed using the software Zen Lite (Zeiss, Oberkochen, Germany) and all images were obtained with a resolution of $100\times$ in bright field.

2.7. Rheological Analysis

Steady shear tests were carried out in a DHR-III rheometer (TA-Instrument, New Castle, DE, USA) at 25 °C, in a shear rate range of 0.1 to 100 s^{-1}, with parallel plate geometry. The results were adjusted to the (Ostwald-de-Waale) Power law model, using the ARES software (TA-Instrument, DE, USA). The evaluation of the linear viscoelasticity range was carried out in all samples by means of a strain sweep in a range of 0.001 to 100%. The results were evaluated by means of the Carreau-Yasuda model, using dynamic complex viscosity. A frequency sweep was carried out at 0.1% strain, ranging from 0.01 to 100 rad/s.

2.8. Statistical Analysis

Data analysis was performed using the ANOVA test and mean comparison tests using the Tukey method ($p < 0.05$). The determination of parameters of the models used was obtained by non-linear estimation, using the Levenberg-Marquadt method, using the Statistica 12 software (StatSoft, Tulsa, OK, USA).

3. Results

3.1. Characterization of the Polyphenolic Profile of Aqueous Extracts of Quercus Resinosa Leaves

The flavonoids profile present in the aqueous extracts of oak leaves (*Quercus resinosa*) is shown in Table 1.

Table 1. Polyphenol characterization of aqueous extracts of *Quercus resinosa* leaves.

	Flavonoids	Concentration (ng/mL)
Flavanols	Procyanidin-B2	0.330 ± 0.19
	(epi)-catechin gallate	0.370 ± 0.00
	(epi)-catechin	0.450 ± 0.02
	Procyanidin-B1	0.710 ± 0.09
	Catechin	1.123 ± 0.18
Flavonols	Quercetin	0.243 ± 0.01
	Rutin	0.516 ± 0.02
	Kampferol-3-O-glucoside	0.820 ± 0.09
Flavanolols	Taxifolin	0.365 ± 0.21
Flavanones	Naringenin	0.335 ± 0.19
	Eriodictyol	0.340 ± 0.19
Flavones	Acacetin	0.380 ± 0.21
	Neohespiridin	0.360 ± 0.20
Others	Phlorizin	0.430 ± 0.25
	Mangiferin	0.290 ± 0.00

Concentration data is mean ± standard deviation.

3.2. Microbiological Assay

The results obtained on the kinetic parameters of growth of the microorganisms *Staphyloccocus epidermidis* and *Cutibacterium acnes* are shown in Table 2.

Table 2. Kinetic parameters of growth of *Staphyloccocus epidermidis* and *Cutibacterium acnes*.

Microorganism	Doubling Time (min)	Generation Number (Generation/4 h)
Staphyloccocus epidermidis	126.31	1.9
Cutibacterium acnes	100	2.4

With the established kinetics, it was possible to identify the various growth zones of both microorganisms from which the inhibitory concentration was evaluated, obtaining the results that are shown in Table 3.

Table 3. Effect of concentration of aqueous extract of *Quercus resinosa* on *Staphyloccocus epidermidis* and *Cutibacterium acnes* inhibition.

Sample	*Staphyloccocus epidermidis*	*Cutibacterium acnes*
	% inhibition	% inhibition
Penicilline G	51.54	96.95
Benzoyl peroxide	100	76.57
Q. resinosa (500 µg/mL)	78.15	64.18
Q. resinosa (1000 µg/mL)	72.43	71.10
Q. resinosa (2000 µg/mL)	71.19	97.15
Q. resinosa (3000 µg/mL)	93.88	97.04
Q. resinosa (4000 µg/mL)	99.84	100

Once the concentrations of aqueous extracts of *Quercus resinosa* leaves to be tested were established, the bigels were prepared with their subsequent loading.

3.3. Microscopy

The microscopy images obtained from the experimental samples are shown in Figure 1.
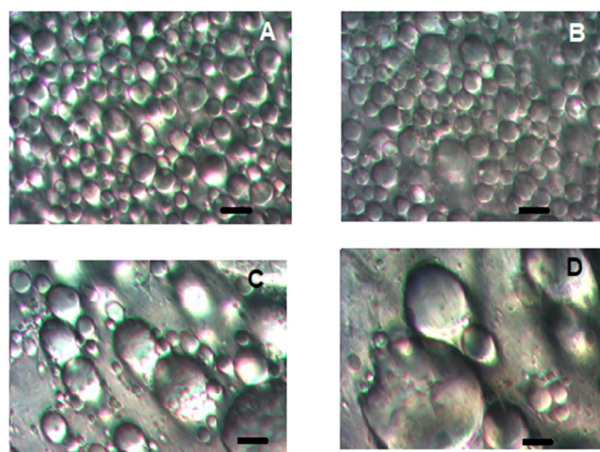
Figure 1. (**A**) unloaded bigel; (**B**) Bigel loaded (500 µg/mL extract of *Q. resinosa*); (**C**) Bigel loaded (1000 µg/mL extract of *Q. resinosa*); (**D**) Bigel loaded (2000 µg/mL extract of *Q. resinosa*). 100×, scale bar size 200 µm.

The images show few differences between the unloaded and loaded bigels at the lowest concentration of extract (500 µg/mL), appreciating slightly larger droplets in terms of diameter. However, in the case of the loaded samples at higher concentrations of extract, the size and appearance of drops of different sizes increased in the same proportion as the concentration of oak leaves aqueous extract increased, which is an indication of bigel instability, caused by the presence of *Q. resinosa* extract.

3.4. Steady Shear Results

The results obtained from the modeling of simple shear rheological data, using the Ostwald de Waale model (Power law), are described in Table 4. showed an adjustment of 0.95 or higher, in all cases, observing that, as the concentration of *Quercus resinosa* leaves aqueous extract increased, the consistency index (K) increased, being the most important increase in the concentrations of 1000 to 2000 µg/mL per bigel sample.

Table 4. Ostwald de Waale Parameters of *Quercus resinosa* extract in loaded and unloaded bigels.

Sample	Concentration µg/mL	n	K (Pa.s^{n})	R^2
Unloaded	0	0.26 ± 0.01	46.95 ± 1.29	0.99
Loaded	500	0.24 ± 0.01	91.50 ± 1.48	0.97
Loaded	1000	0.22 ± 0.01	91.60 ± 1.37	0.96
Loaded	2000	0.22 ± 0.01	84.20 ± 3.96	0.95

Mean ± standard deviation.

3.5. Analysis of the Viscoelastic Behavior of the Bigels

The viscoelastic behavior of unloaded and loaded bigels with aqueous extracts of *Quercus resinosa* leaves were evaluated by frequency sweep tests, taken in the linear viscoelasticity zone (strain < 0.1%). To obtain more detailed information on the viscoelastic behavior of the samples, a modeling was carried out, using log-log graphs of dynamic complex modulus vs. frequency, where the effect of the extract concentration of *Quercus resinosa* leaves on the mechanical behavior of the bigels was tested in the frequency window of 0.3 to 10 Pa.s. According to various authors, the behavior of this type of composite gel systems in an emulsion environment is usually complex, and one of the strategies to follow is the use of models [26]. However, when using them, the fit results very low ($r^2 < 0.1$), thus it was decided to work with the Carreau-Yasuda model. According to such model, at low frequencies a plateau can be observed, which is an indication of the formation of chains that are common in gels, but according to the frequency sweep results, higher values

were always observed. The solid component over the liquid component rate, reveals the formation of three-dimensional structures interacting between hydrogels and oleogels, in addition to the polyphenols from the aqueous extract of *Quercus resinosa* leaves. The summary of parameters obtained is shown in Table 5.

Table 5. Carreau-Yasuda parameters from unloaded and loaded bigels with *Quercus resinosa* extracts.

Sample μg/mL	η_0^* (Pa.s)	λ (s)	a	R^2
Unloaded	1.915×10^3	1.62	0.35	0.98
Loaded 500	3.163×10^3	1.56	0.32	0.97
Loaded 1000	2.420×10^3	1.64	0.33	0.98
Loaded 2000	2.730×10^3	1.18	0.29	0.93

4. Discussion

From the results in Table 1, it is possible to observe the high content of flavanols, which are in higher abundance in comparison to other flavonoids compounds. This result agrees with the reported [27] for aqueous extracts of *Quercus resinosa*. Flavanols have a strong antimicrobial activity against *Staphyloccocus* spp. [28]. Particularly, it has been reported [29] a strong antimicrobial activity against *Staphyloccocus epidermidis* from flavonols; also, there are some claims [30] on flavonols with important antimicrobial activity against *Cutibacterium acnes*. Thus, the flavonoid profile found in aqueous extract of *Quercus resinosa* leaves could be useful to inhibiting growth of microorganisms related with acne.

The doubling time found for *Staphyloccocus epidermidis* was higher than the reported for this microorganism (81 min) [31]. However, these authors comment that there are notable differences in terms of growth parameters, depending on both the strain used, as well as the culturing conditions. Regarding *Cutibacterium acnes*, the doubling time observed was lower than the previously found [32] (4.26 h). It is important to mention that changes in the kinetic parameters may be due to many factors such as the strain, culture conditions, and the inoculum used, among others.

As can be seen in the table above, there is a concentration-dependent effect on the % inhibition of the growth of both microorganisms, with the greatest inhibitory effect being found at the highest concentration of aqueous extract of *Quercus resinosa* leaves. However, such concentration turns out to be too high to be kept in solution without precipitation problems, so it was decided to work with just concentrations of 1000 to 3000 μg/mL. The results obtained for inhibition of microorganisms were much higher than those reported by other authors for aqueous extracts of Mugwoort [33], who at a concentration of 20 mg/mL achieved a 37% inhibition of *Cutibacterium acnes*. These authors did not evaluate the phenolic profile of the aqueous extracts. Besides, according to some reports, it has been found that phloretin, even at low concentrations, has a strong antimicrobial activity against *Cutibacterium acnes*, but this compound was not identified in the present work, therefore, the presence of flavonols was important (Table 1), This group of phenolic compounds has shown great antimicrobial activity against *Cutibacterium acnes* [34], likewise good effects against *Staphyloccocus epidermidis* from flavonol-type compounds have been documented [35].

The rheological behavior of bigels is interesting to be discussed. The structuring agents and the gel proportions used were identical, varying only the aqueous extract concentration. Thus, the increase in flow resistance can be attributed to this variable. Some authors have pointed out that the existence of polysaccharides, such as those used in the present experiment in the hydrophilic part (i.e., xanthan gum and guar gum), can establish non-covalent interactions with polyphenols, which are the predominant molecules in leaf extracts of *Quercus resinosa*. In turn, these interactions can affect the polysaccharide—polysaccharide interactions [36]. However, unlike to these authors, who stated that as the concentration of polyphenols increases, the flow index also increases and the consistency index decreases; in the present experiment, it was observed that there is a

decrease of around 10% in the flow index as the concentration of *Quercus resinosa* leaves extract increases. On the other hand, in the case of the consistency index, the value is lower when no presence of aqueous extract *Quercus resinosa* leaves (46.95 Pa.s), but atth the lowest amount of extract (500 µg/mL), the value rises to 91.9 Pa.s. Such value remains constant up to a concentration of 2000 µg/mL of *Quercus* leaves aqueous extract, where the consistency index drops again (83.42 Pa.s). Such behavior has been described as common in bigel systems [37], but the behavior is different when compared to a system with no presence of polyphenol compounds. It is known that the joint presence of polyphenols and polysaccharides can induce aggregation. In the case of bigels, this implies a lower concentration of gum available for the hydrogel formation, causing a greater influence from the oleogel, which is reflected in changes of the consistency index. In the case of the flow index, the observed behavior is typical of an emulsion, that is, a pseudoplastic or thinning behavior was observed when flowing. Regarding the viscoelastic behavior, in unloaded and loaded bigels with aqueous extract of *Quercus resinosa* leaves, the storage modulus (G') is greater than the loss modulus (G'') throughout the observation window, which implies a prevalence of the solid behavior over the viscous one (i.e., elastic modulus range 11×10^2 to 11×10^3 Pa). In all bigel samples, the differences between the G' and G'' moduli become more evident at higher frequencies; on the other hand, the value of the moduli increases, both in the viscous and the elastic zones.

The behavior modelling using the Carreau-Yasuda model, indicates that the zero-shear viscosity parameter η_0 shows the lowest value in the sample with no presence of the *Quercus resinosa* leaves aqueous extract. This value compares well with other estimates reported for composite gels [38], especially of the polymeric type [39]. With the presence of the aqueous extracts of *Quercus resinosa* leaves, the above parameter was increased, which is an evidence of the physical interaction between the polyphenol compounds in the extract with the polymer chains (i.e., xanthan gum and guar gum) in the hydrophilic gel. This phenomenon has been documented with various molecules of different nature than the tested in the present experimental work [36].

Regarding the relaxation time parameter, this did not show significant differences ($p < 0.05$) between the unloaded and loaded bigels with 500 and 1000 µg/mL. However, at 2000 µg/mL, the relaxation time showed a lower value. Higher numbers of this parameter is indicative of a strong interfacial interaction, a fact that was expected when dealing with two types of gels (i.e., oleogel and hydrogel). This behavior at higher concentration of phenolic compounds, the mobility of the polymeric chains formed is increased, which destabilizes the bigel. About the transition region (i.e., parameter a), a concentration dependence was not observed since the same value was recorded in all conditions. Finally, it is clear, according to the behavior observed in Figure 2, that as frequency increases, the system behavior follows more the Power law, due to the breaking of networks that makes up each of the gels present in the bigel. The above results are reasonable based on whether the high zero shear viscosity at low frequencies or the solid region affects the complex viscosity (i.e., a low zero viscosity at low frequencies would negatively affect the complex viscosity) As the zero complex viscosity is the maximum level during the frequency sweep, this value is directly associated with the complex viscosity of the samples, while a prolonged relaxation time can cause limited molecular mobility. Thus, the complex viscosity depends on two parameters, the viscosity at zero shear and the relaxation time, so it can be said that the Carreau-Yasuda model is appropriate to describe the behavior of bigeles and the effect of polyphenol compounds on its structure. In this sense, it is necessary to mention that similar results to the found in the present experiment were already described [23] to evaluate the effect of carbon nanotubes on composite gels.
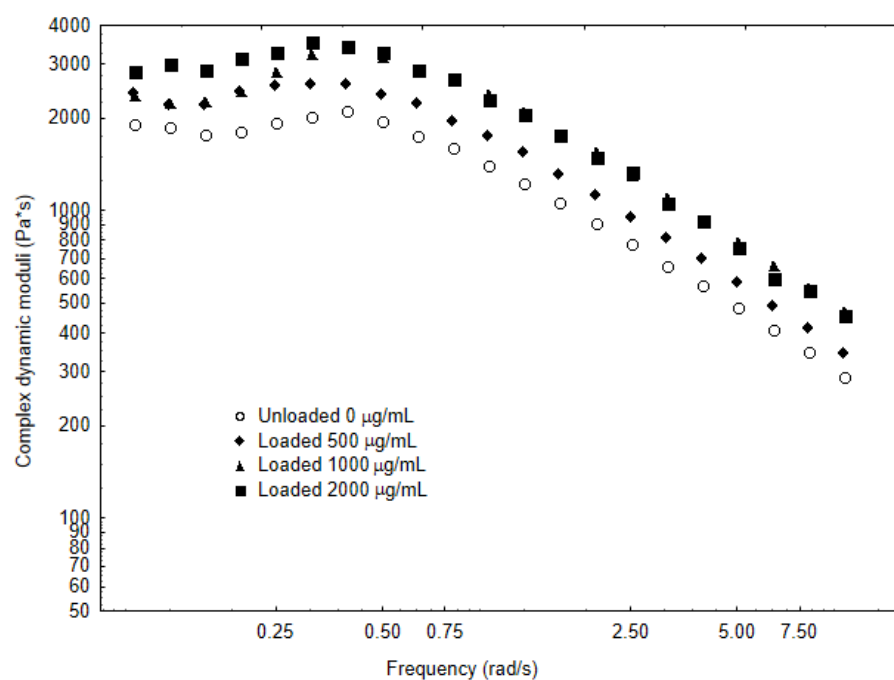
Figure 2. Rheological behavior of complex moduli of the unloaded and loaded bigels with aqueous extract of *Quercus* leaves.

5. Conclusions

The flavonoid profile in special flavonols, found in aqueous extracts from *Quercus* shows strong inhibition against *Cutibacterium acnes* and *Staphyloccocus epidermidis*. The inhibition was concentration dependent, however, the highest concentration of extracts exhibited solubility problems. The behavior of the liquid portion of the bigels fits the Power law model very well, finding a pseudoplastic type behavior ($n < 1$), in all samples, the bigels loaded with aqueous extracts of oak leaf showed a consistency index greater than that of the unloaded samples. Regarding the viscoelastic behavior, the analysis was carried out by approximating the Carreau-Yasuda model to the viscoelastic behavior, observing that the presence at low concentrations of phenolic compounds in the bigels, improves their mechanical properties, increasing the viscosity. complex, without affecting interfacial interactions, except at very high concentrations of polyphenolic compounds, the Carreau-Yasuda model was successful in evaluating the viscoelastic behavior of bigels.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy internal politics.

Conflicts of Interest: The authors declare no conflict of interest.

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