



Preparation and characterization of dressing-type emulsions formulated with hydrocolloids from the mango (*Mangifera indica*) peel

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ABSTRACT

Mango is a popular tropical fruit known worldwide and mango peel is a waste product worthy of valorization. This study explores the stabilizing effect of hydrocolloids extracted from mango peel in dressing-type emulsions (DE). Emulsions stabilized with different ratios of mango (*Mangifera indica*) peel-derived hydrocolloids (PE) and guar gum (1 % wt. total concentration) were prepared and characterized: DE₁ (0.25/0.75), DE₂ (0.5/0.5), DE₃ (0.75/0.25) and DE₄ (1/0). Particle size distribution, ζ -potential, proximal composition, color, microstructure, and rheological properties were evaluated. All the samples showed similar proximal compositions. However, PE/guar gum ratio influences color parameters. For the microstructural analysis, Sauter's mean droplet size ranged from 6.41 to 11.11 μm . The ζ -potential values ranged from -18.03 ± 0.21 to -16.97 mV. Emulsions exhibited shear thinning responses that can be well described by the Williamson model, and gel-like viscoelastic character with G' higher than G'' . The activation energy values (E_a) deduced from the application of an Arrhenius model to the viscous flow behaviour of the emulsions ranged from 108.46 to 143.44 KJ/mol. From the microstructural analysis and the rheological characterization, it can be inferred that PE favors the flocculation of the emulsion droplet in high concentrations. Overall, this research contributes to the sustainable exploitation of a mango waste material, such as the peel, in food emulsions.

1. Introduction

Hydrocolloids are a diverse collection of polymeric compounds that mainly consist of polysaccharides and certain proteins (Jayakody et al., 2023; Manzoor et al., 2022), which are totally or partially soluble, but readily distributed in water and are prone to swelling. Hydrocolloids can modify the physical characteristics of a solution through gelling or thickening, and can assist in emulsifying, coating, and stabilizing dispersions, in general (Gilbert, 2023; Goff & Guo, 2020). Plant-derived compounds such as pectin, modified starches, and cellulose derivatives are examples of food hydrocolloids, as well as seaweed-derived products such as agar and carrageenan, and some animal-derived polymers such as gelatin Pirsá and Hafezi (2023). Hydrocolloids are also used in advanced dressings for the treatment of skin wounds (Dickinson, 2017; Williams & Phillips, 2021). In general, these compounds are used to modify tissues, control crystallization, prevent dehydration, enhance synergy, coat aromatic and flavor materials, increase physical stability, form films, produce gel structures, and improve

the consistency of liquid and soft materials (Jabraili et al., 2021).

Hydrocolloids exhibit the capacity to alter the flow behavior of a given solution, referred to as viscosity, as well as the mechanical properties of food matrices, identified as texture. Changes in the viscosity and texture of food products directly influence their sensory characteristics, affecting how consumers perceive and approve them. Because of this, hydrocolloids are a notable group of food additives widely used in the food industry (Saha & Bhattacharya, 2010). Rheological adjustments achieved by adding hydrocolloids improve sensory characteristics and increase consumer acceptance of food products. As a result, authorized hydrocolloids have substantial utility as food additives in a wide range of culinary applications, where they serve precise functionalities tailored to specific requirements (Milani et al., 2012).

An emulsion constitutes a mixture of two fluids that do not mix naturally, one termed the continuous phase and the other the dispersed phase (Bisht et al., 2020; Saxena et al., 2022). Typically, the dispersed phase takes the form of minuscule spherical droplets dispersed throughout the continuous phase. The culinary landscape

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predominantly features two primary emulsion types: oil-in-water and water-in-oil. Examples of oil-in-water emulsions include milk, cream, dressings, sauces, and beverages, while water-in-oil emulsions are observed in substances such as butter and margarine. Beyond these, various culinary preparations involve distinct dispersed phases. For example, whipped cream incorporates gas bubbles as the dispersed phase, while ice crystals function as the dispersed phase in ice cream. In general, emulsifying and stabilizing agents are introduced into emulsions primarily to stabilize droplets, but also to confer the appropriate texture and sensory attributes inherent to these types of food products (Briceño-Ahumada et al., 2022; Phillips & Williams, 2009). The capacity of some molecules, i.e. emulsifiers, to decrease the oil-water interfacial tension is termed surface activity. Emulsification requires a certain degree of surface activity at the interface between oil and water, allowing the formation and sustained stability of tiny droplets throughout the emulsification process and beyond (Dickinson, 2003; Matindi et al., 2022). However, some hydrocolloids help stabilize the emulsions by modifying the rheological properties of the continuous phase. In addition to stabilizing the emulsion, some polysaccharides frequently used in the food industry, such as gum Arabic, modified cellulose, pectins, modified starches, and specific galactomannans, have been demonstrated to have surface activity (Dickinson, 2009; Li & Nie, 2016).

A significant portion of fruit processing is carried out in developing countries such as India, China, and various countries in Latin America, where it is transformed into pulp, jams, jelly, and confections (Banerjee et al., 2016). Mango processing leads to the generation of "processing waste," which constitutes 30 to 50 % of the original fruit weight. In particular, within this waste, mango peel comprises 40 to 60 % of the entire by-product of mango processing (Banerjee et al., 2018). Most investigations of the use of mango peels have focused primarily on their potential as a source of pectin, a dietary fiber known for its high quality (Berardini et al., 2005). Extracting pectin from discarded mango peels presents an intriguing opportunity for industries to improve both the value of peels and mitigate food and agricultural waste. During the extraction process, pectin is precipitated by introducing the crude extract into ethanol, while phenolic compounds are isolated from the aqueous phase using a resin Chaiwarit et al. (2020).

In this context, the objective of this research is to use and test the hydrocolloids derived from mango peel as stabilizing agents and study the impact on the microstructural and rheological properties of dressing-type emulsions.

2. Materials and methods

2.1. Materials

Mangos (*Mangifera indica*) were collected in their ripe organoleptic state from local plantations. Lecithin, guar gum, salt and saccharose, were purchased from a local market. To ensure proper sanitation, all fruits were sterilized by immersing in a sodium hypochlorite solution (100 mg/l) for a period of 10 min at a temperature of 25 °C. Following the sterilization process, the peel, pulp, and seeds were manually separated using stainless steel knives. The particle size reduction process was performed using an IKA MF 10.2 mill connected to a sieve mechanism, to achieve a particle size below 250 µm. Subsequently, the waste material (peel) was lyophilized during 72 h in a 1.5-liter Lab-conco Freezone benchtop unit. This step was taken to preserve the characteristics of the extracted components and achieve uniform particle sizes for further analysis and applications.

The buffer solutions, consisting of boric acid, potassium chloride, and sodium hydroxide, along with sodium azide and phenolphthalein, were acquired from Sigma-Aldrich (St. Louis, MO). For the hydrocolloid extraction process considered in Table 1, ethanol (Analytical grade, 99.5 %) and glacial acetic acid (99.5 %) were purchased from Panreac (Barcelona-Spain); sodium hydroxide (99.5 %) from EMSURE (Darmstadt Germany) was used.

Table 1

Extraction conditions for hydrocolloids derived from mango peel.

Sample	Waste Material	pH	Ratio (sample: water)	Time (hours)	Yield (%)
PE ₃	Peel	3	1:8	4	7.64 ±0.14 ^b
PE ₇	Peel	7	1:8	4	3.79 ±0.11 ^a
PE ₁₀	Peel	10	1:8	4	7.66 ±0.16 ^b

PE: peel-derived hydrocolloids. The yield results are expressed as mean ± standard deviation, the different letters within column are significantly different ($p < 0.05$).

2.2. Hydrocolloid extraction process

The hydrocolloid extraction process was carried out following the procedures described in a previous study (Marsiglia-Fuentes et al., 2022). Varying pH of solubilization (3, 7, and 10), and using a water-to-material ratio of 1:8, resulted in three different samples (Table 1). The initial step involved the dissolution of the waste material (peel) in distilled water, followed by mixing at 80 °C for 4 h. Before further processing, the pH was adjusted using acetic acid and NaOH 0.1 N. Subsequently, the sample was centrifuged at 4000 rpm for 15 min, allowing the collection of the liquid phase. The viscous phase obtained was then mixed with ethanol in a 1:1 ratio for a period of 3 h at a temperature of 2 °C. This step was intended to facilitate the creation of a hydrocolloid-based extract. Subsequently, the resulting mixture was centrifuged once more, with the subsequent precipitate collected and subjected to freezing drying at -50 °C and 0.02 Pa for a duration of 72 h. The extraction yield of hydrocolloids (expressed as g of hydrocolloid extract / g of mango part × 100) was determined for the peel-derived hydrocolloids (PE).

2.3. Preparation of emulsions

Dressing-type emulsions (DE) were prepared with canola oil, distilled water, soy lecithin as emulsifiers and guar gum and mango peel-derived (PE₃) hydrocolloids as stabilizers, according to the compositions shown in Table 2. For the emulsion preparation, lecithin, guar gum, salt, saccharose and the desired amount of PE₃ were initially dispersed in distilled water with agitation at 14,000 rpm for 15 min and 30 °C. To this aqueous phase, soy lecithin and canola oil were slowly added and dispersed using an ultra-turrax homogenizer (IKA T25 basic, Deutschland, Germany) homogenizer fitted with an S25 N-10ST dispersion tool at 16,800 rpm for 10 min and 30 °C. The samples were stored at 4 °C for 2 days for further analysis.

2.4. Characterization of emulsions

The physicochemical and proximal composition of dressing-type emulsions including, lipids, ash, and protein, were evaluated following the guidelines outlined in the Association of Official Analytical Chemists (AOAC) standard methods. The water content was determined using the AOAC standard method No 926.08, lipids were determined using No 972.28, ash content was evaluated with No 935.42, and the protein content was determined using No 926.123. Titratable acidity was measured by alkalimetric titration with 0.1 N NaOH, using phenolphthalein as an indicator according to AOAC No 967.21. Furthermore, the pH was measured using a Mettler Toledo AG SG2 digital potentiometer, which had previously been calibrated, according to Method 942.05 as described by AOAC standards (Horwitz, 2010).

Color measurements were performed using a colorimeter (UltraScan PRO, HunterLab, America), which evaluated the parameters L* (lightness), a* (red-green coordinates) and b* (yellow-blue coordinates) parameters. Quantification of color changes (ΔE) and determination of the

Table 2
Formulation of dressing emulsion from the valorized fraction of the mango peel.

Sample code	PE ₃ hydrocolloid (%)	Guar gum (%)	Soy lecithin (%)	Water (%)	Canola oil (%)	Salt NaCl (%)	Saccharose C ₁₂ H ₂₂ O ₁₁ (%)
DE ₁	0.25	0.75	5	73	20	0.5	0.5
DE ₂	0.5	0.5	5	73	20	0.5	0.5
DE ₃	0.75	0.25	5	73	20	0.5	0.5
DE ₄	1	–	5	73	20	0.5	0.5
Control (C)	–	1	5	73	20	0.5	0.5

DE: Dressing-type Emulsions. PE: peel-derived hydrocolloids.

whiteness index (WI) were carried out applying Eqs. (1) and (2), where the subscript 'm' represents the dressing samples and c represents the control sample, i.e. without PE₃ hydrocolloid (Rojas-Martin et al., 2023; Wagemans et al., 2022).

$$\Delta E = \sqrt{(L_m^* - L_c^*)^2 + (a_m^* - a_c^*)^2 + (b_m^* - b_c^*)^2} \quad (1)$$

$$WI = 100 - \sqrt{(100 - L)^2 + a^{*2} + b^{*2}} \quad (2)$$

Optical microscopy observations were carried out with a Primo Star model from the Carl Zeiss Primo Star Microscope (GmbH, Jena, Germany), equipped with a 100× magnification objective, to examine emulsion samples (approximately 50 μL). Image acquisition was facilitated by a DCMC310 digital camera connected to the light microscope. The Scope Photo software, version 3.1.615, supplied by Hangzhou Huaxin Digital Technology Co., Ltd., in Zhejiang, China, was used for image processing.

Particle size analysis was performed using a Mastersizer 2000 device (Malvern Instruments, Worcestershire, UK). The samples were diluted in deionized water at 2000 rpm until the obscuration rate remained below 10 %. Mie's theory was applied with reference to a material with a refractive index of 1.52 and an absorption coefficient of 0.1. A power of 16.0 W of ultrasound was applied to each of the dressing formulations at 25 °C. This power level has been chosen according to preliminary tests which were applied at 4.0, 8.0, 12 and 16 w (see Fig. 1) in a control sample without hydrocolloids derived from mango peel. As can be observed, the higher the ultrasound power, the smaller the particle size. Measurements were made in triplicate for each formulation, furthermore, the ζ-potential was determined at 25 °C using a nano-Z Zetasizer (Malvern Instruments, Worcestershire, UK). The mathematical model of

Smoluchowsky was used to convert electrophoretic mobility measurements into ζ-potential values (Sánchez-González et al., 2009). The results were analyzed using the Malvern software, considering conventional particle size distribution parameters, including the volumetric mean droplet size (D_{4,3}) and the Sauter mean diameter (D_{3,2}).

A controlled stress rheometer (Haake Mars-60, Thermo-Scientific, Germany) was used to analyze the rheological properties of dressing-type emulsions, using a coaxial cylinder geometry (inner radius: 12.54 mm, outer radius: 11.60 mm, length: 37.6 mm, bottom gap: 5.30 mm), following the methodology described by Marsiglia R. et al. (Marsiglia et al., 2021). Before subjecting each sample to rheological tests, a 600-second equilibration period was performed to ensure a consistent mechanical history. Rheological tests were performed at different temperatures in the range of 5–80 °C. The temperature was controlled using a Peltier device. Steady-state viscous flow tests were carried out to investigate variations in viscosity over a range of shear rates from 10⁻³ to 10³ s⁻¹. Viscoelastic responses were determined by small-amplitude oscillatory shear (SAOS) tests. To evaluate the linear viscoelastic interval, stress sweeps were performed at a frequency of 1 Hz, using an incremental sequence of stress values from 10⁻³ to 10³ Pa. Subsequently, frequency sweeps from 0.02 to 100 rad/s were performed by applying a stress value within the linear viscoelastic range.

2.5. Statistical analysis

Data were analyzed by ANOVA (unidirectional) using SPSS software (version 17.2 for Windows) to determine statistically significant differences ($p < 0.05$) between samples.

3. Results and discussion

3.1. Physicochemical composition

Hydrocolloids were initially extracted from mango peel at pH 3, 7, and 10 (PE₃, PE₇, and PE₁₀). The hydrocolloid extraction yields relative to the peel were 7.64 ± 0.14 %, 3.79 ± 0.11 %, and 7.66 ± 0.16 %, respectively (Table 1) The treatments at pH 3 and 10 are the most efficient, showing no statistically significant differences after statistical analysis, unlike the treatment at pH 7 which showed significant differences with a low yield. PE₃ sample was selected to study the stabilizing properties in dressing-type emulsions, because the hydrocolloid extracted at pH 10 (PE₁₀) tends to darken the emulsion. At pH 7 (neutral), the polymeric chains of hydrocolloids cannot be properly solubilized for further separation due to ionic changes (Gao et al., 2017). When the solution is subsequently washed with alcohol, this results in a low extraction yield. Based on the yields and functional properties studied in a previous study (Marsiglia-Fuentes et al., 2022), the extract at pH 3 (PE₃) was selected as an ingredient for the formulation of emulsions. Acid extraction, compared to neutral conditions, has been reported to improve the yield of hydrocolloids as it promotes the hydrolysis of long polymer chains associated with the peel structure, resulting in smaller chains that can easily precipitate when ethanol is added, thus increasing the yield (Somboonpanyakul et al., 2006). This is due to exposure to hydrophilic groups that can interact with water and

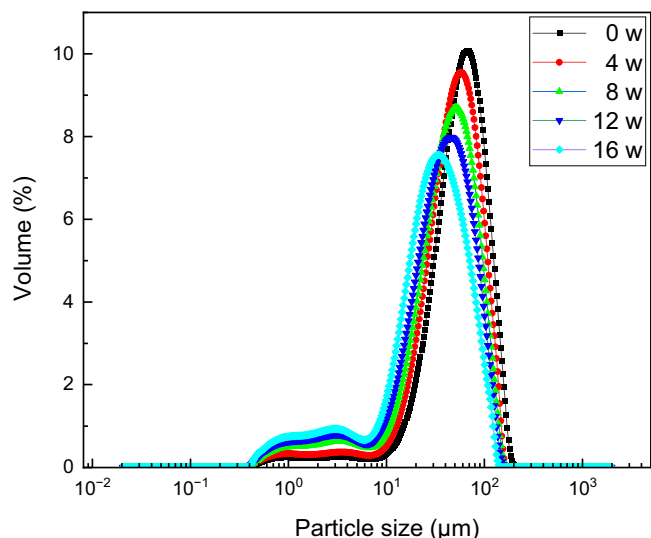


Fig. 1. Evaluation of the droplet size distribution in dressing-type emulsions as a function of the ultrasound effect at 4, 8, 12 and 16 w in the control sample (C).

favor their extraction (Chen et al., 2019). Moreover, despite the yield achieved and functional properties imparted by sample PE₁₀ being not substantially different, this tends to darken the medium in which it is added, and therefore this sample was neglected. The compositional analysis of PE₃ extract can be found elsewhere (Marsiglia-Fuentes et al., 2023).

PE₃ was then used as an emulsion stabilizer together with guar gum in different ratios, as shown in Table 2. The physicochemical composition data of the resulting dressing-type emulsions (DE₁, DE₂, DE₃, and DE₄) are collected in Table 3. Without any adjustment, the pH values of these samples ranged from 6.63 to 6.82 ($p < 0.05$). In terms of titratable acidity, the values ranged from 0.059 to 0.066 mg of citric acid/100 ml of the sample, with no significant variations. The fat content was again very similar, which is essentially the oil used to create the emulsion and the fat content of lecithin and hydrocolloids (Marsiglia-Fuentes et al., 2024; Wagemans et al., 2022). The protein content, ranged from 1.38 % to 1.41 %, similar to what is observed in dressing-type emulsions prepared with egg yolk (1.6 %) (Nikiforidis et al., 2012a). Furthermore, the carbohydrate content did not vary significantly between samples, with values ranging from 4.12 % to 4.59 %. Total soluble solids (TSS) measured as ° Brix were higher in samples DE₂ and DE₁ samples (3.67 and 3.05, respectively) compared to DE₃ and DE₄, which had values of 2.86 and 2.85 respectively, attributed to the presence of substances of high molecular weight in solution and solids dispersed in the liquid phase (González et al., 2011; Williams & Phillips, 2003). Furthermore, a previous study (Marsiglia-Fuentes et al., 2024) observed that the molecular weights of hydrocolloids obtained from mango by-products are slightly lower than those of guar gum, which may explain the slight variation in ° Brix. Finally, the ash content remained constant with values around 0.91 % to 0.93 % in all cases.

3.2. Particle size distribution (PSD) and ζ-potential

The emulsification performance and physical stability of an emulsion can be evaluated by determining the size and distribution of droplets, which reflect the equilibrium between droplet formation and re-coalescence (Krstonošić et al., 2009; Ren et al., 2022). Fig. 2 shows the particle size distribution of samples DE₁, DE₂, DE₃, and DE₄, which represent different emulsion-type dressings stabilized with mango peel hydrocolloids and guar gum at a sonication power of 16 W. As can be seen from the results, the emulsions display a bimodal distribution with a wide range of droplet sizes, predominantly between 10 and 100 μm. The distribution curves of emulsions containing PE₃ concentrations below 1 % nearly overlap. However, the DE₄ sample exhibits a decrease in the number of droplets below 10 μm and a slight shift of the distribution to higher sizes, evincing particle sizes above 100 μm. Moreover,

Table 3
Physicochemical composition.

Parameter	DE ₁	DE ₂	DE ₃	DE ₄
TTA (mg of citric acid /100 ml)	0.066 ± 0.04 ^b	0.065 ± 0.07 ^a	0.066 ± 0.06 ^a	0.059 ± 0.05 ^b
pH	6.67 ± 0.75 ^a	6.82 ± 0.32 ^a	6.63 ± 0.19 ^a	6.64 ± 0.78 ^a
TSS (°Brix)	3.05 ± 0.02 ^c	3.67 ± 0.04 ^b	2.86 ± 0.02 ^a	2.85 ± 0.02 ^a
Protein (%)	1.39 ± 0.05 ^b	1.40 ± 0.03 ^b	1.41 ± 0.05 ^a	1.38 ± 0.04 ^c
Ash (%)	0.91 ± 0.09 ^a	0.93 ± 0.02 ^c	0.92 ± 0.08 ^b	0.91 ± 0.03 ^a
Fat (%)	22.12 ± 0.02 ^b	22.02 ± 0.04 ^b	22.17 ± 0.05 ^a	22.13 ± 0.07 ^b
Carbohydrate (%)	4.15 ± 0.21 ^c	4.12 ± 0.06 ^a	4.59 ± 0.07 ^c	4.43 ± 0.02 ^b

DE: Dressing-type Emulsions. The results are expressed as mean ± standard deviation, the different letters within each row are significantly different ($p < 0.05$).

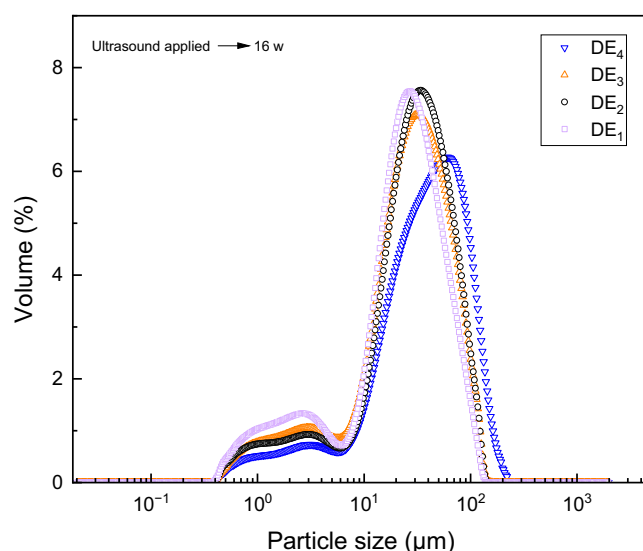


Fig. 2. Evolution of the droplet size distribution in dressing-type emulsion with peel hydrocolloids as a function of the ultrasound effect formulated.

the addition of PE₃ hydrocolloids generally does not result in a significant decrease in the percentage of smaller droplets or an increase in the percentage of medium-sized droplets. This bimodal particle size distribution could indicate an enhancement of droplet flocculation, and/or depletion flocculation caused by the presence of mango peel hydrocolloid (Dickinson, 2019; Krstonošić et al., 2024), taking into account that smaller particle size are generally obtained with better solubilized hydrocolloids (Morales Bagnolo et al., 2023). Relating this characteristic to what was observed in the microstructural analysis, the DE₄ sample, which has a higher percentage of mango peel hydrocolloids, tends to form aggregates of particles, which may lead to the identification of larger particle sizes in the distribution analysis.

Table 4 shows the values of Dx (10), Dx (50), and Dx (90), which corresponds to 10 %, 50 %, and 90 % of the cumulative particle size distribution, as well as D(3,2) and D(4,3) for the different emulsions evaluated. Cumulative Dx (10) generally corresponds to colloidal fragments, while the values of Dx (50) greater than 100 μm may indicate the presence of small fragments undergoing coalescence or undissolved fragments, gradually increasing in size due to attractive forces between particles. Eventually, these clusters coalesce into larger groups, as represented by the values of Dx (90) (Eraso-Grisales et al., 2022).

The dispersion characteristics and stability of the emulsions were determined by monitoring changes in particle size distribution and

Table 4
Particle size distribution data and ζ- potential values of emulsions formulated with mango peel-derived hydrocolloids.

	Control	DE ₁	DE ₂	DE ₃	DE ₄
ζ (mV)	-18.03 ± 0.21 ^c	-17.65 ± 0.13 ^b	-17.46 ± 0.18 ^b	-17.72 ± 0.22 ^b	-16.97 ± 0.23 ^a
Dx (10) μm	1.14 ± 0.05 ^a	2.21 ± 0.03 ^b	3.58 ± 0.07 ^c	3.19 ± 0.03 ^c	6.86 ± 0.09 ^d
Dx (50) μm	5.32 ± 0.07 ^a	29.92 ± 0.06 ^b	29.64 ± 0.09 ^b	27.54 ± 0.02 ^b	42.42 ± 0.02 ^c
Dx (90) μm	54.22 ± 0.01 ^a	62.94 ± 0.08 ^{ab}	73.92 ± 0.03 ^b	74.84 ± 0.03 ^b	136.18 ± 0.06 ^g
D [3,2] μm	3.01 ± 0.08	6.41 ± 0.07	6.87 ± 0.07	7.92 ± 0.05	11.11 ± 0.08
D [4,3] μm	17.54 ± 0.11 ^d	33.3 ± 0.12 ^c	35.4 ± 0.13 ^b	36.9 ± 0.11 ^b	64.52 ± 0.18 ^a

DE: Dressing-type Emulsions. The results are expressed as mean ± standard deviation, the different letters within each row are significantly different ($p < 0.05$).

volumetric ($D_{4,3}$) and Sauter's ($D_{3,2}$) mean droplet diameters. Particle size is a crucial factor in emulsion formulation as it affects the macroscopic properties of the final product, including colour, opacity, rheology and stability (McClements, 2004). Sauter's mean diameter is inversely related to the mean surface area of the emulsion droplets, which is created in the emulsification process (Chanamai & McClements, 2000). Values of 6.41, 6.87, 7.92 and 11.11 μm were obtained for the samples DE₁, DE₂, DE₃ and DE₄, respectively, while no significant alterations were observed in the volumetric mean droplet size ($D_{4,3}$) of

the emulsions DE₁, DE₂ and DE₃, which exhibited values between 33.3 and 33.9 μm , with DE₄ displaying values of 64.52 μm . The increase in Sauter droplet mean diameter values at 1 % PE₃ concentration is probably a result of the overlap concentration of PE₃ in the aqueous phase being reached, which has also led to a shift in the distribution curve towards larger particles. At the overlap concentration, individual polymer molecules begin to interact physically, leading to the formation of larger aggregates (Du et al., 2022). In general, PE₃-containing emulsions exhibit larger droplet sizes than the control emulsion exclusively

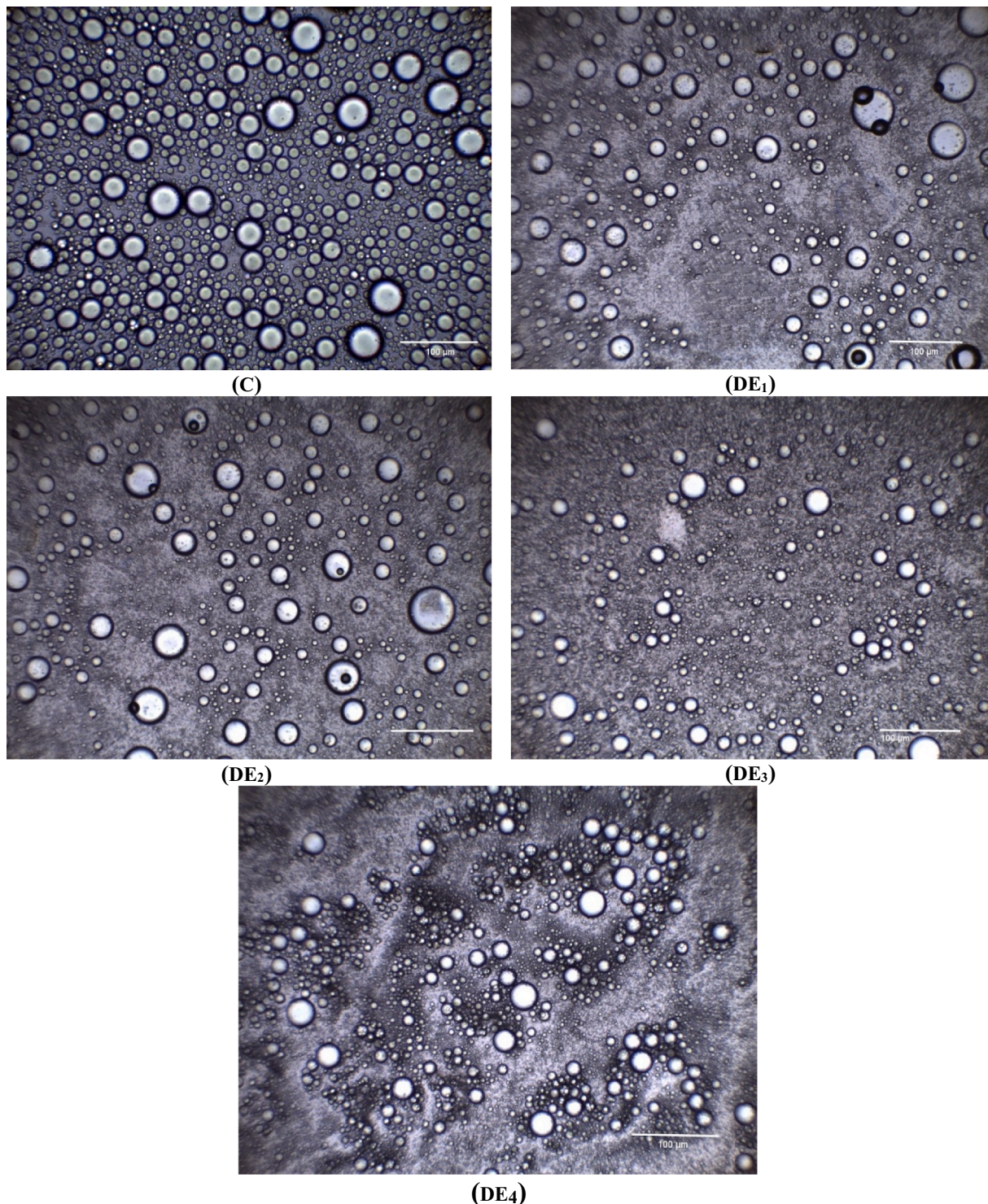


Fig. 3. Microstructure of dressing-type emulsions formulated with hydrocolloids from mango peel. The scale bar corresponds to 100 μm .

stabilized with guar gum.

Dressing-type emulsions made from hydrocolloids derived from mango peel showed ζ -potential values (ζ) ranging from -18.03 to -16.97 mV (Table 4) that were not significantly different ($p < 0.05$), which are very similar to the ζ -potential value measured for the control emulsion. The decrease in ζ is caused by the limited ionizable sites of the hydrocolloid polymer chains, which allow the polymers to accept a negative charge, the magnitude of the charge carried by the emulsion droplets determines the stability of the colloidal dispersion system, consequently, the intensity of the charge carried by the emulsion droplets is critical in defining the stability and functioning of the emulsion (Shanmugam & Ashokkumar 2014). For ease in discussing the results, it is important to note that the ζ -potential is described in terms of its magnitude, regardless of the sign (Loi et al., 2019). Therefore, an increase in the ζ -potential should be understood as an increase in the negativity of the ζ -potential in this context. This parameter is crucial for assessing the physicochemical stability of emulsions, as it mainly shows the strength of electrostatic or repulsive forces between nearby colloidal particles (Yu et al., 2016). The control sample shows slightly higher values, but the effect of PE addition does not significantly affect the ζ -potential.

3.3. Microstructural analysis

Fig. 3 shows the microstructural characteristics of the emulsion samples formulated with hydrocolloids obtained from the mango peel and guar gum. Microstructural analysis highlights notable differences between the hydrocolloid-containing samples and the control sample that become more evident as the percentage of hydrocolloid addition increases. In the control sample (C), less dense areas are observed with an average droplet size of $3.82 \mu\text{m}$ deduced from the image analysis using the Scope Photo Software. Furthermore, in agreement with the PSD data previously discussed, a decrease in droplet size can be observed when initially increasing the PE₃ content from 0.25 to 0.75, with a variation of the average droplet size of $6.97 \mu\text{m}$, $7.12 \mu\text{m}$, $7.98 \mu\text{m}$ and $12.01 \mu\text{m}$, respectively. This slight increase indicates a modification of the interfacial activity of the hydrocolloids blend that directly influences the droplet size of the emulsion (Sharma et al., 2014), which seems to exert a synergistic effect. Furthermore, as shown in Fig. 3, the flocculation of droplets is favored by increasing the PE₃ content, especially when adding PE₃ at 1 % concentration, suggesting that light scattering measurements (see Section 3.2) are also accounting for droplet flocs.

3.4. Color

Colour significantly influences consumer preference (Hutchings, 1994). Table 5 provides an overview of the color values associated with dressing-type emulsions formulated with hydrocolloids from mango

Table 5
Color parameters of the dressing emulsion with hydrocolloids of mango peel.

Parameter	L*	a*	b*	WI	ΔE
C	82.74 ± 0.29 ^d	1.46 ± 0.27 ^b	9.01 ± 0.63	80.48 ± 0.89	–
DE ₁	81.65 ± 0.25 ^c	1.32 ± 0.17 ^{ab}	8.54 ± 0.86 ^a	79.69 ± 0.58	1.22 ± 0.15
DE ₂	81.25 ± 0.45 ^{ab}	1.84 ± 0.62 ^b	7.44 ± 0.15 ^a	79.74 ± 0.43	2.20 ± 0.23
DE ₃	80.73 ± 0.32 ^a	0.94 ± 0.83 ^a	5.86 ± 0.41 ^a	79.84 ± 0.48	3.77 ± 0.14
DE ₄	80.12 ± 0.47 ^a	1.06 ± 0.52 ^a	5.57 ± 0.38 ^b	79.33 ± 0.62	4.34 ± 0.73

DE: Dressing-type Emulsions. The results are expressed as mean ± standard deviation, the different letters within each column are significantly different ($p < 0.05$).

peel. This analysis was performed by evaluating the coordinated luminosity (L*) and red/green (a*), and yellow/blue (b*) parameters. Furthermore, the white index (WI) and the change in color (ΔE) between the control (C) and the samples (DE₁, DE₂, DE₃ and DE₄). It can be seen that the ratio PE₃/guar gum in the hydrocolloid blend influences the color parameters. Significant differences ($p < 0.05$) were obtained for the different emulsion samples, with decreasing L* values as PE₃/guar gum ratio increases. This change in L* values can be attributed to the present of carotenoids in the hydrocolloids derived from mango, responsible for the light golden color (Reyes Parrales et al., 2021). Light absorption and scattering depend on several factors, including refractive index, type and concentration of hydrocolloids, and droplet size distribution, as well as the presence of chromophoric components (Hu et al., 2017; McClements, 2002).

Regarding the a* color component, positive values signify red, while negative values indicate green (Navajas et al., 2010). All samples were observed to have positive values, indicating a tendency toward a red color, having similar values in all samples, with no significant differences. The parameter b* represents a yellow color when it is positive and blue for negative values; all samples showed positive results, indicating a predominant yellow color. These values ranged from 9.01 ± 0.63 to 5.57 ± 0.38 , with significant differences ($p < 0.05$). Higher percentages of PE₃ hydrocolloid resulted in lower b* values. The whiteness index (WI) of the samples did not show significant differences with the additions of PE₃. In general, the color parameters suggest consumer appeal and general acceptability for these types of products (Liu et al., 2007; Sukkwai et al., 2017). The total color change (ΔE), which indicates the difference in color compared to the control sample, was lower in sample DE₁, with a value of 1.22 ± 0.15 ($p < 0.05$). This result suggests that DE₁ does not exhibit a significant color variation with respect to the control sample. However, an increase in PE₃ results in noticeable color changes, altering the visual appearance.

3.5. Rheology

3.5.1. Steady-state viscous flow and temperature dependence

From a sensory point of view, the study of the flow of polymeric and colloidal systems at low and moderate shear rates helps to describe the consistency of food in the mouth (Morris, 1990), while the evaluation of viscosity at high shear rates gives information for processability (Fathi et al., 2018). To comprehensively study the flow properties of food emulsions, especially when hydrocolloids are incorporated, and to gain valuable insight into their industrial applications, it is essential to have a thorough understanding of the relationship between viscosity and shear rate.

Fig. 4 illustrates the variation of viscosity as a function of the shear rate and temperature for samples DE₁, DE₂, DE₃ and DE₄ differing in the ratio PE₃/guar gum (Fig. 5). In all of the emulsions studied, a shear thinning response with a tendency to achieve a constant zero-shear rate-limiting viscosity can be observed regardless of the temperature. This shear thinning flow behaviour has been widely reported for other dressing-type food emulsions (Chatsisvili et al., 2012; Nikiforidis et al., 2012b). This shear thinning behaviour can be satisfactorily described by the Williamson model (Equation 3) ($R^2 > 0.996$):

$$\eta = \frac{\eta_0}{1 + (k\dot{\gamma})^n} \quad (3)$$

where $\dot{\gamma}$ is the shear rate, η_0 is the zero-shear rate-limiting viscosity, k is a constant whose reciprocal coincides with the shear rate at which $\eta = \eta_0/2$, and n is a parameter related to the slope of the shear-thinning region. On the other hand, as the temperature increases, the viscosity of the samples decreases consistently and uniformly over the range of shear rates studied. The values of Williamson's model fitting parameters are shown in Table 6 for the different emulsions and temperatures studied. Regarding the emulsion composition, the viscosity is influenced by the

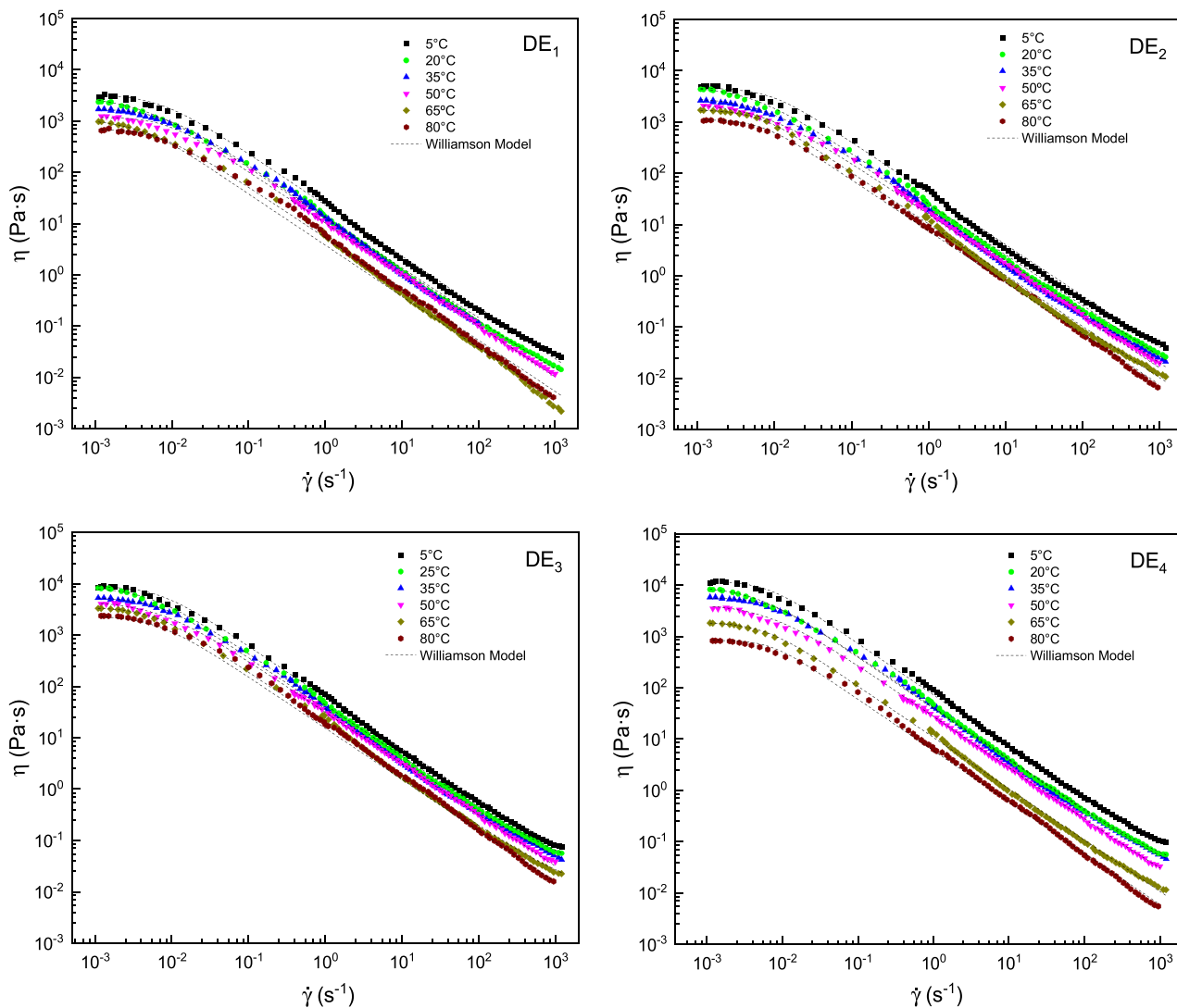


Fig. 4. Fitting the flow curves with the Williamson model for dressing emulsions (DE₁, DE₂, DE₃, and DE₄) at different temperatures (5 °C, 20 °C, 35 °C, 50 °C, 65 °C and 80 °C).

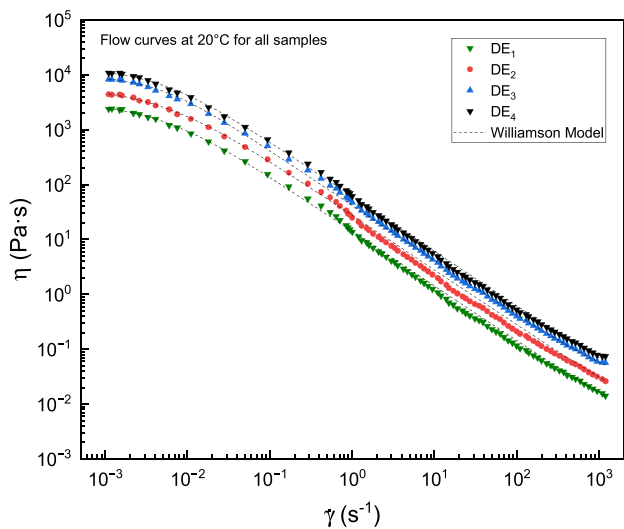


Fig. 5. Influence of the PE-/Guar gum ratio at 20 °C.

PE₃ / gum ratio used as a stabilizer, as illustrated in Fig. 5 for 20 °C. At low and moderate temperatures, the viscosity increases with the PE₃ content (see for instance η_0 values in Table 6). This fact can be attributed to the formation of a stronger network in the continuous medium that traps oil droplets more efficiently (Lastra-Ripoll et al., 2022), as well as to a more extensive flocculation, as previously discussed. However, emulsions with higher contents in mango peel-derived hydrocolloids exhibit a more pronounced temperature dependence. This means that the addition of a certain amount of guar gum is beneficial from a thermorheological point of view, again suggesting a synergistic effect between both types of hydrocolloids.

The Arrhenius model can be used to describe how temperature affects the apparent viscosity of fluids as emulsions (Marsiglia et al., 2020), as expressed in Eq. (4).

$$\eta_o = A \exp\left(\frac{E_a}{RT}\right) \tag{4}$$

where A is the pre-exponential factor, R is the gas constant (8.314 J/mol K), T is the absolute temperature (K) and E_a is the activation energy (J/mol K), a parameter used to evaluate the viscosity thermal dependence. As shown in Fig. 6, the η_0 data show an exponential decrease with increasing temperature, and therefore they could be well modelled using

Table 6
Rheological parameters of the Williamson model in dressing emulsion.

Sample	T °C	η_0	k	n	R ²
DE ₁	5	3401.64 ± 0.89 ^f	1.44 ± 0.08 ^a	0.03 ± 0.02 ^a	0.998
	20	2397.28 ± 0.71 g	1.03 ± 0.05 ^a	0.01 ± 0.01 ^a	0.999
	35	1767.51 ± 0.41 ^h	1.48 ± 0.04 ^a	0.01 ± 0.02 ^a	0.998
	50	1207.48 ± 0.88 ^h	1.75 ± 0.07 ^a	0.02 ± 0.01 ^a	0.999
	65	987.47 ± 0.98 ⁱ	1.03 ± 0.05 ^a	0.02 ± 0.01 ^a	0.998
DE ₂	80	679.33 ± 0.34 ⁱ	2.45 ± 0.04 ^b	0.01 ± 0.01 ^a	0.997
	5	4614.82 ± 1.21 ^e	1.79 ± 0.14 ^a	0.06 ± 0.03 ^{bc}	0.998
	20	4554.48 ± 0.34 ^e	1.26 ± 0.02 ^a	0.01 ± 0.01 ^a	0.999
	35	2984.31 ± 0.87 ^{fg}	1.24 ± 0.03 ^a	0.03 ± 0.01 ^a	0.999
	50	2349.56 ± 0.71 g	1.79 ± 0.14 ^a	0.06 ± 0.03 ^{bc}	0.998
DE ₃	65	1726.41 ± 0.78 ^h	1.90 ± 0.03 ^a	0.01 ± 0.01 ^a	0.997
	80	1128.71 ± 0.96 ^h	1.97 ± 0.07 ^{ab}	0.02 ± 0.01 ^a	0.998
	5	9076.65 ± 1.98 ^b	1.90 ± 0.02 ^a	0.05 ± 0.02 ^a	0.996
	20	8267.68 ± 0.96 ^c	1.26 ± 0.03 ^a	0.08 ± 0.03 ^c	0.999
	35	5632.36 ± 0.51 ^d	1.99 ± 0.05 ^a	0.02 ± 0.03 ^a	0.997
DE ₄	50	4347.69 ± 0.86 ^e	1.12 ± 0.08 ^a	0.01 ± 0.01 ^a	0.998
	65	3479.86 ± 0.64 ^f	1.56 ± 0.12 ^a	0.01 ± 0.02 ^a	0.997
	80	1885.25 ± 0.26 g	2.23 ± 0.06 ^b	0.07 ± 0.04 ^a	0.998
	5	11,821.26 ± 0.01 ^a	1.65 ± 0.02 ^a	0.04 ± 0.01 ^b	0.996
	20	8784.58 ± 0.34 ^c	1.32 ± 0.52 ^a	0.02 ± 0.01 ^a	0.999
35	5489.21 ± 0.98 ^d	1.52 ± 0.55 ^a	0.01 ± 0.02 ^a	0.998	
50	3646.54 ± 0.48 ^f	1.15 ± 0.23 ^a	0.03 ± 0.01 ^a	0.999	
65	1832.69 ± 0.89 ^h	1.75 ± 0.12 ^a	0.02 ± 0.01 ^a	0.997	
80	1219.83 ± 0.94 ^h	1.42 ± 0.44 ^a	0.03 ± 0.02 ^a	0.996	

DE: Dressing-type Emulsions. The results are expressed as mean ± standard deviation, the different letters within each column are significantly different ($p < 0.05$).

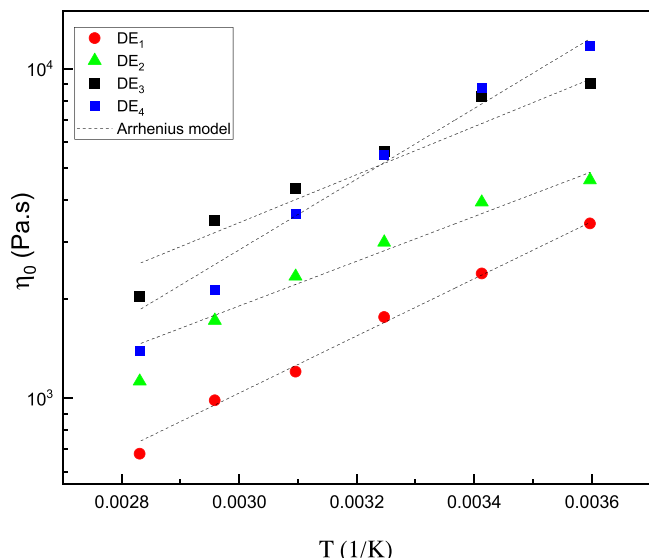


Fig. 6. Fitting to the Arrhenius model for the dressing-type emulsions studied (DE₁, DE₂, DE₃ and DE₄).

Equation (4) ($R^2 > 0.996$). Based on this, and considering the data obtained, the η_0 values of the Williamson model shown in Table 6 were taken and plotted against absolute temperature.

Substances with a high activation energy tend to show a more pronounced viscous behavior, at lower temperatures these substances will be more viscous and at higher temperatures their viscosity will decrease more sharply (Kundu et al., 2015). Regardless of the viscosity values, the E_a values estimated from the fitting of η_0 to eq. (4) were 134.45 ± 4.20 KJ/mol for DE₁, 108.46 ± 2.31 KJ/mol for DE₂, 111.38 ± 3.25 KJ/mol for DE₃, and 143.44 ± 5.24 KJ/mol for DE₄. Therefore, the DE₂ sample presents lower thermal susceptibility, followed by DE₃, DE₁ and finally DE₄ with significant differences ($p > 0.05$) in terms of viscosity variation.

3.5.2. Linear viscoelasticity

Stress sweep tests were performed at 25 °C to determine the linear viscoelastic region of samples formulated with hydrocolloids from the mango peel. All emulsion samples generally exhibited an extended linear viscoelastic region, at least in the range of 1–10 Pa. Once the extension of the linear viscoelastic regime was determined, frequency sweeps were applied and the resulting mechanical spectra, i.e. the evolution of G' and G'' with the angular frequency, were monitored at 25 °C (Fig. 7). In all cases, the typical gel-like response of concentrated and/or flocculated emulsions was obtained, with values of G' greater than those of G'' in the whole frequency range analyzed, indicating predominant elastic behavior. Regarding the emulsion composition, variations in the ratio of the hydrocolloids used (PE₃ extract and guar gum) do not significantly affect the values of the SAOS functions or their frequency dependence. Only the emulsion DE₃, with a PE₃/guar gum ratio of 0.75/0.25 shows slightly higher values of G' , which again supports the hypothesis of a more enhanced synergistic effect at this ratio.

4. Conclusions

Extraction of hydrocolloids from the mango peel, revealed that the treatments the pH 3 (7.64 %) and pH 10 (7.66 %) produced the highest yields, with no statistically significant differences between them after analysis. Sample PE3 was selected for studying the stabilizing properties in dressing-type emulsions because the hydrocolloid extracted at pH 10 (PE10) tends to darken the emulsion. Hydrocolloids derived from mango peel (PE) were evaluated as stabilizers in dressing-type emulsions. Emulsions were satisfactorily stabilized with different PE/guar gum ratios (at 1 % wt. total concentration): DE₁ (0.25/0.75), DE₂ (0.5/0.5), DE₃ (0.75/0.25) and DE₄ (1/0). These emulsion formulations were compositionally similar. As the concentration of PE hydrocolloids increased, the color of the emulsions underwent alterations with respect to the control PE-free emulsion, which is attributed to the presence of carotenoids imparting a light golden color. In general, PE3-containing emulsions exhibit larger droplet sizes than the control emulsion exclusively stabilized with guar gum. A particularly high mean droplet size was found for the DE₄ emulsion stabilized exclusively by PE. The emulsion microstructure shows dense and compact sections dominated by flocs of droplets that become more visible at high PE/guar gum ratios. Instead, the control (PE-free) sample has fewer dense sections and an uneven droplet distribution. However, denser areas promote flocculation, especially in the DE₄ sample. The ζ -potential values (ζ), ranging from -18.03 to -16.97 mV, did not show significant differences ($p < 0.05$). Emulsions exhibited a marked shear thinning flow behaviour and

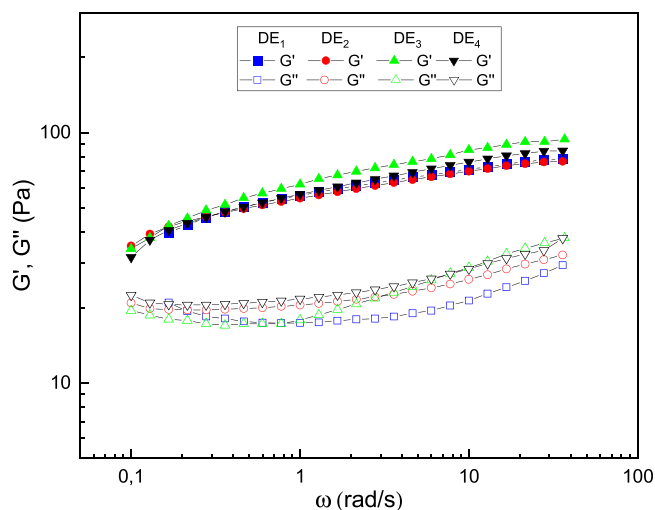


Fig. 7. Evolution of the storage (G') and loss (G'') moduli with frequency (ω), for the dressing-type emulsions studied (DE₁, DE₂, DE₃ and DE₄).

gel-like viscoelastic responses, characteristic of flocculated emulsions. The apparent viscosity generally increases with the PE/guar gum ratios and decreases with temperature more apparently for sample DE₄, exclusively stabilized by PE. Overall, it has been shown that hydrocolloids extracted from mango peel can be valorized as stabilizers in dressing-type emulsions.

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Ethical statement—studies in humans and animals

The authors declare that they no used in this studies the humans and animals.

CRediT authorship contribution statement

Ronald Marsiglia-Fuentes: Writing – review & editing, Methodology, Investigation. **José M. Franco:** Writing – review & editing, Resources, Conceptualization. **Luis A. García-Zapateiro:** Writing – original draft, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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