Rheological and thermal study of structured oils: avocado (*Persea americana*) and sachá inchi (*Plukenetia volubilis* L.) systems

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Revised: 9 October 2018 / Accepted: 6 November 2018 / Published online: 10 December 2018
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Abstract Rheological and thermal characterization was performed in emulsions formulated from avocado oil and sachá inchi oil structured with soy lecithin, glyceryl monostearate and shortening (palm oil). For oleogel formulations, a completely randomized factorial design was considered to study the effect of the type of emulsifier and the proportions of avocado and sachá inchi oils. The rheological results indicated pseudoplastic behavior with semisolid characteristics. Additionally, the phase change studies showed two endothermic events corresponding to melting points from -20.15 to -18.94 °C and from 40.25 to 61.04 °C. The formulation with a ratio of avocado oil to sachá inchi oil of 80/20 and prepared using glyceryl monostearate as an emulsifier was evaluated as the best treatment and had an increased consistency coefficient and an increased loss tangent ($\delta < 0.5$).

Keywords Emulsion · Rheology · Oil · Phase transitions

Introduction

Industrialization has produced many changes in people's eating habits and lifestyles worldwide, where factors such as a sedentary routine and the consumption of unhealthy foods have increased the population suffering from non-communicable diseases (NCDs), in which obesity, diabetes mellitus, cardiovascular problems, hypertension, and cancer, among others, are highlighted (WHO/FAO 2003). The risk of chronic diseases is increasing as more processed foods rich in fats, sugars or high trans fatty acids (AGT) are added to industrial production. AGTs, generally known as “trans fats”, are formed during the partial hydrogenation of liquid vegetable oils to form the semi-solid fats that are used in margarines, cooking oils and many processed foods (Uauy et al. 2007). However, recent studies have shown that consumption of foods rich in trans fats, salt and carbohydrates favors weight gain and risk factors for NCDs (WHO/FAO 2003).

The reduction of trans-unsaturated and saturated triglycerides is one of the main challenges being faced by the food industry. Oleogelation is a novel way to provide structure to liquid oils which is based on the use of the so called “organogelators” whose systems are of interest to food companies who manufacture foods such as polyunsaturated margarines and spreads (Kaushik et al. 2017). These molecules provide solid-like structure with viscoelastic properties to oils at low concentration ($\leq 10\%$ w/w) although containing little amounts of saturated fatty acids, where an oil phase is trapped by a self-sustaining three-dimensional network of the structuring agent (Patel et al. 2014). A nontraditional way to structure oil with reduced levels of Trans and saturated fatty acids is based on the use of structurants which have potential of replacement of the natural network of TAG structure in the

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native fat by different strategies of oleo gel formation: crystalline particle, fibril network, particle fillers, liquid crystalline esophase and polymer network (Kaushik et al. 2017). The use of organogels in food products is a very attractive alternative, as these compounds can ensure characteristics such as consistency and plasticity with absence of TFA, and a significant reduction of the SFA content, resulting in products of strong nutritional and technological appeal (Rogers et al. 2009).

Avocado oil is rich in mono-unsaturated fatty acids and tocopherols that have great benefit when are consumed. It is an important source of vitamins, containing 12 of the 13 existing vitamins, as well as minerals such as magnesium, phosphorus, copper, iron and calcium (Tovar 2003). The sachá inchi oil (*Plukenetia volubilis* L.) obtained from the seeds of this oilseed plant is characterized by a high percentage of polyunsaturated fatty acids, primarily linolenic and linoleic, which represent 82% of the total content of oil (Chirinos and Domínguez 2015). A higher tocopherol content has been reported in sachá inchi oil than in other oilseeds (e.g., peanut, palm, soybean, maize and sunflower), as well as the presence of significant amounts of phytosterols (Chirinos and Domínguez 2015).

Various products prepared from oils and fats are widely used in the preparation of various dishes as food additives; they are also used as flavor additives and taste modifiers. In addition, the extraction and production of vegetable fats and oils and their transformations constitute an industrial sector of great economic importance; of these, the production of margarines and spreads, high-consumption products, are outstanding. Given the health consequences of an unhealthy diet with a high trans-fat content, food alternatives for health care have been developed, including natural foods with the lowest intake of carbohydrates and saturated fats. The use of avocado oil and sachá inchi is a viable option that meets these conditions.

Given the scarce information related to the characterization of emulsions (w/o) using combined systems of sachá inchi oil and avocado oil for the development of margarines and/or spreads, the objective of this study was to evaluate the effect of the addition of emulsifiers such as soy lecithin and glyceryl monostearate (spandex 80) and a vegetable fat (palm oil or shortening) on the rheological and thermal behavior of a structured oleogel.

Materials and methods

Materials

Avocado oil (*Persea americana*) was supplied by Terravocado S.A. (Medellín Colombia), sachá inchi oil (*Plukenetia volubilis*) by a local producer from the

Colombian Amazonia region, and animal shortening from Tecnas S.A. (Medellín Colombia). In addition, emulsifiers such as lecithin (LC) and glyceryl monostearate (ME) and food-grade preservatives such as citric acid, salt and TBQH were obtained from Bell Chem International S.A. (Medellín Colombia).

Formulation of emulsions

In the emulsion preparations (w/o), the lipid phase consisted of avocado oil/sachá inchi oil, shortening and TBQH, and the aqueous phase consisted of pasteurized water, to which preservatives such as sodium chloride and citric acid were added, which are particularly water soluble. The emulsions were thermally homogenized at 50 °C to favor mixing. The proportion of each component was measured by weight to avoid errors due to volume variation by temperature.

In this study, the ratio (w/o) was 20/80, where 30% of the oil phase in all samples corresponded to shortening. Additionally, the concentration of the additives and preservatives such as citric acid and sodium chloride was set at 1% w/w. In the LC/ME mixture the amount of emulsifier added was defined in 1% (0.5% for each one). Homogenization of the two phases was performed using an Ultra-Turrax T25y homogenizer, and tests were performed to determine the optimal values of the variables that were fixed in the preparation of the emulsions: homogenization temperature (50 °C), stirring speed (4000 rpm) and time (10 min).

Experimental design

A completely randomized 3 × 3 experimental design performed in triplicate was established according to Table 1. Experimental data were analyzed statistically at a

Table 1 Oleogel formulations according to the experimental design

Run	Factors	
	Ratio: avocado/sachá inchi oils	Type of emulsifier
E1	70/30	ME
E2	90/10	LC/ME
E3	70/30	LC/ME
E4	70/30	LC
E5	80/20	LC/ME
E6	90/10	LC
E7	90/10	ME
E8	80/20	ME
E9	80/20	LC

significance level of 5% using Statgraphics Centurion XVII software (version 17.1 12, USA).

Rheological measurements

Rotational rheology test

The flow curves were determined in a viscometer (Brookfield, DV-III Ultra, USA), using a concentric cylinder geometry (SC4-21, 2.5 cm diameter) at 25 °C, over a shear rate range from 0 to 100 s⁻¹. To eliminate the history of the samples, two ascending curves and one descending curve were recorded consecutively, using the second reference ascending curve for the rheological analysis. Flow curves were performed in triplicate, and the results were adjusted to different rheological models such as Newton (Eq. 1), power law (Eq. 2), Herschel–Bulkley (Eq. 3) and Casson (Eq. 4):

$$\sigma = \mu(\dot{\gamma}) \quad (1)$$

$$\sigma = K(\dot{\gamma}^n) \quad (2)$$

$$\sigma = \sigma_0 + K(\dot{\gamma}^n) \quad (3)$$

$$\sigma^{0.5} = (\sigma_0)^{0.5} + K(\dot{\gamma}^{0.5}) \quad (4)$$

In these models, n is the flow index (dimensionless), μ is viscosity (Pa s), K is consistency coefficient (Pa s ^{n}), σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (1/s) and σ_0 is yield stress (Pa). The adjustment of various rheological models was studied by regression analysis, and the goodness of fit was based on the coefficient of determination (R^2) and the mean square error (MSE).

Oscillatory rheology test

The viscoelastic measurements were performed within the linear viscoelasticity range using a controlled strain deformation rheometer (Anton Paar, MCR 302, Austria) with a plate-plate geometry with a 25-mm plate diameter and 1 mm plate spacing. To ensure that the viscoelastic variations were in the linear range, for each sample, previous tests were used to choose the value of the amplitude of the deformation. Thus, the frequency sweep between 0.1 and 100 Hz has been selected to execute the experimental work. Rheological tests were performed at 25 °C with three replicates per test. The elastic modulus (G') and viscous modulus (G'') were fitted to a power law model (Eqs. 5, 6), where K' , K'' , n' and n'' are constants and ω is the angular frequency. The loss factor ($\tan \delta = G''/G'$) was estimated at 0.1 Hz to evaluate the effect of the type of emulsifier and the ratio of oils on the stability of the emulsions.

$$G' = K'(\omega)^{n'} \quad (5)$$

$$G'' = K''(\omega)^{n''} \quad (6)$$

Thermal characterization

To determine the phase changes, we used differential scanning calorimetry (DSC) using TA Q2000 equipment (TA Instruments, New Castle, Delaware). Approximately 5 mg of sample (structured oil) was covered in a sealed aluminum vessel, and the sample was heated from – 100 to 100 °C at a heating rate of 10 °C/min. The thermal analysis was processed using TA Universal Analysis 2000 software (TA Instruments, New Castle, Delaware). Each sample was performed in duplicate.

Results and discussion

Characterization of rotational rheology

The rheological data obtained for the various emulsions were adjusted to the Newton, Power Law, Herschel–Bulkley and Casson models. The models (Non Newtonian fluid) were found statistically significant ($p < 0.05$) with a high regression coefficients. The Herschel Bulkley model that relates three parameters, estimated negative values to yield stress, which is physically meaningless. The Newton model presented a regression coefficient in the range between 0.557 and 0.949, Casson from 0.947 to 0.994. The power law was the model that best fitted the experimental data with the highest regression coefficient (R^2) and lowest mean error squares (CME).

Analyses of the rheograms indicated that the different formulations are non-Newtonian, where the best goodness of fit was found for the power law model, which represents the highest regression coefficients ($R^2 > 0.97$) and lower values for the mean squared error (MSE). However, studies performed for unstructured avocado oils obtained from two different varieties (de Tamara et al. 2015) presented Newtonian behavior, where the shear stress is a linear function of the shear rate. Vegetable oils are typical examples of Newtonian fluids with an independent shear rate viscosity but temperature dependence (Steffe 1996). In the present study, the emulsions formulated do not present Newtonian behavior. This particular behavior is due to the addition of high-molecular-weight emulsifiers, which in addition to promoting the development of a network and stabilizing the emulsion, cause a decrease in the flow index (n) in their pseudoplastic response (de Tamara et al. 2015).

The emulsions formulated showed a non-Newtonian behavior of a pseudoplastic nature ($n < 1$), where the

materials described under this model have decreased viscosity as the shear rate increases. Similar studies have explained the behavior of emulsions (w/o) using the power law model in food systems where the oil phase was mainly composed of avocado oil and watermelon seed oil (Logaraj et al. 2008) and in emulsions (w/o) using lecithin as an emulsifier (Bhattacharya et al. 1998).

Figure 1a, b shows the flow curve and rheogram for different formulations indicating a shear thinning behavior characteristic of pseudoplastic fluids. These results have been supported by other researchers for emulsion (w/o) systems (Haj-shafiei et al. 2013). The authors state that at high shear rates, differences in apparent viscosity between emulsions were lower than at low shear rates. This was due to the structural breakdown and the shear rate-induced reordering, a behavior that is visualized in this study. Figure 1b shows a higher viscosity value for emulsions with a ratio of oil of avocado and oil of sacha inchi 80/20 and using ME as an emulsifier treatment (Run E8). This response can be attributed to a higher solubility of glyceryl monostearate (ME) in the oil phase, generating a decrease in the diffusion of the dispersed phase in the continuous phase and delaying the processes of flocculation and coalescence (Moran-Valero et al. 2017).

Table 2 Parameters of adjustment to the power law model for the factorial design of structured emulsions

Type of formulation	Consistency index (K) (Pa s ⁿ)	Flow index (n)	Coefficient of determination (R ²)
E1	9.16	0.70	0.99
E2	7.80	0.70	0.99
E3	4.20	0.74	0.99
E4	3.74	0.77	0.99
E5	8.63	0.63	0.91
E6	3.78	0.78	0.99
E7	6.59	0.74	0.99
E8	21.68	0.53	0.99
E9	4.10	0.76	0.99

Table 2 shows the values for the adjustment parameters of the power law model (consistency index, k, flow index, n). The ANOVA test at the 5% significance level showed that the factors separately, as well as their interaction, have a statistically significant effect. The test of means through the Fisher LSD method yields a higher value of K and a smaller value of n when used the emulsifier was glyceryl monostearate (ME) with an oil ratio of 80/20. The solubility of the glyceryl monostearate (ME) in the oily phase

Fig. 1 Rheological behavior of emulsions: flow curves (a) and rheogram (b)

allows an increase in the apparent viscosity, revealing a greater effect of the emulsifier in reducing the surface tension between the two phases (Fennema 2006). Lecithin (LC) molecules contain one hydrophobic and one hydrophilic part. The phosphate group and the nitrogen base interact with the aqueous phase, whereas the hydrocarbon chains do so with the lipid, resulting in closer physical contact between the two immiscible phases (Badui 2006). The LC component to its emulsifying ME and their hydrophilic and hydrophobic molecular groups to the fatty acid interacts with the oil phase, while the groups (OH) interact with the aqueous phase. Increases in the firmness and stability of the emulsions may be due to the non-polar part of the emulsifier molecules being absorbed at the interface of the oil droplets, reducing the surface tension and therefore the tendency to coalesce.

Moran-Valero et al. (2017) suggest that at the interface, the ME would be pushed into the oil phase and lecithin would prevail on the surface of the oil droplets. As ME is slightly more hydrophobic (HLB 3.8) than lecithin (HLB 4), in forming the emulsion from emulsifiers dissolved in the oil phase, ME could remain mainly in the continuous phase, with lecithin at the surface interacting with water along the phosphocholine head groups. However, it is possible that emulsions prepared with ME produce a more consistent gel due to the formation of a stronger three-dimensional network at low temperatures ($T < 40\text{ }^{\circ}\text{C}$) (Lupi et al. 2017) did not find statistically significant differences in the consistency index (K) in peanut butter using sorbitan monostearate and glyceryl monostearate (ME) as emulsifiers, both of which produced a product of stability and adequate consistency.

The flow index (n) is indicative of the degree of shear thinning of the material, which indicates a decreases in viscosity by increasing the shear rate (Lupi et al. 2011; Thaiphani et al. 2016). In Table 2, emulsions prepared with LC as emulsifier showed a constant value for the flow index (n), and similar results were obtained in emulsions (w/o) (Bhattacharya et al. 1998), where the lowest rates were for emulsions prepared with glyceryl monostearate (ME).

Viscoelastic characterization

The storage modulus G' and the viscous modulus G'' are used to evaluate whether the emulsion is strong or weakly flocculated, and in the second case, if it behaves as a liquid (Thaiphani et al. 2016). Figure 2a, b presents the storage modulus and viscous modulus at $25\text{ }^{\circ}\text{C}$ as a function of frequency (frequency sweep) for emulsions using different emulsifiers and oil ratios. In all the emulsions the elastic character always predominated over the viscous character ($G' > G''$), and therefore, the evaluated emulsions behave

more like a semi-solid. This type of behavior occurs in the majority of suspensions with a network structure, characteristic of emulsions (w/o) (Kowalska and Krzton-maziopa 2015). Similar results were reported in emulsions (w/o), where the oil phase was structured by olive oil (Lupi et al. 2016). To perform the respective statistical analysis, the frequency was set at 0.1 Hz, and the multivariate ANOVA test determined that the separate factors and their interaction have a statistically significant effect ($p < 0.05$) on the storage modulus, whereas the viscous modulus is affected by the type of emulsifier.

For means differences, higher values were obtained for the storage modulus when the emulsions were prepared with a ratio of 70/30 oils and used as an LC/ME emulsifier. Emulsions prepared with a higher fraction of sachá inchi oil tend to exhibit greater stability and greater resistance to flocculation. This was likely because the sachá inchi seed and the lipid fraction of the avocado pulp are rich in polar lipids such as phospholipids, which act as a natural surfactant and are widely used in practice to prepare emulsions (o/w) and (w/o) (Valenzuela 2014). However, other studies have reported that the addition of lecithin regulates the stability of the prepared emulsions due to the reduction of stress at the interface (Kowalska and Krzton-maziopa 2015). Similar results were obtained in emulsions prepared from sunflower oil to obtain oleogels with margarine-like properties (Palla et al. 2017), or wax-stabilized and in w/o emulsions (Haj-shafiei et al. 2013).

The parameters K' , K'' , n' and n'' of the viscoelastic components were fitted to a power law model (Eqs. 5, 6) to evaluate the effect of the ratio of oils to the type of emulsifier. The estimated models were statistically significant ($p < 0.05$), and the determination coefficients were relatively high ($R^2 > 0.96$). Because the magnitudes of $K' > K''$ and the values of n' and n'' were low but non-zero, the rheological behavior of the emulsions can be defined as “weak gels” (Rao 2006), and similar results were reported in emulsions (o/w) (Bortnowska et al. 2014). The set values for K' and K'' ranged from 1.1×10^{-3} to 2.9×10^{-2} Pa s $^{n'}$ and 8.3×10^{-5} to 2.8×10^{-4} Pa s $^{n''}$, respectively. Similar order values were reported for food (o/w) emulsions (Bortnowska et al. 2014) and fishmeal hydrated instant creams (Barragán et al. 2016); values for n' and n'' ranged from 2.08 to 3.93 and from 2.4 to 2.8, respectively. These values are far from zero and had magnitudes similar to those reported in Barragán et al. (2016). The ANOVA test at the 5% significance level showed that the type of emulsifier has a statistically significant effect for K'' and n'' , while K' is affected by the ratio of oils, n' is not affected by any factors. The test of differentiation of means through the Fisher LSD method evidences a lower value of K'' using ME, a higher value of K' for 70/30 ratio of oils and a smaller value of n'' with LC. More stable emulsions (K''

Fig. 2 Viscoelastic behavior of w/o emulsions: elastic modulus (a) and viscous modulus (b)

K' values) are obtained when ME is used because the anionic emulsifiers generally produce smaller droplet size systems, with a high viscosity that is considered important for the desired attributes in the final product (Baby et al. 2008). However, higher values were obtained for K' for a ratio of 70/30 oils, which coincides with that obtained for the storage modulus G' . This is due to the presence of phospholipids in the sacha inchi oil. It is therefore inferred that the elastic component is more frequency dependent than the viscous component because $n' > n''$ (Agara et al. 2016). This behavior is clearly observed when the emulsions are subjected to high frequencies (> 30 rad/s). At high frequencies, the slope of G' approaches G'' , showing an increase in the viscosity for the emulsions because larger numbers of droplets are generated and the movement of the droplets is limited by nearby droplets (Ruiwen et al. 2013). The effect of the frequency and the $G' > G''$ domain has been shown to be typical in w/o emulsions (Razmkhah et al. 2017).

The values of the tangent or loss factor ($\tan \delta$) as a function of the frequency were always less than unity ($\tan \delta < 1.0$), confirming the behavior as a viscoelastic gel of the emulsions. The loss factor is considered a relevant measure of emulsion stability, and it has been found that

when $\tan(\delta) < 0.5$, values are less susceptible to phase separation (Rao 2006). A similar trend in the variation of $\tan(\delta)$ is found in (w/o) of emulsions, structured through the oil phase crystallisation by organogelator agents (mono- and di-glycerides of fatty acids). The oil phase was prepared by blending a high-oleic-acid-containing oil (olive oil) with a natural saturated fatty acids source (cocoa butter) (Lupi et al. 2011). The decreases in loss factor at high frequencies confirm the predominance of the elastic component associated with the incorporation of emulsifiers. If the droplets are not sufficiently coated by the emulsifier, they could coalesce again (Fennema 2006).

The behavior of the viscoelastic parameter $\tan(\delta)$ was analyzed at 25 °C by setting the frequency of 0.1 Hz to evaluate the physical stability of the emulsions. Statistical analyzes indicated that the type of emulsifier significantly influenced the $\tan \delta$ behavior ($p < 0.05$), while the oil ratio was not significant, maintaining the $G' > G''$ trend. The results obtained by Moran-Valero et al. (2017) suggest that in the interface, the ME is pushed to the continuous phase, generating interactions. The alcoholic part of the molecule is hydrophilic, and the fatty acid part is lipophilic, generating an increase in the viscosity of the emulsion. The rheology of the film may affect the stability of emulsions

Fig. 3 Melting curves obtained by applying DSC to emulsions E5 (a), E7 (b) and E8 (c)

(Zinoviadou et al. 2012) because emulsions with lower $\tan \delta$ values may be more resistant to coalescence (Moore Peter et al. 1998).

It can be inferred that desirable rheological properties are perceived as having good consistency ($K > 18.6 \text{ Pa s}^n$) and a viscoelastic gel ($\tan \delta < 0.5$) at 25 °C for emulsions with a ratio of oil of avocado and oil of sachá inchi of 80/20 using ME as an emulsifier treatment. In addition, pseudoplastic behavior ($n < 1$) and a significant increase in the viscosity of the continuous phase are perceived in the same emulsion. Baby et al. (2008) argue that the ability to increase the viscosity of the continuous phase enhances the emulsifier properties of the ME, forming a stronger gel-like structure that confers stability to the food suspensions.

Phase transitions

For all emulsions, thermograms were obtained by DSC, where fusion events were clearly distinguishable, as shown in Fig. 3 for the emulsions E5, E7 and E8. The first event was detected at low temperature from -20.15 to -18.94 °C. This event was associated with the presence of unsaturated fatty acids such as oleic, linoleic and linolenic acid, which are present in avocado and sachá inchi oil (Perez-Monterroza Ezequiel et al. 2014), as well as olein, which is present in palm oil (Tan and Man 2002). The second event was perceived at high temperature from 40.25 °C to 64.21 °C. This behavior can be attributed to the fraction of stearin present in shortening composed of palm oil and specifically to saturated fatty acids such as 1,3-dipalmitoyl glycerol 2-oleoyl (POP). These results are consistent with those reported by other researchers for palm oil (Tan and Man 2002). However, in studies of oleo-structured olive oil with monoglycerides (MGs) as an emulsifier, the melting temperature was close to 65.02 ± 0.43 °C and 16.64 ± 0.31 °C (Lupi et al. 2016), so that the wide range of fusion at high temperatures is possible due to saturated fatty acids from palm oil. No statistically significant differences were found in the variation of the type of emulsifier and the ratio of oils for the first melting point Tf1 and second melting point Tf2, either for the different formulations or for the heat of fusion at the second phase change point Hf2. However, for the heat of fusion at low temperature Hf1, statistically significant differences were found ($p < 0.05$) for the ratio of oils, the type of emulsifier and their interaction.

The means differentiation test using the Fisher LSD method shows that the lowest melting points values are obtained (i.e., melt in a narrower temperature range) when a 90/10 oil ratio and ME as emulsifier are used. This behavior can be explained by the fact that avocado oil has a higher content of oleic acid (Perez-Monterroza Ezequiel et al. 2014), whereas sachá inchi has higher

polyunsaturated content than linolenic acid (Maurer et al. 2012). Oils with a high content of mono-unsaturated fatty acids such as oleic acid melt almost immediately and in a narrow temperature range, while those containing low oleic acid do not instantaneously melt, in agreement with the work of (Jiménez Márquez and Beltrán Maza 2003) with olive oil. Since ME melts above 50 °C, it is likely that at lower temperatures, it does not affect the melting of the fatty acids. Other studies have shown that MGs such as ME generate peaks with lower fusion temperatures and melting enthalpies due to the presence of oils in the emulsions that increase the solubility of the solid crystals (Kouzounis et al. 2017) and also to monoglycerides when heated above (57 °C). The hydrocarbon chain melts, favoring the melting of oils (Wang and Marangoni 2016).

Since the sachá inchi oil has a higher content of polyunsaturated fatty acids, which are more susceptible to oxidation, at a higher content of sachá inchi oil the fatty acids melt in a wider range due to the presence of lipid-oxidized cells that may hinder the transition of fatty acid crystals (Chiavaro et al. 2008). It is also known that the presence of fatty acids, partial glycerides and oil oxidation products tend to displace the melting range at lower temperatures (Tan and Man 2002).

Conclusion

This study has evaluated the effect of addition of emulsifiers and ratio of avocado and sachá inchi oils on the rheological properties and phase changes of emulsions. The oscillatory dynamic tests confirm the semi-solid behavior of weak gel characteristics, due to the predominance of the elastic modulus on the viscous modulus ($G' > G''$). For the emulsions prepared with glyceryl monostearate, lower values were observed for the flow index (n), which indicates a higher shear effect, but higher values for the consistency index reflect higher viscosities. The fatty acids melt in a narrower range using glyceryl monostearate as an emulsifier and an oil ratio of 90/10.

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