Ribes-Llop, S.; Fuentes López, A.; Barat Baviera, JM. (2021). Physical stability, rheology and microstructure of salad dressing containing essential oils: study of incorporating nanoemulsions. British Food Journal. 123(4):1626-1642. https://doi.org/10.1108/BFJ-09-2020-0777

Physical stability, rheology and microstructure of salad dressing containing essential oils: study of incorporating nanoemulsions

Abstract

Purpose - This study aims to evaluate the effect of adding oregano and clove oil-in-water (O/W) nanoemulsions on the physico-chemical, technological, and microstructural properties of minimally processed salad dressings during storage at 8 ºC and 25 ºC.

Design/methodology/approach - Samples were formulated with either free or encapsulated oregano and clove essential oils in O/W nanoemulsions.

Findings - Noticeable differences in the physical stability and microstructure of salad dressings were observed after 11 storage days, and were less marked for the samples formulated with encapsulated oregano or clove oils in the O/W nananoemulsions. Moreover, rheological measurements revealed minor changes in the viscoelastic characteristics of the salad dressings containing the O/W nanoemulsions.

Originality/value - These findings confirm the potential of oregano and clove O/W nanoemulsions for use in minimally processed salad dressings as stabilising and technological agents.

Keywords: Essential oils; Oil-in-water nanoemulsions; Sauces; Stability; Rheology

1. Introduction

In recent years, food processors have paid growing attention to salad dressings because they improve the attractiveness and tastiness of different food commodities (de Melo *et al.,* 2015). Salad dressings can be defined as oil-in-water (O/W) emulsions in which small droplets are dispersed in an aqueous phase. Salad dressings' physical stability is very closely related to their ability to maintain structural integrity over time (McClements, 1999). To this end, several thickening agents like pectin, starch, xanthan gum or carrageenan have been used to confer dressings long-term stability (da Fonseca *et al.,* 2009; Paraskevopoulou *et al.,* 2007). Moreover, commercial salad dressings are composed of other ingredients like weak organic acids, chelators and preservatives to dressings' overall stability. However, increasing consumer demands for "clean label" foods have forced manufacturers to search for naturally-occurring alternatives that guarantee product stability and safety (Ribes *et al.,* 2019).

The use of plant extracts has attracted the interest of both academia and food industry fields thanks to their functional properties (Valduga *et al.,* 2019). These include essential oils (EO), which belong to one of the most promising classes of functional ingredients given their natural character and acceptability by consumers, which make them desirable for use in foods (Burt, 2004; Ribes *et al.*, 2016). Nevertheless, their poor water solubility, high volatility and sensitivity to oxygen and light limited the application of EO to food products. Nowadays, one of the most effective technologies to improve the solubility and stability of EO is their encapsulation in O/W nanoemulsions due to their small particle sizes, increased surface area, and less sensitivity to physico-chemical changes (Bazana *et al.,* 2019). Recently, Ribes *et al.* (2019) evidenced the antifungal effect of oregano and clove nanoemulsions in salad dressings. However, the addition of O/W nanoemulsions to minimally processed salad dressings as systems to improve their physico-chemical and technological characteristics during storage has not yet been investigated.

Hence the main objective of this work was to evaluate the effect of incorporating oregano and clove O/W nanoemulsions on the physico-chemical, technological, and microstructural properties of minimally processed salad dressings during storage time.

2. Materials and Methods

2.1 Materials

For salad dressing formulations, sunflower oil (La Masia, Spain), vinegar (Alcampo, S.A., Madrid, Spain), pasteurised egg yolk (Calidad Pascual, S.A.U., Madrid, Spain), sugar (Acor, Sociedad Cooperativa General Agropecuaria, Valladolid, Spain) and sodium chloride (Sal Bueno, S.L., Xirivella, Spain) were purchased from a local Spanish market. Soluble starch and citric acid were obtained from Sigma-Aldrich (Madrid, Spain).

To prepare O/W nanoemulsions, oregano EO was obtained from Ernesto Ventós S.A. (Barcelona, Spain), and clove EO and Tween 80 were supplied by Sigma-Aldrich (St. Louis, USA). Xanthan gum (XG, Satiaxane^{TM} CX 911) was purchased from Cargill (Barcelona, Spain).

2.2 Preparing oregano and clove nanoemulsions

The O/W nanoemulsions were prepared by mixing oregano or clove EO, Tween 80 and XG for 15 min by a magnetic stirrer. The mixture was processed at 50 MPa by a High-Pressure Homogenisation (HPH) system (Panda Plus 2000, Gea Niro Soavi S.p.A., Parma, Italy). The O/W nanoemulsions contained 10 mg/g of Tween 80 and 5 mg/g of XG. The amount of oregano and clove EO added to the O/W nanoemulsions was calculated to achieve a final concentration of 1.95 mg/g in the salad dressing. These concentrations were established according to the results achieved in a previous work (Ribes *et al.,* 2019).

2.3 Manufacturing salad dressings

Five salad dressing types were prepared in this study: i) control; ii) two salad dressings containing 1.95 mg/g of free or encapsulated clove EO in O/W nanoemulsions; iii) two salad dressing containing 1.95 mg/g of free or encapsulated oregano EO in O/W nanoemulsions.

Minimally processed salad dressings were prepared by mixing deionised water (50% w/w), sunflower oil (30% w/w), vinegar (10% w/w), pasteurised egg yolk (3% w/w), starch (5% w/w), sugar (1% w/w), sodium chloride (0.50% w/w) and citric acid (0.50% w/w) in an electrical food processor (Thermomix TM 31, Vorwerk M.S.L, Spain). The free and encapsulated oregano or clove EO was incorporated into salad dressings before being homogenised to reach a final EO concentration of 1.95 mg/g. The amount of nanoemulsion added to salad dressing was calculated to reach the previously indicated EO concentration. Samples were poured into sterilised glass containers and stored at 8 °C and 25 ºC until analysed after 1 day and 11 days. Each formulation was manufactured twice and all the analyses were run in triplicate.

2.4 Physico-chemical characterisation of salad dressings

A Crison Basic 20+ pH meter (Crison S.A. Barcelona, Spain) was used to measure the pH of salad dressings. For the total titratable acidity (TTA) determinations, 10 g of each sample were mixed with 40 mL of distilled water and titrated with a 0.1 N NaOH solution until a pH value of 8.30. Total titratable acidity was expressed as g acetic acid/100 g of dressing. The water activity (a_w) of samples was measured by an Aqualab dew point hygrometer model 4 TE (Decagon Devices, Inc., Washington, USA) at 25 ºC. The sodium chloride analysis was carried out by an automatic Chloride Analyser (Sherwood Scientific Ltd., Cambridge, UK) and the results were expressed as g NaCl/100 g of sample.

To study the stability of salad dressings against creaming, 5 g of each sample were transferred to a cylindrical glass container, sealed with a plastic cap and stored until analysed. The extent of creaming was calculated by employing Eq. (1):

$$H\% = (H_t/H_0) \times 100 \qquad (1)$$

where H_t represents the visible separation layer and H_0 is the initial emulsion height.

Finally, the colour parameters (L*, a*, and b*) of salad dressings were measured by a spectrocolorimeter (CM-3600d, Minolta Co., Tokyo, Japan) with an observer 10º and illuminant D65. The Whiteness index (WI) was calculated by Eq. (2) and colour variations (ΔE*) by Eq. (3):

$$WI = 100 - ((100 - L^*)^2 + a^{*2} + b^{*2})^{0.5} \qquad (2)$$

$$\Delta E^* = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{0.5} \qquad (3)$$

2.5 Rheological and viscoelastic measurements of salad dressings

The rheological and viscoelastic measurements of salad dressings were taken by a stress controlled rheometer RS1 (ThermoHaake, Karslruhe, Germany). Assays were performed at 8 °C and 25 °C using a C60/2°Ti cone-plate geometry with a 2 mm gap. Samples were allowed to stand for 300 s for structure recovery and temperature equilibration purposes before being tested.

2.5.1 Steady shear rheological tests

The steady shear rheological tests were performed within the 0.01-200 s^{-1} range for 120 s. To avoid any possible dependence on flow time, a 4-step operation (two upward, two downward curves) was applied to samples. The flow curve was fitted to the power law model, and consistency (K) and flow behaviour indices (n) were calculated (Ma *et al.,* 2013). The apparent viscosity (η_{app50}) values were calculated according to Eq. (4):

$$\eta_{app50} = (K \times 50^{n-1}) \tag{4}$$

2.5.2 Dynamic rheological tests

To determine the linear viscoelastic region (LVR), stress sweeps were performed within a stress range from 0.01 to 10 Pa at 1 Hz. Frequency sweep tests were conducted at 1 Pa (in the LVR) to cover a 0.1-10 Hz frequency range. The viscoelastic parameters, particularly elastic or storage modulus (G'), viscous or loss modulus (G''), complex viscosity (|η*|) and loss tangent (Tan δ), were obtained from the rheometer software (RheoWin 3 Data Manager).

2.5.3 Creep and recovery tests

Creep and recovery tests were carried out by applying a constant stress (1 Pa within the LVR) for 180 s. Afterwards, stress was stopped and samples were released for recovery for 180 s. The system's final percentage of recovery (*R*) was calculated by employing Eq. (5):

$$R\ (\%) = (J_{max} - J_{\infty} / J_{max}) \times 100 \tag{5}$$

where J_{max} is the maximum deformation corresponding to the compliance value for the longest time (180 s) in creep rest; J_{∞} is the residual deformation (Kurt *et al.,* 2016).

2.6 Microstructure analysis of salad dressings

The microstructural features of the different salad dressings were evaluated by optical microscopy under a Motic BA310E trinocular light microscope equipped with a Moticam3+ camera (Motic Group, Kowloon, Hong Kong). Micrographs were obtained at the 40x magnification.

2.7 Statistical analysis

The data obtained in the physico-chemical and technological characterisation of salad dressings were analysed by a multifactor analysis of variance (multifactor ANOVA) to evaluate differences among formulations, storage days, and their interaction. The least significance procedure (LSD) was employed to test for differences between averages at the 5% level of significance. The results were statistically processed by the Statgraphics Centurion XVI software.

3. Results and Discussion

3.1 Physico-chemical characterisation of salad dressings

Table I shows the changes in the pH, a_w, TTA, NaCl content and stability of the different salad dressings.

Salad dressings are considered creamy pale yellow products with a pH range of 3.2 to 3.9, being all the formulations evaluated within this range. The main factor in salad dressings that causes death to pathogenic bacteria is low pH, allowing commercial salad dressings do not undergo a heat treatment step. The target pH for dressings and sauces is usually below the 4.75 pKa of acid acetic, which suffices to stop most pathogens and spoilage organisms from growing (Smittle, 2000). It is highlighted that slightly lower pH values were noticed in the samples manufactured with 1.95 mg/g of encapsulated oregano and clove EO in O/W nanoemulsions. This decrease could be related to the acid nature and dissociation in the aqueous solution of some EO compounds as a result of encapsulation (Ribes et al., 2017; Sánchez-González *et al.,* 2011). Furthermore, the pH values of all the samples significantly lowered ($p<0.05$) after 11 storage days, and were less marked in the salad dressing kept refrigerated.

The a_w values remained quite stable throughout the evaluation period in spite of the dressing formulation and storage conditions (Table I). Similar results have been reported by Fernandez *et al.* (2012) for low-in-fat dressings prepared with high-pressure homogenised yeast.

For the TTA values, noticeable differences were found among samples' formulations. The salad dressings containing free or encapsulated oregano and clove EO exhibited lower acidity than the control ones. At the end of the study, a slight rise in the TTA values of the non-encapsulated oregano and the clove EO was perceived compared to the encapsulated EO, regardless of storing temperature. The latter may suggest that the encapsulation of oregano and clove EO in O/W nanoemulsions would display greater antioxidant activity in salad dressings owing to preservation and progressive emission to the matrix during the assessed time.

Concerning the evaluation period, slightly higher TTA values were observed for the salad dressings stored for 11 days (Table I). In line with this, Abu-Salem and Abou-Arab (2008) reported higher acid values for mayonnaise with storage time due to the activity of hydrolytic and oxidative enzymes present in eggs.

Adding salt to salad dressings could destabilise protein-stabilised emulsions due to the reduced electrostatic repulsion among droplets and the modification of the hydrophobic interactions between non-polar amino acids residues, which changes the structural organisation of water molecules at the interface (Martínez *et al.,* 2007; Srinivasan *et al.,* 2000). Srinivasan *et al.* (2000) pointed out that emulsion low stability was generally found in either salt-free emulsions or emulsions containing small amounts of salts (i.e. 0.4%), except for those systems stabilised by high egg yolk contents. Thus, as the concentration of all the dressings herein formulated was 0.50 g NaCl/100 g of product (Table I), we can state that the salad dressing rates would not lead to their destabilisation.

In relation to sample stability, no creaming phenomenon was detected in any formulation after 1 storage day at both temperatures. Conversely, creaming was clearly perceived after 11 storage days, and was more marked for the samples kept refrigerated. Early studies reported that temperature was an important factor in salad dressing stability during storage. Palanuwech and Coupland (2003) observed how low temperatures could cause the crystallisation of the two emulsion phases, which could destabilise O/W emulsions like salad dressings. The greatest instability was noticed for the control sample and the least for the encapsulated EO. The stabilisation action of XG, given the viscosity modification in the continuous phase with lower creaming and coalescence rates (Dickinson, 2009; Espert *et al.*, 2019), could contribute to the better stability of the samples containing the encapsulated EO. Several authors have attributed the creaming phenomenon to the overall oil volume fraction of the emulsion, its droplet-size distribution, and the nature of inter droplet interplays, including effects of non-absorbed polymers and surfactants (Guerra-Rosas *et al.,* 2016).

Regarding colour parameters, slightly lower L* and WI values were detected during salad dressings' storage time (Figure 1), which could be associated with samples' instability (McClements, 1999; Gavahian *et al.,* 2018). It is also important to highlight that the colour differences (ΔE*) of the salad dressings prepared with the encapsulated oregano and clove EO did not exceed the just noticeable difference (Baldevbhai and Anand, 2012). The higher ΔE* exhibited by the refrigerated control and samples containing free EO could be ascribed to these dressings' instability, caused by an increase in their average oil droplet size and/or oil droplet aggregation during storage time (Guerra-Rosas *et al.,* 2016).

3.2 Rheological and viscoelastic measurements of salad dressings

3.2.1 Steady shear rheological tests

Table II summarises the results of the rheological parameters from the steady shear tests of the different salad dressings. Higher K values were observed for the control sample throughout the study. Significant differences ($p<0.05$) were noticed between the K values of the samples prepared with the free and encapsulated EO during both storage periods. Incorporation of encapsulated EO improved salad dressings' consistency, probably due to the capacity of XG to increase the stability and structure of these products by forming larger sized aggregates in their continuous phase (Ma and Barbosa-Cánovas, 1995; Yüceer *et al.*, 2016).

Regarding the evaluation period, lower K values were generally detected in the dressings stored for 11 days at both temperatures. This could be explained by fewer interactions and entanglements among ingredients over time (Ma *et al.,* 2013). Ma and Boye (2013) also reported lower K values of salad dressings supplemented with pulse flours after 12 storage days. Indeed when comparing both temperatures, the K values of the samples stored at 25 ºC lowered more (Table II). Upon cooling, the polymer network present in food emulsions could lead to its chain arrangement and stretching (Bae *et al.,* 2008), providing more consistent products. This behaviour was also reported by Izidoro *et al.* (2008) in mayonnaises formulated with green banana pulp. The flow behaviour index (n) went below 1 in all the tested salad dressings, which indicates the pseudoplastic behaviour of the formulated samples (Primacella *et al.*, 2019). The n values remained quite stable for all the samples throughout the evaluation period in spite of the storage conditions (Table II). Our results fall in line with those reported in previous works (Ma and Barbosa-Cánovas, 1995; Izidoro *et al.,* 2008).

An increase in salad dressings' apparent viscosity (η_{app50}) was observed when incorporating encapsulated EO into O/W nanoemulsions, which could be attributed to the viscosity provided by EO and/or the polymer used to prepare the O/W nanoemulsion. It is well-known that even at low polymer concentrations, XG dispersions exhibit high viscosity values (Laneuville *et al.,* 2013). Despite the minor changes observed in the η_{app50} of the different manufactured salad dressings during the evaluation period, the strong repulsive forces between the oil droplets and other ingredients present in dressings could cause droplets to easily slide, which could generate less viscosity and/or make dressings prone to creaming emulsions (Depree and Savage, 2001). The latter could be connected to the instability of salad dressings during storage time, as previously observed when evaluating their stability (Section 3.1). Similar results were observed by Heggset *et al.* (2020) while evaluating the apparent viscosity of mayonnaises with cellulose nanofibrils as rheology modifiers over the storage time. Finally, slightly lower η_{app50} values were noticed in the samples stored at 25 ºC. These findings fall in line with the data obtained by Izidoro *et al.* (2008), who revealed that the apparent viscosity of all the tested mayonnaises decreased as temperature and the shear rate rose. This scenario could be associated with the structural breakdown of molecules due to the generated hydrodynamic forces and the increased alignment of constituent molecules.

3.2.2 Dynamic rheological tests

Figures 2-3 show the viscoelastic properties of the different manufactured salad dressings. For comparison purposes, the storage modulus (G'), loss modulus (G''), complex viscosity ($|\eta^*|$) and loss tangent (Tan δ) values were considered at a frequency of 1 Hz. A predominant elastic behaviour (G' > G'') was observed throughout the study, which is a common fact in weak viscoelastic systems (Park *et al.*, 2020). The control sample obtained significantly ($p<0.05$) higher G' and G'' values than the salad dressings formulated with the free and encapsulated oregano and clove EO in O/W nanoemulsions. The addition of EO (free or encapsulated) probably weakened the interaction among ingredients, as observed by Santipanichwong and

Suphantharika (2007) in reduced-fat mayonnaise. Moreover, slightly higher G' and G'' values were observed in the samples containing the encapsulated bioactive agents after 1 storage day, which can be probably attributed to the ability of XG to create molecular entanglements, as previously discussed.

Regarding storage temperature, the interactions among droplets were weaker in the samples maintained at 25 ºC, which led to lower G' and G'' values (Figure 2). The G' and G'' values of all the samples dropped during storage, which resulted in a weaker network structure. Ageing of salad dressings resulted in a decrease of the viscoelastic parameters (G' and G''), which suggests that droplet rearrangements continuously took place immediately after samples were prepared. Thus, storage could lead to increased shear sensitivity in the viscoelastic network of the manufactured salad dressings. A similar behaviour has been observed in other studies (Ma and Boye, 2013; Heyman *et al.,* 2010).

The control samples have higher |η*| values, followed by those samples prepared with the encapsulated and free oregano and clove EO (Figure 3). The differences between the samples containing the encapsulated and free bioactive agents were ascribed to the presence of XG, which had a thickening effect on salad dressings and increased their internal cohesive forces. Similar |η*| values were reported by Ariizumi *et al.* (2017) when studying the influence of processing factors on the stability of model mayonnaise with whole egg during long-term storage.

Tan δ indicates if elastic or viscous properties predominate in a sample (Ma and Barbosa-Cánovas, 1995). All the formulations had Tan δ values below 1, which reinforced the notion that elastic properties would prevail over viscous ones. The Tan δ values for all the formulations remained practically constant throughout storage at both 8 ºC and 25 ºC (Figure 3).

3.2.3 Creep and recovery tests

Figure 4 shows the creep and recovery curves of all the studied salad dressings. High *J* values indicate a weaker product structure (Sozer, 2009). The samples formulated with free EO presented the weakest structure, which led to greater deformation than the other dressings. The control sample and the dressings containing the encapsulated EO in O/W nanoemulsions reflected a more elastic behaviour. Thus, the addition of encapsulated EO to salad dressings reinforced their structure, probably due to interactions among the different ingredients composing the dressings and the XG used to prepare each nanoemulsion. These results agree with those observed in Section 3.2.2. Concerning storage time, the *J* values rose after 11 storage days. Hence product ageing caused their structure to soften owing to fewer interactions and enlargements among molecules. Indeed the lower compact packing of oil droplets in the dressing network could be responsible for the changes detected in samples' elastic properties and deformation resistance, which would also affect their stability. Lastly, this phenomenon became more evident at 25 ºC, which falls in line with the data obtained in the viscoelastic properties evaluation (Section 3.2.2).

Figure 5 presents the final percentage recovery (*R*) of the different manufactured salad dressings. The higher the degree of the recovery strain, the greater salad dressings' elasticity (Zhang *et al.,* 2008). Generally, all the samples exhibited good elastic properties at the beginning of the study with mean *R* rates between 45% and 60%, in spite of the storing temperature. However, slightly lower *R* rates were detected in the samples prepared with the non-encapsulated clove EO, probably due to their aforementioned fragility. Despite the differences found between samples, most of their strain was recovered, which was likely owing to the predominantly elastic behaviour of the manufactured dressings. Lower *R* rates were noticed at the end of the study, which reflects the decreased of the dressings to resist stress, probably due to the fewer interactions among their constituents.

3.3 Microstructure analysis of salad dressings

The microstructure of salad dressings were analysed to better understand the impact of adding free and encapsulated EO in O/W nanoemulsions on salad dressings' overall structure with time at 8 ºC and 25 ºC (Figure 6). In general, the control and salad dressings manufactured with the encapsulated oregano and clove EO showed a well dispersed oil-in-water structure characterised by the presence of highly packed oil droplets. On the contrary, the salad dressings containing the non-encapsulated oregano and clove EO exhibited a heterogeneous distribution of fat globules, which gave rise to the alteration to samples' microstructure. Therefore, the more the dispersed particles are, the less cohesive their structure is. This behaviour was also pointed out by Román *et al.* (2018) in sauce model systems.

During storage, noticeable changes in samples' microstructure were observed. Ageing negatively affected droplet size uniformity and distribution of the particles present in salad dressings, which were less marked in the samples containing the O/W nanoemulsions (Figure 6). Indeed more heterogeneous structures were seen after storing samples at 8 ºC for 11 days, which agrees with the observed stability data. Thus, it can be stated that salad dressing prepared with the encapsulated EO in O/W nanoemulsions are the most stable product.

4. Conclusions

The use of oregano and clove O/W nanoemulsions to prepare minimally processed salad dressings enhances physico-chemical and microstructure characteristics compared to the control and the dressings containing the same amount of free oregano and clove EO. At the same time, the colour parameters and viscoelastic properties of the samples prepared with the encapsulated EO were only minimally affected compared to the control sample. The effect of ageing on the physico-chemical and microstructural features of salad dressings was mitigated by incorporating nanoemulsions.

Our results confirm that the incorporation of EO encapsulated in O/W nanoemulsions improves the physico-chemical and microstructure features of salad dressings. These results, together with those obtained in previous studies demonstrating that these nanoemulsions enhance antifungal activity compared to non-encapsulated oils, provide the food industry with natural alternatives to prepare "clean label" salad dressings. Nevertheless, adjustments to product formulation or optimising EO:polymer ratioshould be considered to further enhance the physico-chemical and technological properties of salad dressings throughout storage time.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Abu-Salem, F. M., and Abou-Arab, A. A. (2008), "Chemical, microbiological and sensory evaluation of mayonnaise prepared from ostrich eggs"*, Grasas y Aceites,* Vol. 59 No. 4, pp. 352-360.

Ariizumi, M., Kubo, M., Handa, A., Hayakawa, T., Matsumiya, K., and Matsumura, Y. (2017), "Influence of processing factors on the stability of model mayonnaise with whole egg during long-term storage", *Bioscience, Biotechnology, and Biochemistry,* Vol. 81 No. 4, pp. 803-811.

Bae, I. Y., Oh, I. K., Lee, S., Yoo, S. H., and Lee, H. G. (2008), "Rheological characterization of levan polysaccharides from *Microbacterium laevaniformans*", *International Journal of Biological Macromolecules,* Vol. 42, pp. 10–13.

Baldevbhai, P. J., and Aanand, R. S. (2012), “Color Image Segmentation for Medical Images using L*a*b* Color Space”, *Journal of Electronics and Communication Engineering,* Vol. 1, pp. 24-25.

Bazana, M. T., da Silva, S. S., Codevilla, C. F., de Deus, C., Lucas, B. N., Ugalde, G. A., Mazutti, M. A., Flores, E. M. M., Barin, J. S., da Silva, C. de B., and de Menezes, C. R. (2019), “Development of nanoemulsions containing *Physalis peruviana* calyx extract: A study on stability and antioxidant capacity”, *Food Research International,* Vol. 125, p. 108645.

Burt, S. (2004), “Essential oils: Their antibacterial properties and potential applications in foods-a review”, *International Journal of Food Microbiology,* Vol. 94 No. 3, pp. 223-253.

da Fonseca, V. de C., Haminiuk, C. W. I., Izydoro, D. R., Waszczynskyj, N., Scheer, A. de P., and Sierakowski, M. R. (2009), “Stability and rheological behaviour of salad dressing obtained with whey and different combinations of stabilizers”, *International Journal of Food Science and Technology,* Vol. 44 No. 4, pp. 777–783.

de Melo, A. N. F., de Souza, E. L., da Silva Araujo, V. B., and Magnani, M. (2015), “Stability, nutritional and sensory characteristics of French salad dressing made with mannoprotein from spent brewer's yeast”, *LWT - Food Science and Technology*, Vol. 62, pp. 771-774.

Depree, J., and Savage, G. (2001), “Physical and flavour stability of mayonnaise”, *Trends in Food Science & Technology,* Vol. 12 No. 5–6, pp. 157–163.

Dickinson, E. (2009), “Hydrocolloids as emulsifiers and emulsion stabilizers”, *Food Hydrocolloids,* Vol. 23 No. 6, pp. 1473-1482.

Espert, M., Salvador, A., and Sanz, T. (2019), ʺRheological and microstructural behaviour of xanthan gum and xanthan gum-Tween80 emulsions during in vitro digestion”, *Food Hydrocolloids*, Vol. 95, pp. 454-461.

Fernandez, V. E., Palazolo, G. G., Bosisio, N. A., Martínez, L. M., and Wagner, J. R. (2012), “Rheological properties and stability of low-in-fat dressings prepared with high-pressure homogenized yeast”, *Journal of Food Engineering,* Vol. 11, pp. 57-65.

Gavahian, M., Chen, Y. M., Khaneghah, A. M., Barba, F. J., and Yang, B. B. (2018), “In-pack sonication technique for edible emulsions: Understanding the impact of acacia gum and lecithin emulsifiers and ultrasound homogenization on salad dressing emulsions stability”, *Food Hydrocolloids,* Vol. 83, pp. 79-87.

Guerra-Rosas, M. I., Morales-Castro, J., Ochoa-Martínez, L. A., Salvia-Trujillo, L., & Martín-Belloso, O. (2016), “Long-term stability of food-grade nanoemulsions from high methoxyl pectin containing essential oils”, *Food Hydrocolloids,* Vol. 52, pp. 438–446.

Heggset, E. B., Aaen, R., Veslum, T., Henriksson, M., Simon, S., & Syverud, K. (2020), “Cellulose nanofibrils as rheology modifier in mayonnaise – A pilot scale demonstration”, *Food Hydrocolloids*, Vol. 108, 106084.

Heyman, B., Depypere, F., Delbaere, C., and Dewettinck, K. (2010), “Effects of non-starch hydrocolloids on the physicochemical properties and stability of a commercial béchamel sauce”, *Journal of Food Engineering,* Vol. 99, pp. 115-120.

Izidoro, D. R., Scheer, A. P., Sierakowski, M. R., and Haminiuk, C.W. I. (2008), “Influence of green banana pulp on the rheological behaviour and chemical characteristics of emulsions (mayonnaises)”, *LWT- Food Science and Technology,* Vol. 41, pp. 1018-1028.

Laneuville, S. I., Turgeon, S. L., and Paquin, P. (2013), “Changes in the physical properties of xanthan gum induced by a dynamic high-pressure treatment”, *Carbohydrate Polymers,* Vol. 92 No. 2, pp. 2327–2336.

Ma, L., and Barbosa-Cánovas, G. V. (1995), “Rheological Characterization of Mayonnaise. Part II: Flow and Viscoelastic Properties at Different Oil and Xanthan Gum Concentrations”, *Journal of Food Engineering,* Vol. 25, pp. 409-425.

Ma, Z., and Boye, J. I. (2013), "Microestructure, Physical Stability, and Rheological Properties of Salad Dressing Emulsions Supplemented with Various Pulse Flours", *Journal of Food Research,* Vol. 2 No. 2, pp. 167-181.

Ma, Z., Boye, J. I., Fortin, J., Simpson, B. K., and Prasher, S. O. (2013), "Rheological, physical stability, microstructural and sensory properties of salad dressings supplemented with raw and thermally treated lentil flours", *Journal of Food Engineering,* Vol. 116, pp. 862-872.

Martínez, I., Riscardo, M. A., and Franco, J. M. (2007), "Effect of salt content on the rheological properties of salad dressing-type emulsions stabilized by emulsifier blends", *Journal of Food Engineering,* Vol. 80, pp. 1272-1281.

McClements, D. J. (1999), *Food emulsions: Principles, practice and techniques,* D. J. McClements, New York: CRC Press.

Palanuwech, J., and Coupland, J. N. (2003), "Effect of surfactant type on the stability of oil-in-water emulsions to dispersed phase crystallization", *Colloids and Surfaces A,* Vol. 223, pp. 251-262.

Paraskevopoulou, D., Boskou, D., and Paraskevopoulou, A. (2007), "Oxidative stability of olive oil–lemon juice salad dressings stabilized with polysaccharides", *Food Chemistry,* Vol. 101 No. 3, pp. 1197–1204.

Park, J. J., Olawuyi, I. F., and Lee, W. Y. (2020), "Characteristics of low-fat mayonnaise using different modified arrowroot starches as fat replacer", *International Journal of Biological Macromolecules,* Vol. 153, pp. 215-223.

Primacella, M., Wang, T., and Acevedo, N. C. (2019), "Characterization of mayonnaise properties prepared using frozen-thawed egg yolk treated with hydrolyzed egg yolk proteins as anti-gelator", *Food Hydrocolloids*, Vol. 96, pp. 529-536.

Ribes, S., Fuentes, A., Talens, P., and Barat, J. M. (2016), "Use of oil-in-water emulsions to control fungal deterioration of strawberry jams", *Food Chemistry*, Vol. 211 No. 15, pp. 92-96.

Ribes, S., Fuentes, A., Talens, P., and Barat, J. M. (2017), "Application of cinnamon bark emulsions to protect strawberry jam from fungi", *LWT - Food Science and Technology,* Vol. 78, pp. 265-272.

Ribes, S., Fuentes, A., and Barat, J. M. (2019), "Effect of oregano (*Origanum vulgare* L. ssp. *hirtum*) and clove (*Eugenia* spp.) nanoemulsions on *Zygosaccharomyces bailii* survival in salad dressings", *Food Chemistry,* Vol. 295, pp. 630-636.

Román, L., Reguilón, M. P., and Gómez, M. (2018), "Physicochemical characteristics of sauce model systems: Influence of particle size and extruded flour source", *Journal of Food Engineering,* Vol. 219, pp. 93-100.

Sánchez-González, L., Chiralt, A., González-Martínez, C., Chiralt, A., and Cháfer, M. (2011), "Effect of essential oils on properties of film forming emulsions and films based on hydroxypropylmethylcellulose and chitosan", *Journal of Food Engineering,* Vol. 105, pp. 246-253.

Santipanichwong, R., and Suphantharika, M. (2007), "Carotenoids as colorants in reduced-fat mayonnaise containing spent brewer's yeast β-glucan as a fat replacer", *Food Hydrocolloids,* Vol. 21, pp. 565–574.

Sozer, N. (2009), "Rheological properties of rice pasta dough supplemented with proteins and gums", *Food Hydrocolloids,* Vol. 23 No. 3, pp. 849–855.

Smittle, R. B. (2000), "Microbiological safety of mayonnaise, salad dressings, and sauces produced in the United States: a review", *Journal of food protection*, Vol. 63 No. 8, pp. 1144-1153.

Srinivasan, M., Singh, H., and Munro, P. A. (2000), "The effect of sodium chloride on the formation and stability of sodium caseinate emulsions", *Food Hydrocolloids,* Vol. 14, pp. 497–507.

Valduga, A. T., Gonçalves, I. L., Magri, E., and Finzer, J. R. D. (2019), "Chemistry, pharmacology and new trends in traditional functional and medicinal beverages", *Food Research International,* Vol. 120, pp. 478–503.

Yücer, M., Ilyasoğlu, H., Özçelik, B. (2016), "Comparison of flow behavior and physicochemical characteristics of low-cholesterol mayonnaises produced with cholesterol-reduced egg yolk", *Journal of Applied Poultry Research*, Vol. 25, pp. 518-527.

Zhang, C., Quek, S. Y., Lam, G., and Easteal, J. A. (2008), "The rheological behaviour of low fat soy-based salad dressing" *International Journal of Food Science and Technology,* Vol. 43, pp. 2204–2212.

Table captions

Table I pH, water activity (a_w), total titratable acidity (TTA), NaCl content and stability (*H*) of the different salad dressings manufactured during 11 storage days at 8 ºC and 25 ºC. Mean values (n=3) ± standard deviation.

Table II Rheological parameters from the steady shear tests of the different salad dressing formulations for 11 storage days at 8 ºC and 25 ºC: consistency coefficient (K), flow behaviour index (n) and apparent viscosity (η_{app50}) values. Mean values (n=3) ± standard deviation.

Figure captions

Figure 1 Luminosity (L*) and whiteness index (WI) of the different salad dressings stored for 11 days at 8 ºC (A) and 25 ºC (B); and colour variations (ΔE*) of the different salad dressings after 11 storage days at 8 ºC and 25 ºC (C). Mean values (n=3) ± standard deviation. Lowercase letters (a, b, c) indicate significant differences among formulations (*$p<0.05$*). Capital letters (A, B) denote significant differences between storage times expressed in days (*$p<0.05$*). The concentration of EO in their free or encapsulated form: 1.95 mg/g. (NE: nanoemulsion).

Figure 2 Viscoelastic properties, at a frequency of 1 Hz, of the different salad dressing formulations during 11 storage days at 8 ºC (A) and 25 ºC (B): elastic or storage modulus (G') and viscous or loss modulus (G''). Mean values (n=3) ± standard deviation. Lowercase letters (a, b, c) indicate significant differences among formulations (*$p<0.05$*). Capital letters (A, B) denote significant differences between storage times expressed in days (*$p<0.05$*). The concentration of EO in their free or encapsulated form: 1.95 mg/g. (NE: nanoemulsion).

Figure 3 Complex viscosity ($|\eta^*|$) and loss tangent (Tan δ), at a frequency of 1 Hz, of the different salad dressing formulations during 11 storage days at 8 ºC (A) and 25 ºC (B). Mean values (n=3) ± standard deviation. Lowercase letters (a, b, c) indicate significant differences among formulations (*$p<0.05$*). Capital letters (A, B) denote significant differences between storage times expressed in days (*$p<0.05$*). The concentration of EO in their free or encapsulated form: 1.95 mg/g. (NE: nanoemulsion).

Figure 4 Creep and recovery curves of the different manufactured salad dressings. Figures A.1 and B.1 present the dressings stored for 1 day at 8 ºC and 25 ºC, respectively. Figures A.2 and B.2 show the salad dressings stored for 11 days at 8 ºC and 25 ºC, respectively. Mean values (n=3). The concentration of EO in their free or encapsulated form: 1.95 mg/g. (NE: nanoemulsion).

Figure 5 Recovery rates (*R*, %) of the different salad dressings after 11 storage days at 8 ºC (A) and 25 ºC (B). Mean values (n=3) ± standard deviation. Lowercase letters (a, b) indicate significant differences among formulations (*$p<0.05$*). Capital letters (A, B) denote significant differences between storage times expressed in days (*$p<0.05$*). The concentration of EO in their free or encapsulated form: 1.95 mg/g. (NE: nanoemulsion).

Figure 6 Microphotographs of control salad dressings and salad dressings formulated with free and encapsulated oregano and clove EO after 11 storage days at 8 ºC and 25 ºC. Microphotographs performed at 40x magnification. (NE: nanoemulsion).