Rheological and structural evaluations of commercial italian salad dressings

Avaliação reológica e estrutural de molhos de salada comerciais do tipo italiano

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Abstract

The emulsion stability, composition, structure and rheology of four different commercial italian salad dressings manufactured with traditional and light formulations were evaluated. According to the results, the fat content ranged from 8% (w/w) (light) to 34% (w/w) (traditional), the carbohydrate concentration varied between 3.8% (w/w) (traditional) and 14.4% (w/w) (light) and the pH was between 3.6-3.9 for all samples. The microscopic and stability analyses showed that the only stable salad dressing was a light sample, which had the smallest droplet size when compared with the other samples. With respect to the rheological behaviour, all the salad dressings were characterized as thixotropic and shear thinning fluids. However, the stable dressing showed an overshoot at relatively low shear rates. This distinct rheological behavior being explained by the differences in its composition, particularly the presence of a maltodextrin network.

Keywords: *rheology; microstructure; emulsion; salad dressing.*

Resumo

A estabilidade, composição, estrutura e reologia foram avaliadas para quatro diferentes molhos de salada tipo italiano nas versões light e tradicional. De acordo com os resultados, a quantidade de gordura variou entre 8% (m/m) (molho light) e 34% (m/m) (molho tradicional), a concentração de carboidrato apresentou-se na faixa de 3,8% (m/m) (tradicional) a 14,4% (m/m) (light), e o pH foi cerca de 3,6-3,9 para todas as amostras analisadas. As análises de microscopia e estabilidade mostraram que o único molho de salada estável foi uma amostra light que apresentou o menor tamanho de gotas quando comparada com as outras amostras. Com relação à reologia, todos os molhos de salada foram caracterizados como fluidos tixotrópicos e pseudoplásticos. No entanto, o molho de salada que foi estável apresentou um *overshoot* em baixas taxas de deformação. Tal comportamento reológico foi explicado pelas diferenças em sua composição, particularmente pela presença de maltodextrina.

Palavras-chave: *reologia; microestrutura; emulsão; molho de salada.*

1 Introduction

A wide range of food products is composed of oil-in-water (O/W) emulsions, such as salad dressings, mayonnaise, and sauces. It is well known that emulsions are thermodynamically unstable systems and two kinds of additives are often added to them in order to avoid phase separation: emulsifiers and/or stabilizers. Emulsifiers are mainly surface-active substances which can be adsorbed onto the droplet surface lowering the surface tension and preventing droplet aggregation (GIRARD; TURGEON; PAQUIN, 2002). Stabilizers are substances used to increase the viscosity of the aqueous phase and enhance the emulsion stability by retarding droplet movement (McCLEMENTS, 2005; PARASKEVOPOULOU; BOSKOU; KIOSSEOGLOU, 2005).

Polysaccharides are amongst the most widely used stabilizers in the industry to stabilize oil-in-water emulsions and control their rheological properties (PARASKEVOPOULOU et al., 1997, 2003). Xanthan gum is an extracellular polysaccharide secreted by a wide range of bacteria of the genus *Xanthomonas,* and it can be employed as a thickening or stabilizing agent and, under appropriate conditions, as a gelling agent (MORRIS, 2006). It is often used in sauces and dressings in combination with other thickeners to provide the desired rheological behavior (PANGBORN; GIBBS; TASSAN, 1978; O'CARROLL, 1997). Maltodextrin is a starch hydrolysis product obtained by acid catalysis or a specific enzymatic action, and it is a mixture of high and low molar weight material. This ingredient has the ability to reproduce the same sensation caused by fat because it forms a three-dimensional network during the gelling process (LORET et al., 2004). One of the most common applications of maltodextrins is as a fat mimetic in low-fat salad dressings (ROLLER, 1996).

Salad dressings are produced in two different finished product forms: emulsified and separated. Emulsified or one-phase pourable salad dressings are homogenized or blended to maintain a creamy nonseparating consistency and the homogenization process is responsible to reduce the oil droplet size to produce a smooth and creamy dressing. Separating salad dressings have a separate oil layer above an aqueous phase. These products must be shaken before use and show quick phase separation after pouring. The most popular separating salad

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dressing variety is the italian flavor (O´BRIEN, 2004)**,** an O/W emulsion composed of water, oil, vinegar or lemon juice, salt, pepper, sugar, and a variety of herbs and spices. The rheology of salad dressings has been investigated by several authors due to its importance in the choice of an adequate formulation, the process conditions, and quality control (FRANCO; BERJANO; GALLEGOS, 1997; WENDIN; HALL, 2001; RISCARDO; FRANCO; GALLEGOS, 2003; RISCARDO et al., 2005; DIFTIS; BILIADERIS; KIOSSEOGLOU, 2005; PARASKEVOPOULOU; BOSKOU; KIOSSEOGLOU, 2005; MARTÍNEZ; RISCARDO; FRANCO, 2007). However, the rheological properties and sensory characteristics of salad dressings, such as flavor, mouthfeel and texture are influenced by the fat content. Nowadays, the spread of healthy eating trends has induced an increasing popularity and demand for the so called 'light' products, in particular low-calorie and reduced-fat products. Nevertheless, most of these light products show different properties when compared with the full-fat products due to different characteristic compositions.

Thus, the aim of this work was to measure the chemical and rheological properties of traditional and light italian salad dressings in order to evaluate the influence of their composition on the emulsion structure and their mechanical or textural characteristics.

2 Materials and methods

2.1 Materials

Four commercial samples of two brands of italian salad dressings (samples AT, AL, BT, and BL) were purchased from a local supermarket and used without additional treatment. Samples AT and BT were traditional dressings, whilst the samples AL and BL were their light versions, respectively. The composition of each salad dressing is shown in Chart 1.

Chart 1. Composition of the commercial salad dressings.

Sample	Ingredients
AT	Vegetable oil, water, vinegar, sugar, salt, parmesan cheese, bell pepper, garlic, lemon juice, oregano, onion, carrot, mustard, parsley, basil, celery, monosodium glutamate, citric acid, xanthan gum, potassium sorbate, EDTA, antioxidants BHT, and BHA.
AL	Vegetable oil, water, vinegar, maltodextrin, salt, parmesan cheese, pepper, garlic, lemon juice, oregano, onion, carrot, mustard, parsley, basil, celery, monosodium glutamate, lactic acid, xanthan gum, potassium sorbate, caramel, paprika, EDTA, antioxidants BHT, and BHA.
BT	Water, vinager, soybean oil, sugar, salt, parmesan cheese, red pepper, garlic, onion, mustard, oregano, parsley, black pepper, mixed condiments, jamaican pepper, monosodium glutamate, xanthan gum, potassium sorbate, citric acid, antioxidant TBHQ, and EDTA.
BL	Water, vinager, soybean oil, sugar, salt, parmesan cheese, red pepper, garlic, onion, mustard, oregano, parsley, black pepper, mixed condiments, jamaican pepper, monosodium glutamate, xanthan gum, potassium sorbate, citric acid, antioxidant TBHQ, EDTA, and caramel.

2.2 Stability studies

The salad dressing samples were manually homogenized for 10 seconds according to the instructions on the label, and were immediately poured into 20 mL glass test tubes and stored at room temperature for a period of 9 days. The stability of the samples was evaluated by visually monitoring the development of a bottom phase with storage time. The physical stability was considered to be the period of time during which the emulsions did not show visual phase separation.

The stability of the emulsions was expressed using Equation 1.

$$\%serum = 100 \times \frac{V_t}{V_O} \quad (1)$$

where V_0 represents the initial emulsion volume and V_t the volume of the visible serum separation layer.

2.3 Compositional analysis

The amounts of moisture and ash in the salad dressing samples were measured using the Association of Official Analytical Chemist (1995) official methods 926.08 and 935.42, respectively. The total protein concentration was determined by the Kjeldahl method (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1996) using a nitrogen factor of 6.38. The total fat content was measured using the Bligh and Dyer method (BLIGH; DYER, 1959) and the carbohydrates were calculated by difference.

2.4 Light microscopy

The microstructure of the salad dressings was studied using a Carl Zeiss Model: mf-AKS 24 × 36 EXPOMET light microscope (Zeiss, Germany). The samples were poured onto microscope slides, covered with glass cover slips, and observed under a magnification of ×20. At least 10 replications were prepared for each sample. The microscopic images were analyzed using the public domain software Image J v1.36b (http://rsb.info.nih.gov/ij/). The micrographs were transformed into 8-bit grey scale binary images of 640-480 pixels and then segmented by 'thresholding'. The grey level used to threshold the image was the median of the grey level histogram of each image (PUGNALONI; MATIA-MERINO; DICKINSON, 2005). During this process, the pixels were deemed to be detected only if their grey value was less than the threshold setting. The pixel-scale values were converted into microns by a scaling factor. The droplet areas were subsequently measured using the software and the volume-surface mean diameters (d_{32}) calculated using Equation 2, considering that the oil droplets were spherical.

$$d_{32} = \frac{\sum n_i d_i^3}{\sum n_i d_i^2} \quad (2)$$

where n_i was the number of particles with diameter d_i.

2.5 Rheological measurements

The rheological measurements were carried out using a stress-controlled rheometer (Carri-Med CSL2 500, TA Instruments, England). A 4 cm rough plate geometry with a gap of 750 µm was used in order to avoid wall-slip phenomena (SÁNCHEZ et al., 2001). The rheological tests were carried out at 25 °C in triplicate. Flow curves were obtained by an up-down-up steps program using different shear stress ranges for each sample. This range was determined using a shear rate control experiment, in which the maximum shear rate value was 300 1/s.

3 Results and discussion

3.1 Chemical composition

The chemical composition and pH values of the different commercial italian salad dressings are shown in Table 1. The fat content ranged from 34% in a traditional product (sample BT) to 8% in a light salad dressing (sample AL), while the moisture content ranged from 47 to 74%, respectively. Light products with lower fat contents showed a greater volume of aqueous phase when compared to the traditional sample of the same brand. Thus the fat analysis provided information about the different brands since the traditional sample of brand A (AT) showed lower oil concentration when compared to the other brand (BT). In addition, the fat content observed in the traditional dressing A (AT) was similar to that of the light version of brand B (BL). The carbohydrate content was greater in the light samples, which can be attributed to the addition of gums, modified food starches, and starch hydrolysates with fat-like properties. Such ingredients can interact with water in order to maintain similar textural characteristics to those of traditional products. Protein was not detected in any of the samples. All salad dressings showed a pH value between 3.56 and 3.90, and brand A samples were more acid than brand B ones.

Table 1. Analysis of the chemical composition (%, w/w) and pH of commercial italian salad dressings.

Parameters	Sample AT	Sample AL	Sample BT	Sample BL
Fat (%)	28.12 ± 1.64	7.94 ± 0.14	34.50 ± 1.55	26.71 ± 0.61
Moisture (%)	60.24 ± 0.13	74.00 ± 0.21	47.12 ± 1.66	57.01 ± 0.41
Carbohydrate (%)	7.26 ± 1.55	14.40 ± 0.20	3.77 ± 0.65	12.24 ± 0.12
Protein (%)	0.00	0.00	0.00	0.00
Ash (%)	4.27 ± 0.73	3.51 ± 0.67	4.65 ± 0.85	3.91 ± 1.26
pH	3.75	3.56	3.90	3.82

3.2 Droplet size measurement

The microstructures of the four samples of italian dressing were captured under a optical microscope (Figure 1). These images revealed the presence of spherical lipid droplets surrounded by a continuous aqueous phase which contained the spices and herbs that were added to enhance the product flavor. Moreover, the pictures show that the salad dressings were polydisperse emulsions with different oil droplet sizes.

Table 2 shows surface area weighted mean diameter of the droplets (d_{32}), which were measured using image analysis of the microstructures (Figure 1). The oil droplets of the dressings varied between 26.71 and 124 µm. The largest droplet size was observed for sample AT and the smallest for the salad dressing AL. Nevertheless, most of those values were higher than those reported by Ford et al. (2004), who also characterized traditional and light italian dressings determining droplet sizes of 41.3 and 26.2 µm diameter, respectively. This difference probably occurred because the lipid droplet size is determined by the stabilizers used and the processing method (FORD et al., 2004). Thus, in order to achieve greater emulsion stability, high energy mechanical processes such as homogenization and/or the addition of emulsifier agents are frequently employed. Such mechanisms allow for a reduction in the droplet size leading to greater kinetic stability.

3.3 Stability

Figure 2 illustrates the stability of the dressings with storage time evaluated by macroscopic observations. All samples showed phase separation, exception for the light product AL, which was highly stable and exhibited no sign of serum separation at the bottom of the container during the 9 days of storage. The higher stability of this light dressing may be explained by the presence of maltodextrin (declared by the manufacturer), which can form a three-dimensional network during its gelling process (LORET et al., 2004). In contrast,

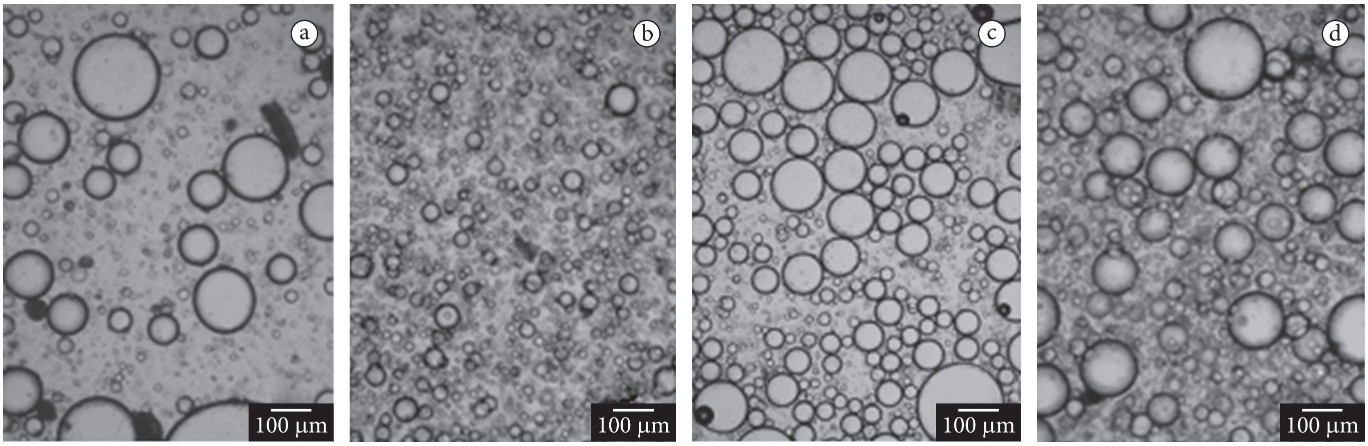

Figure 1. Light microscopy of the different salad dressings (×20). Scale bar = 100 µm. Sample AT (a), sample AL (b), sample BT (c), and sample BL (d).

sample AT, the traditional version of the same product, started to phase separate after only 2 minutes of storage, followed by a structural rearrangement, and reaching equilibrium after two days of storage. An intermediary behavior was observed for brand B samples (BT and BL), which showed phase separation after 2 days and 7 hours, respectively.

Flocculation, creaming, coalescence, and sedimentation, considered as instability mechanisms in dispersion science, could be desirable in italian dressings that only need short-term stability (CHANAMAI; McCLEMENTS, 2000). Droplet coalescence could occur simultaneously when two or more droplets within the flocs merge together to form a single larger droplet. The destabilization velocity of oil-in-water emulsions is strongly influenced by the droplet size and concentration (CHANAMAI; McCLEMENTS, 2000). These results indicate that the stabilization of salad dressings was predominantly affected by larger oil droplet sizes.

Figure 3 shows the visual appearance of the salad dressings after 9 days of storage. The image of sample AL was not shown due to the absence of phase separation. Generally, the top phase was rich in oil and the bottom phase was predominantly aqueous. However, the oil phase was darker than the aqueous phase for sample AT, whereas the opposite effect was verified for brand B samples. This may have occurred because the dye used in brand A was highly hydrophobic but the one used in brand B was more hydrophilic.

3.4 Rheological properties

The rheological measurements of the dressings were carried out at 25 °C to investigate shear effects on the viscosity. Figure 4a shows the time-dependent behavior of the dressings, in which the results of the samples without prior shearing (S1) and in the steady state (S3) could be evaluated. The reduction in shear stress and viscosity from step 1 (S1) to step 3 (S3) was characteristic of thixotropic behavior. In this case, shearing of the materials causes deformation and/or rupture of the aggregated particles decreasing the resistance to flow and therefore reducing the apparent viscosity over time (McCLEMENTS, 2005). Thixotropy can be estimated using the area between curves S1 and S3 (hysteresis) (Table 3) (STEFFE, 1996; SATO; CUNHA, 2007). These measurements can be used as a qualitative comparison between the different samples. The results in Table 3 show that the time-dependence was more pronounced for the traditional salad dressings, mainly for sample AT, which was the most unstable emulsion. Hence, the tixotropy of the samples can be associated with their instability (DOLZ et al., 2007).

Figure 4b shows the flow behavior of the samples under steady state conditions. In this case, all samples exhibited a shear-thinning behavior since the oil droplets become more ordered in the flow field as the shear rate was applied resulting in lower viscosity (McCLEMENTS, 2005). The flow curves of all the samples were fitted to the power law model and the rheological parameters, and the apparent viscosity at 10, 50, and 100 1/s are shown in Table 4. The consistency index (k) and flow behavior index (n) ranged from 0.83 to 2.42 Pa s^{n} and from 0.36 to 0.45, respectively. In general, the k values were related to the viscosity, and the flow behavior index (n) provided information about the effects of shear on the system (TORRES et al., 2007).

Table 2. Droplet size of the four commercial italian salad dressing samples.

Sample	Diameter (μm)
AT	124.05^{A}
AL	29.71^{C}
BT	66.44^{B}
BL	74.73^{B}

Different letters (A–C) correspond to significantly different values ($p < 0.05$)

Table 3. Hysteresis between the curves of the samples without prior shearing and at steady state (thixotropy).

Sample	Thixotropy (Pa/s)
AT	1053.67
AL	21.04
BT	488.61
BL	77.36

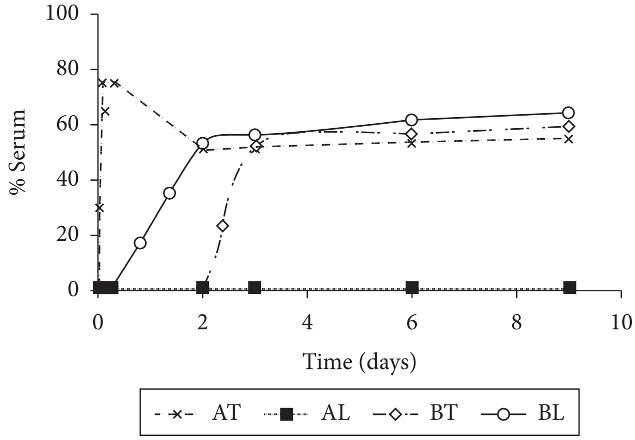

Figure 2. Phase separation as a function of storage time for the commercial italian salad dressings.

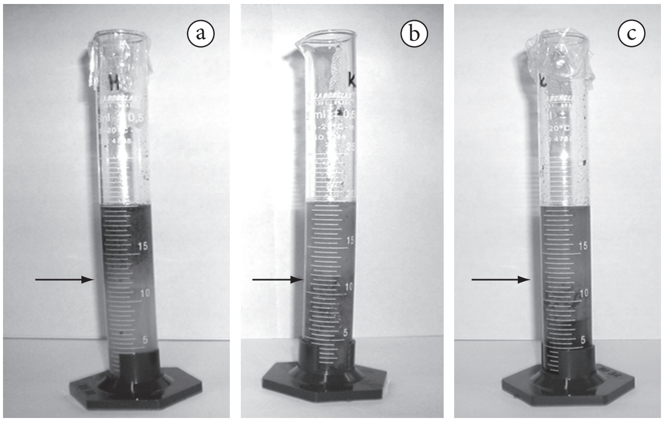

Figure 3. Phase separation in the salad dressings after 9 days of storage. Sample AT (a), sample BT (b), and sample BL (c).

Table 4. Power law parameters and viscosities (η) at shear rates of 10 (η_{10}), 50 (η_{50}), and 100 (η_{100}) 1/s for the commercial italian dressings at 25 °C.

	k (Pa s^n)	n	R^2	η_{10} (Pa s)	η_{50} (Pa s)	η_{100} (Pa s)
Sample AT	2.30 ± 0.36^{A}	0.36 ± 0.02^{A}	0.96	0.52 ± 0.06^{AB}	0.18 ± 0.02^{A}	0.12 ± 0.01^{A}
Sample AL	0.83 ± 0.34^{B}	0.45 ± 0.09^{A}	0.98	0.32 ± 0.13^{A}	0.13 ± 0.03^{B}	0.09 ± 0.02^{B}
Sample BT	2.42 ± 0.14^{A}	0.42 ± 0.01^{A}	0.97	0.64 ± 0.03^{B}	0.25 ± 0.01^{C}	0.17 ± 0.01^{C}
Sample BL	1.23 ± 0.10^{B}	0.43 ± 0.01^{A}	0.98	0.33 ± 0.02^{A}	0.13 ± 0.01^{AB}	0.09 ± 0.00^{B}

Means in the same column followed by different letters are significantly different ($p < 0.05$); and k: consistency index, n: flow behavior index

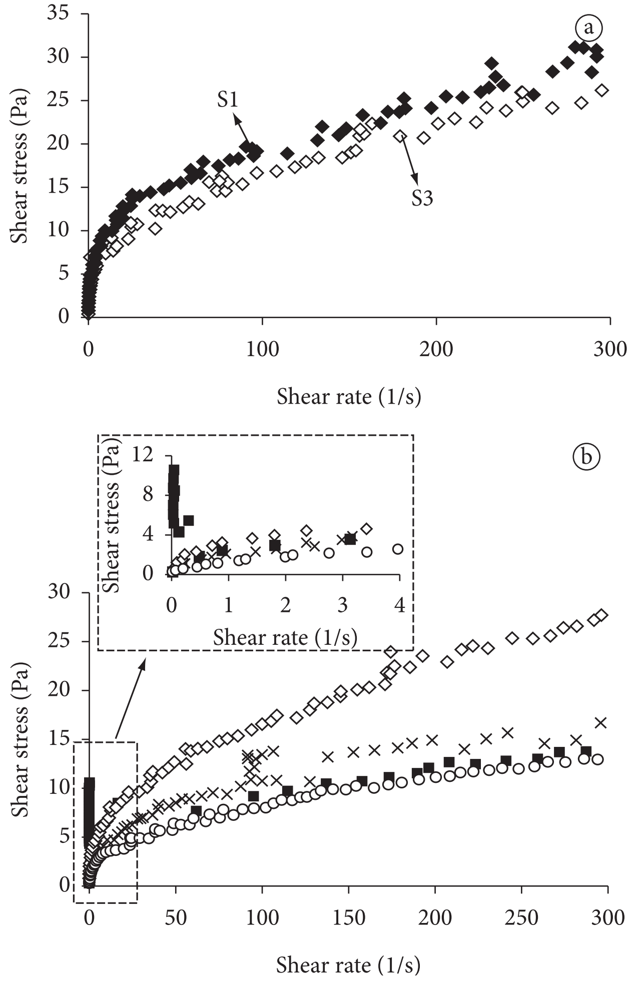

Figure 4. Rheological behavior of commercial italian salad dressings. a) Time-dependence of the dressings. S1: data for sample with no prior shearing; S3: data at steady state; and b) flow curves at steady state. Sample AT (×), sample AL (■), sample BT (◇), and sample BL (○).

Sample AL exhibited a markedly different behavior when compared with the other samples showing a stress overshoot at relatively low shear rates (Figure 4b) followed by a decrease to a small stress value. This behavior indicates the formation of a more developed and resistant structural network (RISCARDO et al., 2005), in agreement with the stability results (Figure 2), probably due to the presence of maltodextrin in its composition. The other light salad dressing sample (sample BL) showed very similar values for all rheological parameters (k, n, and η) but showed no overshoot. On the other hand, the traditional version of the dressings (samples AT and BT) also exhibited similar fitted parameters (k and n) (Table 4). The apparent viscosities at 10, 50, and 100 1/s were significantly greater than those for the light samples; the highest values were found for sample BT.

From the results obtained for the droplet size, rheological properties, and chemical composition, it is possible to explain the stability of the samples. As previously mentioned, sample AL was the most stable system probably due to its higher polysaccharide concentration. This structure immobilized the oil droplets hindering their coalescence and resulting in smaller droplets (Table 2). Sample AT was the most unstable system probably due to its larger droplet diameter (Table 2). As the droplet size increases, the number of droplets per unit volume of the emulsion decreases and consequently the average separation distance between the droplets also decreases. Therefore, the droplets become more mobile and show less resistance to flow (CHANAMAI; McCLEMENTS, 2000). The relative stability of sample BT can be explained from its higher viscosity and relatively smaller droplets, which could be attributed to the higher oil concentration and lower moisture content (Table 1). Even though sample BL showed higher carbohydrate concentration (Table 1) than sample BT, the latter was more unstable, probably due to its lower oil content, which decreased the viscosity.

4 Conclusion

The stability of the italian salad dressings studied was greatly dependent on their droplet size and rheological behavior. Both parameters were greatly affected by the fat content and the presence of polysaccharides in their composition. Sample AL was the most stable system due to its higher polysaccharide concentration, which hindered droplet aggregation. The light dressing of the other brand (BL) showed a higher oil content and bigger droplets, which made this sample much more unstable than AL even though their rheological parameters were similar. On the other hand, the traditional dressing AT showed a similar fat concentration to that of BL, but it was the most unstable system. This occurred due to the higher polysaccharide concentration of sample BL, which promoted better stability of the emulsion. The other traditional dressing (BT) was the sample showing the highest fat content leading to an increase in viscosity and a consequent decrease in droplet size. This explains its higher stability when compared to its light version.

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