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RHEOLOGICAL BEHAVIOR OF LOW-FAT DULCE DE LECHE WITH ADDED XANTHAN GUM

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ABSTRACT

Dulce de leche (DL), a typical jam of South America, is commercialized with diverse flow characteristics that corresponds to its different uses. In order to predict the adequate composition to obtain target rheological properties, low-fat dulce de leche (LF-DL) samples with different water (23.7–60.3%) and xanthan gum (0.173–0.555%) contents were prepared using skim milk (0% fat), sucrose (172.7 g/L) and glucose (28.98 g/L) following the traditional method, and their flow behavior was measured. Steady-state flow curves were modeled and the obtained Herschel-Bulkley's parameters were regressed as a function of water and xanthan gum contents; from this set of equations, an adequate composition to produce LF-DL with flow behavior similar to a premium commercial brand was predicted. The procedure was experimentally validated. A mathematical useful tool for the industry to calculate a suitable formulation to obtain a given type of LF-DL is presented.

PRACTICAL APPLICATIONS

Dulce de leche (DL) is a complex biopolymeric matrix, with milk proteins, sugar and more than 6% of fat. This paper studies the effect of moisture and xanthan gum (as fat replacer) in the rheological properties of a low-fat dulce de leche (LF-DL). It provides a tool for understanding the flow behavior of LF-DL and to determine the required composition of this system needed to achieve a selected rheological behavior.

In order to obtain a mathematical model to predict the compositon that would present the desired viscosity for each product application, the formulation of LF-DL with xanthan gum as fat replacer was related with viscosity of the product.

Employing the proposed methodology, it was possible to select the combination of components to obtain LF-DL with similar rheological characteristics to a traditional commercial brand well accepted by consumers.

INTRODUCTION

Dulce de leche (DL), an intermediate moisture product with a minimum fat content of 6%, is consumed as a sweet or spread as a jam and also as an ingredient in different sweet snacks and desserts. Its texture varies among these products having the confectionary higher viscosity than the one used as a spread (Ranalli *et al.* 2012).

DL is prepared by concentrating the milk to ~70% total solids (water activity = 0.85) by heating at atmospheric pressure in the presence of sucrose, $NaHCO_3$ (to increase the pH value to ~6.0 and preventing protein coagulation) and vanilla as a flavoring agent. In some cases, sucrose is partially replaced by glucose and lactose is partially hydrolyzed to avoid crystallization. Due to heating, nonenzymatic browning reaction takes place giving the product its attractive flavor and brown color. Finally, up to 1000 mg/g of potassium sorbate can be added to the final product to inhibit the growth of fungi (Oliveira *et al.* 2009). The resulting mixture of carbohydrates, proteins and fats, and therefore its moisture content, determines its rheological, thermal and structural properties, thus affecting its functional characteristics. During DL processing, evaporation causes major physicochemical and structural modifications to the milk that are reflected in its flow properties because water removal causes a reduction in the spacing between particles, such as casein micelles, fat globules, whey proteins, lactose and minor constituents (Prentice 1992). Those major interactions between milk solids, in which proteins and lipids are the most altered milk constituents, and the physicochemical changes within components seriously affect the rheological behavior of milk (Vélez-Ruiz and Barbosa-Cánovas 1998).

DL has a typical texture that is important for consumers (Hough *et al.* 1986), thus texture characterization of a low-fat dulce de leche (LF-DL) alternative is required for product standardization, process development, quality control and consumer acceptability. Many ingredients and different technological strategies have been developed for the specific objective of fat replacement in food products (Romeih *et al.* 2002). Among fat replacers, carbohydrate-based substances such as starch, cellulose, pectin, inulin, xanthan gum or carrageenan are of growing interest because, besides their physicochemical properties, they also have health-friendly characteristics (Bayarri *et al.* 2010). Regarding dairy products, numerous studies have been published dealing with the effect of fat content on its rheological behavior and sensory properties, mainly on flavor and texture perception (González-Tomás *et al.* 2008).

Xanthan gum, a natural heteropolysaccharide produced by *Xanthomonas campestris* NRRL B-1459, has been used in a wide variety of foods for a number of important reasons, including emulsion stabilization, temperature stability, compatibility with food ingredients and its pseudoplastic rheological properties. Xanthan solutions are highly viscous even at low polymer concentrations (García-Ochoa *et al.* 2000), they are pseudoplastic, or shear thinning, and the viscosity decreases with increasing shear rate (Kang and Pettitt 1993). Regarding applications of xanthan gum by the dairy industry, Zhao *et al.* (2009) found a positive correlation between xanthan gum level and firmness, cohesiveness, or viscosity of whipped cream. Krystyjan *et al.* (2012) studied tailored sensory, rheological and textural properties of caramel sauces with different potato starch and xanthan gum combinations. Texture was improved with an increase in xanthan gum concentration, and such improvement was also observed in the sauces after storage. In a consumer survey among sauces prepared under laboratory conditions, those thickened with 0.3% potato starch and 0.02% xanthan gum, received the highest score.

The regional production, mainly in South America, explains the scarce scientific references in literature about this product. Limited studies have been published on the rheological behavior of DL. Flow behavior of commercial DL was used as a model for the development of products containing ultrafiltered whey protein concentrate (Heimlich *et al.* 1994). The spreads (water content 70.1–72.6%) followed Herschel-Bulkley's (H-B) model with a flow behavior index of 0.67 and a significant yield stress constant (between 9.25 and 13.41 Pa). The partial substitution of milk protein by ultrafiltered whey protein concentrate did not change significantly the flow behavior of the samples.

Using oscillatory dynamic tests, Pauletti *et al.* (1990), Navarro *et al.* (1999) and Pedrero *et al.* (2001) found that the rheological behavior of DL was intermediate between a concentrated solution and a gel, depending on the type and the solid content. Corradini and Peleg (2000) evaluated lubricated squeezing flow as an alternative method to assess the consistency of this product.

Physicochemical and rheological characterization of different types of commercial samples of DL, traditional, confectionary and reduced calories or fat was carried out by Ranalli *et al.* (2012). Although all the samples presented a shear-thinning behavior, clear differences were found in rheological characteristics among various types of products. The confectionary DL presented higher values of both storage and loss moduli than traditional DL due to the inclusion of cornstarch in the formulation, which increased the elastic characteristic of the system. For commercial reduced fat products with similar moisture and fat contents, a more solid-like behavior was observed in one that included gums and starch in the formulation.

The objective of the present work was to relate the formulation of LF-DL prepared with different moisture levels and xanthan gum as fat replacer with the viscosity of the products, and to obtain a mathematical tool to predict the composition that would present the desired viscosity for each product application.

MATERIALS AND METHODS

LF-DL was produced from HTST sterilized skim (defatted) milk (0% fat, SanCor, Cooperativas Unidas Ltda., Sunchales, Santa Fe, Argentina), that was standardized to 13° Dornic acidity with sodium bicarbonate before used. Sucrose (172.7 g/L, Ledesma, Jujuy, Argentina), glucose (28.98 g/L, Parafarm, Saporiti, Buenos Aires, Argentina) and xantham gum (Sigma Aldrich, St. Louis, Missouri) were also used (Hynes and Zalazar 2009).

LF-DL Formulation and Processing

Xanthan gum was dissolved in part (300 mL) of total milk at 60C during 3 h with constant stirring, above the order-disorder temperature of xanthan (51C) in water (Khouryieh *et al.* 2006; Lorenzo *et al.* 2008). Afterward all the ingredients

TABLE 1. TOTAL SOLUBLE SOLIDS (°BRIX), WATER AND XANTHAN GUM CONTENTS OF THE ASSAYED LF-DL FORMULATIONS. REGRESSED PARAMETERS OF THE H-B MODEL

				H-B parameters			
LF-DL code	°Brix	Water (% w/w)	Xanthan gum (% w/w)	σ_0 (Pa)	K (Pa s^n)	n	R^2
1	52	48.1^{e}	0.173^{m}	14.6(0.3)^{ef}	28.3(0.4)^{c}	0.39(0.01)^{cd}	0.996
2	56.5	43.5^{f}	0.188^{l}	40.6(0.4)^{d}	52(1)^{c}	0.38(0.01)^{cd}	0.996
3	67	33.4^{h}	0.221^{k}	201(14)^{b}	246(12)^{b}	0.34(0.01)^{e}	0.990
4	>78	23.7^{j}	0.253^{j}	647(8)^{a}	1157(155)^{a}	0.47(0.01)^{a}	0.998
5	46.5	60.3^{a}	0.263^{i}	2.48(0.01)^{f}	7.3(0.1)^{c}	0.41(0.01)^{bcd}	0.998
6	50	56.4^{b}	0.289^{h}	4.1(0.2)^{f}	16(2)^{c}	0.38(0.01)^{d}	0.998
7	52.5	52.5^{c}	0.314^{g}	8.8(0.9)^{ef}	29.6(0.3)^{c}	0.38(0.01)^{d}	0.999
8	56	47.4^{e}	0.349^{f}	21.8(0.5)^{e}	52(6)^{c}	0.41(0.01)^{bc}	0.998
9	62	40.9^{g}	0.392^{e}	65(1)^{c}	111(9)^{bc}	0.43(0.01)^{b}	0.999
10	45.5	56.8^{b}	0.428^{d}	3.8(0.5)^{f}	13.9(0.6)^{c}	0.31(0.01)^{f}	0.999
11	48	53.6^{c}	0.460^{c}	7.0(0.7)^{f}	21(2)^{c}	0.33(0.01)^{ef}	0.999
12	51	50.0^{d}	0.495^{b}	10.6(0.2)^{ef}	28.8(0.3)^{c}	0.34(0.01)^{e}	0.998
13	57.25	43.9^{f}	0.555^{a}	22.10(0.06)^{e}	63(4)^{c}	0.33(0.01)^{ef}	0.997

*Standard errors of the mean are given between parentheses. Different superscripts within the same row indicate significant differences ($P < 0.05$).

were mixed in a stainless steel pan with glass spheres to avoid overheating and fouling at the bottom of the pan. Thermal treatment was made over an electric heating plate (IKA, RCT basic, China) and lasted about 3 h in a temperature range 97–105C. The temperature was controlled throughout the process using a calibrated type K thermocouple connected to an acquisition device A Digit-080 refractometer (CETI Optical Instruments, Brussels, Belgium) was used to determine if the desired soluble solid content had been reached (Moro and Hough 1985). Once LF-DL was obtained, it was emptied into a steel container for rapidly cooling over an ice-water bath, poured in glass jars, and stored at 20°C for 48 h before analysis. The procedure followed to obtain the products strictly respects the standards used by national industry (INTI 2010).

Thirteen formulations of LF-DL (1–13) with different water and xanthan gum contents were prepared (Table 1). Xanthan gum level ranged from 0.173 to 0.555%, while water content varied between 23.7 and 60.3%. These wide range levels were chosen to obtain LF-DL products adequate for different applications (from a pourable sauce up to a confectionary DL). Two additional formulations were prepared: LF-DL without xanthan gum (water 43.8%) and regular fat product (RF-DL) made with whole milk (3% fat) as a control, using the same equipment and procedure.

Water content in the product was analyzed according to Ranalli *et al.* (2012) following the provisional standard of The International Dairy Federation (IDF 1982). Then, xanthan gum concentration was calculated from a mass balance.

Steady-State Flow Curves

Rheological measurements were carried out using a controlled stress rheometer (Haake RS600, ThermoGap, Germany) with a serrated parallel plate fixture (diameter 35 mm with gap of 1 mm) at 20 ± 0.1C controlled by means of a controlled fluid bath unit and an external thermostatic bath. After positioning the sample on the sensor system, it was allowed to rest for 10 min before starting the corresponding measurement. To minimize dehydration, samples were covered with a thin layer of silicone oil; also, a solvent trap was employed. At least three measurement replicates were performed for each formulation.

To obtain steady-state flow curves (viscosity η versus shear rate $\dot{\gamma}$) shear stress was measured by increasing the shear rate in steps between 0.01 and 100 s^{-1}. The maximum measuring time per point was set at 300 s, but all the measurements were obtained before the cut-off time, so it could be assumed that steady-state was almost attained.

Mathematical Modeling

H-B model (Steffe 1996) was used to model steady-state flow curves and to calculate the corresponding parameters. H-B model in terms of the variation of shear stress (σ) as a function of shear rate ($\dot{\gamma}$) is written as

$$\sigma = \sigma_0 + K\dot{\gamma}^n \tag{1}$$

where K is the consistency coefficient, n is the flow behavior index and σ_0 is the yield stress. When flow characteristics are expressed in terms of apparent viscosity it becomes:

$$\eta = \frac{\sigma}{\dot{\gamma}} = \frac{\sigma_0}{\dot{\gamma}} + K \cdot \dot{\gamma}^{(n-1)} \tag{2}$$

Scheffe's equation (Scheffe 1958, Eq. 3) was used to determine the relationship between the parameters of H-B model (K, n and σ_0) and LF-DL composition, choosing a stepwise

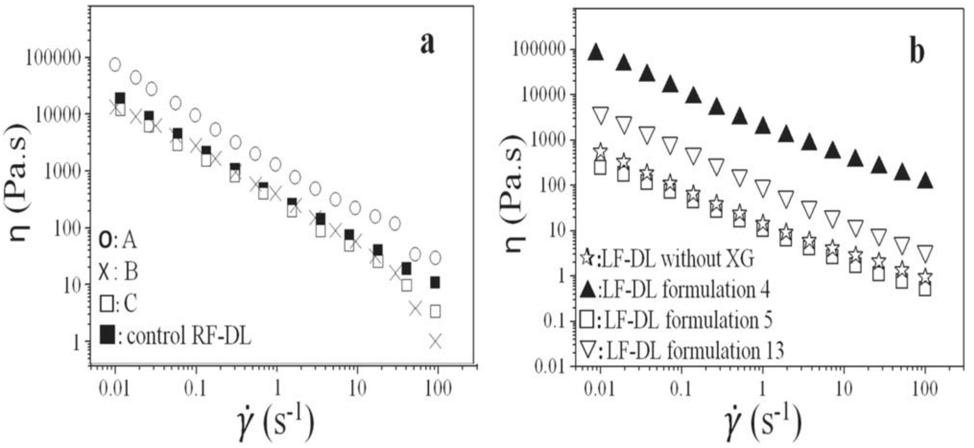

FIG. 1. FLOW CURVES OF (a) COMMERCIAL BRANDS OF TRADITIONAL DULCE DE LECHE (*A*, *B* AND *C*) AND A CONTROL REGULAR FAT-DL FORMULATION (RF-DL); (b) LOW FAT-DL FORMULATION WITHOUT XANTHAN GUM (43.8% W/W WATER) AND LF-DL FORMULATIONS: 4, 5 AND 13

procedure to eliminate nonsignificant terms ($P > 0.05$). Afterward the three mathematical expressions obtained were combined and Eq. (1) was rewritten in terms of the dependence of each parameter (y) with xanthan gum and water contents (Eq. 3). Changes on apparent viscosity at 7.2 s^{-1} as a function of composition were also regressed using Eq. (3):

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_3/x_1 + a_4/x_2 + a_{11} {x_1}^2 + a_{22} {x_2}^2 + a_{12} x_1 x_2 \qquad (3)$$

where y represents the independent variable (K, n, σ_0 or apparent viscosity at 7.2 s^{-1}) and x_1 and x_2 are xanthan gum and water contents (%), respectively.

Verification of the Model. Flow characteristics of three commercial DL brands (*A*, *B* and *C*) were measured, and their water content determined. Afterward, one of the brands (brand B) was selected as target to develop an LF-DL with xanthan gum in order to verify the predictive capabilities of the chosen model. A MATLAB iterative procedure was used to solve the developed equation that relates shear stress with formulation and shear rate; it minimized the sum of square differences between the experimental stress of the commercial DL and the predicted values, according to Eq. (4):

$$\sum \left(\sigma_{\exp} - \sigma_{pred}\right)^2 \qquad (4)$$

Afterward an LF-DL was prepared with the optimized xanthan gum and water contents; its flow curve was determined in duplicate and was compared to the commercial product. The relationship between apparent viscosity at $\dot{\gamma} = 7.2\ s^{-1}$ and composition of the LF-DL was also used to calculated the amount of xanthan gum to included in the product to reach a certain viscosity for a fixed water content, according to the proposed use.

Statistical Analysis

Statistical and regressional analyses were performed using SYSTAT software (SYSTAT Inc., Evanston, Illinois. Least significant difference (LSD) test was chosen for simultaneous pair wise comparisons. Differences in means and F tests were considered statistically significant when $P < 0.05$.

RESULTS AND DISCUSSION

Figure 1a shows flow curves obtained from different commercial DL samples (*A*, *B* and *C*) and the RF-DL control prepared in our laboratory. Water content of these formulation (% w/w) was: $A = 30.32$, $B = 32.38$, $C = 33.00$ and RF-DL = 31.92; only formulation *A* significantly differ from the others according to the LSD test. Steady-state flow curves of all samples corresponded to a structured fluid with a clear shear-thinning behavior, also known as pseudoplastic behavior. The four commercial products and control sample presented qualitatively similar flow curves showing that the procedure used in the lab was adequate to reproduce industrial conditions (Ranalli *et al.* 2012). Observed flow differences between formulations *B*, *C* and RF-DL might be explained by variations in type and amount of sugars used.

LF-DL samples without and with different xanthan gum and water contents also showed shear thinning characteristics (Fig. 1b). The initial resistance to flow, which denotes a plastic component was indirectly detected through the yield stress value found through fitting the H-B equation (Table 1). At the measured shear rates, the apparent viscosity diminished as shear rate increased, in agreement with the characteristics informed by other authors for traditional or reduced

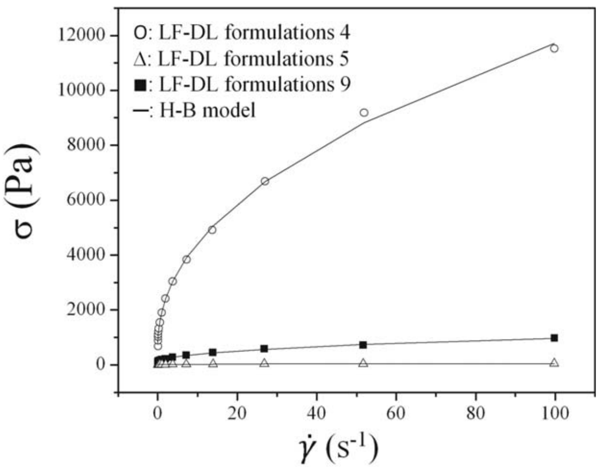

FIG. 2. STRESS (σ) VERSUS STRAIN ($\dot{\gamma}$) CURVES CORRESPONDING TO LF-DL FORMULATIONS 4, 5 AND 9. CONTINUOUS LINES REPRESENT H-B MODEL FITTED TO EXPERIMENTAL DATA

fat DL (Pauletti *et al.* 1990; Ares *et al.* 2006; Ranalli *et al.* 2012). As water content increased and xanthan gum content disminished, LF-DL became less viscous.

Figure 1b shows, as an example, average flow curves of LF-DL formulations 4 and 5, which represent the highest and lowest viscosities found in the assayed range of shear rates, respectively. Given that xanthan gum concentration in formulations 4 and 5 was very similar, it is clear the preponderant role that water content plays on apparent viscosity in LF-DL. In addition, LF-DL formulation 13 and LF-DL without hydrocolloid (both 43.8% water content) were included in Fig. 1b to illustrate the influence of xanthan gum.

An important characteristic of H-B materials is the presence of a yield stress (σ_0) which represents a finite stress required to achieve flow, it is related to the resistance of the reticular structure to be destroyed by shearing. In H-B fluids, apparent viscosity will decrease with higher shear rates when $0 < n < 1.0$, but behave in the opposite manner when $n > 1.0$. Figure 2 shows the excellent fitting of the H-B model to experimental stress data; H-B parameters predicted for the LF-DL formulations studied are presented in Table 1. Both the consistency coefficient (K) and yield stress (σ_0) depended strongly on water content, increasing when water contents decreased; the opposite effect was observed for xanthan gum concentration, although much less markedly. Flow index values ranged between 0.55 and 0.47, which correspond to a shear thinning fluid but did not correlate with any variable.

Rovedo *et al.* (1991) studying the rheological behavior of commercial household and confectionery DL reported that H-B model was the most adequate to explain flow diagrams for both types of DL, in comparison with other models tested (Heinz-Casson, Casson, Bingham plastic, power law). Moreover, Pauletti *et al.* (1990) characterized DL flows by Casson's, H-B and Michaels-Bolger's models. The comparison of K and n for traditional and confectionery DL made by Rovedo *et al.* (1991) indicated that the latter has more consistency (larger K) and was more pseudoplastic (lower n) because of the amount of starch added during its preparation. Our results showed that the higher K values were associated with samples with higher soluble solids content, while n parameter did not show a clear tendency.

Hough *et al.* (1988) measured flow properties of traditional DL made in a pilot plant cooker (solids content between 55 and 70%). They informed that H-B model was adequate to describe flow behavior of DL; except for the most concentrated samples at low temperatures. They reported that yield stress and consistency coefficient increased with solids content (lower water content), being in agreement with the results obtained in this work. The flow behavior index at 20C was nearly constant with an average value of 0.748, higher than our main value (0.380), which can be explained by the fact that xanthan gum may increase the pseudoplastic characteristics of the sample.

In the present study, changes in water content produced a larger effect on H-B parameters than modifying xanthan gum concentration. With less available water, both the viscosity and the minimum shear to flow, σ_0, were higher. This could be explained by an increase in the number of interactions between macromolecules in the product, caused by a higher concentration of the components in the sample. Doublier and Durand (2008) found the same relationship between shear stress and shear rate working on dispersions of cross-linked starch in full fat milk. Flow behavior indexes (n) were always less than 1 which corresponds to the shear-thinning behavior of all the LF-DL formulations.

The obtained parameters of the H-B model were regressed as a function of LF-DL composition according to Eq. (3), the resulting fitted equations and corresponding correlation coefficients were

$$\begin{aligned}\sigma_0 = & -2.8\cdot 10^3 + 43.7\cdot x_2 + 6.1\cdot 10^4/x_2 - 2.9\cdot 10^2\cdot x_1^2 \\ & -0.23\cdot x_2^2 + +3.9\cdot x_1\cdot x_2 \\ & \left(R = \ 1.000, P < 10^{-3}\right)\end{aligned} \tag{5}$$

$$\begin{aligned}K = & -1.0\cdot 10^4 + 2.6\cdot 10^3\cdot x_1 + 188\cdot x_2 + 45/x_1 \\ & +1.6\cdot 10^5/x_2 - 1.8\cdot 10^3\cdot x_1^2 - 1.2\cdot x_2^2 - 17\cdot x_1\cdot x_2 \\ & \left(R = \ 0.990, P < 10^{-3}\right)\end{aligned} \tag{6}$$

$$\begin{aligned}n = & -3.3 + 6.5\cdot x_1 + 0.05\cdot x_2 + 0.10/x_1 + 28.1/x_2 \\ & -4.6\cdot x_1^2 - 3.1\cdot 10^{-4}\cdot x_2^2 - 0.051\cdot x_1\cdot x_2 \\ & \left(R = \ 0.950, P < 10^{-5}\right)\end{aligned} \tag{7}$$

where x_1 and x_2 are xanthan gum and water contents (%), respectively.

After model fitting was performed, residual analysis was conducted which included calculating case statistics to identify outliers and examining diagnostic plots such as normal and residual plots. The proportion of variance explained by the polynomial models obtained was given by the multiple coefficients of determination, and the quality of the developed models was verified using a "lack of fit" test (Walpole 1993).

To predict the LF-DL composition to obtain a given flow behavior Eq. (1) was rewritten in terms of water and xanthan contents, using Eq. (5–7):

$$\begin{aligned}\sigma=&(-2.86\times10^3+43.7*x_2+6.15\times10^4/x_2-2.90\times10^2*x_1^2-0.23*x_2^2+3.95*x_2*x_1)\\&+(-1.02\times10^4+2.64\times10^3*x_1+1.89\times10^2*x_2+45.2/x_1+1.65\times10^5/x_2-1.84\times10^3*x_1^2\\&-1.19*x_2^2-17.8*x_2*x_1)*\dot{\gamma}(-3.30+6.52*x_1+5.67\times10^{-2}*x_2+9.59\times10^{-2}/x_1\\&+28.1/x_2-4.62*x_1^2-3.15\times10^{-4}x_2^2-5.14\times10^{-2}*x_2*x_1)\end{aligned} \tag{8}$$

Then, chosen as target, the steady-state flow curve determined for a commercial premium DL (brand B in Fig. 1a), water and xanthan contents that minimized the sum of residuals in Eq. (4) were predicted as explained in Materials and Methods section. This procedure was chosen to avoid the problem that would arise if the predictive relationships of the H-B parameters (Eq. 5–7) were used; it would result in an overspecified system (three equations and two unknowns).

The predicted water and xanthan gum contents were 35.4% and 0.18%, respectively, and the H-B parameters calculated according to Eq. (5–7) resulted in $\sigma_0 = 153.5$ Pa, $K = 173.3$ Pa s^n and $n = 0.34$. Afterward an LF-DL was prepared trying to reach the predicted composition; the obtained DL contained 31.9% water and 0.22% xanthan gum. Figure 3 shows the apparent viscosity as a function of the applied shear rate of the commercial DL chosen as target (brand B in Fig. 1a) and the LF-DL prepared to verify the usefulness of the proposed calculation procedure. The absolute percentual error between experimental and predicted viscosities was 12%, which may be mainly attributed to the difference between the predicted and the actual water and xanthan contents obtained.

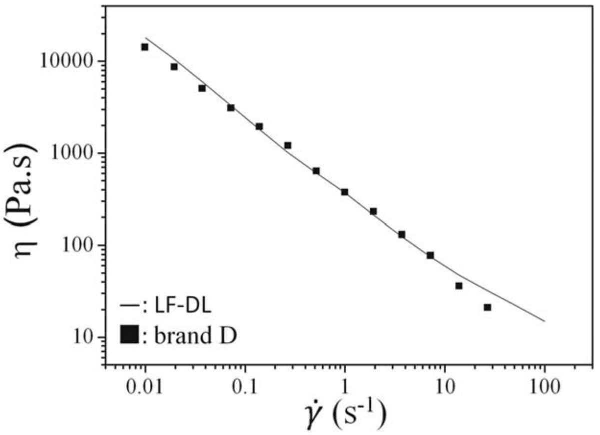

FIG. 3. STEADY-STATE FLOW BEHAVIOR FOR: LF-DL (——31.9% W/W WATER AND 0.227% W/W XANTHAN GUM); ■ TARGET COMMERCIAL PRODUCT (BRAND *B*, 32.4% W/W WATER)

A single point apparent viscosity value is sometimes used as a measure of mouthfeel of fluid foods (Steffe 1996). In dairy products, "creaminess" is associated to their consistency and/or viscosity (van Vliet *et al.* 2009); in particular, systems with a viscosity above 10 Pa s are usually evaluated at a constant shear rate of about 10 s^{-1} (Kokini *et al.* 1977). Thus a simplified procedure to predict the composition of LF-DL with a given flow behavior was also investigated. First apparent viscosities at 7.2 s^{-1} of the LF-DL formulations were fitted as a function of water and xanthan gum contents according to Eq. (3), and the obtained quadratic polynomial expression was:

$$\begin{aligned}\ln\eta_{\dot{\gamma}=7.2\,s^{-1}}=&-1.2-2.0\cdot x_1+0.22\\&\cdot x_2-0.51/x_1+159/x_2-2.7\cdot10^{-3}\cdot x_2^2-0.07\cdot x_1\\&\cdot x_2\ \left(R=\ 0.999, P<10^{-6}\right)\end{aligned} \tag{9}$$

where η is the apparent viscosity at $\dot{\gamma} = 7.2$ s^{-1}, x_1 is xanthan gum content (%) and x_2 corresponds to the water content (%) of the LF-DL product. When the flow curve of a design product is not known and the only interest is focused on the mouthfeel viscosity, this correlation could be used to obtain a rapid estimation of the required concentration. In this case, the commercial product chosen and the prepared LF-DL has an apparent viscosity at 7.2 s^{-1} of 68 Pa s; considering a water content of 32% Eq. (9) predicts a xanthan gum concentration of 0.17%, which was similar to the one, predicted previously.

The simplicity of the described procedure allowed the prediction of isoviscosity curves as a function of composition. Thus depending on the proposed use of a product and the desired water content, which determines process yield, xanthan gum concentration adequate to achieve the desired viscosity may be predicted from Fig. 4. This results show

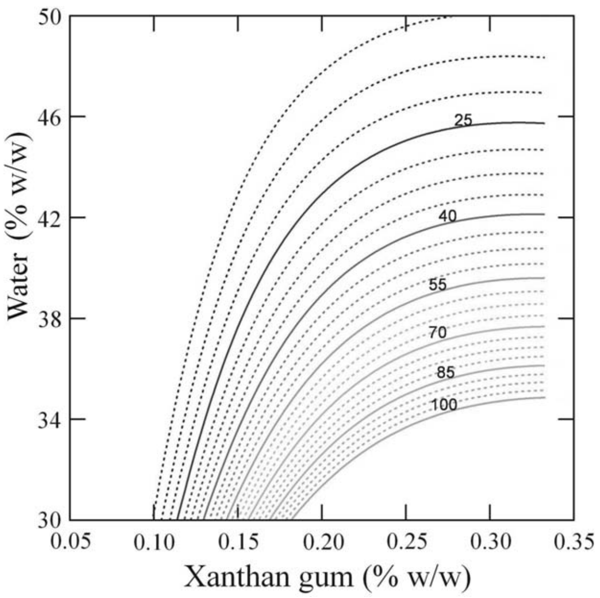

FIG. 4. ISOVISCOSITY CURVES OF LF-DL, EXPRESSED AT $\dot{\gamma} = 7.2\ \mathrm{s}^{-1}$ ($\eta_{\dot{\gamma}=7.2\mathrm{s}^{-1}}$, Pa s) AS A FUNCTION OF XANTHAN GUM AND WATER CONTENTS (% W/W)

that viscosity could be increased up to a certain value by raising xanthan content beyond which water content must be reduced thus lowering product yield.

CONCLUSIONS

The H-B model was adequate to describe the flow behavior of LF-DL. The relationship between H-B parameters and xanthan gum and water contents was established, showing that changes in water content produced a larger effect on H-B parameters than modifying xanthan gum concentration. With less available water, both the viscosity and the minimum shear to flow, σ_0, were higher. With the proposed methodology, it was possible to select the right combination of components to obtain an LF-DL with rheological characteristics similar to a commercial brand well accepted by consumers.

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