MODELING OF RHEOLOGICAL BEHAVIOUR OF TOMATO SPREADS

Rosa, E., Peinado, I., Heredia, A. and Andrés*, A.

Institute of Food Engineering for Development
Universitat Politècnica de València
Camino de Vera s/n
46022 Valencia (Spain)
*aandres@tal.upv.es

ABSTRACT
The knowledge of the rheological properties of a material is very useful in the quality control of foods, equipment design and analysis of the structural changes produced during the processing/storage. In addition, it plays an important role in the consumer acceptance and can be used in the development of new products since allows to evaluate the effect of new ingredients/elaboration methods on its structure. The aim of this work was to model the rheological behaviour of tomato spreads elaborated under different processing variables (type of sugar, elaboration method and pectin percentage). All the products presented a non-Newtonian behaviour and the results could be fitted to Herschel-Bulkley model with a yield stress between 4.3 and 71.2 Pa. The statistical analysis showed higher consistency for the parameters obtained in the sucrose spreads compared to the products elaborated with isomaltulose. Finally, different equations are presented for predicting the rheological parameters as a function of the type of sugar and pectin percentage.

Keywords: rheology, isomaltulose, fruit spreads, osmotic dehydration.

1. INTRODUCTION

In recent years, changes in the lifestyle have increased the consumption of prepared food or ready-to-eat. However, consumers are aware that can demand products with a high nutritional and functional value and in some cases as close as possible to the fresh product as it is the case of fruit and vegetables.

Additionally, several epidemiological studies have pointed out the relation between a regular consumption of tomatoes and tomato based products and the prevention of cardiovascular diseases and determinate types of cancers (Clinton 1998; Giovannuci 1999; Miller *et al.* 2002).

In this sense, the development of new tomato products with high lycopene content and rich in other original nutrients such as ready-to-eat spreadable products could be interesting.

Fruit spread products present similar characteristics to fresh fruit but they are more stable than the fresh ones as the water activity and moisture of the products are reduced (Peinado *et al.* 2009, Rosa *et al.* 2009).

Osmotic dehydration can be used for water removing and sugar addition in concentration processes, avoiding the heating process since water removal takes place by osmosis. Besides, osmotic process can also be applied by using dry sugar instead of sugar solutions, similar to in dry salting process commonly applied to meat and fish products. In these processes, a concentrated solution, rich in volatile compounds, vitamins and water soluble minerals from the fruit itself is generated due to water out-flow and its volume is considerably lower than the volume used in wet osmotic dehydration processes.

Furthermore, sucrose could be replaced by other sugars with low glycemic index, such as isomaltulose, in order to obtain healthier products.

On the other hand, the syneresis process (separation into pulp and serum) is a defect very usual in conventional tomato-based products which could be reduced by increasing the consistency of the product; a high-consistency tomato juice has almost no syneresis (Porretta *et al.* 1995). In this way, spreadable tomato products would have a lower risk of suffering syneresis during the storage because they present a higher consistency than natural tomato puree by addition of pectin and increasing of soluble solids in their formulation.

Rheological measurements of these innovative products might be very useful to evaluate the effect of the different processing variables on its structural changes.

The aim of this study was to model the rheological flow behaviour of 20 Brix tomato spreadable products formulated with different processing variables: type of sugar (sucrose or isomaltulose), elaboration method (dry or wet osmotic dehydration, and proportion of fruit), and pectin percentage (0.5, 1, 1.5 %).

2. MATERIAL AND METHODS

2.1. Raw Material

Pear tomatoes (*Lycopersicon esculentum Mill.*) acquired in a local supermarket were manually selected to homogenise the samples in terms of shape, colour and ripeness, avoiding those with physical damage. Samples were cleaned with chlorinated water, peeled and cut into cubes of approximately 1 cm^3.

2.2. Methodology

Equilibrium stage: two different osmotic dehydration methods at 25 ºC were used, Wet Osmotic Dehydration (WOD), in which the tomato cubes were immersed in a hypertonic osmotic solution (40 Brix) and Dry Osmotic Dehydration (DOD), in which the tomato cubes were directly covered with the solid osmotic agent, similar to the dry salting process commonly applied to meat and fish products. The ratio tomato:osmotic agent was calculated by mass balance to reach an equilibrium concentration of 20 Brix. In this stage either sucrose or isomaltulose were used like osmotic agents.

Product formulation: the ingredients in the spread formulations were dehydrated tomato, final osmotic solution, olive oil 2 %, salt 0.4 %, apple pectin (0.5, 1, 1.5 %) as a gelling agent and potassium sorbate (500 ppm) as a preservative (% refers to the final product). According to the different proportions of dehydrated tomato:final osmotic solution and depending on the type of osmotic dehydration (W or DOD), three elaboration methods were selected:

- W: WOD and formulation with a dehydrated tomato:final osmotic solution ratio of 70:30.
- D1: DOD and formulation with a dehydrated tomato:generated osmotic solution ratio comparable to the proportion achieved during the equilibrium stage (≈50:50).
- D2: DOD and formulation with a dehydrated tomato:generated osmotic solution ratio of 70:30.

Finally, 18 tomato spreads were formulated depending on the different processing variables: kind of sugar, elaboration method and pectin percentage (table 1).
Products were homogenized with a mixer for 3 minutes. Then they were stored for 24 hours to allow correct gel stabilization before to perform the analysis.

2.3. Rheological Analysis

Rheological properties were obtained with a controlled stress rheometer (RheoStress 1, Haake), at 25 ºC. All measurements were carried out in duplicate with plate-plate geometry and a 2.0 mm gap (Sato and Cunha 2009).
Steady state measurements were carried out with shear rate ranging from 0 to 300 s-1, in 3 sweeps (up, down and up-cycles), in order to eliminate the thixotropy. The data obtained in the third sweep were fitted to rheological models using the software Rheowin Data Manager (Haake) to find the best suitable model.

Table 1: Selected processing variables to obtain the different 20 Brix spreadable tomato products.

	Osmotic Agent	Elaboration	% Pectin
1	Sucrose	W	0.5
2			1
3			1.5
4		D1	0.5
5			1
6			1.5
7		D2	0.5
8			1
9			1.5
10	Isomaltulose	W	0.5
11			1
12			1.5
13		D1	0.5
14			1
15			1.5
16		D2	0.5
17			1
18			1.5

2.4. Statistical Analysis

Statgraphics Centurion was used to perform the statistical analyses. Analyses of variance (multifactor ANOVA) were carried out to estimate the significant effect of the processing variables (type of sugar, elaboration method and pectin percentage) on the final spreadable product.

3. RESULTS AND DISCUSSION

3.1. Rheological Modeling

After removing the thixotropy, the flow curves of the tomato spreads showed a shear thinning behaviour with yield stress. Therefore, Herschel–Bulkley model (equation 1) was the model that best fitted the experimental data.

$$\tau=\tau_0+k\cdot\gamma^n \quad (1)$$

Where, τ is the shear stress (Pa), τ_0 the yield stress (Pa), γ the shear rate (s^{-1}), k the consistency index ($Pa\cdot s^n$) and n the flow behaviour index.
This rheological behaviour is one of the most common in fruit and vegetables products like purees, jams or spreadable products (Sharma *et al.* 1996; Maceiras, Álvarez and Cancela 2007; Tonon *et al*. 2009; Sato and Cunha 2009; Peinado 2011).
Table 2 shows the rheological parameters obtained for the 18 tomato spread products with values of R^2 between 0.839 and 0.999. The differences observed between samples could be attributed to the different ratios fruit-osmotic solution as well as to the pectin percentages.

Table 2: Rheological parameters of Herschel–Bulkley model fitted to data of 20 Brix tomato spreadable products: τ_0 is the yield stress (Pa), k the consistency index ($Pa \cdot s^n$) and n the flow behaviour index.

	τ_0	k	n
1	8.3 (0.6)	4.38 (0.05)	0.3757 (0.0007)
2	29.6 (1.2)	13.2 (0.3)	0.354 (0.005)
3	54 (15)	26 (5)	0.306 (0.009)
4	4.5 (1.9)	2.308 (1.015)	0.38 (0.03)
5	15.5 (1.5)	4.0 (0.8)	0.39 (0.04)
6	53.030 (-)	19.070 (-)	0.3500 (-)
7	7.2 (0.2)	2 (2)	0.3169 (-)
8	23 (4)	3.1 (0.3)	0.449 (0.004)
9	64.970 (-)	20.980 (-)	0.3575 (-)
10	8.0 (0.6)	1.784 (1.119)	0.4263 (-)
11	32.4 (0.5)	14 (3)	0.34 (0.05)
12	60 (3)	21.9 (0.3)	0.3356 (0.0109)
13	4.263 (-)	0.107 (-)	0.6900 (-)
14	20 (3)	7.1 (0.6)	0.395 (0.008)
15	32 (11)	9 (3)	0.373 (0.009)
16	13.8 (0.7)	1.6 (0.7)	0.53 (0.05)
17	25.830 (-)	4.208 (-)	0.3364 (-)
18	71.22 (1.03)	20.17 (0.08)	0.3277 (0.0007)

To evaluate the influence of the processing variables on the rheological parameters obtained, an ANOVA factorial analysis was performed. The table 3 shows the F-ratio values and the significance levels (p-value) of the effect of the different variables obtained in the statistical analysis.

Table 3: F-ratio values and significance levels (p-value) of Herschel-Bulkley model parameters obtained in the ANOVA factorial analysis.

Variables	F-ratio	P-value
τ_0		
A: Type of sugar	0.15	0.6983
B: Elaboration	**17.08**	**0.0000**
C: % Pectin	**220.04**	**0.0000**
AxB	2.78	0.0839
AxC	1.11	0.3462
BxC	**4.78**	**0.0063**
k		
A: Type of sugar	**6.09**	**0.0218**
B: Elaboration	**35.10**	**0.0000**
C: % Pectin	**230.47**	**0.0000**
AxB	1.67	0.2106
AxC	**8.64**	**0.0017**
BxC	**9.52**	**0.0001**
n		
A: Type of sugar	**15.27**	**0.0008**
B: Elaboration	**9.72**	**0.0009**
C: % Pectin	**23.01**	**0.0000**
AxB	**4.91**	**0.0173**
AxC	**27.54**	**0.0000**
BxC	2.53	0.0699

The statistical results revealed than the variable with a higher influence on the yield stress (τ_0) and the consistency index (k) was the pectin percentage (F-ratio value much higher than the rest of variables). However, in the case of flow behaviour index (n), both the kind of sugar and the pectin percentage presented an important effect.
These results were similar to those obtained for strawberry spread products elaborated with the same sugars (Peinado 2011).

3.2. Prediction Equations for the Rheological Parameters of Herschel-Bulkley Model

The equations for predicting the rheological parameters of Herschel-Bulkley model were obtained as a function of the type of sugar and pectin percentage, since the statistical results showed a higher influence on these parameters (table 4).
It can be noticed that in the case of sucrose spreads, the flow behaviour index (n) is constant, regardless of the percentage of pectin used.

Table 4: Prediction equations obtained for the parameters of Herschel-Bulkley model of spreadable tomato products depending on the kind of sugar and the pectin percentage (P).

	Prediction Equations	R^2
Sucrose		
τ_0	$\tau_0=24.7795P^{1.9457}$	0.9956
k	$k=8.9967P^{1.7627}$	0.9377
n	$n=0.36\pm0.04$	-
Isomaltulose		
τ_0	$\tau_0=27.0999P^{1.6593}$	0.9990
k	$k=7.0306P^{2.4840}$	0.9844
n	$n=0.3908P^{-0.4411}$	0.9119

It can be observed than in the case of yield stress parameter (τ_0), the proposed equations for both sugars (sucrose and isomaltulose) are very similar. This fact agrees with the previous statistical results, where no significant influence was found in the yield stress (τ_0) depending on the type of sugar. However, the equations of the consistency index (k) for both sugars show a higher increase of 'k' with the pectin addition in isomaltulose tomato spreads as compared to sucrose products. This fact could be related to the lower solubility of the isomaltulose, which implies more free water in the food matrix and the pectin addition would be more effective.
The suitability of the predicted models for describing the type of sugar and the pectin percentage-dependent behaviour of the tomato spreads was checked by comparing the experimental data with the theoretical values (figures 1 and 2).

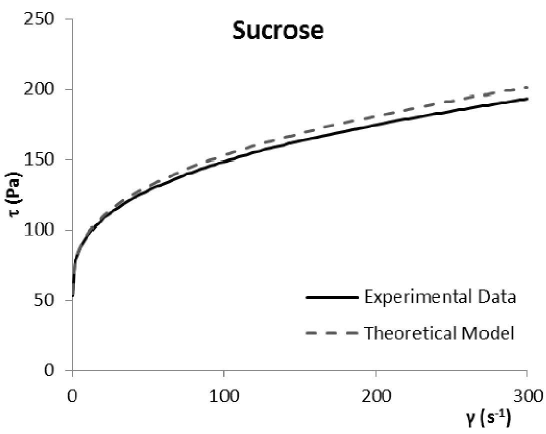

Figure 1: Example of the correlation between the experimental data and the theoretical curve for 20 Brix sucrose tomato spreads.

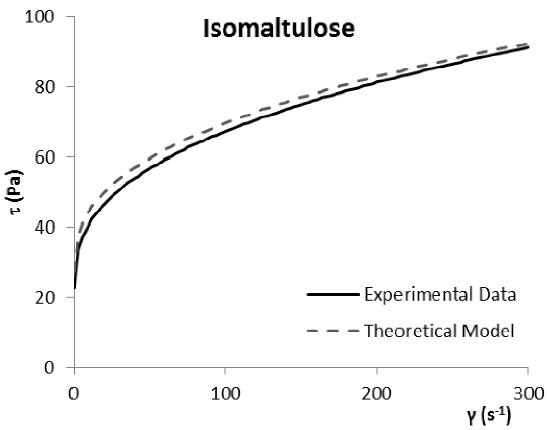

Figure 2: Example of the correlation between the experimental data and the theoretical curve for 20 Brix isomaltulose tomato spreads.

It can be observed than the theoretical values were in accordance with experimental data obtained for both sugars (sucrose and isomaltulose). Therefore, the proposed equations appear to be suitable to describe and predict the rheological parameters of the Herschel-Bulkley model for tomato spreads within the range of the studied processing variables.

4. CONCLUSIONS

Sugar and pectin percentage variables were seen to have a greater influence than the elaboration method on the rheological behaviour of spreadable tomato products. Since this type of product presents a shear thinning behaviour with yield stress, the Herschel-Bulkley model was found to be the one that best fitted the experimental data.

The pectin percentage had a very strong influence on the yield stress values (τ_0), but they did not exhibit significant differences for the different sugars used (sucrose and isomaltulose).

The values of the consistency index (k) and the flow behaviour index (n) were influenced by all the processing variables (type of sugar, elaboration method and pectin percentage). The highest values for consistency and therefore the lowest for fluidity were obtained in the tomato spreads elaborated with the highest proportion of fruit (W and D2) and percentage of pectin.

The proposed mathematical equations can be used to estimate the rheological parameters in the Herschel-Bulkley model of 20 Brix spreadable tomato products taking into account the type of sugar and the pectin percentage used in their elaboration.

These results could be very useful for designing and developing new tomato-based products, though subsequent studies would be necessary to increase the range of pectin percentage or to introduce new ingredients into the formulation.

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AUTHORS' BIOGRAPHIES

A. Andrés is a Full Professor in the *Universitat Politècnica de València* and the Director of the Institute of Food Engineering for Development in Valencia (Spain). **A. Heredia** is a Lecturer in the *Universitat Politècnica de València* and a Researcher member of the Institute of Food Engineering for Development in Valencia (Spain). **I. Peinado** acquired her PhD. in Food Technology in the *Universitat Politècnica de València* in 2011 and at present is a carrying out a post-doctoral fellowship in Northumbria University (United Kingdom). **E. Rosa** has a Bachelor's Degree in Food Science and Technology and currently is completing her PhD. in the *Universitat Politècnica de València* (Spain).