RHEOLOGICAL CHARACTERISTICS OF HEALTHY SUGAR SUBSTITUTED SPREADABLE STRAWBERRY PRODUCT

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ABSTRACT

Full replacement of sucrose with healthier sugars such as fructose and/or isomaltulose is possible in spreadable strawberry products. These products formulated with different sugars (sucrose, isomaltulose, sucrose-glucose, and fructose-isomaltulose) were rheologically analysed. Static tests characterized them as Herschel-Bulkley fluids. The values of the consistency index (*k*) and yield stress (τ_0) were influenced by the type of sugar, the elaboration method and the pectin levels; while the fluidity index (*n*) was not affected by the different sugars, but by the elaboration method and the levels of pectin. The dynamic tests permitted classification of some of the products as weak gels. The strength of the network "*A*" increased with the pectin level, while the "coordination number" "*z*" did not show a clear trend depending on the different process variables.

Key words: isomaltulose, fructose, sucrose, rheology, spreadable strawberry

1. Introduction

Strawberries (*Fagaria vesca*) are one of the most valued fruits, not only because of their high content in vitamins and minerals, but also because of their organoleptic characteristics such as taste and aroma. They are rich in vitamin C, sometimes in even higher concentrations than oranges; they are also rich in fibre, minerals and organic acids (Rizzolo *et al.*, 1995; Forney *et al.*, 1996; Azodanlau *et al.*, 2003, 2004; Ávila *et al.,*2009). Nevertheless, strawberries are very problematic for industrial processing as they are seasonal, and have a high water content which makes them very perishable. Therefore, some other means of preservation, like freezing or canning is necessary. Preserved products such as jams and jellies are examples of value-added foods that can be made from strawberries.

Jam is a food with intermediate moisture prepared by boiling fruit pulp with sugar, pectin, acid, and other ingredients (preservative, colouring and flavouring agents) to a reasonably thick gel consistency (Baker *et al.,* 2005). Total soluble-solids content of the finished jam should be between 60-65% or greater and the product should contain at least 45% fruit. The big difference between a spreadable fruit product and a jam is that in the former, cooking to reach a final soluble solid content is avoided, as it provokes the greatest changes from a nutritional, sensorial and functional point of view. Moreover, a fruit spread does not have any restriction related to sugar content (BOE 04/07/07; RD: 863/2003).

The addition of sugar in spreadable formulations is necessary to attract and bind water during gelation of high methoxyl (HM) pectin; sucrose being the standard sugar used for these products (Rauch, 1987; Mckeel *et al*., 2000). Nevertheless, it presents some disadvantages from the point of view of human health such as its high glycemic and cariogenic indexes (Weidenhagen & Lorenz, 1957; Zengo & Mandel, 1972; Pereira *et al.,* 2005). In fact, health conscious consumers and especially those with diabetes are demanding reduced or no-sugar added products, leading manufacturers to develop a variety of new healthy products. Hence, sucrose replacement by other sugars such as fructose and/or isomaltulose for instance, is interesting to obtain new healthier products. Fructose has a lower glycemic index but higher sweetener index than sucrose and glucose (Martínez & García, 2001). Moreover, isomaltulose, a sugar obtained from sucrose by means of a transglucosilation reaction (Schiweck *et al*., 2000), and characterized by one of the lowest glycemic and cariogenic indexes among sugars, is especially suitable for diabetics, children and sportspeople (Pawlak *et al*., 2004; Pereira *et al*., 2005; Jeffery *et al*., 2006). Nevertheless, isomaltulose presents some technical handicaps such as 30 % lower solubility at 25ºC and half the sweetness of sucrose (Kaga & Mizutani, 1985; Schiweck *et al*., 2000).

Wet Osmotic Dehydration has been proposed by several authors for the elaboration of jam and jellies without heat treatment as water removal takes place without phase exchange, and therefore, damage to colour, taste and aroma is minimized (Shi *et al*., 1996; Moreno *et al*., 2000; García-Martínez *et al*., 2002). However, it involves some disadvantages related to the handling of large volumes of osmotic solutions and high water consumption. Dry Osmotic Dehydration (DOD) might be an option since the volume of solution generated is considerably lower than the volume managed in the wet method. There is also a greater concentration of aromatic compounds, and soluble vitamins and minerals, as this solution comes from the product itself. DOD consists of covering the product with a solid osmotic agent (avoiding the use of a solution), and leaving this to perform for a period of time provoking the egress of water from the interior of the product. Therefore, as in traditional osmotic dehydration, the obtained product would be more stable than the fresh one as moisture content and water activity decrease (Rosa *et al*., 2008; Peinado *et al*., 2009).

Static and dynamic rheological measurements during manufacturing of these alternative products may be useful in product quality control. Static rheological tests permit characterization of the product in terms of flow behaviour; while dynamic rheological tests in the linear viscoelastic region provide fundamental information about the three-dimensional pectin network gel structure. Depending on G' (storage modulus) and G'' (loss modulus), the food material can exhibit both solid like and fluid like behaviour (Sato & Cunha, 2009; Basu *et al*., 2011)

The aim of this work was to analyze the influence of type of sugar (sucrose and or glucose, fructose, isomaltulose), elaboration method (dry or wet osmotic dehydration, and percentage of fruit) and pectin percentage (1, 1.5 and 2 %) on the rheological properties of 30 and 50 Brix spreadable strawberry products.

2. Material and methods

2.1. Raw material

Strawberries (*Fragaria vesca*) acquired in a local supermarket were sorted to eliminate damaged fruit and homogenize the sample for colour, shape and level of ripeness. Samples were dipped in chlorinated water to eliminate possible pesticide residues, and then they were cut into cubes approximately 1 cm^3.

2.2. Methodology

Two types of spreadable strawberry products were formulated with different concentrations of sugar, one group of samples with a high sugar content (50 Brix), and another group with a low sugar content (30 Brix). Different spreadable products were formulated within the two different groups (30 and 50 Brix) varying the different processing variables: type of sugar (sucrose and/or glucose, fructose, isomaltulose), elaboration method (dry or wet osmotic dehydration, and percentage of fruit) and percentage of pectin (1, 1.5 and 2 %), as is explained as follows:

Equilibrium of the samples:

Samples were equilibrated using two osmotic dehydration processes. Wet Osmotic Dehydration (WOD), traditional osmotic dehydration in which samples were immersed in hypertonic solutions, and Dry Osmotic Dehydration (DOD) in which samples were directly covered with the solid osmotic agent. This last method is similar to the dry salting process commonly applied to meat and fish products. The osmotic dehydration was carried out until samples achieved 30 or 50 Brix (equilibrium concentration). Sucrose and isomaltulose were used as osmotic agents to obtain 30 Brix spreadable products, and only sucrose or blends of sucrose-glucose and fructose-isomaltulose (1:1 (w/w)) for the 50 Brix spreadable products. Appropriate fruit-solution ratios were calculated with the correspondent mass balances. The processes were carried out at 25 ºC. The final control point was determined by refractometry measuring the soluble solids concentration in the osmotic solution.

Sucrose was used as the reference sugar in both kinds of products. For 50 Brix spreadable products, it was necessary to mix the isomaltulose with other sugars due to its low solubility (approximately 30 % at 20 ºC, Kaga & Mizutani, 1985; Schiweck *et al*., 2000). Fructose was selected to mix with isomaltulose as it is also considered to be a healthy sugar. Finally the sucrose-glucose blend was chosen with the objective of getting products with similar sweetness to those obtained with the other sugars.

Jellification

Once equilibrium was reached, the dehydrated fruit was separated from the osmotic solution in order to formulate different spreadable products. The ingredients in the formulations were: dehydrated strawberry, osmotic solution, apple pectin (1, 1.5 or 2

%) as a gelling agent and potassium sorbate at a fixed concentration of 500 ppm (as a microbiological preserver) (Karabulut *et al*., 2001; Castelló *et al*., 2006). According to the sugar content as well as the different proportions of dehydrated strawberry-osmotic solution and dehydration method (wet or dry), six different strawberry spreads were elaborated, three of 30 Brix and three of 50 Brix. The 30 Brix spreadable strawberry products were: 30W (obtained by WOD and formulated at a dehydrated fruit-osmotic solution ratio of 70:30), 30D1 (obtained by DOD and formulated with the total amount of the obtained dehydrated fruit and osmotic final solution) and 30D2 (obtained by DOD and formulated at a dehydrated fruit-osmotic solution ratio of 70:30). The 50 Brix spreadable strawberry products were: 50W (obtained by WOD and formulated at a dehydrated fruit-osmotic solution ratio of 60:40), 50D1 (obtained by DOD and formulated with the total amount of the obtained dehydrated fruit and osmotic final solution) and 50D2 (obtained by DOD and formulated at a dehydrated fruit-osmotic solution ratio of 60:40).

Finally, all products were formulated with three pectin levels (1, 1.5 and 2%); therefore, a total of 18 low sugar strawberry spreads (table 1) and 27 high sugar strawberry spreads (table 2) were compared. Products were homogenized with a mixer for 3 minutes. Then, they were stored for 24 hours to allow correct gel stabilization before performing 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 triplicate with plate-plate geometry and a 2.0 mm gap for steady state and oscillatory tests (Sato & Cunha, 2009)

Steady state measurements were performed with a shear rate ranging from 0 to 100 s^{-1}, in 3 sweeps (up, down and up-cycles), in order to eliminate thixotropy. The data obtained in the third sweep were fitted to different equations (Newtonian, Power Law and Herschel–Bulkley) to find the best suitable model.

Oscillatory stress sweep tests were performed at a frequency of 1 Hz in order to determine the range of linear viscoelastic response (limit of linearity σ_{0lim}) under oscillatory shear conditions. The frequency sweep measurements were carried out within the linear viscoelastic region, in the range of 0.01-10 Hz, to obtain G' (storage modulus) and G'' (loss modulus).

Analysis of dynamic rheological data

The power law describes the mechanical spectrum within the linear viscoelastic region in terms of storage (G') and loss (G'') modulus as a function of frequency (equations 1 and 2) (Subramanian *et al*., 2006; Basu *et al*., 2011):

$$G' = a \times w^b \quad (1)$$

$$G'' = c \times w^d \quad (2)$$

Where, *a* is the low frequency storage modulus (Pa); *b* is the power law index for the storage modulus (dimensionless); *c* is the low frequency loss modulus (Pa); and, *d* is the power law index for the loss modulus (dimensionless).

Weak gel model

Gabriele *et al.*, (2001) introduced the concept of power law relaxation modulus to describe the rheological behaviour of dough, jam, and yoghurt. The weak gel model parameter z, is the 'coordination number', which is the number of flow units interacting with each other to give the observed flow response, and the flow regime is characterized by the following equation:

$$|G''| = \sqrt{\left(G'(w)\right)^2 + \left(G''(w)\right)^2} = A \times w^{1/z} \qquad (3)$$

where, *A* is a constant which can be interpreted as the 'interaction strength' between the rheological flow units. The three-dimensional structure characterizing a gel is described in terms of '*A*', which is related to the overall stiffness or resistance to deformation within the linear viscoelastic region at an angular frequency of 1 rad/s. The coordination number, *z*, can be used as a convenient measure for the strength of interaction of a gel. Material functions of food systems in the linear viscoelastic regime can be described well by only two parameters (*A* and *z*) (Gabriele *et al.*, 2001; Basu *et al.*, 2011).

2.3.Statistical analysis

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

3. Results and discussion

3.1.Steady state

After thixotropy elimination, the flow curves of the spreadable strawberry products showed a typical shear thinning behaviour (figure 1), and all the samples presented a good correlation to the Herschel-Bulkley model (equation 4).

$$\tau = \tau_0 + k \times \gamma^n \quad (4)$$

Where, τ is the shear stress (Pa), τ_0 the yield stress (Pa), γ the shear rate (s^{-1}), k index of consistency (Pa·s) and n index of fluidity.

Tables 1 and 2 show the rheological obtained parameters. The difference observed between samples can be attributed to the different fruit-osmotic solution proportions as well as to the different pectin levels. The increase of these factors determines a higher interaction as well as the presence of a thick three-dimensional structure so the shear stress increases considerably.

Table 3 shows the homogeneous groups obtained for the rheological parameters after the ANOVA. As it could be expected, these rheological properties revealed the presence and proportion of the different ingredients. Samples obtained by wet method (W) or dry method eliminating liquid phase (D2), showed higher indices of consistency (*k*) and yield stress'(τ_0) values due to the higher content in soluble solids of these products (Sato & Cunha, 2009), so the effect was more noticeable in the 50 Brix samples. In addition, it can be observed that the increase of pectin level provoked an increase in the rheological parameters, as a result of the pectin interactions with the other components of the food matrix. Regarding sugar, those 30 Brix products containing isomaltulose, and the 50 Brix products containing the blend isomaltulose-fructose, showed lower indices of consistency (*k*) and yield stress'(τ_0) values than the ones formulated with sucrose or sucrose-glucose respectively; the latter ones being the ones which the higher values of these rheological parameters. These results are consistent with those obtained in previous works where sucrose and sucrose-glucose produced products with higher consistency and cohesiveness values (Peinado *et al.,* 2009; Rosa et al., 2009).

Finally, no differences were observed in the fluidity index (*n*) considering the different sugars, but there was an influence due to the elaboration method as well as the levels of pectin. This index was higher for the products formulated with the dry method without eliminating liquid phase (D1), and those with lower pectin levels.

3.2. Oscillatory tests

Figure 2 shows the rheological results of the dynamic assays where the frequency dependence of storage (G') and loss (G'') moduli of the spreadable strawberry products with 1.5 % pectin can be observed. This test determines the relative elastic/viscous nature of the product. When G’>G’’, the food exhibits a typical semi-solid behaviour, which means that it will be more elastic than viscous, typical gel behaviour. When G’=G’’, the food material will behave like a concentrated solution. Finally when G’<G’’ the food material is a semi-liquid, so the product will behave like a diluted solution.

Different slope values are indicative of different bonding natures in food; figure 2 shows that practically all samples showed the same slope which means the same bonding nature. On the other hand, all the 30 and 50 Brix spreadable strawberry products formulated by means of Dry Osmotic Dehydration without liquid phase elimination (D1) behaved as concentrated solutions, as G’ and G’’ where basically equal (figure 2). These results are probably a consequence of a major proportion of liquid phase in these products, as the levels of pectin were not high enough to allow jellification.

Nevertheless, spreadable strawberry products formulated by the other two methods behaved as gels as G’>G’’ in all cases, independently of the dehydration method used, wet (W) or dry (D2). This indicates a dominant contribution of the elastic component to the viscoelasticity of spreadable strawberry products, typical behaviour for a viscoelastic solid. Similar responses have been reported for different food systems; ovalbumin gel (Nakamura *et al*., 1997), jam and yoghurt (Gabriele *et al*., 2001), starch gel (Rosalina & Bhattacharya, 2001), and lacto-globulin gel (Goncalves *et al*., 2004)

In addition, the dependence of G’ and G’’ on frequency (*w*) was adequately described by the power law function (equations (1) and (2)) ($R^2 > 0.9815$). The power-law model parameters for spreadable strawberry samples are listed in tables 4 and 5. As was expected the parameters “*a”* and “*c”* increased as the pectin level increased in both kinds of spreadable products 30 or 50 Brix, their values being higher for samples formulated by Wet (W) or Dry Osmotic Dehydration eliminating liquid phase (D2) and for the 50 Brix products. Finally the sugar used also seemed to have an influence on the rheological properties, the 30 Brix sucrose and the 50 Brix sucrose-glucose products had the highest “*a”* and “*c”* values, while the 30 Brix isomaltulose and the 50 Brix isomaltulose-fructose products had the lowest “*a”* and “*c”* values. However, parameters “*b*” and “*d*” did not show a clear trend considering the different variables.

The gelation process during the manufacturing of spreadable products is attributed to the alignment and stretching of the pectin polymer chains in the sucrose and fruit pulp mix, resulting in more sites becoming available for the formation of intermolecular hydrogen bonding. In this process, the polymeric pectin chains hydrogen bond to each other to form an interconnected three-dimensional gel network. Sucrose molecules are held within this three-dimensional pectin gel network structure (Basu *et al*, 2011).

Pectin forms a network of fibrils with water, where sugar acts as a dehydrating agent that disturbs the equilibrium existing between water and pectin. The barrier to self-association of pectin chains into gel junctions is intermolecular electrostatic repulsion between charged carboxyl groups in pectin, and polymeric pectin-water interactions acting in competition with polymer-polymer interactions (Evageliou *et al.,* 2000). Sucrose provides additional hydroxyl groups to stabilize the structure of junction zones and promote hydrogen bonds to immobilize free water (Nishinari *et al*., 1990). The results observed in this work suggest that concentration as well as type of sugar used influence the water availability in the pectin-sugar-acid mix and thus the formation of hydrogen bonds and possible association of water with the polymeric pectin chain.

The characteristics of weak gels are: G' > G''; both G' and G'' are largely independent of frequency; and, the linear viscoelastic strain limit is small ($\gamma < 0.05$) (Ross-Murphy, 1995). Based on the results of strain and frequency sweep tests, it can be said that 30 and 50 Brix spreadable strawberry products formulated by Wet (W) and Dry Osmotic Dehydration eliminating liquid phase (D2) might be classified as weak gels irrespective of type of sugar or pectin level. The strength of the network, "*A*", and the coordination number, "*z*", were obtained using equation 3 and are shown in tables 6 and 7**.** '*A*' values increased with the pectin level, their values being highest for samples formulated by Wet process (W) and for the 50 Brix products.

Nevertheless the “z” value did not show a clear behaviour considering the different process variables.

Table 8 lists the homogeneous groups obtained from the factorial ANOVA. These results confirmed that “*A*” values were affected by the three process variables in the 50 Brix samples, while in 30 Brix samples only the elaboration method and the level of pectin had an influence on them. Moreover, it is important to note that in the 30 Brix samples, the differences due to pectin level became more important in those products formulated with sucrose and formulated by D2. In the same way, in the 50 Brix samples, the differences due to pectin level and elaboration method became greater in those products formulated with the sucrose-glucose blend. Finally, the “z” parameter was not influenced by any process’ variables in the 50 Brix samples. However, it was affected by the elaboration method as well as the pectin level in the 30 Brix samples, the effect of the elaboration method being more important in samples containing sucrose. These results suggest that the influence of the different ingredients in the food system does not only depend on their concentration or distribution within the different system phases but also on the different component interactions in each phase.

4. Conclusions

From the results of the steady state tests it was found that the spreadable strawberry products presented a typical shear thinning behaviour and had a good correlation with the Herschel-Bulkley model. The values of the index of consistency (*k*) and yield stress (τ_0) were influenced by the type of sugar, the elaboration method and the pectin levels. The higher content in soluble solids of the spreads obtained by the wet (W) and dry method eliminating liquid phase (D2) with higher levels of pectin, resulted in higher values of these parameters. In addition those 30 Brix products containing isomaltulose, and the 50 Brix products containing the blend isomaltulose-fructose, showed the lowest indices for consistency (*k*) and yield stress'(τ_0). Finally, the fluidity index (*n*) was not affected by the different sugars, but by the elaboration method and the levels of pectin, this index being higher for the products formulated with the dry method without eliminating liquid phase (D1), and those with the lowest pectin levels.

The results of the dynamic tests showed that the power law function adequately described the dependence of G' and G'' on frequency (*w*). Dry Osmotic Dehydration without eliminating liquid phase (D1) resulted in spreads which behaved as concentrated solutions as G' ≈ G'', due to a higher liquid phase in these products.

On the other hand, the wet (W) or dry method eliminating liquid phase (D2) gave products with gel behaviour as G'>G'', which can be classified as weak gels irrespective of type of sugar or pectin level. The "strength of the network", "*A*" increased with the pectin level, its value being higher for samples formulated by the wet method (W) for the 50 Brix products. However, the "coordination number", "*z*" did not show a clear trend related to the different process variables.

These results suggest that replacing sucrose with healthier sugars could have a good acceptability among consumers. Nevertheless, aspects of the final quality of the products obtained, as well as the advantages and disadvantages of each of the methods, considering handling and the environment, must also be considered.

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6. References

Ávila, J. M., Beltrán, B., Cuadrado, C., Del Pozo, S., Rodríguez, M. V. & Ruiz, E. (2009). La Alimentación Española: características nutricionales de los principales alimentos de nuestra dieta. Ministerio de Agricultura, Pesca y Alimentación. Fundación Española de la Nutrición. España. 632.

Azodanlau, R., Darbellay, C., Luisier, J. L., Villettaz, J. C., & Amado, R. (2003). Quality assessment of strawberries (*Fragaria* species). *Journal of Agricultural and Food Chemistry, 51*, 715–721

Azodanlau, R., Darbellay, C., Luisier, J.L., Villettaz, J.C. & Amado, R. (2004). Changes in flavour and texture during the ripening of strawberries. *European Food Research Technology, 218:*167–172.

Baker, R.A., Berry, N., Hui, Y.H. & Barrett, D.M. (2005). Food Preserves and Jams, 2nd edition. In: Barrett, D.M., Somogyi, L., Ramaswamy, H.S. (Eds.). CRC Press, Boca Raton, FL, USA. 113–125.

Basu, S., Shivhare, U. S., Singh, T. V. & Beniwal, V. S. (2011). Rheological, textural and spectral characteristics of sorbitol substituted mango jam. *Journal of Food Engineering 105,* 503–512.

B.O.E. 04/07/07. Real Decreto 863/2003. Norma de calidad para la elaboración, comercialización y venta de confituras, jaleas, mermeladas de frutas y cremas de castañas.

Castelló, M.L., Fito, P.J. & Chiralt, A. (2006). Effect of osmotic dehydration and vacuum impregnation on respiration rate of cut strawberries. *LWT-Food Science and Technology, 39,* 1171–1179.

Evageliou, V., Richardson, R.K. & Morris, E.R. (2000). Effect of pH, sugar type and thermal annealing on high-methoxy pectin gels. *Carbohydrate polymer, 42*, 245-259.

Forney, C. F., Kalt, W., McDonald, J. E., & Jordan, M. A. (1996). Changes in strawberry fruit quality during ripening on and off the plant. *Acta Horticulturae,* 464-506.

Gabriele, D., De Cindio, B. & D'Antona, P. (2001). A weak gel model for foods. *Rheologica Acta, 40*, 120–127.

García-Martinez, E.; Ruiz-Diaz, J; Martinez-Monzó, J.; Camacho, M.M.; Martinez-Navarrete, N. & Chiralt, A. (2002). Jam manufacture with osmodehydrated fruit . *Food Research International*, *35,* 301-306.

Goncalves, M.P., Sittikijyothin, W., Da Silva, M.V. & Lefebvre, J. (2004). A study of the effect of locust bean gum on the rheological behaviour and microstructure of a b-lactoglobulin gel at pH 7. *Rheologica Acta, 43*, 472-481.

Jeffery, R., Baxter, J., Mcguire, M. & Linde, J. (2006). Are fast food restaurants an environmental risk factor for obesity? *International Journal of Behavioral Nutrition and Physical Activity, 3*: 35.

Kaga, T. & Mizutani, T. (1985). "Verwendung von Palatinose fur Nahrungsmittel. *Seito Gijutsu Kenkyukaishi*" *34*, 45-57.

Karabulut, O.A., Lurie, S. & Droby, S. (2001). Evaluation of the use of sodium bicarbonate, potassium sorbate and yeast antagonist for decreasing posthavest decay of sweet cherries. *Postharvest Biology and Technology, 23:* 233-236.

Martínez, J. & García, P. (2001).Nutrición Humana. Ed. Servicio de publicaciones de la Universidad politécnica de Valencia.

Mckee1, L. H., Garcia-Whitehead, G. & Remmenga, M. (2002). Quality characteristics of red raspberry fruit spread made with four sweeteners. *Plant Foods for Human Nutrition, 57*, 343–352.

Moreno, J.; Chiralt, A.; Escriche, I. & Serra, J.A. (2000). Effect of blanching/osmotic dehydration combined methods on quality and stability of minimally processed strawberries. *Food Research International, 33(7),* 609-616.

Nakamura, K., Kiriyama, M., Takada, A., Maeda, H. & Nemoto, N. (1997). Structure and dynamics of ovalbumin gel III. Solvent effect. *Rheologica Acta, 36*, 252-261.

Nishinari, K., Watase, M., Williams, P.A. & Phillips, G.O. (1990). K-carrageenan gels: effect of sucrose, glucose, urea, and guanidine hydrochloride on the rheological and thermal properties. *Journal of Agricultural Chemistry, 38(5),* 1188-1193.

Pawlak, D.B., Kushner, J.A. & Ludwig, D.S. (2004). Effects of dietary glycaemic index on adiposity, glucose homoeostasis, and plasma lipids in animals. *The lancet, 364,* 778–785.

Peinado, I., Rosa, E., Heredia, A. & Andrés, A. (2008). Estudio comparativo del color en fresa deshidratada osmóticamente con sacarosa, sorbitol e isomaltulosa. Póster-Artículo, Congreso Iberoamericano sobre Seguridad Alimentaria. V Congreso Español de Ingeniería de Alimentos. (CESIA). (5-7/11/2008), Barcelona, Spain. Book of Abstracts, p. 165.

Peinado, I., Rosa, E., Heredia, A. & Andrés, A. (2009). Influence of Dry and Wet Osmotic Dehydration on Colour and Texture of a Spread Strawberry Product. 'New Challenges in Food Preservation'. European Federation of Food Science and Technology (EFFoST) (11-13/11/09), Budapest, Hungary.

Pereira, M., Kartashov, A., Ebbeling, C., Van Horn, L., Slattery, M., Jacobs, D. & Ludwig, D. (2005). Fast-food habits, weight gain and insulin resistance (the CARDIA study): 15-year prospective analysis. *The lancet*, *365,* 36-42.

Rauch, G.H. (1987). Fabricación de mermeladas. Ed. Acribia, S.A. Zaragoza. España.

Rizzolo, A., Lombardi, P., Lovati, F., Tagliabue, S., & Testoni, A. (1995). Valutazione della componente aromatica dei frutti di fragola. *L'Informatore Agrario, LI (44*), 37–41.

Rosa, E., Peinado, I., Heredia, A. & Andrés, A. (2008). Deshidratación osmótica de frutas por vía seca. Una alternativa al uso de disoluciones. Póster-Artículo, Congreso Iberoamericano sobre Seguridad Alimentaria. V Congreso Español de Ingeniería de Alimentos. (CESIA). (5-7/11/2008), Barcelona, Spain. Book of Abstracts, p. 168.

Rosa, E., Peinado, I., Heredia, A. & Andrés, A. (2009). New Processing Methods and Healthier Sugars in Strawberry Spread Fruit Manufacturing. 'New Challenges in Food Preservation'. European Federation of Food Science and Technology (EFFoST). (11-13/11/09) Budapest, Hungary.

Rosalina, I. & Bhattacharya, M. (2001). Flow curves, stress relaxation and creep measurements of starch gels. *Journal of Texture Studies, 32*, 247-269.

Ross-Murphy, S.B. (1995). Structure–property relationships in food biopolymer gels and solutions. *Journal of Rheology, 39*, 1451-1463.

Sato, A. C. & Cunha, R. L. (2009). Effect of particle size on rheological properties of jaboticaba pulp. *Journal of Food Engineering 91*, 566–570.

Shi, X.Q.; Chiralt, A.; Fito, P.; Serra, J.A.; Escoin, C. & Gasque, L. (1996). Application of osmotic dehydration technology on jam processing. *Drying Technology*, *14(3-4),* 841-857.

Schiweck ,H., Munir, M., Rapp, K. M., Schenider, B. & Bogel, M. (2000). New developments in the use of sucrose as an industrial bulk chemical. *Zuckerindustrie, 115*, 555-565.

Subramanian, R., Muthukumarappan, K. & Gunasekaran, S. (2006). Linear viscoelastic properties of regular- and reduced- fat pasteurized processed cheese during heating and cooling. *International Journal of Food Properties, 9*, 377–393.

Weidenhagen & Lorenz (1957). Palatinose (6-alpha-Glucopyranosido fructofuranose), ein neues bakterielles Umwandlung-sprodukt der Saccharose, Zeitschrift fur die Zuckerindustrie 7, 533-534.

Zengo, A. N. & Mandel, I.D. (1972). Sucrose tasting and dental caries in man. *Archives of Oral Biology, 17(3),* 605-607.

Table 1. Rheological parameters of Herschel–Bulkley model fitted to data of 30 Brix strawberry spreadable products depending on the process variables: elaboration method (W: Wet Osmotic Dehydration; D1: Dry Osmotic Dehydration without eliminating liquid phase; D2: Dry Osmotic Dehydration eliminating liquid phase), type of sugar (S: sucrose; I: isomaltulose) and pectin percentage (1, 1.5 and 2%. τ_0 the yield stress (Pa), k index of consistency (Pa·s) and n index of fluidity.) (n=3).

30 Brix		τ_0	**k**	**n**	R^2
Elaboration	**% Pectin**				
		sucrose			
W	1	15.1 (0.5)	12.9 (0.3)	0.47 (0.02)	0.997
	1.5	31.23 (0.18)	26.4 (0.3)	0.462 (0.013)	0.998
	2	38.3 (1.9)	29 (3)	0.435 (0.002)	0.992
D1	1	4.03 (0.04)	6.1 (0.8)	0.535 (0.015)	0.999
	1.5	10.7 (0.7)	13.7 (1.3)	0.487 (0.002)	0.998
	2	16.19 (0.13)	19.6 (2.6)	0.495 (0,002)	0.990
D2	1	19.9 (0.9)	16.18 (0.19)	0.456 (0.002)	0.998
	1.5	27.75 (1.09)	22.9 (0.8)	0.455 (0.005)	0.999
	2	55 (6)	36.5 (1.6)	0.447 (0.004)	0.997
		isomaltulose			
W	1	13.4 (0.4)	12.3 (0.4)	0.472 (0.005)	0.999
	1.5	27.9 (0.2)	25.2 (0.8)	0.451 (0.008)	0.997
	2	30.6 (1.9)	26 (3)	0.444 (0.005)	0.999
D1	1	4.31 (0.17)	7.29 (0.02)	0.484 (0.006)	0.999
	1.5	6.6 (0.2)	10.74 (0.02)	0.494 (0.006)	0.999
	2	10.05 (0.09)	16.5 (0.4)	0.486 (0.002)	0.998
D2	1	13.3 (0.8)	13.6 (0.5)	0.475 (0.002)	0.999
	1.5	22.6 (0.7)	19.9 (0.3)	0.469 (0.002)	0.999
	2	36 (2)	28 (2)	0.455 (0.002)	0.996

Table 2. Rheological parameters of Herschel–Bulkley model fitted to data of 50 Brix strawberry spreadable products depending on the process variables: elaboration method (W: *Wet Osmotic Dehydration*; D1: *Dry Osmotic Dehydration without eliminating liquid phase*; D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; SG: sucrose-glucose; IF: isomaltulose-fructose) and pectin percentage (1, 1.5 and 2 %). τ_0 the yield stress (Pa), *k* index of consistency (Pa·s) and *n* index of fluidity. (n=3).

50 Brix		τ_0	**k**	**n**	R^2
Elaboration	**% Pectin**				
		sucrose			
	1	108 (5)	47.3 (0.9)	0.422 (0.002)	0.995
W	1.5	123 (12)	61 (3)	0.422 (0.003)	0.993
	2	165 (22)	69 (2)	0.42 (0.02)	0.990
	1	7 (1)	14 (2)	0.482 (0.002)	0.999
D1	1.5	20.1 (0.2)	25.07 (0.02)	0.472 (0.002)	0.998
	2	41 (1)	38 (2)	0.455 (0.005)	0.997
	1	46 (2)	31 (1)	0.433 (0.002)	0.998
D2	1.5	120 (1)	60 (1)	0.391 (0.002)	0.997
	2	137 (6)	64 (1)	0.416 (0.002)	0.995
		sucrose-glucose			
	1	123 (6)	53 (1)	0.420 (0.002)	0.995
W	1.5	143 (12)	65 (5)	0.415 (0.012)	0.991
	2	190 (16)	76 (6)	0.40 (0.02)	0.993
	1	8.2 (0..4)	14 (1)	0.527 (0.009)	0.999
D1	1.5	27 (1)	26 (1)	0.492 (0,002)	0.997
	2	47 (6)	44 (2)	0.467 (0.103)	0.996
	1	76 (2)	40 (1)	0.432 (0.002)	0.996
D2	1.5	129 (3)	63 (2)	0.41 (0.03)	0.993
	2	151 (4)	70 (3)	0.402 (0.112)	0.982
		isomaltulose-fructose			
	1	76 (3)	38(1)	0.434 (0.002)	0.997
W	1.5	99 (6)	52.91 (0.02)	0.415 (0.004)	0.997
	2	158 (4)	66.5 (0.3)	0.432 (0.003)	0.993
	1	6.8 (0.2)	12.5 (0.2)	0.477 (0.002)	0.999
D1	1.5	13 (1)	21.3 (0.9)	0.468 (0.003)	0.997
	2	37 (5)	38.3 (0.6)	0.446 (0.004)	0.996
	1	31 (2)	25 (1)	0.432 (0.003)	0.999
D2	1.5	61 (3)	38 (7)	0.45 (0.04)	0.998
	2	91 (5)	56 (3)	0.418 (0.004)	0.996

Table 3. Homogeneous groups identified for the rheological parameters of Herschel-Bulkley model (τ_0 the yield stress (Pa), *k* index of consistency (Pa·s) and *n* index of fluidity), from the ANOVA factorial performed depending on the process variables: elaboration method (W: *Wet Osmotic Dehydration*; D1: *Dry Osmotic Dehydration without eliminating liquid phase*; D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; I: isomaltulose; SG: sucrose-glucose; IF: isomaltulose-fructose) and pectin percentage (1, 1.5 and 2%).

30 Brix	**Type of Sugar**		**Elaboration method**		**Percentage of Pectin**	
	S	25 (3) (b)	W	26 (3) (b)	1	12 (3) (a)
τ_0			D1	10 (3) (a)	1.5	21 (3) (b)
	I	17 (2) (a)	D2	27 (3) (b)	2	31 (3) (c)
	S	20 (1) (b)	W	22 (2) (b)	1	11 (1) (a)
k			D1	12 (2) (a)	1.5	20 (1) (b)
	I	17 (1) (a)	D2	22 (2) (b)	2	25 (1) (c)
	S	0.471 (0.006) (a)	W	0.456 (0.008) (a)	1	0.472 (0.008) (a)
n			D1	0.497 (0.008) (b)	1.5	0.467 (0.008) (a)
	I	0.470 (0.006) (a)	D2	0.459 (0.008) (a)	2	0.465 (0.008) (a)
50 Brix	**Type of Sugar**		**Elaboration method**		**Percentage of Pectin**	
	S	85 (6) (b)	W	85 (6) (b)	1	53 (6) (a)
τ_0	SG	99 (6) (c)	D1	99 (6) (c)	1,5	82 (6) (b)
	IF	64 (6) (a)	D2	64 (6) (a)	2	113 (6) (c)
	S	45 (2) (b)	W	45 (2) (b)	1	30 (2) (a)
k	SG	50 (2) (c)	D1	50 (2) (c)	1,5	46 (2) (b)
	IF	39 (2) (a)	D2	39 (2) (a)	2	58 (2) (c)
	S	0.435 (0.008) (a)	W	0.435 (0.008) (a)	1	0.450 (0.007) (c)
n	SG	0.440 (0.008) (a)	D1	0.440 (0.008) (a)	1.5	0.438 (0.007) (b)
	IF	0.441 (0.008) (a)	D2	0.441 (0.008) (a)	2	0.429 (0.007) (a)

Table 4. Power law model (equations (1) and (2)) parameters for the 30 Brix spreadable strawberry products depending on the different process variables: elaboration method (W: *Wet Osmotic Dehydration*; D1: *Dry Osmotic Dehydration without eliminating liquid phase*; D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; I: isomaltulose) and pectin percentage (1, 1.5 and 2 %).

30 Brix		**G'**			**G''**		
Elaboration	**% Pectin**	***a***	***b***	**R^2**	***c***	***d***	**R^2**
		sucrose					
W	1	167.62	0.3804	0.9940	98.26	0.3271	0.9948
	1.5	208.21	0.3878	0.9941	128.69	0.3637	0.9994
	2	247.75	0.4575	0.9966	141.76	0.4553	0.9957
D1	1	41.64	0.5583	0.9942	37.92	0.5604	0.9866
	1.5	70.02	0.5247	0.9977	65.35	0.4524	0.9975
	2	91.79	0.5116	0.9954	79.53	0.4631	0.9999
D2	1	159.72	0.3686	0.9961	88.76	0.3239	0.9973
	1.5	238.64	0.3981	0.9911	149.74	0.3629	0.9960
	2	347.24	0.4233	0.9908	220.50	0.4116	0.9990
		isomaltulose					
W	1	144.19	0.3803	0.9955	83.314	0.3340	0.9948
	1.5	175.30	0.4242	0.9945	102.900	0.4013	0.9993
	2	192.42	0.4756	0.9939	127.320	0.4612	0.9971
D1	1	40.23	0.5727	0.9953	36.579	0.5735	0.9896
	1.5	62.89	0.5590	0.9985	57.369	0.4868	0.9981
	2	88.32	0.5320	0.9962	82.891	0.4684	0.9998
D2	1	143.55	0.3861	0.9950	84.616	0.3713	0.9987
	1.5	166.61	0.3854	0.9973	101.310	0.3892	0.9977
	2	222.23	0.4372	0.9953	137.710	0.4280	0.9974

Table 5. Power law model (equations (1) and (2)) parameters for the 50 Brix spreadable strawberry products depending on the different process variables: elaboration method (W: *Wet Osmotic Dehydration*; D1: *Dry Osmotic Dehydration without eliminating liquid phase*; D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; SG: sucrose-glucose; IF: isomaltulose-fructose) and pectin percentage (1, 1.5 and 2 %).

50 Brix		G'			G''		
Elaboration	**% Pectin**	***a***	***b***	**R^2**	***c***	***d***	**R^2**
		sucrose					
W	1	914.88	0.3369	0.9859	500.79	0.2653	0.9956
	1.5	1044.80	0.3554	0.9899	531.94	0.2656	0.9986
	2	1038.90	0.3721	0.9977	597.46	0.2975	0.9972
D1	1	49.28	48.799	0.9978	47.96	0.5048	0.9999
	1.5	99.19	0.5363	0.9975	89.71	0.4854	0.9997
	2	190.93	0.5138	0.9989	161.41	0.4472	0.9987
D2	1	437.06	0.3647	0.9919	236.65	0.3196	0.9960
	1.5	667.50	0.3447	0.9989	362.08	0.3144	0.9999
	2	705.14	0.3750	0.9975	398.86	0.3367	0.9937
		sucrose-glucose					
W	1	1836.00	0.3137	0.9860	717.24	0.3569	0.9423
	1.5	2337.00	0.3399	0.9911	1139.20	0.2670	0.9926
	2	2679.90	0.3224	0.9821	1295.10	0.2020	0.9911
D1	1	48.80	0.639	0.9978	51.25	0.5191	0.9997
	1.5	71.47	0.6235	0.9991	75.85	0.5125	0.9990
	2	111.01	0.6598	0.9986	126.08	0.5254	0.9966
D2	1	849.84	0.3173	0.9898	383.79	0.2052	0.9957
	1.5	1433.60	0.3162	0.9988	676.83	0.2954	0.9923
	2	1631.30	0.3398	0.9924	858.71	0.2462	0.9972
		isomaltulose-fructose					
W	1	664.63	0.3303	0.9966	341.32	0.3123	0.9994
	1.5	672.52	0.4097	0.9841	400.52	0.3139	0.9815
	2	854.19	0.3617	0.9976	481.87	0.3151	0.9977
D1	1	45.19	0.6234	0.9966	44.22	0.4968	0.9998
	1.5	87.35	0.5763	0.9968	82.76	0.4806	0.9993
	2	151.11	0.5247	0.9990	131.57	0.4739	0.9991
D2	1	87.35	0.5763	0.9968	82.76	0.4806	0.9993
	1.5	232.49	0.3679	0.9996	287.88	0.3881	0.9991
	2	433.94	0.4057	0.9993	389.49	0.3805	0.9986

Table 6. Weak gel model ("*A*" interaction strength, "*z*", coordination number, equation (3)) parameters for the 30 Brix spreadable strawberry products depending on the different process variables: elaboration method (W: *Wet Osmotic Dehydration*; D1: *Dry Osmotic Dehydration without eliminating liquid phase*; D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; I: isomaltulose) and pectin percentage (1, 1.5 and 2 %).

30 Brix		**G***		
Elaboration	**% Pectin**	***A***	**z**	**R^2**
		sucrose		
W	1	195 (13)	2.74 (0.05)	0.9966
	1.5	232 (7)	2.48 (0.06)	0.9965
	2	307 (58)	2.2 (0.2)	0.9912
D2	1	183 (10)	2.80 (0.12)	0.9965
	1.5	432 (22)	2.63 (0.05)	0.9981
	2	626 (35)	2.57 (0.09)	0.9955
		isomaltulose		
W	1	167 (2)	2.7 (0.2)	0.9965
	1.5	242 (3)	2.61 (0.12)	0.9961
	2	256 (13)	2.14 (0.07)	0.9954
D2	1	167 (13)	2.61 (0.13)	0.9975
	1.5	283 (34)	2.58 (0.12)	0.9943
	2	400 (10)	2.25 (0.04	0.9987

Table 7. Weak gel model ("*A*" interaction strength, "*z*", coordination number, equation (3)) parameters for the 50 Brix spreadable strawberry products depending on the different process variables: elaboration method (W: *Wet Osmotic Dehydration*; D1: *Dry Osmotic Dehydration without eliminating liquid phase*; D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; I: isomaltulose) and pectin percentage (1, 1.5 and 2 %).

50 Brix		**G***		
Elaboration	**% Pectin**	***A***	**z**	**R^2**
sucrose				
W	1	1047 (18)	3.12 (0.13)	0.9935
	1.5	1176 (13)	3.01 (0.07)	0.9949
	2	1220 (13)	2.80 (0.12)	0.9966
D2	1	498 (32)	2.8 (0.2)	0.9958
	1.5	760 (26)	2.96 (0.03)	0.9992
	2	814 (11)	2.76 (0.09)	0.9893
sucrose-glucose				
W	1	2029 (193)	1.8 (0.4)	0.9931
	1.5	2626 (450)	3.2 (0.2)	0.9909
	2	2999 (316)	3.40 (0.07)	0.9840
D2	1	953 (67)	3.62 (0.05)	0.9912
	1.5	1588 (154)	3.22 (0.09)	0.9954
	2	1850 (294)	3.14 (0.17)	0.9954
isomaltulose-fructose				
W	1	766 (107)	3.07 (0.07)	0.9976
	1.5	809 (25)	2.9 (0.2)	0.9935
	2	982 (48)	2.86 (0.07)	0.9973
D2	1	260 (10)	2.61 (0.16)	0.9964
	1.5	454 (22)	2.651 (0.06)	0.9996
	2	516 (25)	2.50 (0.09)	0.9994

Table 8. Homogeneous groups identified for the rheological parameters of Weak gel model ("*A*" interaction strength, "*z*", coordination number, equation (4)), from the ANOVA factorial performed depending on the process variables: elaboration method (W: *Wet Osmotic Dehydration* and D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; I: isomaltulose; SG: sucrose-glucose; IF: isomaltulose-fructose) and pectin percentage (1, 1.5 and 2 %).

30 Brix	**Sugar**		**Elaboration method**		**% Pectin**	
	S	266 (15) (a)	W	233 (15) (a)	1	177 (18) (a)
A					1.5	254 (18) (b)
	I	252 (15) (a)	D2	285 (15) (b)	2	345 (18) (c)
	S	2.56 (0.09) (b)	W	2.48 (0.09) (a)	1	2.717 (0.105) (c)
z					1.5	2.573 (0.105) (b)
	I	2.49 (0.09) (a)	D2	2.57 (0.09) (b)	2	2.282 (0.105) (a)
50 Brix	**Sugar**		**Elaboration method**		**% Pectin**	
	S	919 (65) (b)	W	1517 (54) (b)	1	926 (47) (a)
A	SG	2008 (65) (c)			1.5	1236 (47) (b)
	IF	631 (65) (a)	D2	855 (54) (a)	2	1397 (47) (c)
	S	2.8 (0.8) (a)	W	2.9 (0.7) (a)	1	2.8 (0.8) (a)
z	SG	2.9 (0.8) (a)			1.5	3.0 (0.8) (a)
	IF	3.1 (0.8) (a)	D2	2.9 (0.7) (a)	2	2.9 (0.8) (a)

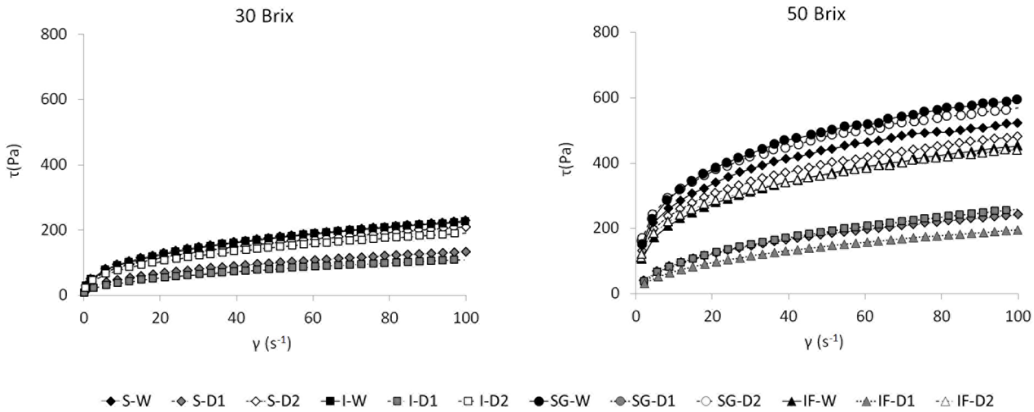

Figure 1. Flow curves obtained with the steady state analysis of the spreadable strawberry products containing 1.5 % of pectin, depending on the process variables: elaboration method (W: *Wet Osmotic Dehydration;* D1: *Dry Osmotic Dehydration without eliminating liquid phase* and D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; I: isomaltulose; SG: sucrose-glucose; IF: isomaltulose-fructose).

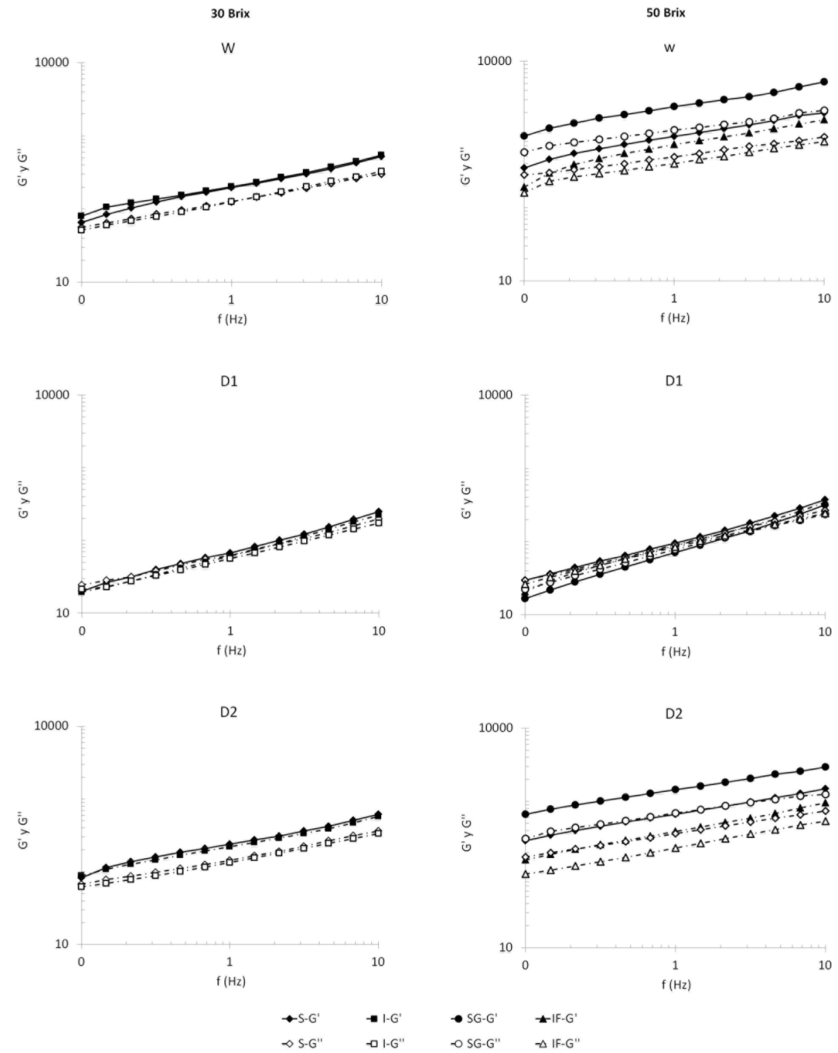

Figure 2. Frequency sweep data obtained with the dynamic analysis of the spreadable strawberry products containing 1.5 % of pectin, depending on the process variables: elaboration method (W: *Wet Osmotic Dehydration;* D1: *Dry Osmotic Dehydration without eliminating liquid phase* and D2: *Dry Osmotic Dehydration eliminating liquid phase*), type of sugar (S: sucrose; I: isomaltulose; SG: sucrose-glucose; IF: isomaltulose-fructose).