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ORIGINAL RESEARCH PAPER

RHEOLOGIC BEHAVIOR OF PASTRY CREAMS♦

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Abstract: The increased social and economic importance of ready–made food production, together with the complexity of production technology, processing, handling and acceptance of these fragile and perishable products requires extensive knowledge of their physical properties. Viscoelastic properties play an important role in the handling and quality attributes of creams.
Our study was to investigate the rheological properties of different confectionary creams, by scanning the field of shear rates at constant temperature and frequency, angular frequency scanning at small deformations and quantification of rheological changes during application of deformation voltages. The creams tested were made in the laboratory using specific concentrates as fine powders, marketed by the company “Dr. Oetker” compared with similar creams based on traditional recipes and techniques. Following the researches conducted we could conclude that both traditional creams and the instant ones are semi fluid food products with pseudoplastic and thixotropic shear flow behavior, with structural viscosity. Instant and traditional creams behaved as physical gels with links susceptible to destruction, when subjected to deformation forces.

Keywords: *instant creams, rheologic behavior, traditional creams, viscoelastic properties*

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INTRODUCTION

Confectionery products are complex food featuring high quality of nutrients and energy. They have pronounced sweet taste and special flavor. The shape, appearance and color of deserts cause pleasant visual, smell and taste sensations.
The main component of energy supply in confectionery is the cream. Creams are used to fill cakes, but as sweetener in the kitchen. Besides supplying energy, cream contributes to improve the appearance and taste of confectionery products.
The dessert role is less dessert to feed and more to add a touch of entertainment. Most desserts are sweet, sensation perceived as a voluptuous taste, even at the end of the meal when man feels sick and the threshold of the lingual buds increased. Desserts are always present at celebrations or festive occasions.
Creams, like most foods, are obtained today with modern technologies and processes, and the growing demand leads to overproduction and a varied supply from food producers. Thus, every effort is made to make food successful, to be preserved for as long as possible, to have attractive colors and to be rich in vitamins, even if obtained artificially.
Any research that highlights the issue of food additives can only be welcomed given that today there is almost no one recipe without preservatives, antioxidants, colorants, conditioners, etc.
Food additives, as substances intentionally added to food during processing, have contributed and contribute to ensuring hygienic qualities, their sensory and nutritional properties. They are innovation factors in agro-food processing.
Currently, the food market is developing in a difficult environment: consumers are demanding, attentive to new sensory attributes, a longer shelf life, the highest quality, all at a price as low as possible.
The use of additives combined with the use of new technologies allows obtaining products adapted to the requirements of modern life: cuisine, spicy sauces, desserts, pastries and cakes, dietetic or reduced calorie products, milk or fruit desserts, etc., food required by both food or catering units. For convenience and economic reasons, the supply is made in advance and in large quantities, hence the need for a longer duration of storage / preservation of the food quality.
The historical presence of additives in culinary practices and food production technologies confirms their functional role and particular usefulness. Their current use is a logical modern extension of ancient culinary habits adapted to the peculiarities of modern technologies and current consumption. Used according to well-established rules, the additives are elements with manifold sides of food development and promotion in the modern era.
The use of food additives, turned into ingredients in the preparation of products, is possible, however, with the approval of lower sensory quality of culinary preparations, but with a higher "economic value" by:

- shorter time to prepare culinary product directly affecting the economic output;
- ensure increased efficiency of food production and constant quality of such food.

Thus, semi-products food additives provide superior culinary properties: glossy, silk-smooth texture, fineness, a special flavor and very good stability at refrigeration.
Creams are semisolid foods that can exert different rheological properties depending on their composition and mode of preparation. It is known that semi fluid products

generally carry out non-Newtonian pseudoplastic flow, with voltage threshold and thixotropic behavior [1].
Rheological properties of processed creams depend on solid phase particle size. These properties can be created or modified by controlling the particle size distribution in the manufacturing process. Creams properties are also influenced by the fat fraction and the addition of thickeners [2].
The increased social and economic importance of ready-made food production, together with the complexity of production technology, processing, handling and acceptance of these fragile and perishable products require extensive knowledge of their physical properties. Viscoelastic properties play an important role in the handling and quality attributes of creams.
Most foods are subjected to temperature variations during processing, transport, storage, preparation and consumption. Changes in temperature may cause impaired physical and chemical properties of food products, including creams, which further influence the general properties of the finished product, its taste, appearance, texture, consistency and stability. Various chemical reactions can be promoted (hydrolysis, oxidation or reduction) and physical changes (evaporation, crystallization, aggregation or gelatinous process) [3].
To understand and even improve the performance of creams processing, it is necessary to have knowledge of both the cream flow behavior and other rheological properties.
From these considerations, the aim of our study was to investigate the rheological properties of different pastry creams by scanning the field of shear rates at constant temperature and frequency, by scanning the angular frequency range to small deformations and quantification of rheological changes during application of voltage distortion, in an attempt to find a correlation between types of creams and their rheological behavior.

MATERIALS AND METHODS

Three types of instant creams and three types of traditional milk-based creams were analyzed. "Dr. Oetker" instant creams were purchased from Kaufland store in Galați and the traditional creams were prepared in the Cuisine Laboratory of the Food Science and Engineering Faculty of "Dunărea de Jos" University of Galați:

1. *Instant Vanilla Cream "Dr. Oetker"* contains the following ingredients: glucose syrup, hydrogenated vegetable fat, modified maize starch, mono- and diglycerides emulsifiers and their acetic ester, gelatin, milk protein, potassium phosphate, vanillin, ethylvanillin, quinoline yellow, yellow–orange S;
2. *Instant Chocolate Cream "Dr. Oetker"* contains the following ingredients: low-fat cocoa powder (11% cocoa butter), glucose syrup, hydrogenated vegetable fat, modified corn starch, food gelatin, mono and diglycerides emulsifiers and their acetic ester, protein from milk, potassium phosphate, chocolate flavor;
3. *Instant Lemon Cream "Dr. Oetker"* contains the following ingredients: glucose syrup, hydrogenated vegetable fat, modified maize starch, mono and diglycerides emulsifiers and their acetic ester, food gelatin, milk protein, citric acid, potassium phosphate, lemon flavoring, yellow coloring quinoline;

4. *Traditional Vanilla Cream* contains the following ingredients: 2 egg yolks, 50 g vanilla sugar, 20 g starch, 250 mL milk;
5. *Traditional Cocoa Cream* contains the following ingredients: 2 egg yolks, 50 g vanilla sugar, 20 g starch, 250 mL milk, 20 g cocoa;
6. *Traditional Lemon Cream* contains the following ingredients: 2 egg yolks, 50 g powder sugar, 20 g starch 250 mL milk, 3 g lemon salt (citric acid).

Traditional milk-based creams - have as basic materials milk, egg, mixed with starch. They are subjected to a boiling process which allows them a full and easy assimilation. The technological scheme for traditional creams production involves the following steps:

1. *Raw materials quality control*
2. *Raw materials dosage*
3. *Primary processing of raw materials* to obtain a mix in which the constituents are as evenly distributed;
4. *Thermal treatment* which results in protein coagulation leading to the desired consistency of creams;

Instant creams are obtained by dissolving cream powder in cold milk, followed by mixing until consistent foam.

Determination of rheological characteristics

Rheological measurements were performed in duplicate using a voltage controlled rheometer (AR 2000, TA Instruments, New Castle, DE) attached to computer control software (Rheology Advantage Data Analysis Program, TA, New Castle, DE). The temperature was monitored by using a Peltier temperature control system.
All rheological measurements were made using plate geometry of 40 mm, with an angle of 2° and a gap of 1000 µm. For each test, approximately 2 g of cream was placed on the rheometer plate bottom. To prevent dehydration low viscosity silicone was added around the plate edges. Measurements were made at constant temperature and different angular frequencies (6.283 to 628.3 rad/s). Changes in the storage (G') and loss (G") module and the phase or deformation angle (δ) were recorded.
Also, the technique of measuring the shear tension and apparent viscosity has been used by gradually and progressively controlling the shear rate from 0.1 to 100 s^{-1} in order to obtain data on the dependence of shear tension or apparent viscosity on the shear rate. All measurements were performed at constant temperature of 20° C, frequency 10 Hz, in double samples. For each test, the sample was maintained for 5 minutes to balance the temperature.

RESULTS AND DISCUSSIONS

Shear flow rheology

For the purpose of the rheological study, different creams were prepared where viscosity was monitored over the range of shear rates ranging from 0.1 to 100 s^{-1}. Rheograms of apparent viscosity versus shear rate for different creams are presented in Figures 1-3. Rheological tests were conducted at a temperature of 20°C. All creams tested showed shear softening behavior, as is obvious in the rheograms, while showing a decrease in viscosity at increasing shear rate.

The destruction of molecular aggregates and the orientation tendency of the macromolecular constituents of creams in the direction of flow under the action of shear forces are responsible for the softening behavior of the pseudo-plastic non Newtonian fluids that creams being analyzed are. The softening trend is important in the practice of mixing, pipelines conveying, pump design choice for transport and packing.

Downward curve of viscosity variation depending on shear rate curve does not overlap with the ascending curve; the values of the apparent viscosity on the descending branch were lower than the ascending branch values. This property is characteristic to thixotropic time-dependent fluids having structural viscosity. Structural restoration of molecular aggregates within complex systems, represented by creams, is not fully realized. It should be noted that all instant creams (Figures 1a, 2a, 3a) showed substantial reductions in the apparent viscosity, particularly in the first decade of the shear rates, after which the viscosity decreased moderately to reach a minimum value, which virtually remains constant, when de-structuring and alignment are considered complete.

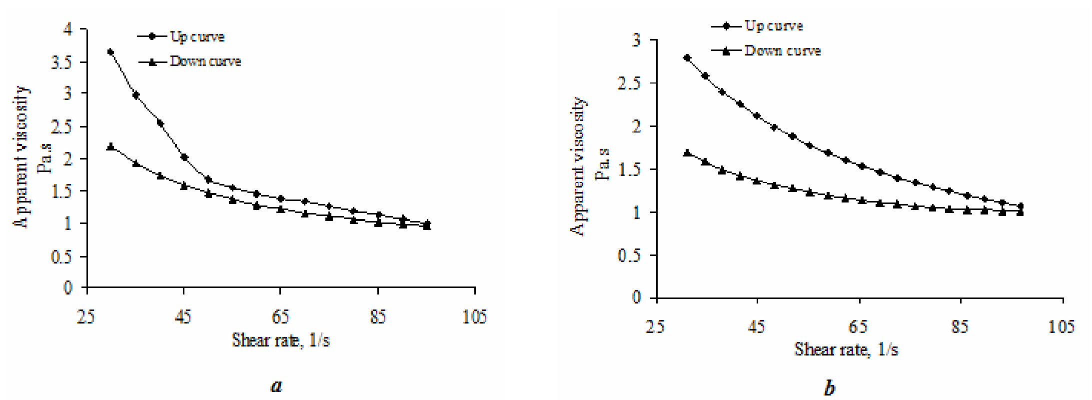

Figure 1. *Rheological diagram: apparent viscosity vs. shear rate*
a) Instant vanilla cream; b) Traditional vanilla cream

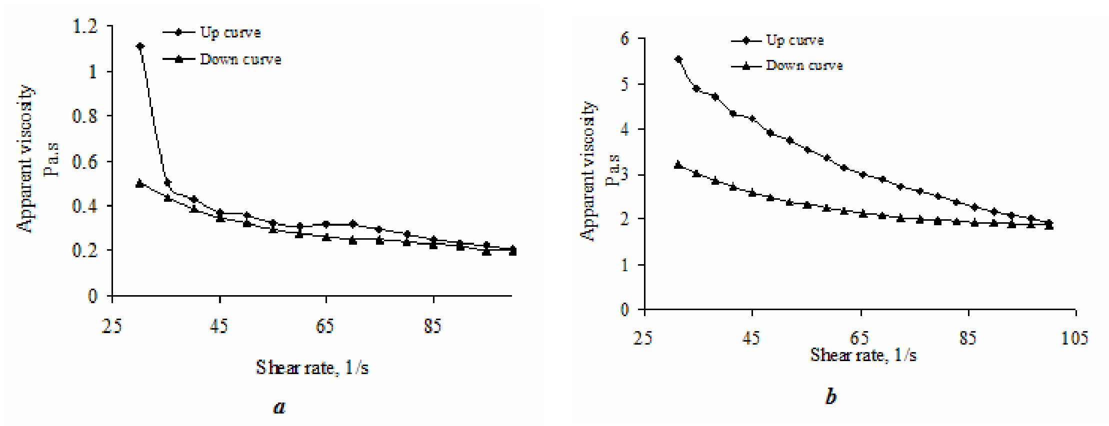

Figure 2. *Rheological diagram: apparent viscosity vs. share rate*
a) Instant cocoa cream; b) Traditional cocoa cream

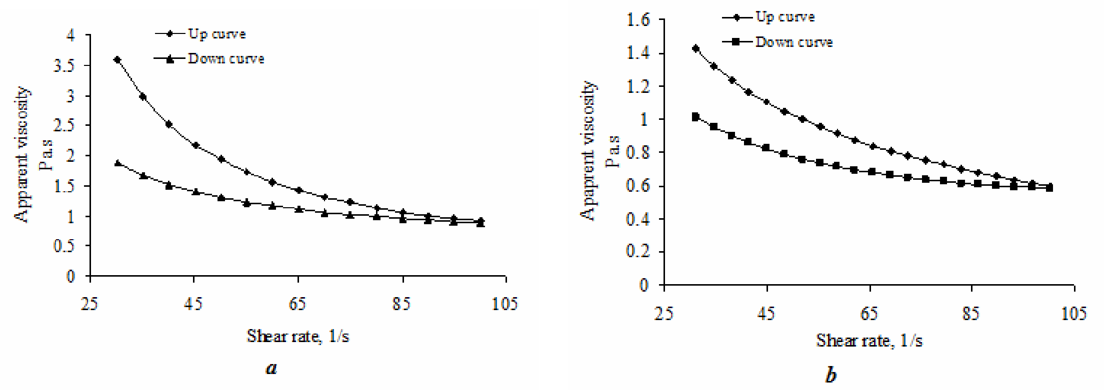

Figure 3. *Rheological diagram: apparent viscosity vs. share rate*
a)Instant lemon cream; b) Traditional lemon cream

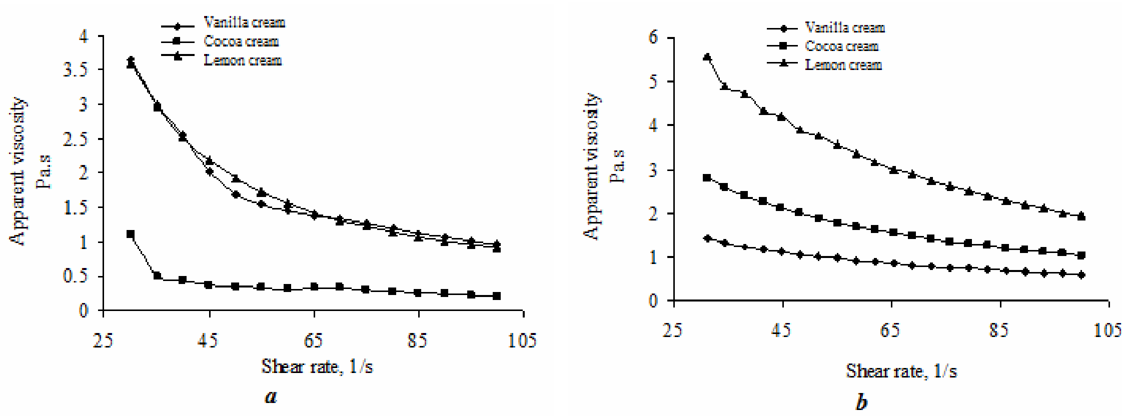

Figure 4. *Comparison of apparent viscosity depending on the type of cream*
a) Instant creams; b) Traditional creams

The cream featuring the best behavior to shear flow was instant vanilla cream, followed by instant lemon cream, while instant cocoa cream underwent a pregnant process of destructuring, structure rebuilding being extremely low. In Figure 4a one can see differences in the viscosity of instant creams over the shear rates range between 30÷100 s^{-1}. Instant vanilla and lemon creams behaved similarly, the corresponding rheograms being coincident. In contrast, instant cocoa cream showed a different pattern, values of viscosity versus shear rates range being much lower.

Traditional creams showed the same behavior to flowing as the instant creams (Figures 1b, 2b, 3b). Apparent viscosity values of traditional creams were generally higher compared to instant creams. As shown in Figure 4b there are significant differences between the apparent viscosity values for the three types of cream, in traditional versions.

Traditional vanilla and lemon creams showed larger thixotropy areas than similar instant creams, which imply a more pronounced dissolution of constituent parts under shear forces and a slower less pregnant recovery. Traditional cocoa cream behaves completely different from instant cocoa cream, reaching the highest values of apparent viscosity (Figures 4a, b). The structures developed by creams are accounted for by the presence of macromolecules, proteins, fats and complex polyglucides which through interactions contribute to the texture, in-mouth behaviour, creamy sensation and general lubricating sensations of creams [4, 5].

Dynamic rheology tests: scanning the angular frequency domain

Generally, dynamic rheological tests are suitable for studying the semi-fluid characteristics such as gelatinous effect and softening, since creams are known as viscoelastic materials. The dynamic rheological tests, performed in the viscoelastic linear range, lead to acquiring of the storage moduli G' and G" and their ratio, tg δ = (G"/G').

The value of G' is a measure of the deformation energy stored in the sample during the shear (deformation) process, which represents the elastic behavior of a sample. On the contrary, the value of G" is a measure of the deformation energy used by the sample during the shear test and subsequently lost, representing the viscous behavior of a sample [6, 7].

If G' is higher than G", the material will behave closer to a solid, the deformations will be essentially elastic and recoverable. Conversely, if G" is greater than G', the energy used to deform the material is viscously dissipated and the material behaves like a liquid [8].

A phase angle $\delta = 0$ or tg $\delta = 0$ corresponds to an elastic response, and $\delta = 90°$ or tg δ = 1 to a viscous response. If the phase angle is located within the limits $0 < \delta < 90°$, the material shows viscoelastic behavior [6, 9, 10].

To obtain useful properties of creams (jellification and softening) different dynamic tests can be conducted: (i) frequency scanning, when G' and G" are determined by frequency (ω) at fixed temperature; (ii) time scanning when G' and G" are calculated according to time at fixed temperature and frequency [11].

In the case of creams, our rheological studies have focused on the dynamic test of frequency scanning, which allowed the moduli G' and G" to be determined at constant temperature and small deformations.

Over a critical volume of fraction of particles, the strong enough attraction between molecules leads to formation of gel structures. Gelling/gelatinization represent a process of gradual transition from one ground to a viscoelastic gel; the knowledge of rheological properties of creams appears to be particularly useful. The dynamic rheological characteristics were determined on the angular frequency range from 0.6283 to 628.3 rad/s at 20°C.

Rheological diagrams of the storage and relaxation moduli and phase angle are shown in Figures 5 – 7. Dynamic rheology tests in the linear viscoelasticity range performed by scanning the angular frequency domain showed that the values of storage and loss moduli have been influenced by both the type of cream and the frequency of oscillation. Storage modulus for all different creams showed different increases, particularly in the angular frequency range between 0.6283 and 100 rad/s. The increase of G' suggests an improvement of the elastic component of food creams and a loss of flexibility, the structure becoming slightly more rigid by forming new more dense gel networks when applying higher angular frequency.

The values of G' ranged from 369.8 to 2006 Pa for instant vanilla cream and 44.14 to 134.4 Pa for traditional vanilla cream; 32.1 to 68.68 Pa for instant cocoa cream and

77.41 to 260.3 Pa for traditional cocoa cream; 320 to 1475 Pa for instant lemon cream and 32.69 to 118.3 Pa for traditional lemon cream. Values of G' for all creams were higher than the values of G" which shows a predominance of elastic properties comparative with the viscous ones. When oscillation frequency and storage modulus increased, we could also see an increase in the loss modulus. This may be due to structural changes that occur in some cream components when energy is consumed. Only with the instant cocoa cream has been found an intersection point between the curves of G' and G", represented by the transition of the mixture from elastic to viscous behavior (Figure 7a). The intersection point was in the angular frequency range between 314.9 to 396.4 rad/s. The strong frequency dependence of G' and G" indicates a typical viscoelastic behavior of creams, considered to be physical gels [12].
Physical gels network consist of connections susceptible to destruction when subjected to a deformation force.

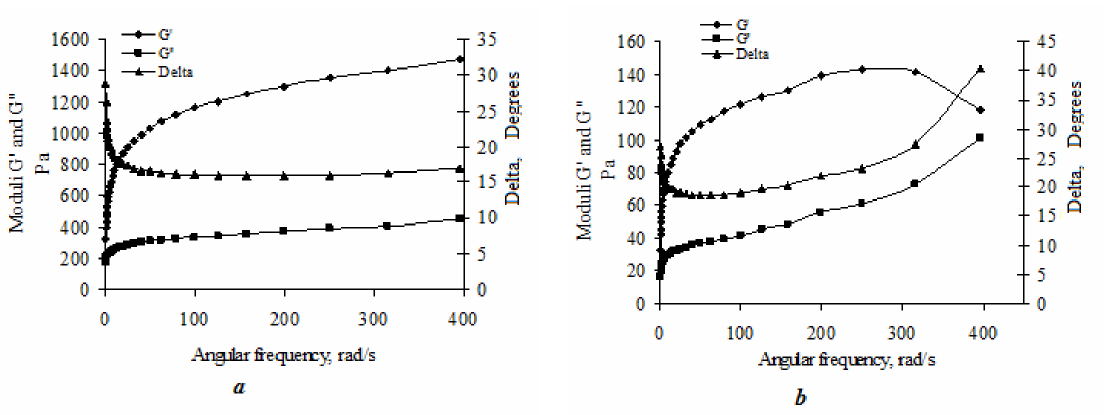

Figure 5. *Rheological diagram: storage modulus (G') and loss modulus (G") and phase angle (δ) versus angular frequency*
a) Instant lemon cream; b) Traditional lemon cream

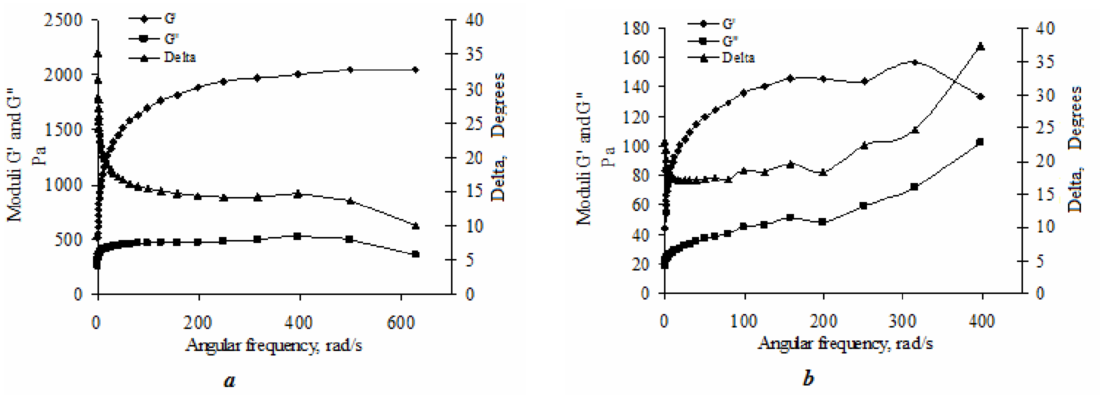

Figure 6. *Rheological diagram: storage modulus (G') and loss modulus (G") and phase angle (δ) versus angular frequency*
a) Instant vanilla cream; b) Traditional vanilla cream

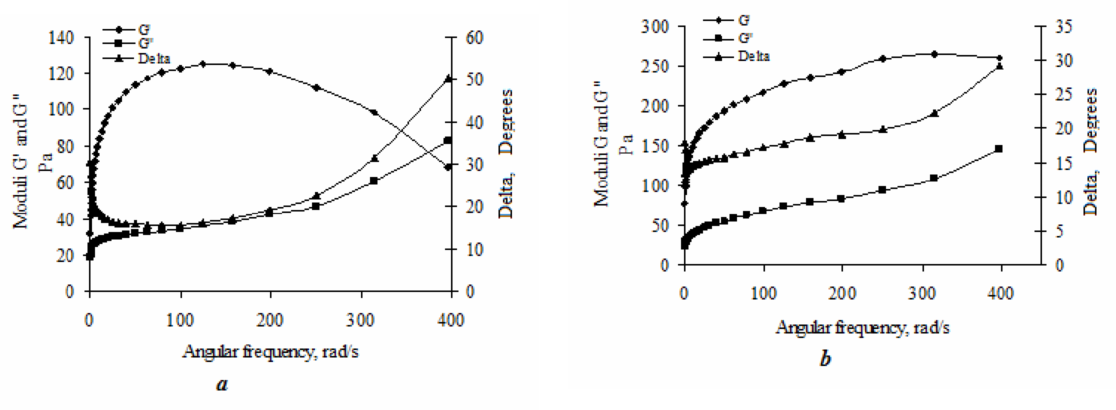

Figure 7. *Rheological diagram: storage modulus (G') and loss modulus (G") and phase angle (δ) versus angular frequency*
a) Instant cocoa cream; b) Traditional cocoa cream

The values of deformation angle (δ) confirm the different elastic properties of creams depending on the prescription and preparation technique. According to the rheograms in Figures 5 – 7 the deformation angle values increased continuously with increasing angular frequency with traditional creams and instant cocoa cream, as effect of cream smoothing under the deformation forces. With instant lemon and vanilla creams, the deformation angle values decreased with increased angular frequency, which highlights much more elastic systems.
Figures 8 and 9 show a comparison between the values of storage modulus (G') and loss modulus (G") for instant and traditional creams.

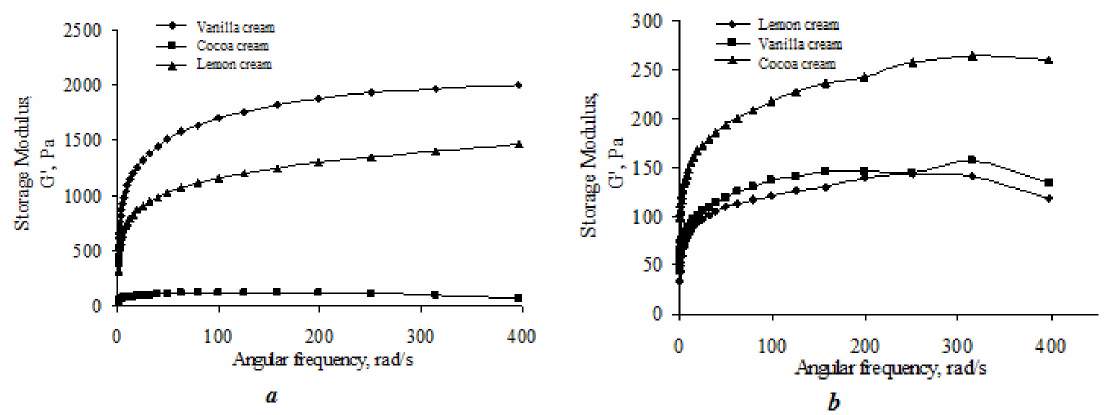

Figure 8. *Comparison of the storage modulus (G'):*
a) Traditional creams; b) Instant creams

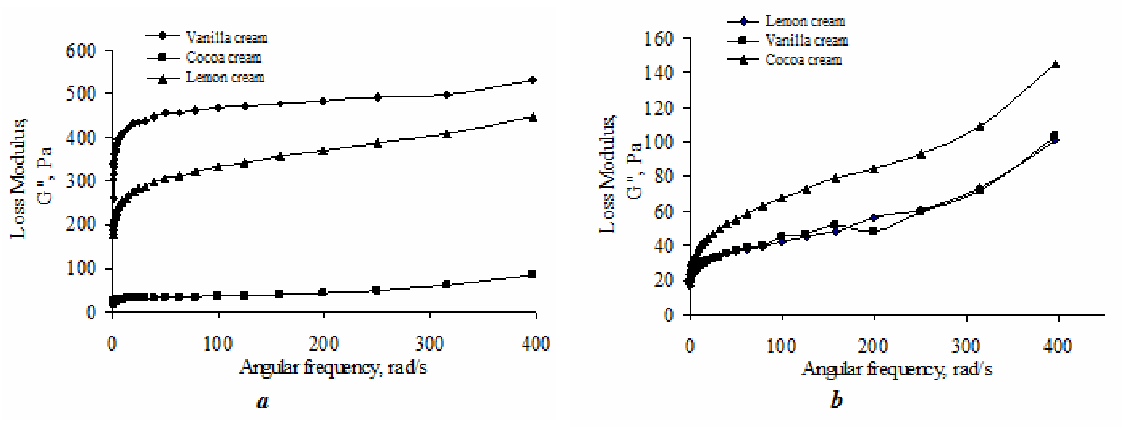

Figure 9. *Comparison of the loss modulus (G"):*
a) Traditional creams; b) Instant creams

It is highlighted significant differences between samples depending on the formulations and processing techniques. The traditional lemon and vanilla creams feature a slight tendency to reduce the elastic properties at angular frequency higher than 300 rad/s. With the traditional cocoa cream and instant creams all elastic properties are improved across the range of frequencies tested, especially in the range 0.6283 to 100 rad/s.
With traditional creams, the loss moduli showed upward trends, significantly different compared with cocoa cream and vanilla and lemon creams for which values were quite close. Instant creams had loss moduli values significantly differences between samples along with upward trends.

CONCLUSIONS

Instant and traditional creams and food are semi fluid products with pseudo-plastic thixotropic shear flow behavior and structure-dependent viscosity. The values of apparent viscosity like those of thixotropy index depended on the shear rate, the cream compositions and cooking techniques. Developments of storage and loss moduli point out to viscoelastic feature of creams having elastic properties with significant viscous properties.
Instant and traditional creams behaved as physical gels with links susceptible to destruction, when they were subjected to a force. At industrial level, this behavior is of special importance in the case of using pumps for conveying and mechanical dosing for packing.
The creams featuring the best behavior to shear flow were instant creams, the order being: instant vanilla cream followed by instant lemon cream; instant cocoa cream underwent an accentuated process of destructing, rebuilding the structure being extremely low.

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