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RHEOLOGICAL PROPERTIES OF SELECTED FOOD PRODUCTS IN THE MALAYSIAN MARKET

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ABSTRACT

Food products are complicated mixtures of ingredients which can be scientifically described by rheological measurements. The aim of this study is to evaluate the rheological properties, spreadability and microstructure of commercial processed foods, namely chocolate spread, cheese, chicken rice paste, mayonnaise and chocolate syrup. Cheese, chocolate spread, and mayonnaise had storage modulus (G') higher than loss modulus (G'') indicating viscoelastic properties and semi-solid form. These products also had compact crystal networking, with G' remaining constant is called the linear viscoelastic region (LVR) and started to drop at higher applied forces (shear stress) as compared to chicken rice paste and chocolate syrup. The oscillatory sweeps test indicated that the viscoelasticity of the products were very much dependent on the type of foods and their microstructural properties. These attributes may also help manufacturers decide on the proper product packaging, storage and method of serving. Therefore, the information obtained from this study would help the food manufacturers to have a better understanding of simple rheological and microstructural properties, which are closely related to the final product properties in terms texture, spreadability and shelf-life.

Keywords: rheology, viscoelasticity, storage modulus, loss modulus, microstructure.

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INTRODUCTION

Rheology is the study of the deformation and flow of matter under the influence of applied stress and strain (Borwankar, 1992; Bell *et al*., 2006). Rheological properties of food are important as they are associated with the quality and acceptance of food by consumers. Furthermore, rheology measurements of a food are related to other physical properties such as stability, shelf-life, sensory, texture *etc*. According to Fischer *et al*. (2011), rheological research in food science is closely linked to the development of food products and could address the processes involve in the industrial production of food (stirring, pumping, dosing, dispersing and spraying), home-based cooking as well as consumption of food (oral perception, digestion, well-being).

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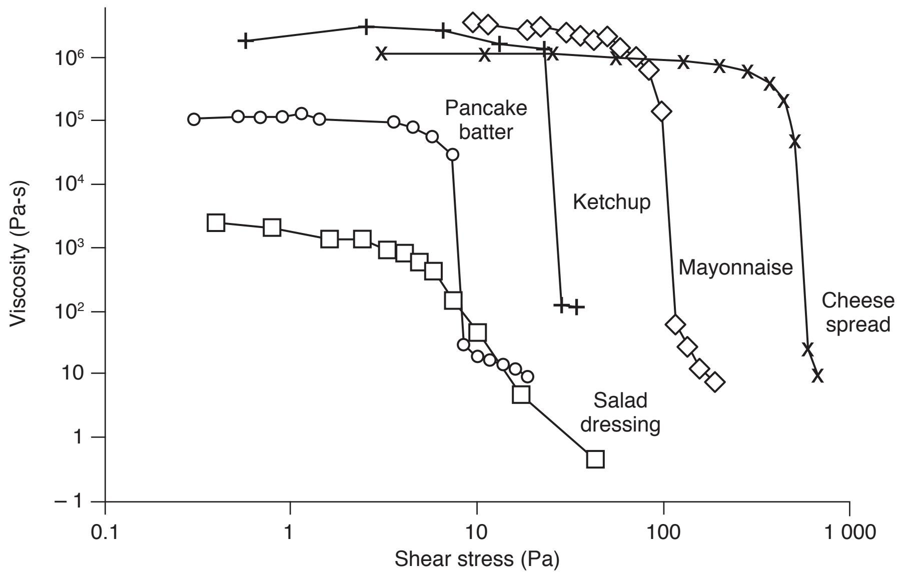
In the food industry, rheology has been applied in determining the functionality of food ingredients in product formulation in relation to food texture, structure, sensory and process conditions (Bourne, 1992; McKenna, 2003; Danthine, 2011). Food products are complex mixtures that consist of liquid, semi-solid and solid materials which their physical properties can be determined using rheological measurements as shown in *Figure 1*. As indicated in this figure, different food products had different yield stress and viscosity when subjected to shear stress. At high shear stress the structure of products started to deform and flow. Products with very low viscosity (liquid) could be delivered via pouring or spraying, while spreading is for creams and rubbing for semi-solid products. The types of packaging that are suitable for liquids which can easily deform and flow could be bottles or pumps. On the other hand, tubes or tubs are suitable for soft solid products such as spreads and margarines (Howard, 2007). It is usually necessary for the microstructure of these spreadable products to retain their shape over a relatively wide



Source: Tabilo-Munizaga *et al*. (2005).

Figure 1. The equilibrium yield stress through a creep experiment in a variety of food products.

range of temperatures but be easily deformed at high shear stress. Thus, the products must exhibit the appropriate viscoelastic behaviour in (elastic behaviour below the yield stress and less viscous above the applied yield stresses).

The complexity of food systems encourages food technologists to measure the physical attributes of the complex processed foods particularly rheological behavior. Hesso *et al*. (2015a) and Hesso *et al*. (2015b) reported that starch and protein in combination with other ingredients such as sugar and fat are fundamental to the structure, rheology and other physical properties of the baked products. Studies by Liu *et al*. (2010); de Clercq *et al*. (2012); Miskandar *et al*. (2014); and Zaliha *et al*. (2015) also mentioned that basically palm-based products such as margarine and shortening are formulated to melt some degrees below body temperature and totally melt in the mouth. Rheologically, the products must be spreadable and uniform so that they can be easily deformed and spread at end-use temperature for serving. The product microstructures are very sensitive to storage temperatures and external forces which cause the solid product tend to slowly be deformed and liquefied. Lipid composition, crystallisation behaviour, microstructure and mechanical properties of fats are required for improvement of the texture of palm oil-based margarine. For processed food, the composition and the addition of ingredients to obtain a certain food quality and product performance requires profound rheological understanding of individual ingredients, their relation to food processing, and their final perception (Fischer *et al*., 2011). Therefore, understanding of the fundamental knowledge of physical properties of new materials, processing and end-products is necessary. Moreover, rheology study is important to give a proper scientific description of the raw materials and products for research and engineering purposes. In this study, the rheological properties such as viscoelasticity, spreadability and microscopy observation of ready to be served commercial food products were determined at ambient temperature (± 25.0°C). This study would help industries to have a better understanding about rheology in product development, process design, packaging, handling and human perception.

MATERIALS AND METHODS

Materials

Commercially available chocolate spread, cheese, chicken rice paste, mayonnaise and chocolate syrup were obtained from a supermarket in Bangi, Selangor, Malaysia and kept at room temperature (± 25.0°C) before analyses.

Methods

Viscoelasticity. The rheological properties of the products were determined using a Rheostress RS 600 Rheometer (Thermo Haake, Karlsruhe, Germany) fixed with a water circulator at the base of a 35.0 cm serrated parallel measuring plate. The oscillatory shear sweep tests were performed to determine the linear viscoelastic region (LVR). Within the LVR, the structure of the sample remains stable, as it is not being affected by the increased effort or applied forces. Under these determined conditions, frequency sweeps were applied at constant values of stress or strain within the LVR limits.

For sample preparation, round plastic molds with thickness of 2 mm and a diameter of 35 mm were used. Samples were pipetted into the moulds and were immediately transferred into a controlled temperature incubator (set at 25°C) for one day prior to measurements. An oscillatory stress sweep of 50 to 10 000 Pa was performed to determine the G′ within a LVR at a frequency of 1 Hz to evaluate the G′, G′′ and loss phase angle of tangent delta (Tan δ) (Zaliha *et al*., 2015). All the tests were carried out in duplicate. The recorded G′ within the LVR indicates the elastic behaviour and the G′′ describes the viscous behaviour of the sample. The Tan δ was calculated using Equation (1):

$$\text{Tan}\ \delta = G'/G'' \quad \ldots\ldots\ldots\ldots \quad \text{Equation (1)}$$

Spreadability

Spreadability was determined as a deformation under an external load using TA.XT2 plus texture analyser stable micro system (Stable Micro System, Surrey England). The temperature, compression and tension (TTC) spreadability fixture is a set of precisely matched male and female Perspex 90 cones. The material is allowed to set up in a lower cone or was filled into the lower cone with a spatula. The material was pressed down only so much as was needed to eliminate air pockets which were visible through the Perspex cones, and then the surface was leveled with a flat knife. Before testing, the male cone probe was calibrated against the female cone so that the starting point was at the same height for each test *e.g.* 25.0 mm over the female cone. The measurements were carried out at room temperature (± 25.0°C). The method is according to www.stable microsystems.com/TAXT plus.

Microscopy Observation

The sample was tempered at 25°C for one day prior to microscopy observation. A Leica DMLP polarised light microscope (Wetzlar, Germany) equipped with a Linkam THMS 600 temperature controller stage and a JVC 3-CCD colour video camera was used (Zaliha *et al*., 2015a).

RESULTS AND DISCUSSION

Rheological Properties of Various Food Products

Oscillatory sweeps test. *Figure 2* shows the responses of different products at 25°C. At a certain amount of force or shear stress, the microstructure of the products had yield a LVR before it reached a critical point and started to deform and flow. The LVR of the products were determined before being ruptured and started to deform. Simultaneously, increasing of shear stress caused the sample to be more viscous and loss of phase angle of Tan δ as indicated in *Figure 2*. The LVR was identified using oscillatory sweeps stress. This small amplitude test was conducted in order to identify the beginning of destruction of the crystal network (Zaliha *et al*., 2011; 2015b).

Viscoelastic Properties

The crystal networks of the product under oscillatory sweeps test yielded a linear response (constant G′) to the applied forces or shear stress before a sudden decrease in the G′ and simultaneous increase in the tan δ were observed in *Figures 2* and *3* respectively. These results indicated that the products behave differently from one to another by producing different LVR of storage moduli when subjected to the same applied shear stress at room temperature (± 25.0°C). Within these LVR, the crystal network of the product was able to store, and retain their shape and hardness while some of the energy was dissipated out causing the crystal network to be ruptured and flow. Thus, different products show different viscoelasticity and exhibit plastic properties. The crystal network of cheese indicated the highest storage moduli (2.20×10^4 Pascal) compared to the crystal network of chocolate spread (1.68×10^4 Pascal), and mayonnaise (1.89×10^2 Pascal), and started to deform at different critical point of LVR and shear stress. Simultaneously, the crystal network of the products started to deform and were totally ruptured beyond the critical point. This implied that, cheese is the most viscoelastic product and ruptured at the highest shear stress with smaller Tan δ compared to the other products. Results also indicated that the cheese was highly packed and formed a stronger, elastic and compact crystal networking. This could be due to the formulated fat used for making the cheese. According to Marangoni (2005) and Bell *et al*. (2006), the nature of the fat crystal network in plastic fats influences the rheology of spreads, composition of the fat and interaction between fat crystal aggregates of fat crystals in a network.

All the crystal network of the products show their G′ were higher than G″ (G′ > G″) which indicated that the products behave viscoelastic properties except for the chocolate syrup that shows the flow behaviour as the G″ > G′. The viscosity of the products also started to decrease, with increase in the Tan δ at the high applied shear stress as shown in *Figure 3*.

Figure 4 shows the spreadability of the products in terms of their firmness, work of shear, stickiness and work of adhesion. Rheological testing is a rapid useful tool to predict the spreadability of product formulation (http://www.rheologylab.com). The results indicated that chicken rice paste was the least spreadable and firmer compared to the chocolate syrup, mayonnaise and chocolate spread at 25°C.

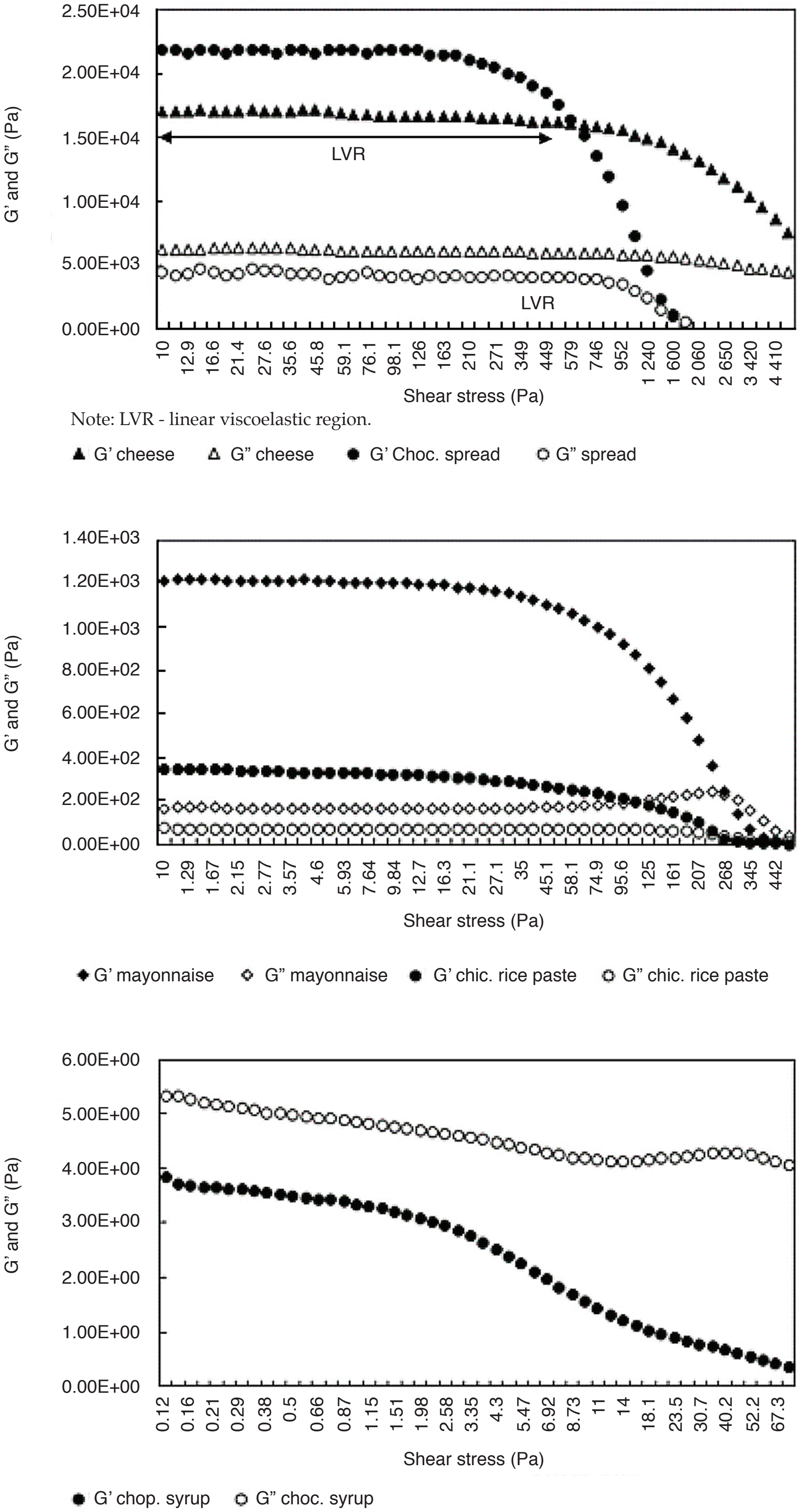


Figure 2. Viscoelastic moduli as a function of shear stress. Close symbol G' are storage moduli and open symbols G'' are loss moduli of the consumer products under oscillatory stress sweep test at T= ± 25°C.

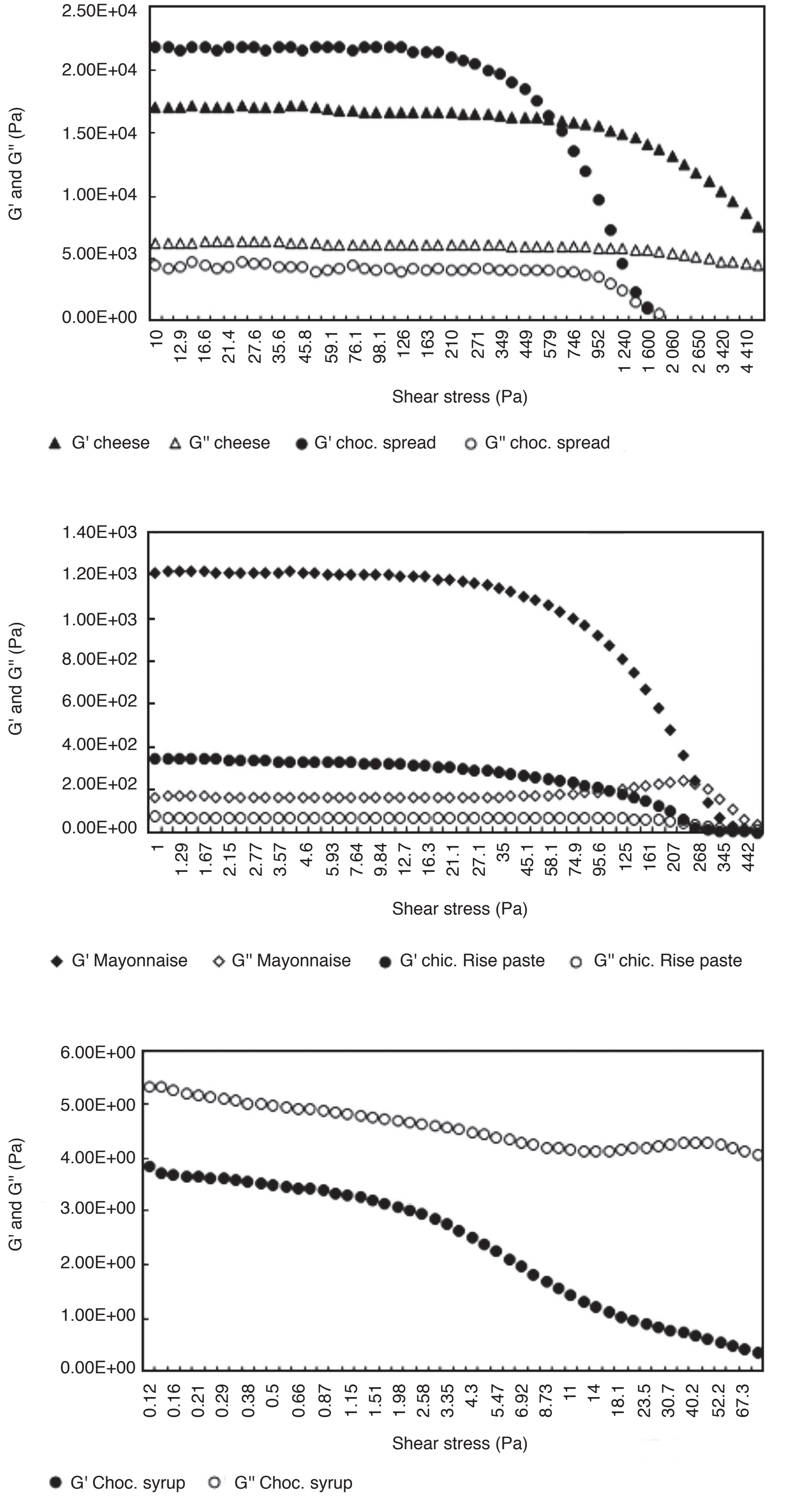


Figure 3. Viscosity as a function of shear stress of food products under oscillatory stress sweep at T= ± 25°C.

The highest negative regions of the plotted graph indicated that chocolate spread also showed the most sticky and adhesive properties as compared to the other products. Therefore, higher shear forces are needed to be applied for the chocolate spread, cheese and mayonnaise during serving. While low shear rates caused the chicken rice paste and chocolate syrup to flow and retain their structure during storage. Hence, these products need less force to make them flow upon application. This finding was consistent with the highest G', longest LVR of the cheese and chocolate spread in semi-solid form as indicated by the tightly packed microstructure shown in *Figure 5*.

Microscopy Observation

Figure 5 shows the microscopy observation of the products at room temperature (± 25.0°C). Chocolate spread shows different sizes and shape of crystals which were tightly packed compared to cheese and chicken rice paste. For mayonnaise, the crystals were well distributed within the droplets and the liquid fraction of the products. On the other hand, the chocolate syrup showed loosely packed crystals and was more liquidised. These findings were consistent with the viscoelasticity properties of the products as discussed earlier. The chocolate spread had the highest G′ followed by cheese, mayonnaise and chicken rice paste and should be packed in plastic containers, while the chocolate syrup is pourable and should be kept in bottles.

CONCLUSION

The cheese and chocolate spread appeared to have the highest viscoelasticity, stickiness and adhesiveness compared to chicken paste and chocolate syrup.

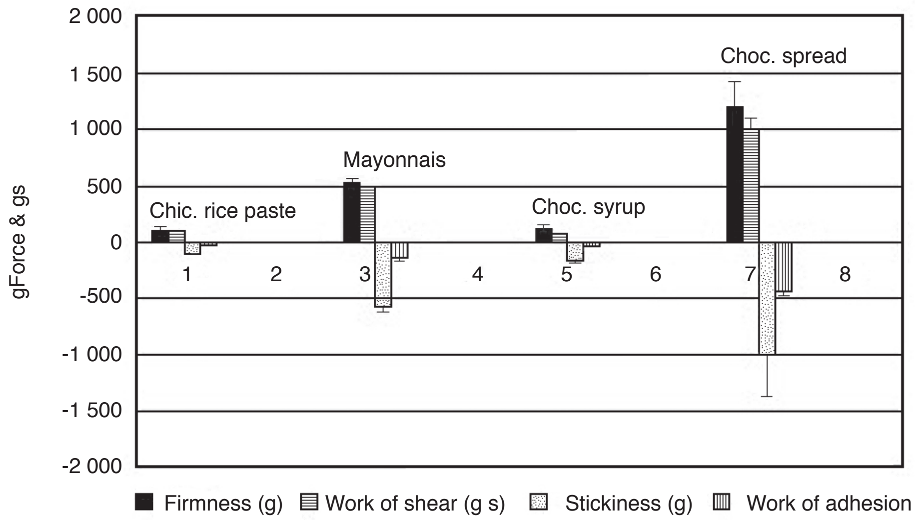


Figure 4. Spreadability properties of products at room temperature (± 25°C).

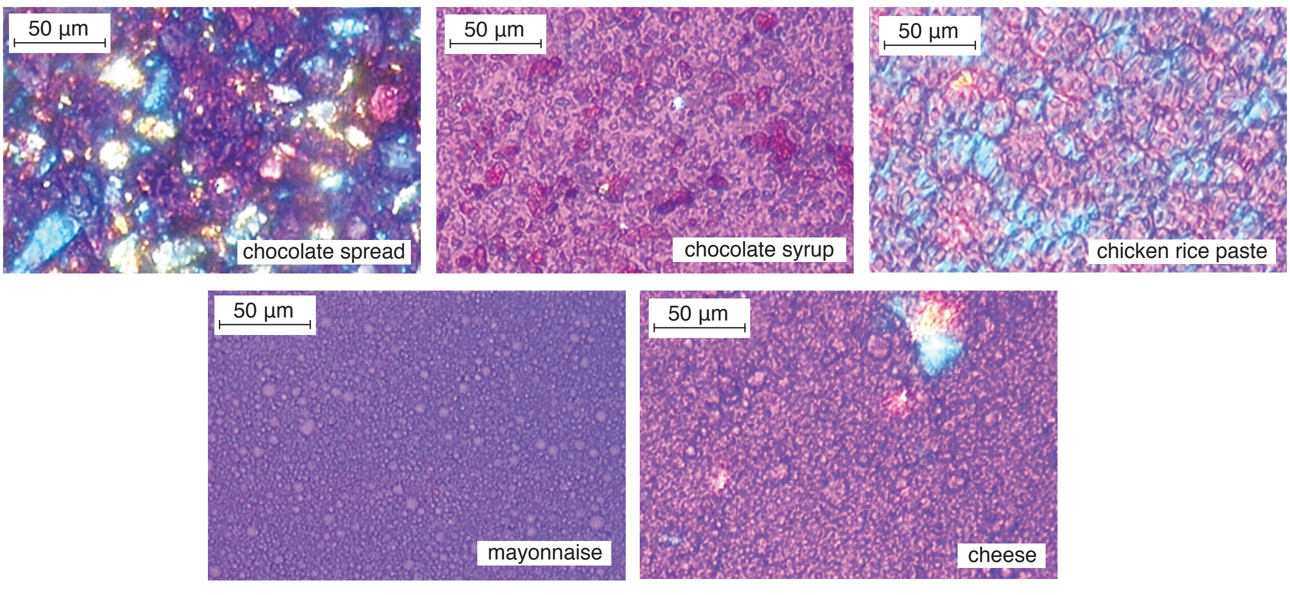


Figure 5. Photomicrograph of the product microstructures at 25°C.

The rheological data of the finished products is very important to help decide on the suitable packaging, methods of handling and delivering as well as storage temperatures for the food products. All the information from this study could give a better understanding to food industries involved in food formulation, product development, processing, and food handling.

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