

# Characterization of Coconut Oil Flow Behavior

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**Abstract.** Blending is widely used for modification of the physicochemical properties of fats to enhance their commercial applications. This paper studied the flow behavior of coconut oil (NHCO) under variation in the temperature and proportion of fully hydrogenated coconut oil (FHCO). The oscillatory results showed that there is a change in the linear viscoelastic region, storage ( $G'$ ) and loss ( $G''$ ) moduli with increasing proportion of FHCO in NHCO. In rotational tests, the blends showed shear-thinning behavior. The viscosity of oils and their blends were investigated at different temperatures. The Herschel-Bulkley model was fitted to flow curves (shear stress in function of shear rate) of the samples. During heating, NHCO approached Newtonian behavior earlier than FHCO, because of their loosely-packed structure. Thus it indicated that the fatty acid composition affects these behaviors of the oil. The blending of fully hydrogenated coconut fat improved the elastic and textural character of the coconut oil.

**Keywords:** viscosity, spreadability, storage modulus ( $G'$ ), loss modulus ( $G''$ ) and Herschel-Bulkley model

## 1. Introduction

Coconut oil is a multi-component mixture of various triglycerides (TAGS) containing approximately 50% lauric acid and more than 15% of C6, C8, and C10 fatty acid. Coconut oil belongs to vegetable oils, it is considered to be the richest source of medium chain fatty acids which have been reported to promote human health (Canapi et al., 2005). Coconut oil is one of the mostly used fats in baking industries, processed foods, infant formulas and pharmaceuticals in Southeast Asia and also famous in European countries. Due to its melting and crystallization characteristics, margarine and shortening production, as well as confectionary industry, consider coconut

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oil as a basic material in product formulations. Coconut oil is extensively used in the food industries as a confectionary fat particularly in the preparation of ice creams.

Most vegetable oils have a limited technological application in their original forms because of their specific chemical and physical properties (Hashempour-Baltork et al., 2016). To enhance their commercial application, vegetable oils are often modified using four different methods; hydrogenation, interesterification, fractionation, and blending. Hydrogenation of vegetable oils to obtain oils/fats with improved texture and oxidative stability has been used for a long time (O'Brien 2009). Unfortunately, during partial hydrogenation trans fatty acid formed, which has shown an adverse effect on human health in a research study (Iqbal, 2014). The blending of vegetable oils/fats with different properties is one of the simplest methods to create new products with desired textural and oxidative properties. The rheological and textural properties of fats are important to their behavior during processing, packing, and storage. These properties are more significant to the overall structure and nanostructure formation with high impacts on food formulation and structuring approaches. The objective of this research was to study the effect of blending of fully hydrogenated coconut oil with non-hydrogenated coconut oil at different proportions on rheological and textural properties.

## **2. Materials and Method**

### **Materials**

Fully hydrogenated coconut oil (FHCO) and non-hydrogenated coconut oil (NHCO) were generously provided by local industry from Budapest.

### **Blends preparation**

The blends were prepared in the proportion of 25:75 (Blend 1), 50:50 (Blend 2) and 75:25 (Blend 3) non-hydrogenated coconut oil:fully hydrogenated coconut oil (w/w), melted at 100 °C and homogenized for 10 min at that temperature to melt the crystal completely. All blends and pure fat samples were stored in a refrigerator at 10 °C until use.

## **Rheological measurements**

### **Oscillatory rheology**

Rheological measurements were performed by a controlled stress-strain rheometer (MCR 301, Physica/Anton Paar, Ostfildern Germany-Europe) connected to a circulating water bath for the temperature control. The viscoelastic behavior of the samples was evaluated from 10 °C to 25 °C by using a parallel plate (diameter: 50 mm) and a gap distance of 2 mm. Excess sample protruding from the edge of the sensor was trimmed off carefully with a thin blade. In our measurement, an oscillatory shear strain was applied to the sample at a constant frequency of 10 rad/sec and a constant strain amount of 0.1%, which satisfies the linear viscoelastic condition. The storage modulus ( $G'$ ) and the loss modulus ( $G''$ ) were recorded continuously.

### **Dynamic viscosity tests**

Dynamic viscosity tests were conducted by using the same rheometer with a coaxial cylindrical measurement system. The tests were carried out at different temperatures 30 °C, 40 °C, 50 °C, 60 °C, 70 °C and 80 °C, respectively. This test consists of transferring the fat to a measuring cup until it reaches a predefined mark designed inside the cup, then this cup containing the sample is inserted to a temperature jacket that is fixed to a measuring head with a cylindrical spindle connected. The spindle rotates inside the measuring cup with the oil and the rheological information is monitored by the measuring head. A total 31 readings were obtained varying the shear rate from 100 s<sup>-1</sup> to 1500 s<sup>-1</sup>. As most of the oils and the mixtures presented a Newtonian behavior, the average value of all the readings was reported as shear stress at respective temperature.

### **Determination textural properties**

Spreadability test was performed to determine textural properties of the formulations using a software-controlled penetrometer (TA-TX Plus, Stable Micro System, UK) equipped with a 2 kg load cell. The samples were heated in a microwave oven at 80 °C for complete melting of the crystals and placed in 50 mL beakers. The conditioning was performed in an incubator

for 24 hours at 5 °C for the pre-crystallization of the fat and then for 24 hours at the 25 °C temperature. Fat samples were initially transferred into TMS spreadability jig and pressed down in order to eliminate air pockets. An analytical probe was twice penetrated into each fat sample to a defined depth (15 mm) and at a defined rate (2 mm/s) (Campos, 2005). Any excess of a sample was scraped off with a knife. Experiments were carried out at least five times. As a result of this study, a force-time curve was obtained. Hardness is the force required to attain a given deformation and the altitude of the first peak gives the hardness value. The areas under the curves were also determined and they represented the amount of work required to perform the shearing process; that is, to spread the samples along the surfaces of the female cone.

### Statistical analysis

All of the data were subjected to a one-way analysis of variance (ANOVA) followed by Duncan's multiple range test at 95% of confidence level ( $p < 0.05$ ) using statistica v.12. (Statsoft India Pvt.Ltd., New Delhi)

## 3. Results and Discussion

### Rheological measurements

Viscoelasticity studies provide valuable data that can be correlated to fat crystal network structure. The parameter derived from small-amplitude oscillatory shear tests includes storage modulus (solid-like or elastic,  $G'$ ) and loss (liquid-like or viscous,  $G''$ ) moduli.

*Figures 1–5* show amplitude test graphs for all samples. In our study, we observed that during a heating process, crystallized coconut fat showed a viscoelastic crystalline structure with  $G' > G''$ . But above a certain temperature coconut fat melted fastly to a liquid state, the value of  $G'$  and  $G''$  decreased drastically (*Fig. 1*). On the other hand,  $G'$  and  $G''$  of fully hydrogenated coconut fat remains constant with increased temperature until 22 °C and showed viscoelastic solid structure (*Fig. 2*). Higaki et al. (2004) found that  $G'$  and  $G''$  values typical of the gel-like state changed to those typical of the liquid-like state with fully hydrogenated rapeseed oil and sal fat olein. In *Figs 3, 4* and *5*, blends containing more FHCO contents had higher  $G'$  and  $G''$  as a function of temperature. The non-hydrogenated

coconut fats showed linear viscoelastic region until 18 °C whereas fully hydrogenated coconut oil showed until 21 °C. As the concentration of fully hydrogenated coconut oil increased in non-hydrogenated coconut fat the linear viscoelastic region slightly increased with increase in relative temperature.

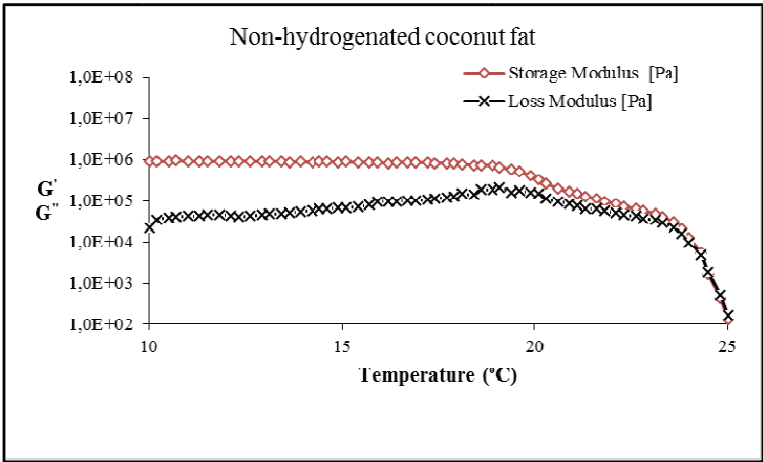


Fig. 1. Rheological properties in terms of storage modulus ( $G'$ ) and loss modulus ( $G''$ ) of non-hydrogenated coconut fat as a function of temperature

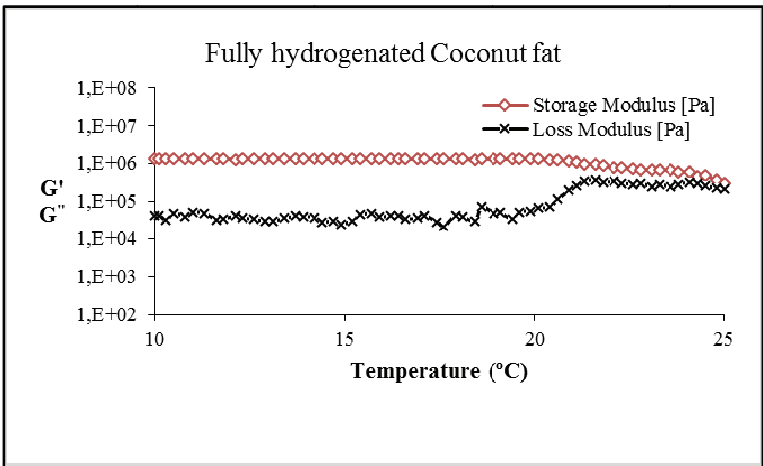


Fig. 2. Rheological properties in terms of storage modulus ( $G'$ ) and loss modulus ( $G''$ ) of fully hydrogenated coconut fat as a function of temperature

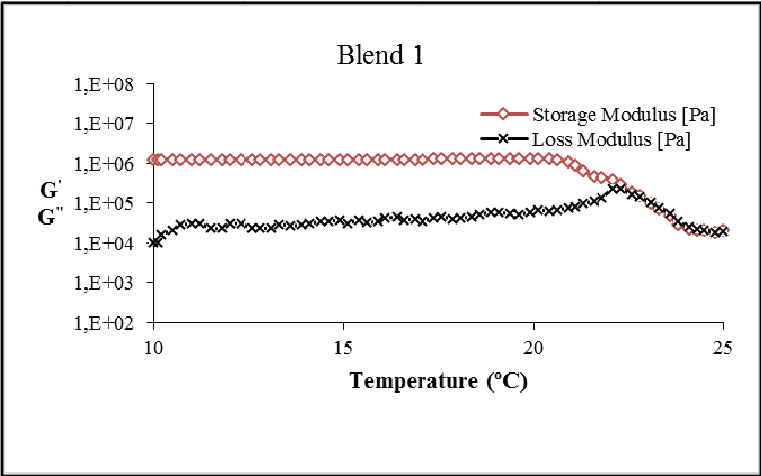


Fig. 3. Rheological properties in terms of storage modulus (G') and loss modulus (G'') of fat blend 1 as a function of temperature

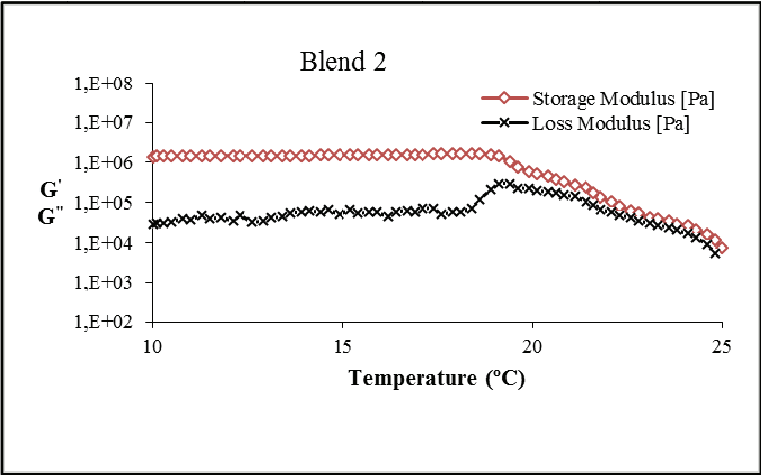


Fig. 4. Rheological properties in terms of storage modulus (G') and loss modulus (G'') of fat blend 2 as a function of temperature

All fat samples were investigated in the temperature range of 30 °C to 80 °C. From Fig. 6 to Fig. 10, it was clear that fluidized fat samples are subjected to Newtonian behavior at high temperatures, which is independent of shear rate. It was found that the viscosity of all oils investigated had shown shear rate and temperature dependence where the

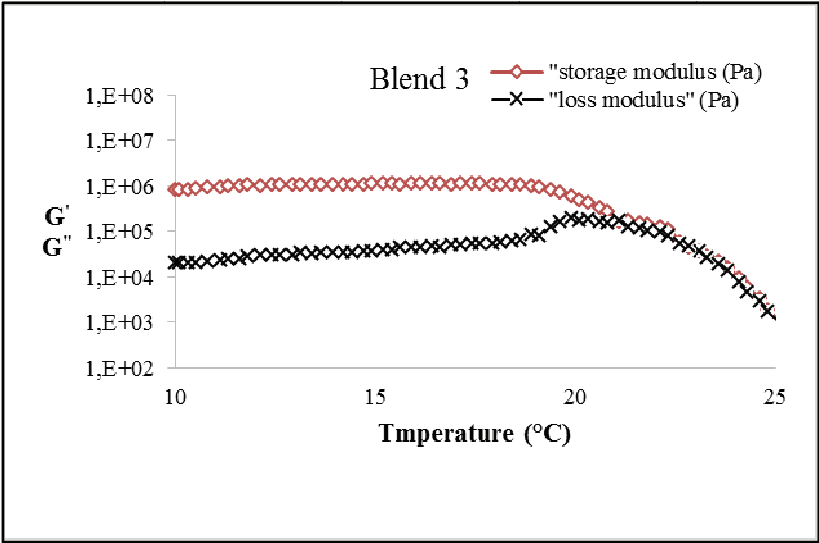


Fig. 5. Rheological properties in terms of storage modulus ( $G'$ ) and loss modulus ( $G''$ ) of fat blend 3 as a function of temperature

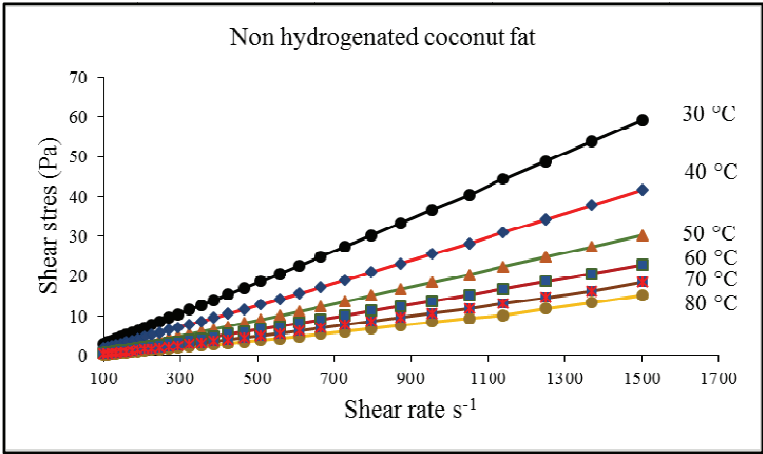


Fig. 6. Flow curve of non-hydrogenated coconut fat in a temperature range of 30  $^{\circ}\text{C}$  to 80  $^{\circ}\text{C}$

viscosity of the oils reduces as the temperature and shear rate increase. The fat samples exhibiting gel-like behavior are shown as Bingham plastic fluid curve with the apparent yield value at 30  $^{\circ}\text{C}$ , 40  $^{\circ}\text{C}$ , and 50  $^{\circ}\text{C}$ . This rheological behavior is similar to the results observed by Santos et al. (2004)

for some vegetable oils on heating at a different temperature. The Herschel-Bulkley model was fitted to flow curves of non-hydrogenated coconut fat, fully hydrogenated coconut fat and their three blends with R<sup>2</sup> values 0.9999.

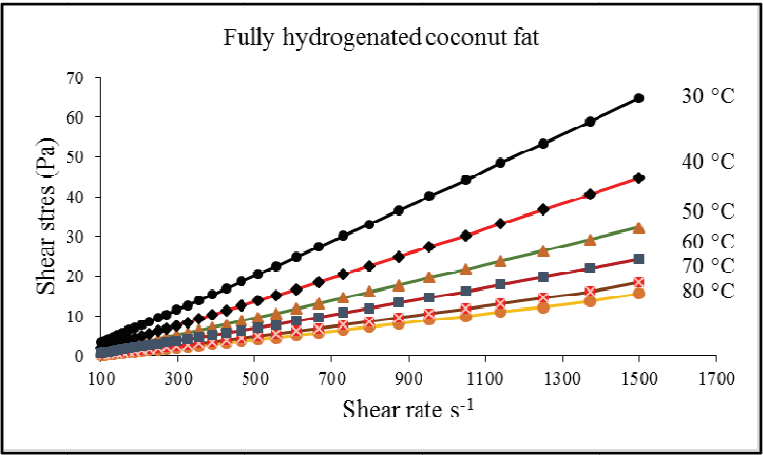


Fig. 7. Flow curve of fully hydrogenated coconut fat in a temperature range of 30 °C to 80 °C

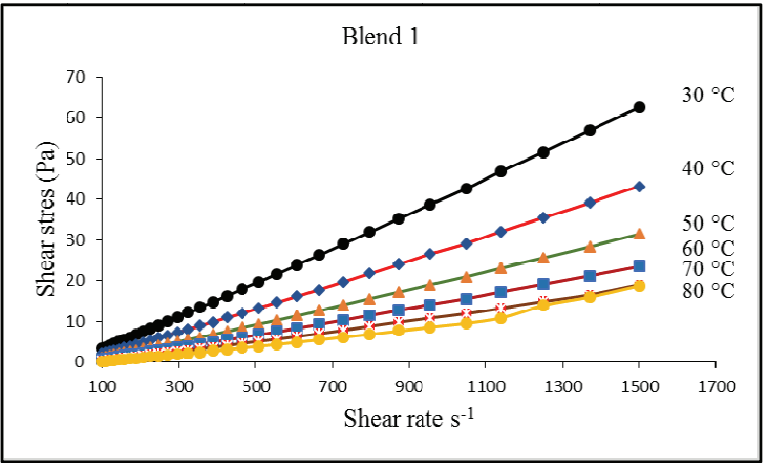


Fig. 8. Flow curve of fat blend 1 in a temperature range of 30 °C to 80 °C

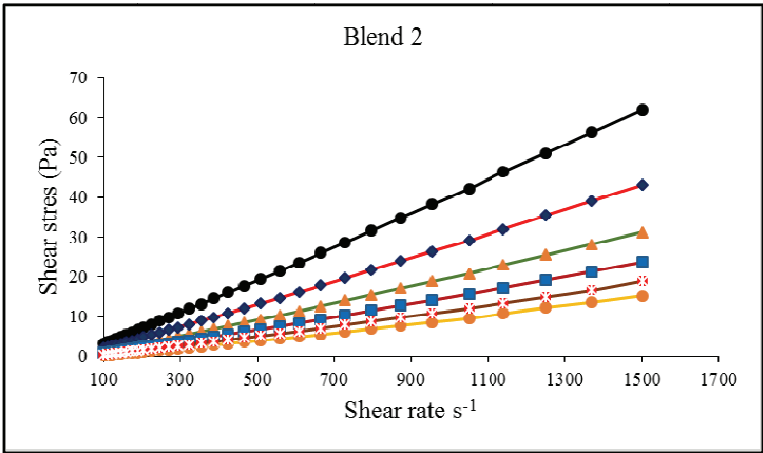


Fig. 9. Flow curve of fat blend 2 in a temperature range of 30 °C to 80 °C

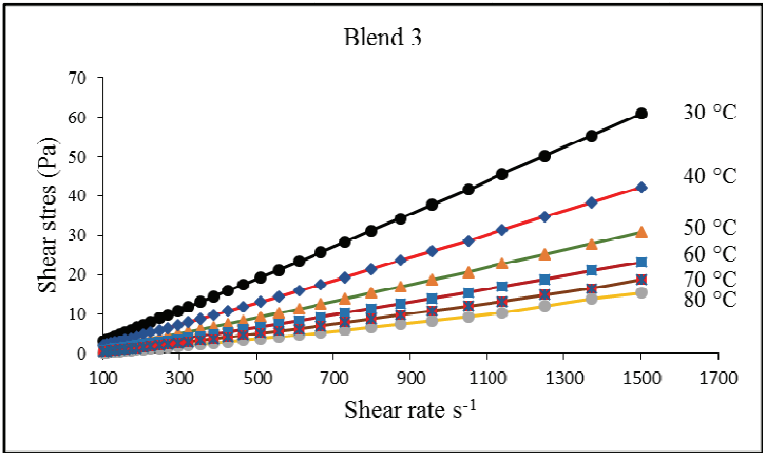


Fig. 10. Flow curve of fat blend 3 in a temperature range of 30 °C to 80 °C

### Textural properties

The textural properties of fats are mainly defined by their solid fat content. The hardness, cohesiveness, adhesiveness, adhesive force and chewiness of fat samples at the temperature of 25 °C are presented in Table 1. The pure fully hydrogenated coconut fat (FHCO) has the highest value of hardness (11.22 N) and cohesiveness (33.95 g), which is not the case with the pure non-hydrogenated coconut fat. We observed that with the addition of

FHCO to non-hydrogenated coconut fat at different concentrations leads to increase in values of textural parameters, proportional to the increase in FHCO concentration. The same results were obtained after the addition of small amounts of hard fats to palm oil. (de Oliveira et al., 2015).

*Table 1.* Textural properties of original fats and their blends

Samples	Hardness (N)	Cohesiveness (N.mm)	Adhesiveness (N.mm)	Adhesive force (N)	Chewiness (N/mm)
NHCO	1.67 <sup>d</sup>	2.57 <sup>d</sup>	-0.13 <sup>d</sup>	-1.38 <sup>d</sup>	61.54 <sup>a</sup>
FHCO	11.22 <sup>a</sup>	33.95 <sup>a</sup>	-2.09 <sup>a</sup>	-9.74 <sup>a</sup>	19.47 <sup>d</sup>
Blend 1	6.74 <sup>b</sup>	20.04 <sup>b</sup>	-0.14 <sup>b</sup>	-6.27 <sup>b</sup>	44.89 <sup>b</sup>
Blend 2	3.69 <sup>c</sup>	10.86 <sup>c</sup>	-0.87 <sup>c</sup>	-3.53 <sup>c</sup>	28.36 <sup>c</sup>
Blend 3	3.42 <sup>c</sup>	11.17 <sup>c</sup>	-0.73 <sup>c</sup>	-3.29 <sup>c</sup>	26.18 <sup>cd</sup>

Results are expressed as mean values. Means in a column with different superscripts are significantly different.(P < 0.05)

## 4. Conclusion

This study showed that blending fully hydrogenated coconut fat at different concentration (25%, 50%, and 75%) in non-hydrogenated coconut oil affected their rheological and textural properties. The results also showed that the flow behavior of blends were modified by increasing the concentration of fully hydrogenated coconut fat. Compared to blends non-hydrogenated coconut fat had lower melting point and  $G'$  and  $G''$  modules. This sample is a Newtonian liquid across a wide temperature range and shear rate. The hardness, cohesiveness, adhesiveness and chewiness of samples were influenced by the blending of FHCO. We would conclude that blending of fully hydrogenated coconut fat with non-hydrogenated coconut fat favors the use of coconut oil in confectionary industries.

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