Effect of blending on rheological and textural properties of non-hydrogenated coconut fat

Vinod Dhaygude[1*], Anita Soós[1], Réka Juhász[2] and László Somogyi[1]

1. Department of Grain and Industrial Technology, Faculty of Food Science, Szent István University, Villányi út 29-43, H-1118 Budapest, Hungary.
2. Department of Food preservation, Faculty of Food Science, Szent István University, Villányi út 29-43, H-1118 Budapest, Hungary.

* Corresponding author: vinod.dhaygude05@gmail.com

Abstract

Blending is widely used for modification of the physicochemical properties of fats to enhance their commercial applications. The rheological and textural properties of non-hydrogenated coconut oil, fully hydrogenated coconut oil and their blends were investigated. The blends were prepared in proportion of 25:75, 50:50, 75:25 (w/w) non hydrogenated coconut oil (NHCO) to fully hydrogenated coconut oil (FHCO). The rheological properties were tested with oscillatory and rotational method by using a MCR301 rheometer. The spreadability of all samples measured by texture analyzer. The oscillatory results showed that there is change in linear viscoelastic region, storage (G') and loss (G'') moduli with increasing proportion of fully hydrogenated coconut fat in non-hydrogenated coconut fat. In rotational tests the blends showed shear-thinning behavior. The viscosity of oils and their blends investigated at different temperature. The Herschel-Bulkley model was fitted to flow curves (shear stress in function of shear rate) of the samples. During heating, non-hydrogenated coconut oil approached Newtonian behavior earlier than fully hydrogenated coconut oil, which indicated that a more rapid viscosity change with temperature in the oils containing more double bonds due to their loosely-packed structure. Thus it indicated that the fatty acid composition affect the oils behavior. The hardness, cohesiveness, chewiness and adhesiveness were higher in blends in which proportion of fully hydrogenated coconut fats. The blending of fully hydrogenated coconut fat improved the elastic and textural character of the non-hydrogenated coconut fat.

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's considered to be the richest source of medium chain fatty acids which have been reported to promote to human health (Canapi et al., 2005). Coconut oil is one of mostly used fat 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 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 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 oil 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. Unfortunately, during partial hydrogenation trans fatty acid formed which shown adverse effect on human health in research study (Iqbal, 2014). Blending of vegetable oils/fats with different properties is one of the simplest method 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. This properties are more significant to overall structure and nanostructure formation with high impacts on food formulation and structuring approaches. The objective of this research to study 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 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 sample were stored in 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 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 a same rheometer with a coaxial cylindrical measurement system. The tests were carried out at different temperatures respectively 30°C, 40°C, 50ºC, 60ºC, 70ºC and 80°C respectively. This test consists on 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^{-1} to 1500 s^{-1}. As most of the oils and the mixtures presented a Newtonian behavior, the average value of all the readings were 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 penetrate into each fat sample to a defined depth (15 mm) and at a defined rate (2 mm/s) (Campos, 2005). Any excess of 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.

Figure.1, **Figure.2**, **Figure.3**, **Figure.4 and Figure.5**shows amplitude test graphs for all samples. In our study we observed that during heating process, crystallized coconut fat showed a viscoelastic crystalline structure with $G' > G''$. But after certain temperature coconut fat melted fastly to liquid state, the value of G' and G''decreased drastically (**Figure.1)**. On the other hand G' and G'' of fully hydrogenated coconut fat constant linearly with increased temperature until 22ºC and showed viscoelastic solid structure (**Figure.2)**. Higaki et al., 2004 found 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 **Figure.3, Figure.4 and Figure.4,** 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 shown until 21ºC.As the concentration of fully

hydrogenated coconut oil was increased in non-hydrogenated coconut fat the linear viscoelastic region slightly increased with increase in relative temperature.

All fat samples were investigated in the temperature range of 30ºC to 80°C. From**Figure.6** to **Figure.10**, it was clear that fluidized fat samples are subjected to Newtonian behavior at high temperatures which is independent from shear rate. It was found that the viscosity of all oils investigated had shown shear rate and temperature dependence where the viscosity of the oils reduces as the temperature and shear rate increase. The fat samples exhibiting gel like behavior is shown as Bingham plastic fluid curve with the apparent yield value at 30ºC, 40ºC and 50ºC. This rheological behavior is similar to the results observed by Santos et al., 2004 to some vegetable oils on heating at 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^2 values 0.9999.

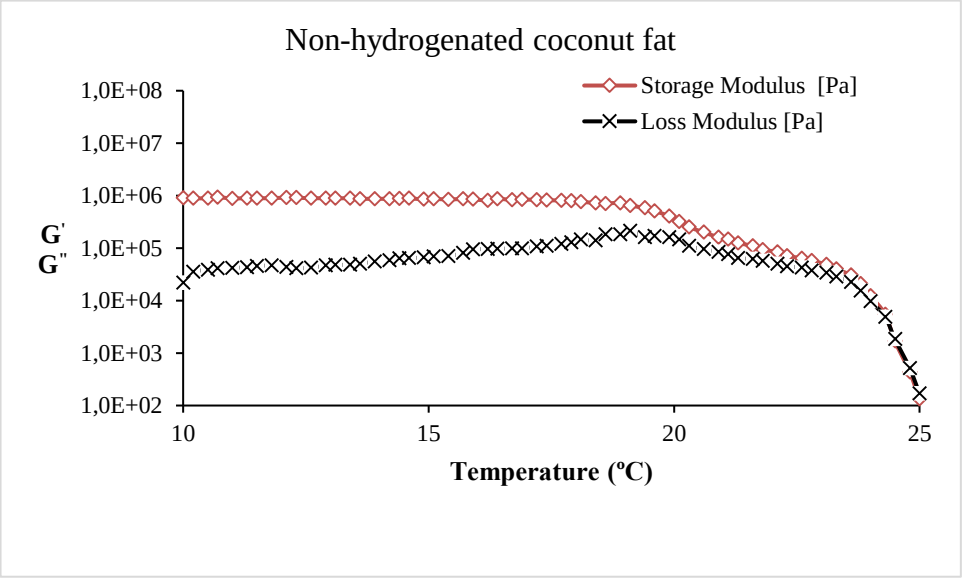

Figure.1 Rheological properties in terms of storage modulus (G') and loss modulus (G") of non-hydrogenated coconut fat as a function of temperature.

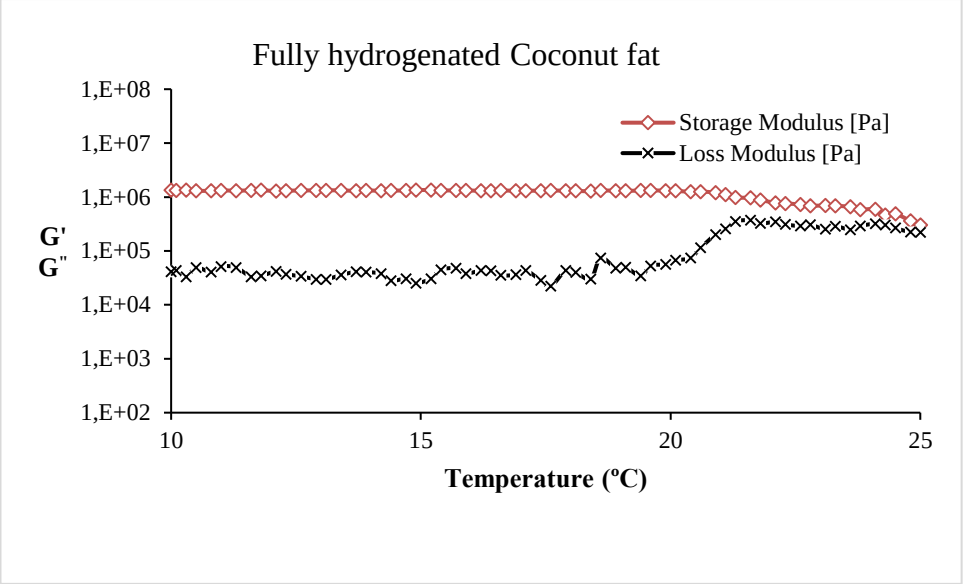

Figure.2 Rheological properties in terms of storage modulus (G') and loss modulus (G") of fully hydrogenated coconut fat as a function of temperature.

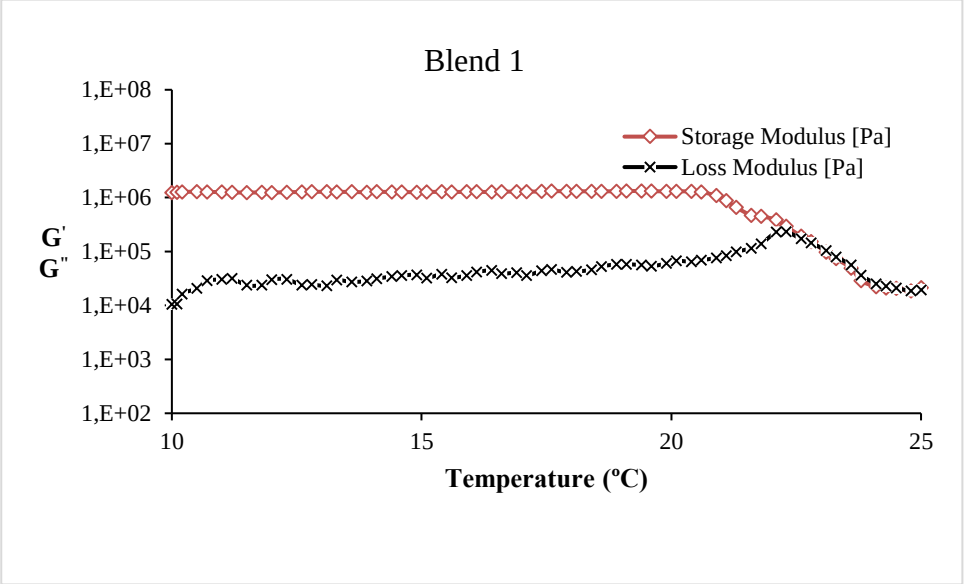

Figure.3 Rheological properties in terms of storage modulus (G') and loss modulus (G") of fat blend 1 as a function of temperature.

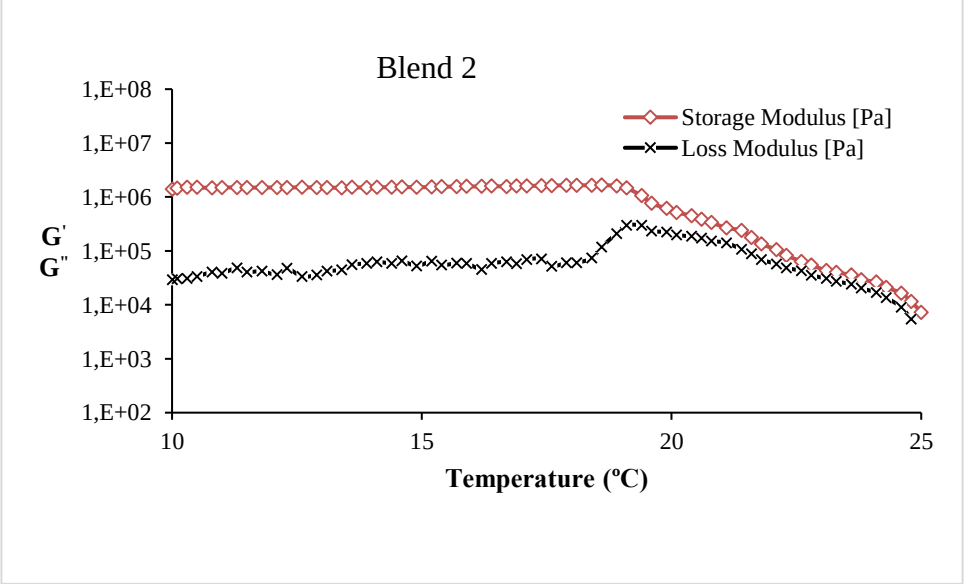

Figure.4 Rheological properties in terms of storage modulus (G') and loss modulus (G") of fat blend 2 as a function of temperature.

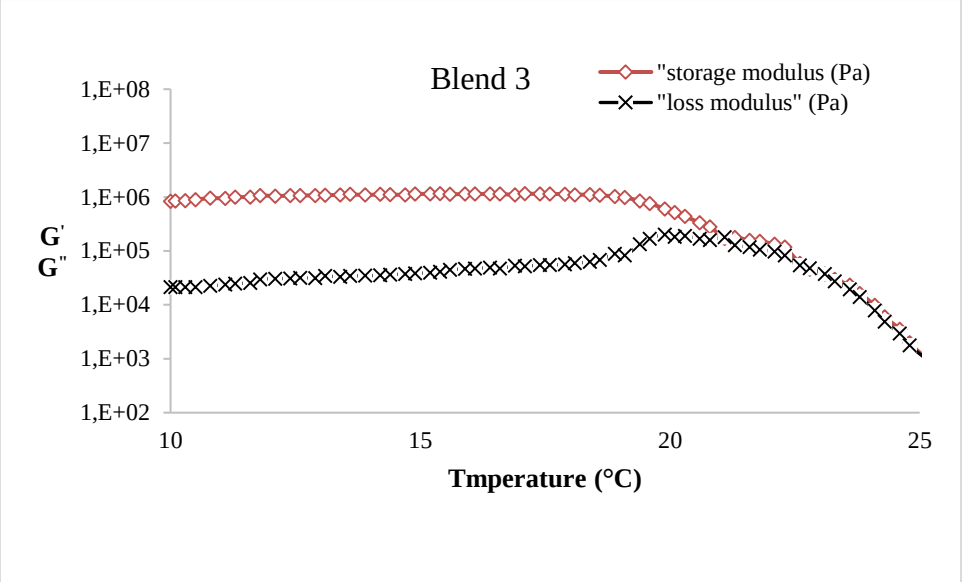

Figure.5 Rheological properties in terms of storage modulus (G') and loss modulus (G") of fat blend 3 as function of temperature.

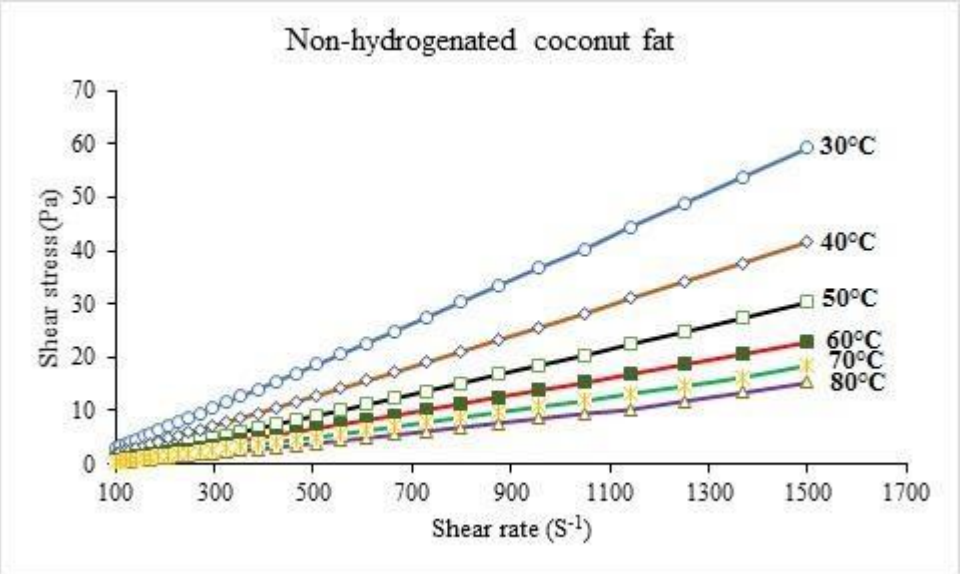

Figure.6 Flow curve of non-hydrogenated coconut fat in a temperature range of 30°C to 80°C.

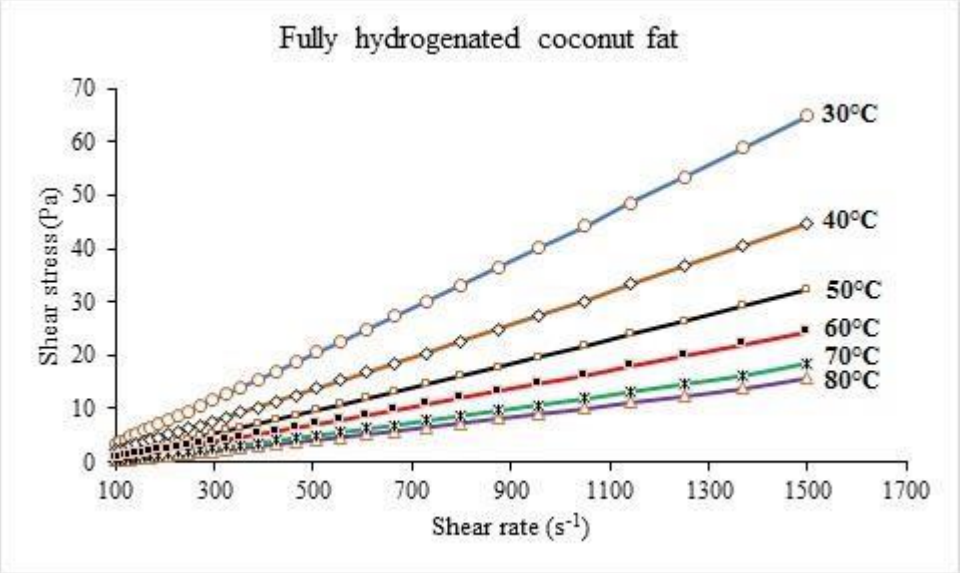

Figure.7 Flow curve of fully hydrogenated coconut fat in a temperature range of 30°C to 80°C.

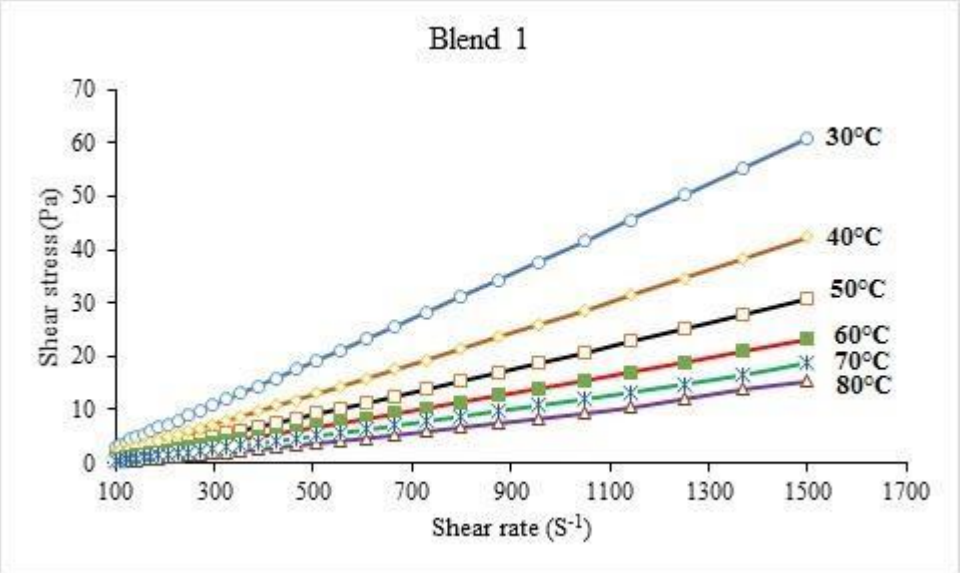

Figure.8 Flow curve of fat blend 1 in a temperature range of 30°C to 80°C.

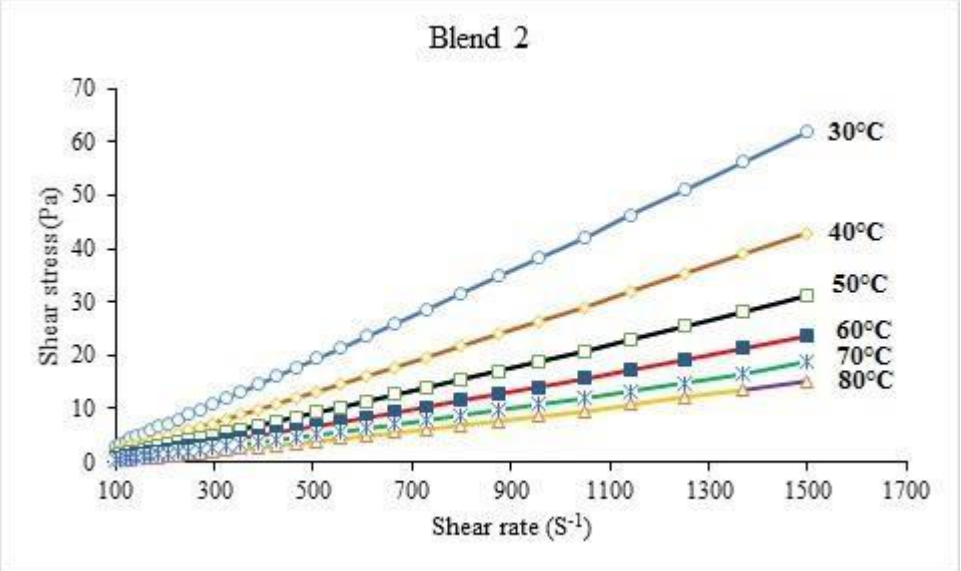

Figure.9 Flow curve of fat blend 2 in a temperature range of 30°C to 80°C.

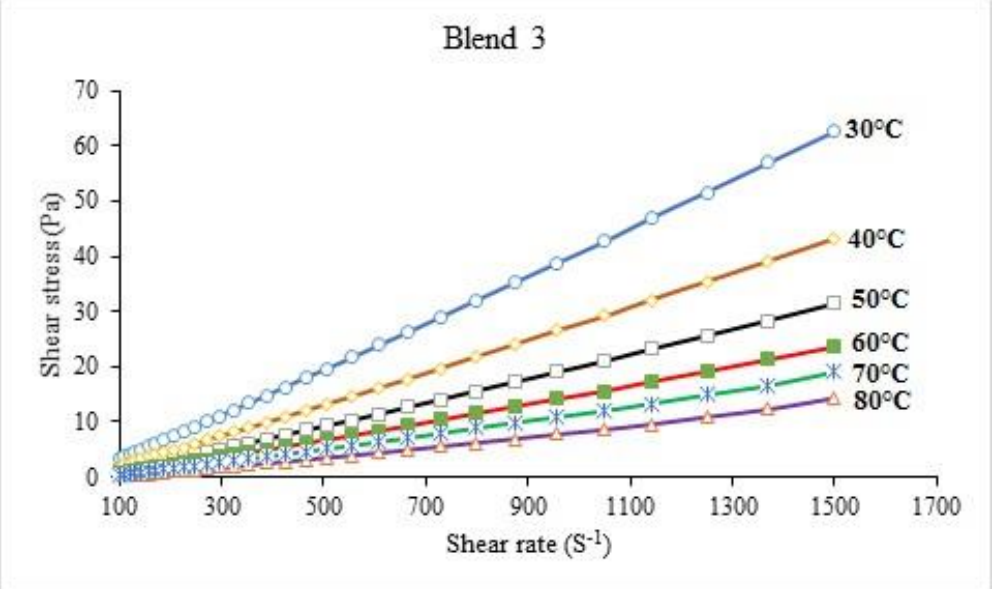

Figure.10 Flow curve of fat blend 3 in a temperature range of 30°C to 80°C.

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 (1143.87 g) and work of shearing (3462.88g), 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 obtained in 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 (g)	Cohesiveness (g.mm)	Adhesiveness (g.mm)	Adhesive force (g)	Chewiness g/mm
NHCO	170.37^{d}	262.18^{d}	-132.86^{d}	-140.74^{d}	6275.78^{a}
FHCO	1143.87^{a}	3462.88^{a}	-2299.01^{a}	-994.16^{a}	1985.96^{d}
Blend 1	687.63^{b}	2047.14^{b}	-1495.35^{b}	-639.55^{b}	4577.53^{b}
Blend 2	376.47^{c}	1108.06^{c}	-929.92^{c}	-360.30^{c}	2892.43^{c}
Blend 3	349.76^{c}	1139.22^{c}	-783.02^{c}	-335.55^{c}	2670.75^{cd}

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 rheological parameters of blends were modified by increasing concentration of fully hydrogenated coconut fat. Compared to blends non-hydrogenated coconut fat had lower melting point and $G^{'}$ and $G^{''}$ modules. This samples 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.

5. References

Campos, R. (2005). Experimental methodology. In A. G. Marangoni (Ed.), Fat crystal networks (pp. 267-349). Boca Raton, FL: CRC Press.

Canapi, E.C., Agustin, Y.T., Moro, E.A., Pedrosa E. Jr., Bendano, M.L.J. (2005). Coconut oil. vol. 2. 6th edition. Bailey's Industrial Oil and Fat Products,(pp. 123–147).

De, Oliveira, G. M., Ribeiro, A.P.B., Kieckbusch T.G. (2015) Hard fats improve technological properties of palm oil for applications in fat-based products. LWT - Food Science and Technology 63, 1155-1162.

Hashempour-Baltork, F., Torbati, M., Azadmard-Damirchi, S., Savage, G.P. (2016). Vegetable Oil Blending: A Review of Physicochemical, Nutritional and Health Effects, Trends in Food Science & Technology, Volume 57, Part A, Pages 52–58.

Higaki, K. Koyano, T. Hachiya, I. Sato, K.Suzuki, K. (2004). Rheological properties of β-fat made of binary mixtures of high- and low-melting fats Food Res Int, 37, pp. 799–804.

Iqbal, M.P. (2014) Trans fatty acids – A risk factor for cardiovascular disease Pakistan Journal of Medical Sciences, 30, pp. 194–197.

O'Brien, R. D. (2009). Fats and oils: Formulating and processing for applications (3rd Ed.). Boca Raton, NY: CRC Press.

Santos, J. C. O., Santos, I. M. G., Conceicao, M. M., Porto, S. L., Trindade, M. F. S., Souza, A. G., et al. (2004) Thermoanalytical, kinetic and rheological parameters of of commercial edible oils. Journal of Thermal Analysis and Calorimetry, 2, 419-428.