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Rheology of lard

Ioana Stanciu

University of Bucharest, Faculty of Chemistry, Department of Physical Chemistry, 4-12 Elisabeta Blvd, 030018, Bucharest, Romania

***Corresponding Author**: Ioana Stanciu

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Abstract

This work investigates the rheological behavior of lard, an animal fat widely used in the food industry and in traditional applications. Lard exhibits a complex temperature-dependent behavior, changing from a viscoelastic semisolid to a viscous liquid with increasing temperature. The study aimed to determine the dynamic viscosity as a function of temperature and shear rate, using a rotational rheometer. The results indicate a weak pseudoplastic behavior in the molten state, with a significant decrease in viscosity from approximately 160 mPa•s at 1 s^{-1} to 65 mPa•s at 1000 s^{-1} at 40°C. Lard also exhibits thixotropy and a marked transition around the melting point (30–40°C), where the solid crystalline structure breaks down. The Ostwald-de Waele model was applied to describe the flow curves, providing a simplified but useful characterization of the rheological behavior. The conclusions highlight the importance of rheological control in the formulation, processing and application of lard in various industries.

Keywords: *rheology, lard, pork.*

Introduction

Rheology, the science that studies the deformation and flow of matter, plays a crucial role in understanding the physical behavior of food systems, particularly those rich in lipids. Among such systems, lard—rendered fat derived primarily from pork—has long been an important ingredient in both traditional and industrial food applications. Its functional properties, including spreadability, plasticity, and mouthfeel, are directly influenced by its rheological characteristics. Therefore, investigating the rheology of lard is essential for optimizing its use in food formulations, improving product quality, and understanding its behavior under different processing and storage conditions.

Lard is a complex semi-solid material composed mainly of triglycerides, which are esters formed from glycerol and fatty acids. The composition of these fatty acids—typically a mixture of saturated, monounsaturated, and polyunsaturated types—plays a fundamental role in determining the physical structure and mechanical properties of lard. At room temperature, lard exhibits characteristics of a viscoelastic material, meaning it displays both solid-like and liquid-like behavior depending on the applied stress or deformation. This dual nature makes its rheological study particularly relevant, as it influences how lard behaves during mixing, spreading, heating, and consumption [1-5].

The microstructure of lard consists of a network of fat crystals dispersed within a liquid oil phase. This crystalline network is responsible for the material's firmness and stability. The size, shape, and distribution of these crystals are influenced by factors such as cooling rate, thermal history, and processing conditions. For example, rapid cooling can lead to the formation of smaller, more numerous crystals, resulting in a firmer structure, whereas slow cooling tends to produce larger crystals and a softer consistency. Rheological measurements provide a means to quantify these structural differences and relate them to macroscopic properties such as hardness and viscosity.

Temperature is one of the most significant factors affecting the rheological behavior of lard. As temperature increases, the solid fat content decreases due to melting of fat crystals, leading to a transition from a semi-solid to a more fluid-like state. This change is reflected in a reduction of viscosity and elastic modulus. Conversely, at lower temperatures, the increased proportion of solid fat enhances the rigidity and resistance to deformation. Understanding these temperature-dependent transitions is critical for applications such as baking, where lard must maintain structure during dough preparation but melt appropriately during cooking to contribute to texture and flavor.

Lard generally exhibits non-Newtonian flow behavior, meaning its viscosity changes with the applied shear rate. Specifically, it often demonstrates shear-thinning behavior, where viscosity decreases as shear rate increases. This property is advantageous in food processing, as it allows lard to flow more easily under mechanical stress (such as mixing or pumping) while maintaining a stable structure at rest. Additionally, lard may show yield stress behavior, requiring a minimum applied stress before it begins to flow. This characteristic is important for applications where shape retention is desired, such as in spreads or pastry fillings.

The rheological properties of lard are also influenced by compositional factors, including fatty acid profile and the presence of minor components such as mono- and diglycerides. Variations in animal diet, breed, and processing methods can lead to differences in lard composition, which in turn affect its mechanical behavior. For instance, higher levels of saturated fatty acids typically result in a firmer and more elastic material, whereas increased unsaturation leads to softer and more fluid characteristics. These compositional variations highlight the importance of rheological analysis in quality control and product standardization [6-12].

In the food industry, lard is valued for its ability to impart desirable textural and sensory attributes to products such as pastries, biscuits, and traditional dishes. Its rheological properties influence dough handling, aeration, and the final texture of baked goods. For example, the plasticity of lard allows it to be easily incorporated into dough, while its melting behavior contributes to flakiness and tenderness. A thorough understanding of its rheology enables food technologists to tailor formulations and processing conditions to achieve specific product characteristics.

Beyond food applications, rheological studies of lard also provide insights into the broader field of lipid-based materials. Similar principles apply to other fats and oils, as well as to structured lipid systems such as margarine and shortening. By studying lard as a model system, researchers can develop general frameworks for understanding fat crystallization, network formation, and mechanical behavior.

In conclusion, the rheology of lard is a key aspect of its functionality and performance in various applications. Its complex viscoelastic nature, influenced by temperature, composition, and microstructure, makes it an interesting and important subject of study. Through rheological analysis, it is possible to link microscopic structural features with macroscopic properties, enabling better control over product quality and processing efficiency. As consumer demand for consistent and high-quality food products continues to grow, the importance of understanding materials like lard at a fundamental level remains highly relevant [13-19].

Materials and methods

Lard samples were obtained from commercially available sources and stored under refrigeration at 4 °C prior to analysis. Before testing, samples were allowed to equilibrate to room temperature (approximately 20–25 °C) for at least 1 hour to ensure uniform consistency. Care was taken to avoid thermal history effects by minimizing repeated heating and cooling cycles.

Rheological measurements were performed using a controlled-stress rheometer equipped with a parallel plate geometry (diameter 40 mm). The gap between plates was set to 1 mm, and excess sample was carefully trimmed to avoid edge effects. A solvent trap was used to minimize moisture loss during measurements.

Temperature control was maintained using a Peltier system with an accuracy of ±0.1 °C. Measurements were conducted at multiple temperatures (10 °C, 20 °C, 30 °C, and 40 °C) to assess the temperature dependence of lard's viscoelastic properties. Each sample was equilibrated at the target temperature for 10 minutes prior to testing.

Additionally, steady shear tests were conducted over a shear rate range of 0.1–100 s^{-1} to evaluate flow behavior and viscosity. All measurements were performed in triplicate to ensure reproducibility.

Data were analyzed using the rheometer's software, and average values with standard deviations were reported. The results were used to characterize the structural and flow properties of lard, providing insight into its behavior under different thermal and mechanical conditions.

For the rheological determinations of lard, the rheometer in Figure 1 was used.

Fig. 1 Rheometer AMETEK Brookfield DVNext Con-Placa

Results and discussions

The composition of lard varies slightly depending on the breed of pig, feeding, and processing method, but in general, it is mainly made up of triglycerides (esters of glycerol with fatty acids). Here is a detailed overview:

Table 1. Composition of lard

Compound	Percentage (%) of total mass
Triglycerides	98–99%
Phospholipids	< 0.5%
Free fatty acids	0.5–1.5%
Water	< 0.1% (in well-refined lard)
Solid impurities (proteins, residues)	< 0.1%

The exact values of dynamic viscosity as a function of shear rate for lard may vary depending on: working temperature, origin and composition of the fat and the degree of processing (raw vs. rendered and refined).

Figure 2 shows the dependence of dynamic viscosity of lard at different shear rates and temperature of 40 ^{0}C.

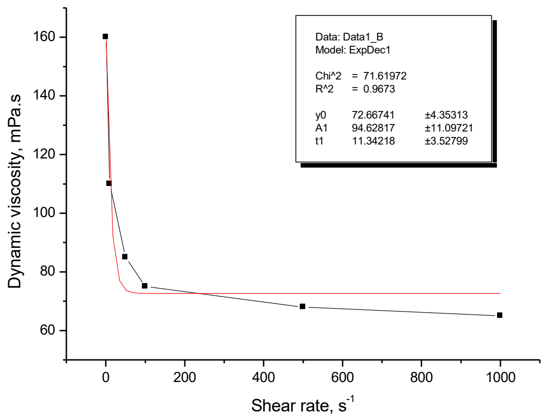

Fig.2. Dependence of dynamic viscosity on shear rate for lard at 40 ^{0}C

At 40 °C, lard exhibits a marked dependence of dynamic viscosity on shear rate, characteristic of non-Newtonian fluids. As the shear rate increases, the dynamic viscosity decreases, confirming shear-thinning (pseudoplastic) behavior. This response can be attributed to the progressive disruption of the residual fat crystal network and the alignment of triglyceride molecules in the direction of flow. At this temperature, lard is close to or slightly above its melting range, meaning the solid fat content is significantly reduced, yet still sufficient to influence flow behavior at low shear rates.

At lower shear rates, higher viscosity values are observed due to the presence of remaining structural interactions between crystalline and liquid phases. However, as shear increases, these interactions are weakened or broken down, leading to a smoother flow and reduced internal resistance. This transition enhances processability, allowing lard to be more easily pumped, mixed, or spread under applied stress.

Overall, the shear-dependent viscosity of lard at 40 °C highlights its adaptable flow behavior under mechanical forces. Understanding this relationship is essential for optimizing industrial processes and ensuring consistent performance in food applications where temperature and shear conditions vary.

Figure 3 shows the dependence of dynamic viscosity on temperature for lard at shear rate 10 s^{-1}.

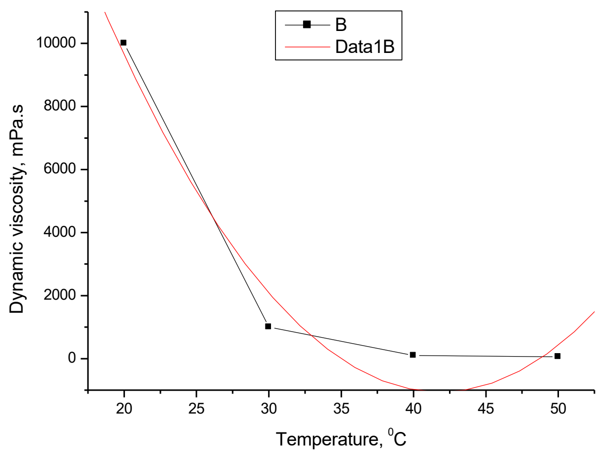

Fig. 3. Temperature dependence of dynamic viscosity for lard at shear rate 10 s^{-1}.

It can be described by a simplified version of the Ostwald-de Waele (power-law) model:

$$\eta = K \cdot \dot{\gamma}^{n-1}$$

where:

η = dynamic viscosity (Pa•s)

$\dot{\gamma}$ = shear rate (1/s)

K ≈ 120 (Pa·s^n)

n ≈ 0.90 (slightly pseudoplastic)

The dynamic viscosity of lard shows a strong dependence on temperature when measured at a constant shear rate of 10 s^{-1}. As temperature increases, viscosity decreases significantly, reflecting the thermally induced changes in the internal structure of the fat. At lower temperatures, lard contains a higher proportion of solid fat crystals, which form a three-dimensional network that restricts molecular mobility and results in higher resistance to flow. Consequently, viscosity values are elevated under these conditions.

With increasing temperature, progressive melting of fat crystals occurs, leading to a reduction in the solid fat content. This disrupts the crystalline network and enhances the mobility of the liquid oil phase, causing a marked decrease in viscosity. Around and above the melting range, lard behaves more like a viscous liquid, and the rate of viscosity reduction becomes less pronounced as most crystalline structures have already melted.

At a shear rate of 10 s^{-1}, the applied deformation is sufficient to maintain consistent flow conditions, allowing the observed viscosity changes to be primarily attributed to temperature effects rather than structural breakdown due to shear. Overall, the results demonstrate that temperature is a critical factor in controlling the flow behavior of lard, with important implications for processing, handling, and application in food systems.

Figure 4 shows the dependence of shear stress on shear rate at temperatures between 20 and 40 ^{0}C.

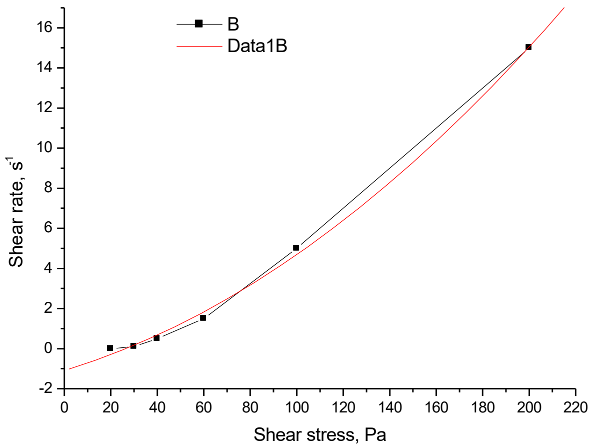

Fig. 4. Shear stress dependence on shear rate at temperatures between 20 and 40 ^{0}C.

Factors influencing rheological behavior:

- Temperature, i.e. as the temperature increases, the yield stress decreases and the lard becomes more fluid.
- The crystalline structure affects the way it flows, especially at temperatures close to the melting point (30–40°C).
- The composition, i.e. the proportion of saturated versus unsaturated fatty acids, affects viscosity.

Conclusions

The rheological study of lard revealed a complex behavior, significantly influenced by temperature and shear rate. In the semi-solid state, at temperatures below 30°C, lard exhibits viscoelastic properties due to the presence of a crystalline network of triglycerides. At higher temperatures (≥40°C), the crystalline structure melts completely, and the lard behaves as a weak pseudoplastic liquid, with viscosity decreasing slightly as the shear rate increases.

The values obtained for the dynamic viscosity as a function of shear rate confirm that the melted lard does not behave perfectly Newtonian, but presents a slight thixotropy and dependence on mechanical stress. The Ostwald-de Waele rheological model has proven adequate for describing the flow behavior in the liquid domain.

These findings have practical relevance both in the food industry and in traditional or pharmaceutical applications, where the handling, processing or local application of lard depend on its rheological properties. In conclusion, the rheological characterization of lard is essential for optimizing its use in products with specific requirements for texture, stability, and performance at variable temperatures.

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