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RHEOLOGICAL EVALUATION OF AVOCADO OILS SUBJECTED TO DIFFERENT EXTRACTION PROCESSES

AVALIAÇÃO REOLÓGICA DE ÓLEOS DE ABACATE SUBMETIDOS A DIFERENTES PROCESSOS DE EXTRAÇÃO

EVALUACIÓN REOLÓGICA DE ACEITES DE AGUACATE SOMETIDOS A DIFERENTES PROCESOS DE EXTRACCIÓN

Fernanda Doring Krumreich
E-mail: fernandakrumreich@ufba.br
Josiane Kuhn Rutz
E-mail: josianekr@gmail.com
Fabiane do Espirito Santo de Jesus
E-mail: fabianej@ufba.br
Gerson Lubke Buss
E-mail: gersonlubke@yahoo.com.br
Carla Rosane Barboza Mendonça
E-mail: carlaufpel@hotmail.com
Caroline Dellinghausen Borges
E-mail: caroldellin@hotmail.com
Rui Carlos Zambiazi
E-mail: zambiazi@gmail.com

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ABSTRACT:
Avocado is a fruit with high lipid content in its pulp, making it a viable raw material for oil production. In this context, understanding the viscosity of the oil obtained from this fruit is important for identifying the effect of variations in processing conditions, as well as for evaluating the quality of the final product. Therefore, the objective of this study was to perform a rheological evaluation of avocado oils from the 'Breda' and 'Margarida' varieties. The pulps were subjected to different drying methods and distinct oil extraction processes. The rheological evaluation of the oils was carried out using a rheometer with a C50-1 spindle over a shear rate range of 0 to 1000 s^{-1}. The results showed that the avocado oils, regardless of the extraction method, exhibited non-Newtonian behavior at shear rates below 200 s^{-1}. Increasing the drying temperature reduced viscosity due to lower flow resistance, while the use of a vacuum attenuated this reduction. This behavior was similar to that observed in other vegetable oils, demonstrating the technological potential of avocado oil. However, further studies under different processing conditions are necessary to deepen the understanding of its rheological properties and industrial applications.

KEYWORDS: *Vegetable oil. Solvent extraction. Mechanical pressing.*

RESUMO:

O abacate é uma fruta com alto teor lipídico em sua polpa, tornando-se uma matéria-prima viável para a produção de óleo. Nesse contexto, compreender a viscosidade do óleo obtido dessa fruta é importante para identificar o efeito de variações nas condições de processamento, bem como para avaliar a qualidade do produto final. Portanto, o objetivo deste estudo foi realizar uma avaliação reológica de óleos de abacate das variedades 'Breda' e 'Margarida'. As polpas foram submetidas a diferentes métodos de secagem e distintos processos de extração de óleo. A avaliação reológica dos óleos foi realizada utilizando um reômetro com fuso C50^{-1} em uma faixa de taxa de cisalhamento de 0 a 1000 s^{-1}. Os resultados mostraram que os óleos de abacate, independentemente do método de extração, apresentaram comportamento não newtoniano em taxas de cisalhamento abaixo de 200 s^{-1}. O aumento da temperatura de secagem reduziu a viscosidade devido à menor resistência ao fluxo, enquanto o uso de vácuo atenuou essa redução. Esse comportamento foi semelhante ao observado em outros óleos vegetais, demonstrando o potencial tecnológico do óleo de abacate. No entanto, estudos adicionais em diferentes condições de processamento são necessários para aprofundar o entendimento de suas propriedades reológicas e aplicações industriais.

PALAVRAS-CHAVE: Óleo vegetal. Extração por solvente. Prensagem mecânica.

RESUMEN:
El aguacate es una fruta con un alto contenido lipídico en su pulpa, lo que la convierte en una materia prima viable para la producción de aceite. En este contexto, comprender la viscosidad del aceite obtenido de esta fruta es importante para identificar el efecto de las variaciones en las condiciones de procesamiento, así como para evaluar la calidad del producto final. Por lo tanto,

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el objetivo de este estudio fue realizar una evaluación reológica de los aceites de aguacate de las variedades 'Breda' y 'Margarida'. Las pulpas se sometieron a diferentes métodos de secado y distintos procesos de extracción de aceite. La evaluación reológica de los aceites se llevó a cabo utilizando un reómetro con un husillo C50-1 en un rango de velocidad de corte de 0 a 1000 s^{-1}. Los resultados mostraron que los aceites de aguacate, independientemente del método de extracción, exhibieron un comportamiento no newtoniano a velocidades de corte inferiores a 200 s^{-1}. El aumento de la temperatura de secado redujo la viscosidad debido a una menor resistencia al flujo, mientras que el uso de vacío atenuó esta reducción. Este comportamiento fue similar al observado en otros aceites vegetales, lo que demuestra el potencial tecnológico del aceite de aguacate. Sin embargo, se requieren más estudios en diferentes condiciones de procesamiento para comprender mejor sus propiedades reológicas y sus aplicaciones industriales.

PALABRAS CLAVE: Aceite vegetal**.** Extracción por disolventes. Prensado mecánico.

INTRODUCTION

Avocado (*Persea americana* Mill.) is a fruit native to Central America, widely cultivated in warm temperate and subtropical regions. The main producers of avocado oil include New Zealand, Mexico, the United States, South Africa, and Chile (Flores et al., 2019).

According to projections from the Food and Agriculture Organization of the United Nations (FAO) (OECD/FAO, 2024), the avocado has the potential to become the second most traded tropical fruit by 2030, surpassing mango and pineapple. Global avocado production is forecast to reach 14 million tons by 2033, tripling the volume recorded in 2013 (OECD/FAO, 2024).

In Brazil, one of the world's largest consumers, production is led by the states of São Paulo, Minas Gerais, and Paraná, which are responsible for 85.7% of the national output. Among the most cultivated varieties, 'Breda' and 'Margarida' are notable for their sweet taste and suitability for salads, respectively (Aguiar et al., 2020). For the food industry, the primary attraction is the high lipid content in the fruit's pulp (mesocarp), which ranges from 10% to 30% (Krumreich et al., 2018; Jinadasa et al., 2022).

Avocado oil is valued for its rich composition of bioactive phytochemicals, such as carotenoids (lutein), tocopherols (vitamin E), and phytosterols (β-sitosterol) (Nascimento et al., 2025). Among its main fatty acids, oleic acid (67-71%) is the principal monounsaturated fatty acid, linked to cardiovascular and anti-inflammatory benefits, complemented by saturated fatty acids (16%) and polyunsaturated fatty acids (13%) (Olas, 2024). Despite the growing nutritional interest in this oil, its specific international quality parameters are still being finalized by the Codex Alimentarius (FAO, 2025).

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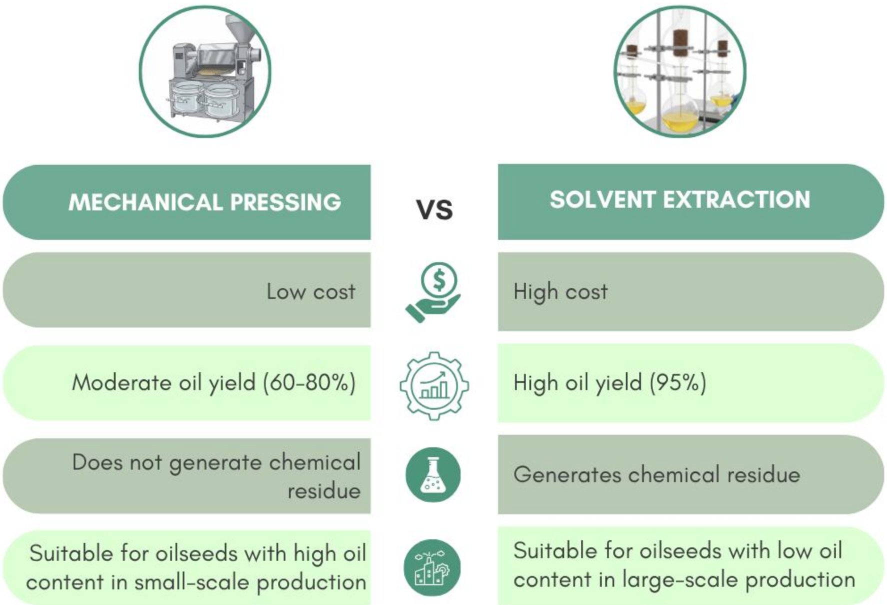
However, oil extraction presents technological challenges. Mechanical methods, such as cold pressing, are affected by the high moisture content of the pulp (approximately 77%), which reduces the yield and requires pre-treatments like drying [Cervantes-Paz and Yahia, 2021; Quin and Zhong, 2016).

Consequently, extraction with organic solvents (e.g., hexane, acetone, petroleum ether), with the Soxhlet method being widely used, offers a higher yield but involves significant costs and the risk of chemical residues in the product, as shown in Figure 1, limiting its use in food and pharmaceuticals (Satriana et al., 2018; Quin and Zhong, 2016). As a drying step, the use of a vacuum is an interesting alternative as it allows for dehydration at lower temperatures and with reduced exposure to oxygen, which helps preserve the oil's integrity against oxidation (Krumreich et al., 2024).

Figure 1 - Oil extraction techniques and their characteristics.



Adapted from Santos et al. (2022).

The efficiency of these extraction processes is directly linked to the physical properties of the raw material. Avocado pulp is a multiphase system, and its flow characteristics, such as viscosity and viscoelasticity, are crucial not only for industrial processes but also for food formulations and quality control (Yang et al., 2021). Rheology is used to evaluate these

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properties, which in vegetable oils are influenced by the chain length and degree of unsaturation of the fatty acids (Martínez-Padilla, 2023; Kim et al., 2010).

Therefore, considering the growing demand for functional foods, this study aims to characterize the rheological profile of avocado oil from two distinct varieties, evaluating the impact of different pulp drying and oil extraction methods on these parameters.

MATERIALS AND METHODS

The Breda and Margarida avocado varieties were used in this study. A total of 23 fruits from each variety, at an immature stage of ripening, were provided by a producer in São Sebastião do Paraíso, MG (Minas Gerais). Subsequently, the avocados were stored at 28 ± 1 °C until they reached the ideal stage of maturation. This stage was determined by assessing pulp texture and soluble solids content (7–8 °Brix).

Once mature, the avocados were washed under running water, sanitized in a chlorinated water solution (200 mg L^{-1}) for 15 minutes, and subsequently cut. The pulp was separated and immersed in a 1% citric acid solution for 15 minutes to prevent enzymatic browning. The pulp was then divided into portions, and each portion was subjected to one of three drying methods: a forced-air oven at 40 °C, a forced-air oven at 60 °C (Marconi, model MA035), or a vacuum oven at 60 °C (Vacuoterm, model 6030A). The drying process continued until a final moisture content of 5–6% was achieved.

The dried samples were packaged in polyethylene bags, protected from light, and stored in a freezer (-18 °C) until oil extraction. The extraction was performed using two distinct methods: mechanical pressing, where the dried pulp was subjected to a 9-ton force in a mechanical press (Marconi, Brazil) at ambient temperature; and Soxhlet extraction with petroleum ether, where approximately 15 g of the sample was weighed and placed into a previously defatted filter paper thimble. The Soxhlet process was conducted for 6 hours, after which the residual solvent was eliminated by bubbling with nitrogen gas.

Figure 2 below presents a simplified schematic of the methodology employed for the drying and oil extraction from the Breda and Margarida avocado varieties.

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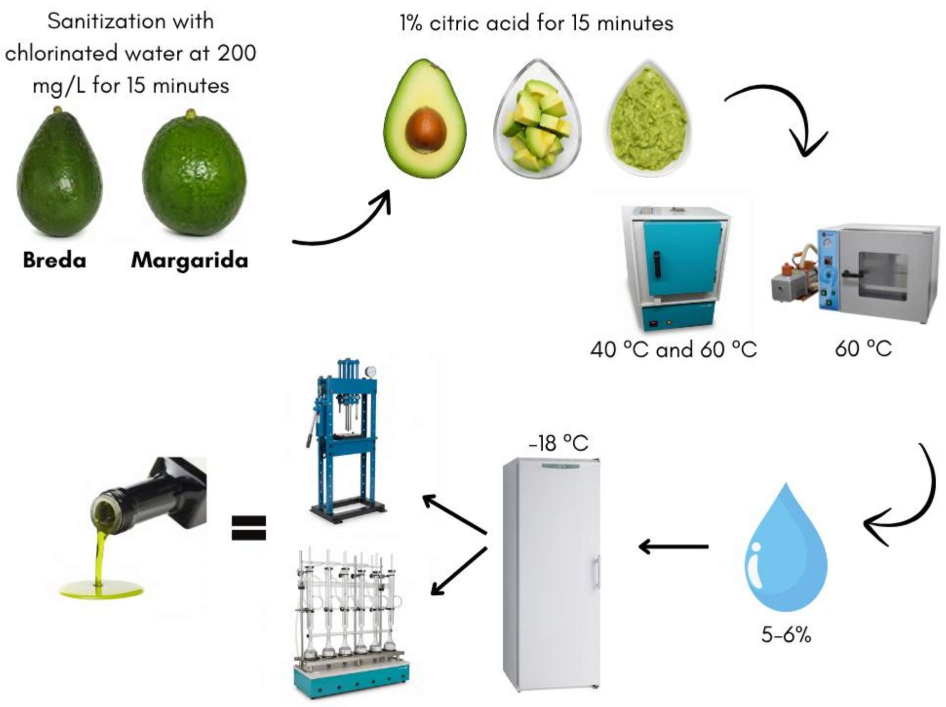
Figure 2 - Schematic of the drying and oil extraction process for the Breda and Margarida avocado varieties.



Source: The figures were created on the graphic design website CANVA (Sydney, Australia, 2012).

RHEOLOGICAL BEHAVIOR

The rheological analysis of the avocado oils was conducted using a rheometer (Brookfield RS-CPS, USA) at a controlled temperature of 30 °C. A cone-plate geometry (spindle C50^{-1}) was employed, and the shear rate was programmed to range from 0 to 1000 s^{-1}. Data were processed with SigmaPlot 11 software to generate the flow curves, representing viscosity (Pa·s) as a function of shear rate (s^{-1}).

RESULTS AND DISCUSSION

Rheology studies the deformational behavior and flow of matter induced by applied stress (shear). Liquids deform continuously when stress is applied, unlike solids, which deform until the stress is removed. It should be noted that for liquids, the rheological property of interest is viscosity (Martínez-Padilla, 2023).

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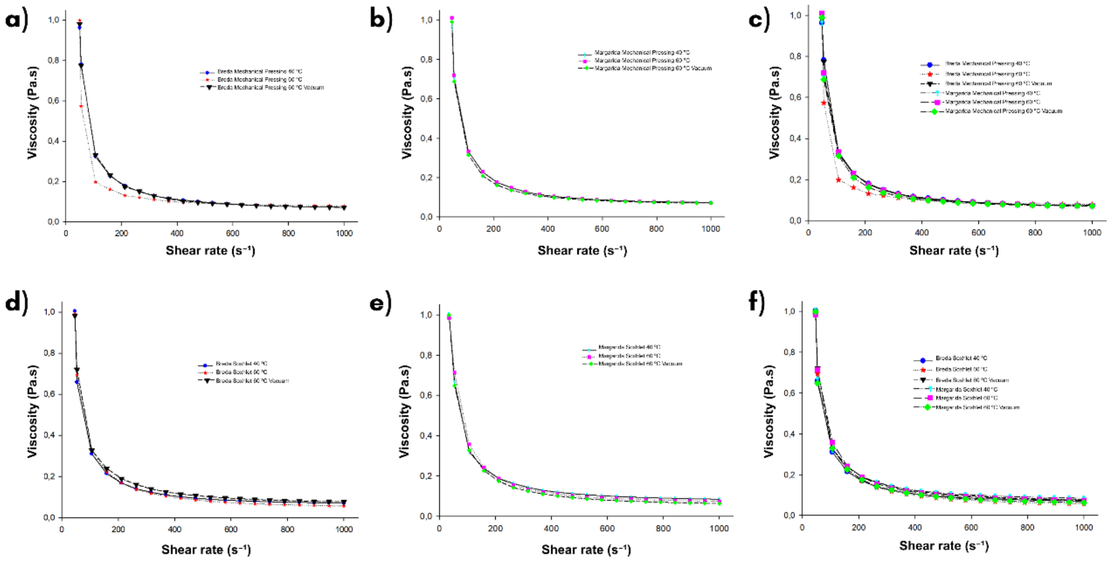
In various stages of the food industry, determining the viscosity of fluids is fundamental for the quality control of raw materials and for assessing the effects of variations in processing conditions, both during manufacturing and in the final product (Steffe, 1996).

Viscosity is directly associated with the stability and preservation of food, as changes in fluidity can indicate the onset of deterioration processes, especially in liquid products (Xu et al., 2022). Furthermore, mastering this rheological parameter allows for the optimization of production processes, a reduction in ingredient costs, and the achievement of products with better consistency and uniformity, which may be related to swallowing and digestion processes (Raymundo et al., 2020; Marín-Sánchez et al., 2025).

Fluids are classified according to their rheological behavior by analyzing the relationship between shear stress and strain rate under established temperature and pressure conditions. Rheologically, fluids are divided into two categories: Newtonian and non-Newtonian (Steffe, 1996; Martínez-Padilla, 2023). When viscosity does not vary as a function of the applied force, the fluid is said to have Newtonian behavior. In cases where viscosity varies with the applied force under the same temperature and pressure conditions, the fluid is considered non-Newtonian (de Alcântara et al., 2016).

Figure 3 (a, b, and c) presents the results of viscosity as a function of shear rate for avocado oil from the 'Breda' and 'Margarida' varieties, obtained through different pulp drying processes and mechanical pressing extraction. A non-Newtonian pseudoplastic behavior, typical of shear-thinning fluids, was observed, where viscosity decreases with an increasing shear rate. This behavior was most evident at low shear rates (0–200 s^{-1}). According to Hasan and Khan (2020), shear-thinning results from the reversible destruction of the oil's internal structures as shear force is applied. At higher rates, this structural reorganization is complete, so there is no further reduction in viscosity.

Figure 3 - Rheological behavior of avocado oils from the Breda and Margarida varieties. The avocado pulps were dehydrated at temperatures of 40°C, 60°C, or 60°C under vacuum, and the oil was extracted by mechanical pressing from the Breda variety (a), Margarida variety (b), and a combination of Breda and Margarida (c); and by Soxhlet extraction with petroleum ether from the Breda variety (d), Margarida variety (e), and a combination of Breda and Margarida (f).



Source: Own authorship (2025).

In the present study, at shear rates above 400 s^{-1}, Newtonian-like behavior was observed, with a viscosity of 0.1 Pa.s, regardless of the increase in shear rate. This behavior was also described by Brock et al. (2008) in vegetable oils such as corn, cottonseed, canola, olive, sunflower, and rice bran. At low rates (<5 s^{-1}), they observed significant variations in viscosity, suggesting non-Newtonian or even Bingham-like fluid behavior. Above 5 s^{-1}, the viscosity became constant, again characterizing it as Newtonian.

Figure 3 (d, e, f) shows the viscosities of avocado oil from the 'Breda' and 'Margarida' varieties, obtained by different pulp drying processes and by Soxhlet extraction with petroleum ether. The viscosity behavior was similar to that observed for mechanical pressing: a decrease with increasing shear rate, followed by stabilization above 400 s^{-1}, forming what is known as the second Newtonian region (Hasan and Khan, 2020). It is important to note that the chemical composition of the oil directly influences its viscosity, which can vary according to its origin and extraction method.

A comparative study with avocado and watermelon oils showed that at shear rates below 200 s^{-1}, both exhibited non-Newtonian and shear-thinning behavior, with avocado oil (0.1647 ± 0.027 Pa.s) being more viscous than watermelon oil (0.1125 ± 0.001 Pa.s) (Logaraj, et al., 2008). Tello et al. (2023) observed similar behavior in emulsions with avocado oil, attributing it to the breakdown of internal networks under shear. In general, increasing temperature and shear rate reduces the viscosity of vegetable oils, as reported in recent studies, due to molecular orientation and lipid composition (Stanciu, 2022; Ostrikov et al., 2023).

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The effect of drying temperature (40°C, 60°C, and 60°C under vacuum) in both extraction methods showed a slight reduction in viscosity with increasing temperature, which is consistent with expectations for vegetable oils, where heating reduces flow resistance due to greater molecular mobility (Figures 3-a and 3-d). The use of a vacuum seemed to mitigate this reduction, possibly due to less thermal degradation and the maintenance of lipid compound integrity. The difference between the 'Breda' and 'Margarida' varieties is also observable; there was no difference between the drying temperatures for the 'Margarida' variety (Figures 3-b and 3-e), which can be attributed to variations in fatty acid composition and other compounds that influence viscosity. Furthermore, processes under vacuum can preserve higher concentrations of tocopherols, phytosterols, and phenolic compounds (Wang et al., 2023).

Similar results were reported by Moura et al. (2023), who observed variations in the viscosity of avocado and flaxseed oil mixtures as a function of composition and temperature. Another study analyzed several vegetable oils, including avocado oil, and reported a decrease in viscosity with increasing temperature (0.0576 ± 0.0002 Pa.s at 26°C and 0.0287 ± 0.0006 Pa.s at 50°C) (Diamante and Lan, 2014).

On the other hand, Jorge et al. (2015) reported Newtonian behavior for refined avocado oils from the 'Margarida' and 'Hass' varieties, suggesting that the non-Newtonian behavior observed in this study may be related to the presence of residual microstructures or compounds not removed during mechanical extraction. These differences reinforce that both processing and composition directly influence the rheological properties of vegetable oils. Additionally, studies indicate that viscosity is a determining factor in the stability and functionality of food systems and can guide technological applications, such as for fat substitutes in chocolates (Soto et al., 2020).

FINAL CONSIDERATIONS

This study demonstrated that avocado oils from the 'Breda' and 'Margarida' varieties exhibit non-Newtonian behavior at shear rates below 200 s^{-1}, with viscosity decreasing as shear increases. The use of a vacuum during extraction and the differences between varieties slightly influenced viscosity, indicating that the oil maintains relatively stable rheological properties under different processing conditions. These findings highlight the potential of avocado oil for industrial applications, such as a fat substitute in food formulations. However, further studies are needed to deepen the understanding of its rheological behavior under different extraction methods and processing conditions to optimize its performance and expand its technological applications.

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