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"Sensory and texture properties of cosmetic formulations for hair and skin care containing *Orbignya oleifera* oil"

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1. Introduction

The development of sustainable cosmetics has become a key focus in the industry, driven by growing environmental concerns and consumer demand for safer, more responsible products. This approach emphasizes the use of renewable raw materials, environmentally friendly extraction processes, and biodegradable ingredients, aiming to minimize ecological impact across the product life cycle [1,2].

In this context, vegetable oils have gained prominence as multifunctional ingredients that align with these principles, offering both efficacy and sustainability. These oils offer multifunctional benefits due to their rich composition of fatty acids, vitamins, sterols, and polyphenols, which contribute to maintaining the integrity of the skin and hair fibers [3,4]. Acting as both emollients and occlusive, vegetable oils form a barrier on the skin that helps retain moisture, improve texture, and defend against external aggressors. Their antioxidant and antimicrobial properties further support their role in promoting healthy skin and hair, reinforcing their value in cosmetic formulations [5].

Brazilian rich biodiversity offers a variety of native oils with high potential for cosmetic applications. Among them, babassu oil (*Orbignya oleifera;* SisGen A54B35E) is a promising resource, obtained from the babassu palm, typical of the transition region between the Cerrado, Amazon and Caatinga biomes [6]. Its relevance to the regional extractive economy lies in its versatility, as the entire fruit can be used across the food, biofuel, and cosmetic sectors [7,8]. The oil is extracted from the seeds inside the coconut and is mainly composed of lauric acid (34.7%) and myristic acid (19.1%), as well as phenolic compounds, tocopherols, and carotenoids [6-10]. These components are associated with anti-inflammatory, healing, antibacterial, and antioxidant activities, reinforcing babassu oil's potential in ecological and functional cosmetic formulations [9, 11-12].

To preserve these bioactive compounds, the oil is extracted using supercritical CO_2, a green technology that prevents thermal degradation and is more sustainable than conventional solvent-based methods, which have low selectivity, high energy consumption, and may result in the loss of key compounds during solvent removal [10].

Due to its sustainable origin, multifunctional composition, and broad applicability, babassu oil stands out as a promising ingredient in cosmetic formulations for both skin and hair care. In this context, this study aimed to develop and evaluate the sensory and physico-mechanical properties of cosmetic formulations containing babassu oil.

2. Materials and Methods

2.1. Development of the formulations

A leave-in and a gel-cream formulations were developed. The leave in was prepared with the following ingredients: aqua, glycerin, disodium EDTA, behentrimonium chloride, cetyl alcohol, cetearyl alcohol, butylhydroxytoluene, dimethicone, caprylic/capric triglyceride, xylitol (and) caprylic acid (and) potassium sorbate (and) glycerin (and) water, propylene glycol. The formulation was added or not (L1 - vehicle) with 3% of babassu oil (L2). The gel-cream was prepared with the following ingredients: aqua, glycerin, disodium EDTA, butylhydroxytoluene, polyglyceryl-10 myristate (and) triethylhexanoin (and) glycerin (and) water, xylityl sesquicaprylate (and) caprylyl glycol, butylene glycol. The formulation was added or not (F1 - vehicle) with 3% of babassu oil (F2).

2.2. Accelerated stability study

In the preliminary stability tests, the formulations were evaluated in terms of rheological behavior, pH analysis, organoleptic characteristics and rheological behavior. For this, the formulations were stored in glass containers at room temperature (25 °C) and challenged by thermal stress at 37 °C and 45 °C under controlled humidity (70 % RH). Rheological behavior, values of pH, and organoleptic changes of the formulations were evaluated at 24 h and 7, 14, 21, and 28 days after preparation.

2.3. Texture profile and rheological behaviour

The texture and spreadability profile was evaluated using the Texture Analyzer TA.XT Plus® texturometer (Extralab Brasil, Brazil), operating with Exponent software.

The texture profile analysis was carried out using the 40 mm Back Extrusion Rig (A/BE) analytical probe to determine firmness, consistency, cohesiveness and viscosity index parameters [Bonilha et al., 2020; Calixto & Maia Campos, 2017]. The spreadability analysis consisted of measuring the work of shear with the TCC Spreadability Rig (HDP/SR) probe. This parameter was calculated from the area under the positive curve in the graph of force (N) as a function of time (t) [13,14].

The rheological behavior of the formulations was analyzed using a Brookfield DV3T cone-and-plate rheometer equipped with a CP-52 spindle. The measurements were performed by progressively increasing and then decreasing the rotation speed, allowing the construction of shear rate vs. shear stress curves. From these data, the flow index, consistency index, apparent minimum viscosity, and hysteresis area were determined using the Rheocalc® and Origin 9.75 software, with curve fitting based on the Ostwald model [13].

2.4. Sensory analysis

The sensory analysis of the formulations was performed with 20 healthy participants, untrained panel, aged 19 to 28 years, phototypes II and III (CAAE: 66403822.7.0000.5403). For the evaluation of the gel-cream formulation, two circles of 20 cm² were marked on the forearm, where the F1 and F2 formulations were applied. At the time of application, the study participant spread the formulation with their own finger using 20 circular motions and evaluated the spreadability parameter. After 10 minutes, the participants assessed the following attributes: hydration, oily residue, white residue, stickiness, and formulation preference.

For the sensory analysis of the leave-in formulations, standardized strands of virgin brown hair were used. The strands were initially pre-washed with a 3% Sodium Laureth Sulfate (LESS) solution and dried with a hairdryer. They were then washed again with shampoo for 1 minute and dried. Next, the strands were dampened according to their weight, using a proportion of 0.08 g of water per 1 g of hair. Following this step, the hair strands were divided into three groups: M1 (untreated control), M2 (vehicle), and M3 (babassu leave-in), and treated at a ratio of 0.05 g of product per 1 g of hair. All strands were dried for 2 minutes and 30 seconds. After treatment, participants evaluated the strands based on combability, hydration, softness, oily residue, frizz control, and gloss.

The sensory properties of the formulations were assessed with the Sensorimeter® SR 100 (Courage-Khazaka, Germany), an instrument capable of translating subjective opinions into numerical and objective data. The participant moves a button on a scale from 0 to 100, with higher values indicating a greater impact on the analyzed characteristic [15].

2.5. Statistical Analysis

Data were analyzed statistically using the Prism GraphPad 8.4.3 (San Diego, USA) and Origin 9.75 (Massachusetts, USA) software. The results were presented in the form of tables, graphs and figures, with a discussion based on data from the literature consulted.

3. Results

During the study period, no changes in color, odor, or homogeneity were observed in the formulations, indicating stability of their organoleptic characteristics. The pH of the leave-in ranged from 4.5 to 4.7, which is compatible with the pH of hair conditioning formulations [16]. The gel-cream formulations presented a pH between 4.98 and 5.73, aligning with the pH of the skin [13].

The formulations under study exhibited non-Newtonian rheological behavior with a thixotropic pseudoplastic flow, with viscosity recovery observed after shear reduction [17]. The flow index was lower than 1, ranging from 0.35 to 0.5 for the leave-in and from 0.20 to 0.25 for the gel-cream.

The rheological evaluation of the leave-in formulations showed that the addition of babassu oil (L2) significantly reduced ($p < 0.05$) the hysteresis area compared to the vehicle. Texture parameters such as firmness, cohesiveness, consistency, and viscosity index showed a significant increase ($p < 0.001$), along with work of shear ($p < 0.05$) (Figure 1).

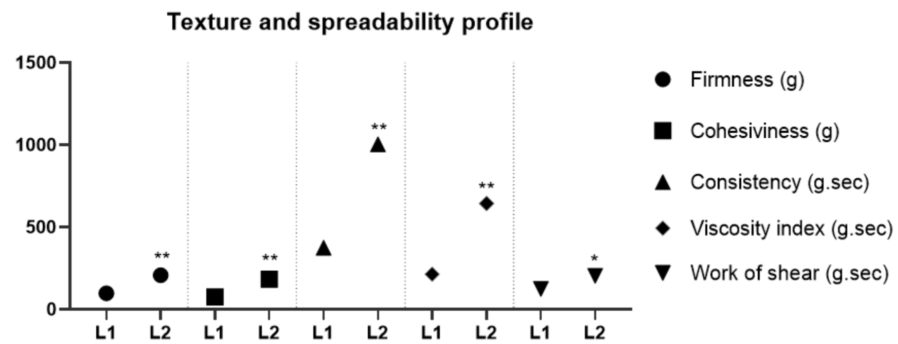

Figure 1. Texture profile − parameters of firmness, cohesiveness, consistency, and shear work − spreadability of vehicle leave-in (L1) and leave-in containing 3% of babassu oil (L2) after 24 h of preparation. * significant difference compared to L1 ($p < 0.05$), ** significant difference compared to L1 ($p < 0.001$).

In addition, gel-cream formulation added with babassu oil (F2) presented a significant reduction ($p < 0.05$) in the hysteresis area, indicating a shorter time for viscosity recovery after shearing. A significant reduction ($p < 0.001$) in texture parameters (firmness, consistency, cohesiveness, and viscosity index) was observed, along with decreased work of shear ($p< 0,05$) (Figure 2).

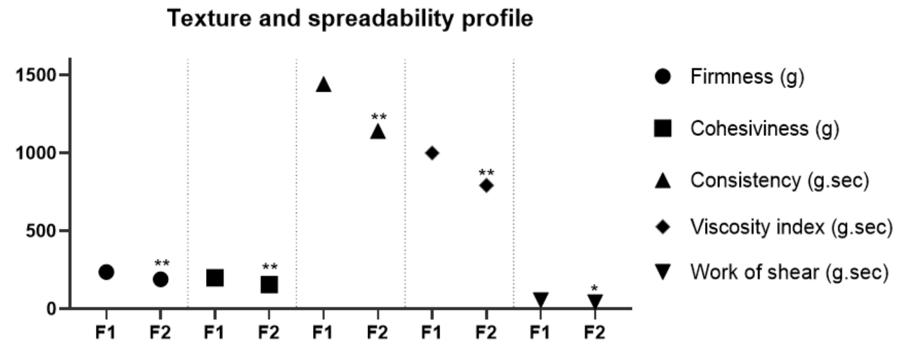

Figure 2. Texture profile − parameters of firmness, cohesiveness, consistency, and shear work − spreadability of vehicle gel-cream (F1) and gel-cream containing 3% of babassu oil (F2) after 24 h of preparation. * significant difference compared to L1 ($p < 0.05$), ** significant difference compared to L1 ($p < 0.001$).

In the sensory analysis of the treated hair strands, the control strand (M1) received the lowest ratings across all parameters. When comparing the vehicle strand (M2) with the babassu leave-in strand (M3), the formulation containing babassu oil was significantly better assessed ($p < 0.05$) in terms of combability, hydration, and softness. Additionally, M3 showed superior performance in frizz control and gloss (Figure 3).

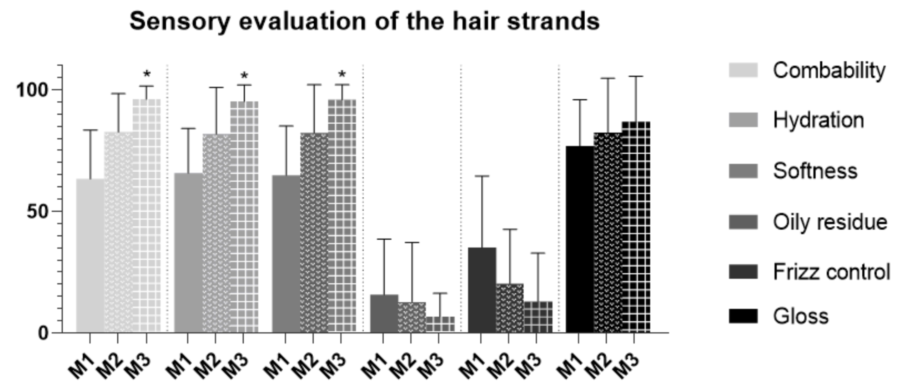

Figure 3. Sensory evaluation of the hair strands: M1 (untreated control), M2 (vehicle leave-in), and M3 (leave-in containing 3% of babassu oil), * significant difference compared to M2 ($p < 0.05$).

Finally, in the sensory analysis, the gel-cream formulation containing babassu oil showed better performance in both spreadability and hydration parameters ($p < 0.05$) compared to the vehicle (Figure 4). Moreover, it did not leave an oily residue on the skin and was the preferred formulation among participants, reinforcing its favorable sensorial characteristics.

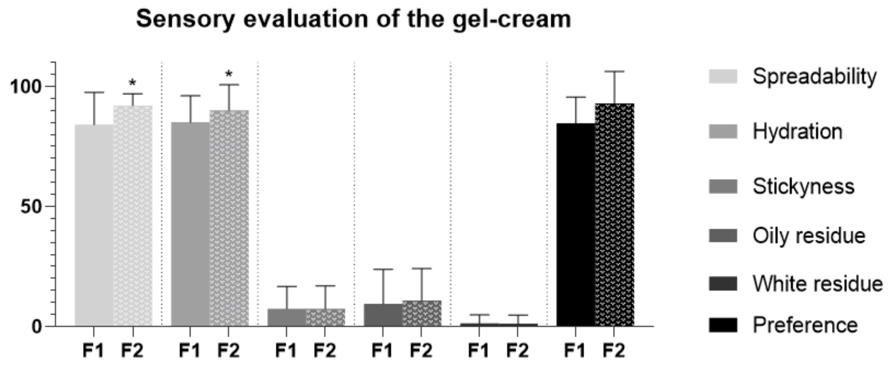

Figure 4. Sensory evaluation of vehicle gel-cream (F1) and gel-cream containing 3% of babassu oil (F2). * significant difference compared to F1 ($p < 0.05$).

4. Discussion

The non-Newtonian pseudoplastic behavior with thixotropy is desirable in cosmetic formulations, especially in leave-in products, since the viscosity of the formulation temporarily decreases when shear stress is applied during application to the hair strands but recovers once the stress is removed, ensuring product adhesion [18]. This behavior allows for smooth and uniform distribution of the formulation and the formation of a protective layer over the hair, enhancing its efficacy.

Additionally, the hysteresis area, calculated between the ascending and descending flow curves, is associated with the thixotropic phenomenon, indicating the time required for viscosity recovery after shear reduction. Therefore, the smaller the hysteresis area, the lower the thixotropy, meaning a shorter time for the formulation to reorganize itself and return to the initial structure [17]. In this context, the reduction in hysteresis area observed with the addition of babassu oil indicates an improvement in the formulation's rheological behavior, contributing to better performance during application.

On the other hand there was an increase in texture parameters and work of shear with the addition of babassu oil. This profile may be associated with the fatty acid composition of the oil, which is predominantly composed of lauric acid (C12:0 - 34.70%), myristic acid (C14:0 - 19.10%), and oleic acid (C18:1 - 19.45%) [Oliveira et al., 2019]. The reduced presence of unsaturations in the fatty acid chains promotes lower lipid fluidity by decreasing intermolecular forces, resulting in a higher melting point and viscosity [4]. Consequently, this contributes to the observed increase in texture parameters in formulations containing babassu oil.

Regarding the gel-cream, the addition of babassu oil (F2) also led to a reduction in hysteresis area, suggesting a potential film formation on the skin and a shorter time for viscosity recovery after shear stress [17], which is desirable for topical application. Unlike the leave-in, which is an emulsion, the incorporation of babassu oil into the gel-cream interacts distinctly with the formulation’s microstructure, leading to a reduction in texture parameters.

The observed decrease in firmness, consistency, cohesiveness, viscosity index, and work of shear are directly related to the mechanical resistance of the formulation when applied to the skin, thus influencing how easily the product spreads and the stickiness sensation after application [13, 19-20].

The work of shear is inversely correlated with the spreadability perceived during sensory evaluation, since spreading a formulation on the skin requires the application of force, resulting in shear. Therefore, the lower the work of shear value, the less force is needed to spread the product, favoring a lighter application and a more pleasant user experience [13, 21].

These instrumental findings corroborate with the sensory analysis results since the gel-cream with babassu oil (F2) was significantly better rated in spreadability ($p < 0.05$) and did not leave a sticky sensation, indicating that the improvements observed in rheological and texture parameters translated directly into enhanced user perception. These findings highlight the importance of integrating texture and sensory analyses to develop formulations with optimized sensorial performance.

Additionally, the participants reported significantly higher skin hydration ($p < 0.05$) with the gel-cream formulation containing babassu oil. The evaluation of hydration perception is essential, as it is closely related to the skin barrier function. In healthy skin, hydration is regulated by a balance between the natural moisturizing factor (NMF) and the production of lipids such as ceramides, cholesterol, and free fatty acids, which act occlusively to retain water and fill the spaces between corneocytes in the stratum corneum [22,23]. In this context, the use of babassu oil as an emollient in the formulation can contribute to a pleasant sensation of hydration, as its fatty acids may fill intercellular spaces, resulting in a smoother surface texture [22].

Finally, babassu oil is rich in lauric acid, a medium-chain saturated fatty acid with low molecular weight and high affinity for hair proteins [24]. Its molecular characteristics allow it to easily penetrate the hair shaft, forming a lubricating film that reduces internal friction. This mechanism not only enhances the softness and hydration of the strands, but also facilitates detangling, improving overall combability and reducing mechanical damage during hair manipulation [3,25]. Additionally, by smoothing the hair cuticle, the formulation promotes a more uniform surface, which increases light reflection and, consequently, contributes to the enhanced gloss observed in the sensory analysis [26,27].

5. Conclusion

The formulations were stable and exhibited non-Newtonian pseudoplastic thixotropy rheological behavior with viscosity recovery after shear reduction. The addition of babassu oil significantly influenced the rheological and texture parameters of both leave-in and gel-cream formulations, resulting in more spreadable and sensory-appealing products. In the sensory analysis, formulations containing babassu oil were better assessed in key parameters such as combability, softness, hydration, and gloss for hair, as well as spreadability and hydration for skin, without leaving an oily residue. These effects are attributed to the composition of babassu oil, rich in fatty acids that improve skin feel and promote hair fiber alignment and protection. Finally, according to the obtained results, babassu oil shows great potential for use in innovative and sustainable cosmetic products that value Brazilian biodiversity while promoting effective benefits for both hair and skin care.

6. References

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