

A multi-functional rinse-off and leave-on conditioner for straight and curly hair with sustainable benefits related to water and energy consumption.

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Abstract (Maximum of 200 words)

This study presents a sustainable hair conditioner to address straight and curly hair needs. With a cold process formulation three times more concentrated than traditional conditioners, it prioritizes sustainability while delivering superior performance in a multi-functional application. Performance evaluations on various hair types demonstrated significant improvements in combing and friction reduction, as well as in sensory attributes for rinse-off treatments. As a leave-on product, it effectively aligns hair fibers, defines curls, and controls frizz and volume over time, even under high humidity conditions. Results show that performance should not be compromised to achieve sustainability goals and that silicones are formulator's allies to achieve both goals. The proposed concentrated formulation is produced via a cold process, eliminating the need for heating, and decreasing energy consumption, distinguishing itself from traditional waxy conditioners that require heat in the manufacturing process. Notable features include low water content, energy-efficient production, minimal packaging, and space-saving in storage and transportation, embracing eco-conscious attributes.

Keywords: Concentrated; Conditioner; Sustainable; High-performance; Multi-functional

Introduction.

The latest hair care trends emphasize eco-friendly practices associated with superior performance, and both attributes can be achieved with a selection of raw materials and optimization of the manufacturing process.

In a society that runs on performance and strives for sustainability, silicones are invaluable tools. In particular, dimethicones, are extensively used in hair conditioners due to their ability to protect hair from damage, enhancing shine by reflecting light, and reducing frizz. Other silicones, as aminosilicones, provide diverse benefits such as increased deposition and conditioning performance such as improved wet and dry combing. In general, conditioners contain cationic ingredients and silicones to improve hair manageability, restore hydrophobicity, seal cuticles, and reduce friction and breakage. Incorporating lubricating products like silicones and oils are crucial for maintaining hair health [1] [2].

Silicones have a long-standing history of safe use in personal care because of their unique properties and efficacy at low use levels. Quartz is used as the main feedstock in the manufacturing of silicones, composed of two basic elements: silicon (the second most abundant element on the planet after oxygen), and oxygen. Silicones are expected to ultimately be broken down in the environment through natural processes like hydrolysis and photolysis back to natural substances such as silicic acid, silica, and carbon dioxide.

The cold process manufacturing can significantly reduce the energy consumption in the production process compared to traditional hot processes. Cold emulsification requires lower energy input and operational costs, contributing to environmental sustainability by lowering carbon emissions associated with manufacturing. Implementing cold processes in cosmetic production presents a promising strategy to enhance energy efficiency and promote eco-friendly practices in the cosmetic industry [3].

This study aims to develop a sustainable concentrated hair conditioner to meet the needs of both straight and curly hair. It can serve as a versatile rinse-off or leave-on hair product, offering multiple conditioning and shaping benefits while prioritizing environmental care.

Materials and Methods.

I. Materials:

The concentrated conditioner has different silicones in its composition, all of them are supplied by The Dow Chemical Company: PEG-12 Dimethicone, Bis-Diisopropanolamino-PG-Propyl Disiloxane/Bis-Vinyl Dimethicone Copolymer dispersed in Butyloctanol, Bis-Hydroxy/Methoxy Amodimethicone and Dimethicone. The formulation has other non-silicone components: Dicetylmonium Chloride, Sorbitan Oleate, Isododecane, Ethyl Lauroyl Arginate HCl, and Butylated Hydroxytoluene. The percentage of water is reduced, containing about 50% water in the final composition. The final composition is described in Table I.

Table I. Concentrated conditioner formulation.

| Phase | INCI name | Wt. % |
|-------|--|--------------|
| A | Dicetylmonium Chloride | 7.50 |
| | Butylated Hydroxytoluene | 0.10 |
| | PEG-12 Dimethicone | 12.00 |
| | Sorbitan Monoleate | 5.00 |
| | Dimethicone | 9.80 |
| B | Isododecane | 5.30 |
| | Bis-Diisopropanolamino-PG-Propyl Disiloxane/Bis-Vinyl Dimethicone Copolymer | 4.50 |
| | Bis-Hydroxy/Methoxy Amodimethicone | 3.00 |
| C | Water | 52.70 |
| D | Ethyl lauroyl arginate HCl | 0.10 |

The following procedure details the method for preparing the formulation, ensuring optimal stability and consistency throughout the process: Mix the ingredients of phase A in the specified order at 800 rpm. Sequentially add each component of phase B under continuous stirring at 800 rpm, as altering the sequence may negatively impact stability. Slowly incorporate water while

stirring at 1400 rpm, then add phase D. Initially, the formulation will exhibit a thicker consistency, which will decrease in viscosity over the course of one hour, reaching the final desired texture.

Masstige and Prestige Rinse-off Conditioners Market References

Two benchmarks were selected according to masstige and prestige category. Masstige refers to affordable products with higher perceived value than typical mass-market products, and prestige refers to a high-quality product only accessible to a group of consumers.

Masstige benchmark: focused on moisturizing curly hair, delivering frizz control and the main ingredients are (label disclosed): cetearyl alcohol, behentrimonium chloride, dimethicone, and amodimethicone.

Prestige benchmark: focused on damaged hair for repairing the structure of the fiber, leaving strands sealed, conditioned, and protected. The main ingredients are (label disclosed): cetearyl alcohol, behentrimonium chloride, behentrimonium methosulfate, quaternium-33, dimethicone, and amodimethicone.

II. Hair Tresses:

Three types of hair were included in this study: four hour bleached Caucasian tresses with flat configuration weighting 3.00g, curly virgin tresses with round configuration weighting 5.00g, and virgin frizzy tresses with round configuration weighting 4.00g.

III. Methods

Oscillatory Rheology:

Rheology studies were performed using the Physica MCR 301 rheometer manufactured by Anton Paar, with RheoCompass 1.30 software. A plate-plate configuration, with a 50 mm plate and 1 mm gap, was selected to generate flow curves. Temperature was held at 22°C by a Peltier thermoelectric bath, shear rate (1/s) was varied from 0.1 to 50 s⁻¹ and viscosity was monitored. Viscosity and flow curves were plotted in Microsoft Excel spreadsheet.

Pre-treatment of hair tresses:

All tresses were pre-treated with a 9% Sodium Lauryl Sulfate solution applied at 0.20g/g of hair. The tresses were massaged for 30 seconds with the solution and rinsed under running tap water ($40^{\circ}\text{C} \pm 3^{\circ}\text{C}$) for 60 seconds.

Treatment with rinse-off conditioners:

On wet tresses, the benchmarks masstige and prestige were applied at the dosage of 0.40 g/g of hair, massaged for 30 seconds (1.20g/tress), meanwhile the concentrated conditioner was applied at a dosage of 0.13 g/g and massaged for 30 seconds. Tresses were rinsed under running tap water ($40^{\circ}\text{C} \pm 3^{\circ}\text{C}$) for 30 seconds.

Treatment with leave-on conditioner:

Doses for the concentrated conditioner varied according to the instrumental technique. Caucasian and curly tresses were treated with 0.05g of concentrated conditioner per gram of hair and frizzy tresses were treated with 0.037g of concentrated conditioner per gram of hair. The product was applied for one minute and the tresses were hanged and left to dry overnight.

Wet and Dry Combing:

The combing analysis was conducted on a Diastron MTT-175 Tensile Tester with an UV-1000 Control Unit controller and UvWin software. This technique measures the total work (J) done to pass a comb through a hair tress and the results are correlated with hair conditioning. Two tresses per treatment and six measurements per tress were performed, reporting the mean and standard deviation along with paired T-test analysis to identify statistically significant differences at a 95% confidence level. For dry combing, hair tresses were analyzed after drying, and for wet combing the tresses were analyzed after dipping it in tap water in-between measurements.

Coefficient of Friction (COF):

Coefficient of friction was analyzed on Diastron MTT-175 Tensile Tester with an UV-1000 Control Unit controller and UvWin software, with a parallelogram accessory and rubber probes in a horizontal setup against a normal weight of 200g. This technique measures the necessary work to drag a rubber along the hair tress from root to tip. Studies were performed in duplicate with four measurements per tress, reporting the mean and standard deviation along with paired T-test analysis to identify statistically significant differences at a 95% confidence level.

Sensory Analysis:

After all instrumental analyses were executed, the same hair tresses were evaluated by a panel of 9 experienced individuals. The panelists were asked to score each tress based on the following attributes: shine, volume, alignment, smoothness, slipperiness, residue, ease of untangling, and ease of combing. Scores were assigned comparatively on a scale of 1 to 5. Mean and standard deviation were reported along with paired T-test analysis to identify statistically significant differences at a 95% confidence level.

Hair Fiber Alignment and Curl Definition:

Conducted on Rumba (Supplier: Bossa Nova Technologies) for measuring the orientation of randomly organized hair fibers using a polarization analysis technique based on the acquisition of raw images, extraction of modulated sigma pixel by pixel and deduction of angles. For straight hair, alignment coefficient (1/deg) was calculated and provided by the software, along with color coded pictures. Curl definition was evaluated by color coded pictures generated by Rumba's software after drying naturally and after exposure at 80% relative humidity (25°C) for 24 hours. Treatments were tested in duplicates. For the Caucasian hair tresses, mean and standard

deviation for alignment coefficients are calculated and statistical significance at 95% confidence level was obtained with paired T-tests.

Frizz and Volume Control:

The analysis was conducted on Bolero (Supplier: Bossa Nova Technologies) and using a ClimaCell climate chamber to expose tresses at high humidity. Tresses previously submitted to the treatment were dried with a blow dryer, straightened with flat iron, and immediately positioned in the equipment to perform the initial frizz analysis. Throughout the test, the tresses were placed into a climate chamber previously stabilized at 85% relative humidity and temperature of 25°C. The volume and frizz of the tresses were analyzed over time at intervals of 0, 15, 30, 60, 90, 120, 180, 300 minutes. Treatments were tested in duplicate generating a mean and standard deviation of each time point. Statistical significance at 95% confidence level was obtained with paired T-tests.

Results

The proposed concentrated conditioner is free of waxes and cold-emulsified using a combination of silicone and organic emulsifiers, enabling a manufacturing process without heating. Cosmetics rheology involves the characterization or measurement of flow, which can be associated with cosmetic processing, packaging, transport, storage, and consumer use. The term closely associated with rheology is viscosity, defined as the resistance to flow, determined by ratio of shear stress (force applied) to shear rate (movement) [4].

Even with a different formulation structure from traditional conditioners, the rheological behavior exhibits a comparable texture, as demonstrated by the viscosity changes with shear rate in Figure 1. The flow curve shows that conditioners generally have a non-Newtonian shear thinning behavior, changing viscosity depending on the shear rate [4]. This parameter is associated with spreading and ease of applying the product onto hair fibers.

Each shear rate corresponds to distinct stages of cosmetic product use and application, as many terms used to describe products are related to rheological properties, such as smooth, silky, and creamy. At low shear rates, sagging refers to the tendency of a fluid to flow downward due to gravity when applied on a vertical surface, while leveling refers to the ability of a material spread uniformly over a surface. Medium shear rates relate to liquid deformation when poured, which is crucial for ensuring smooth pouring. High shear rates are related to the product's behavior when applied to hair fibers [4]. For hair conditioners, good spreading properties at high shear rates ensure that the product can be distributed evenly and absorbed effectively, providing a uniform and a desirable sensory experience.

The concentrated conditioner has a higher steady-state viscosity (measured at the lowest shear rate), translating to a higher apparent viscosity when at rest. At the highest shear rates, however, it presents similar viscosity compared to the benchmarks, translating to an equivalent experience during the application onto the hair as illustrated in Figure 1.

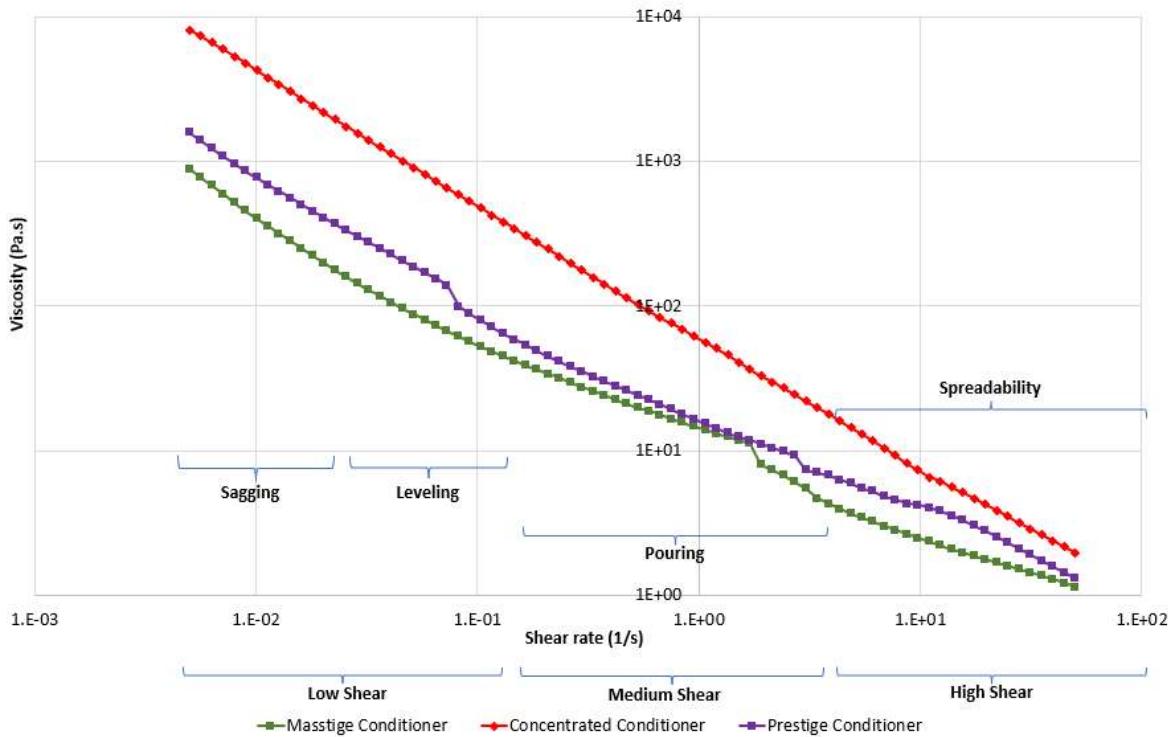


Figure 1. Conditioners flow rate.

The results below demonstrate the conditioning performance of the concentrated conditioner, which has a three times higher concentration compared to commercial references. For this reason, hair tresses were treated with one-third of recommended dose of traditional formulations for rinse-off and leave-on applications.

Dry combing data for rinse-off conditioners show a reduction of 85% in dry combing work compared to untreated hair, while performing equivalently to both benchmarks. Wet combing results reveal a 40% reduction in work compared to the prestige benchmark. These results are presented in Figures 2 and 3, respectively.

The coefficient of friction (COF) correlates well with the perception of smoothness - an increase in COF indicates higher friction force and, thus, a rougher surface. Lower COF indicates better performance. Masstige conditioner has a COF 60% lower than untreated tresses, while the prestige and concentrated conditioner generate an additional 20% reduction in coefficient of friction performance compared to the masstige benchmark as illustrated in Figure 4.

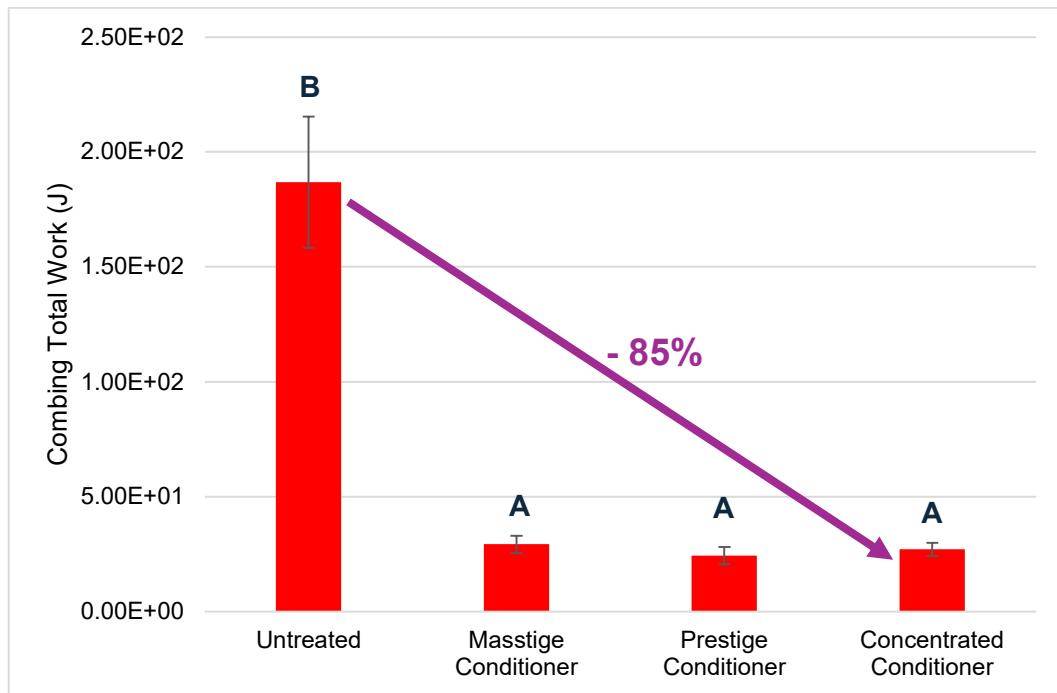


Figure 2. Total work (J) needed to comb dry tresses with different rinse-off treatments. Different letters indicate statistically significant differences at 95% confidence level.

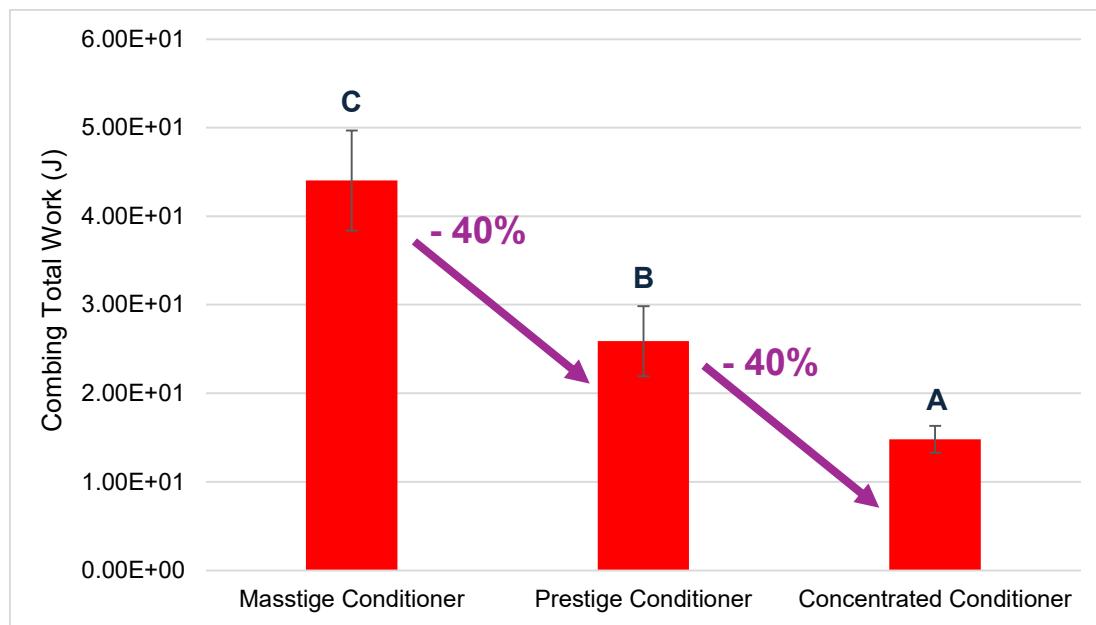


Figure 3. Total work (J) needed to combing wet tresses with different rinse- off treatments. Different letters indicate statistically significant differences at 95% confidence level.

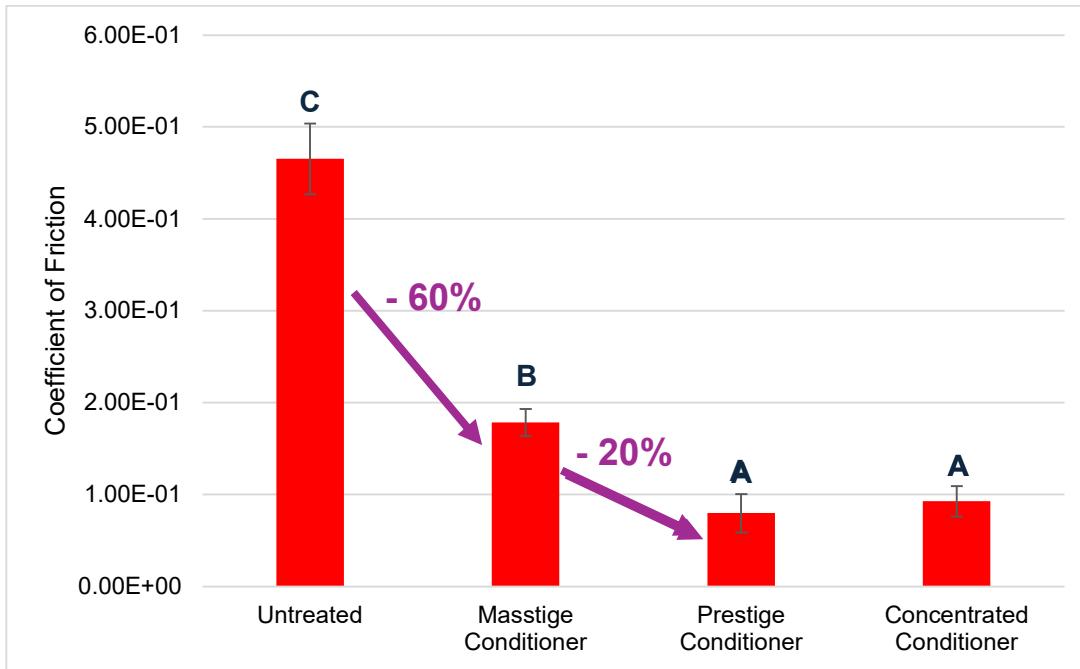


Figure 4. Coefficient of friction of tresses with different rinse-off treatments. Different letters indicate statistically significant differences at 95% confidence level.

Figure 5 is showing the results from the sensory analysis. All treatments performed equivalently to untreated tresses for shine and hair alignment, indicating no improvement for these parameters. For smoothness and slipperiness, all treatments outperformed the untreated tresses. The prestige benchmark performed better in volume control and ease of untangling compared to concentrated and masstige conditioners, although it left a perceivable residue on the fibers. For ease of combing, the concentrated conditioner performed equivalently to both the prestige and masstige benchmarks.

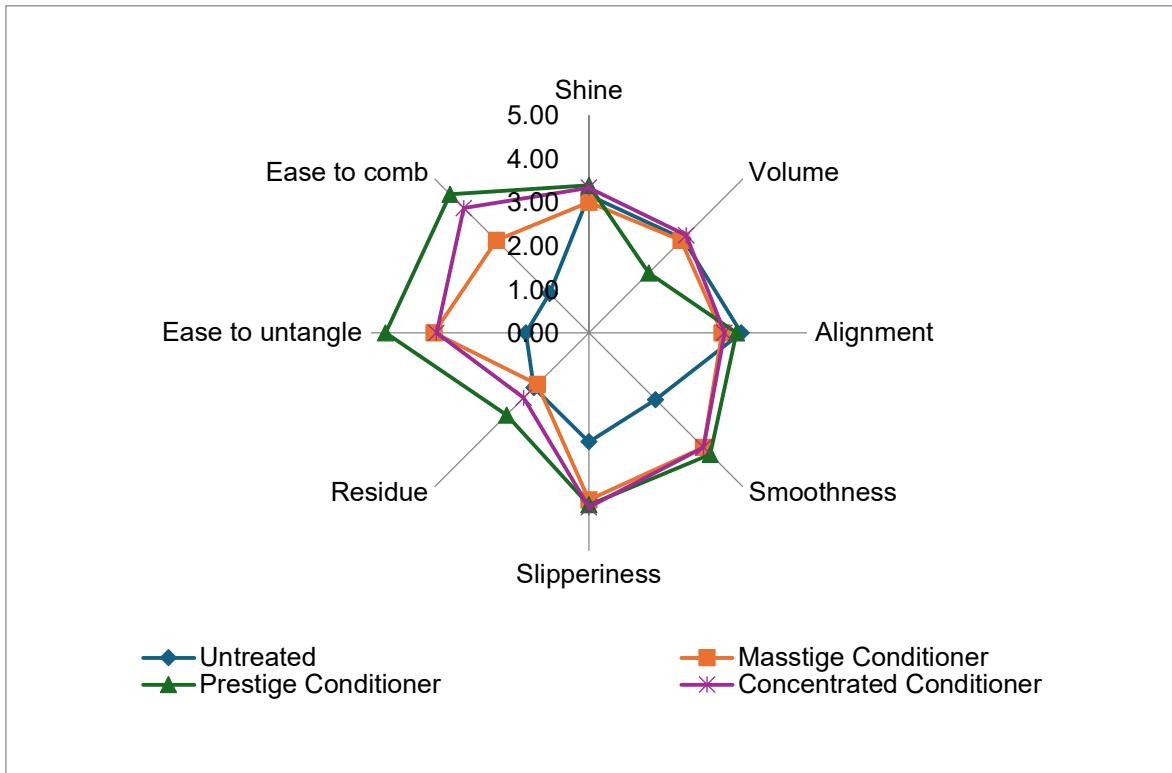


Figure 5. Results of sensory analysis for different parameters after rinse-off treatment.

The concentrated conditioner was also studied as a leave-on product in comparison to untreated tresses. In response to market trends and needs, this formulation was evaluated on two types of hair (Caucasian and curly), and the benefits investigated were fiber alignment, curl definition, frizz control, and volume control over time.

In Figure 6, treatment with concentrated conditioner significantly aligns hair fibers compared to untreated hair. Figure 7 illustrates curl definition after treatment and after exposure to 80% relative humidity during 24 hours. Curls treated with the concentrated conditioner are tighter, with less volume and more defined than untreated tresses, even after exposure to high humidity levels, which is beneficial to the shape of curly hair.

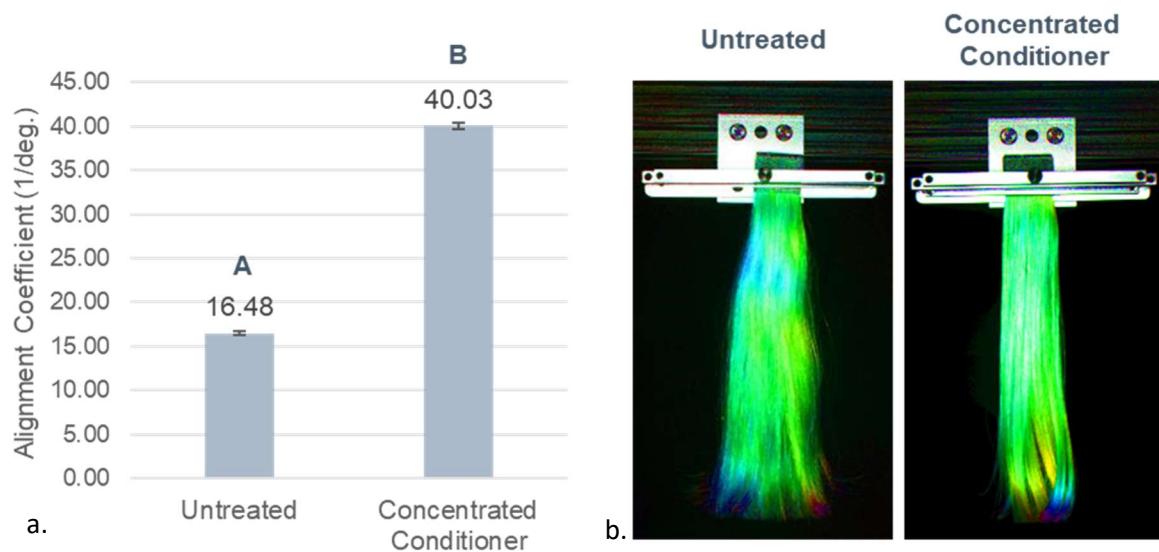


Figure 6. a. alignment coefficient; b. representative color coded pictures of flat ironed Caucasian hair tresses. Different letters indicate statistically significant differences at 95% confidence level.

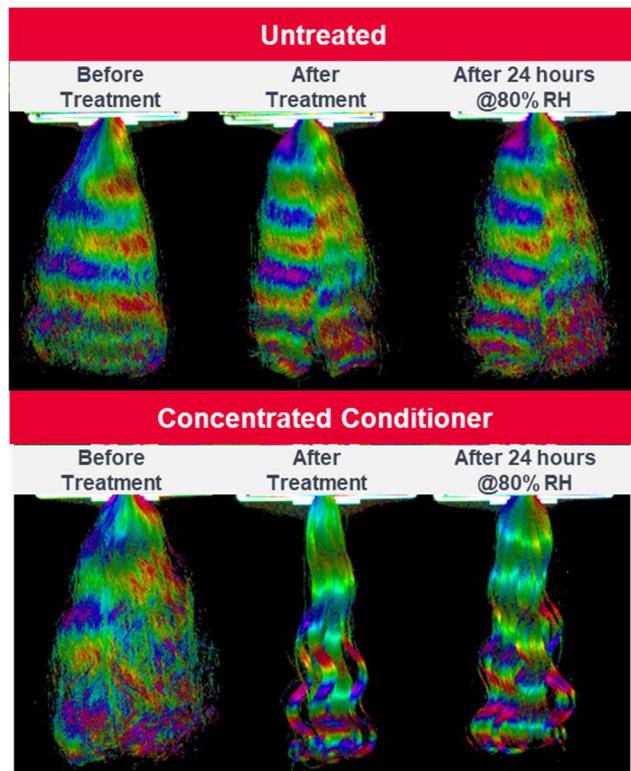


Figure 7. Curl definition before treatment, after treatment, and after 24 hours at 25°C and 80% of relative humidity.

Another critical parameter for leave-in products is frizz and volume control over time, particularly under high relative humidity. Results show that frizzy hair tresses treated with the concentrated conditioner exhibits 65% less frizz and 55% less volume than untreated tresses when exposed to high humidity for 5 hours as illustrated in Figures 8,9 and 10.

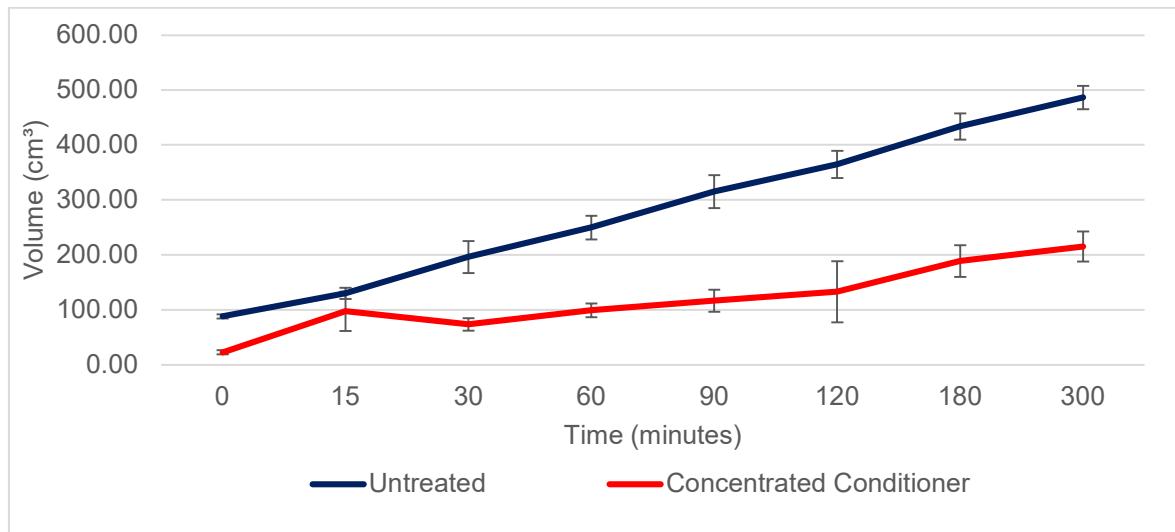


Figure 7. Volume evolution over time for untreated and treated tresses.

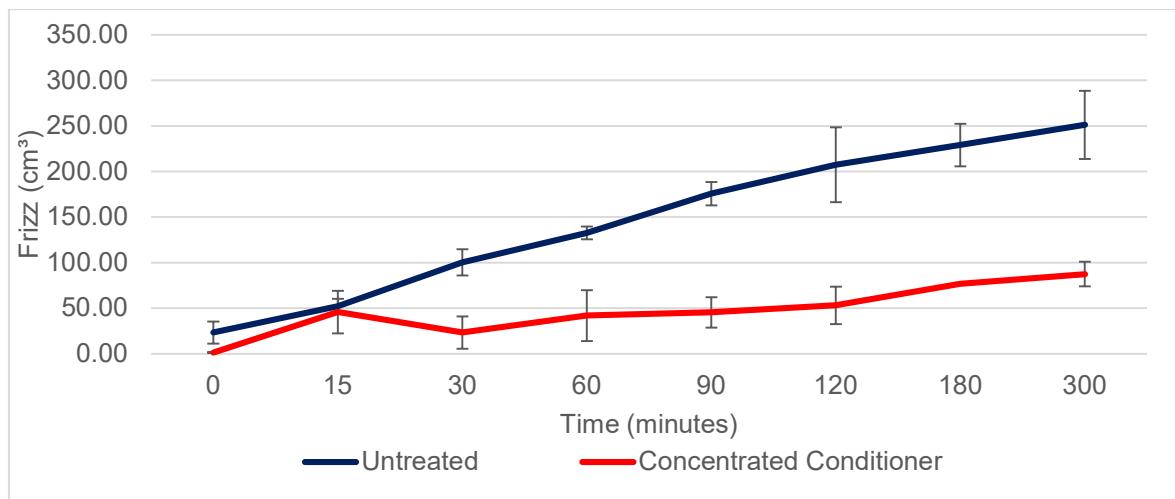


Figure 8. Frizz evolution over time for untreated and treated tresses.

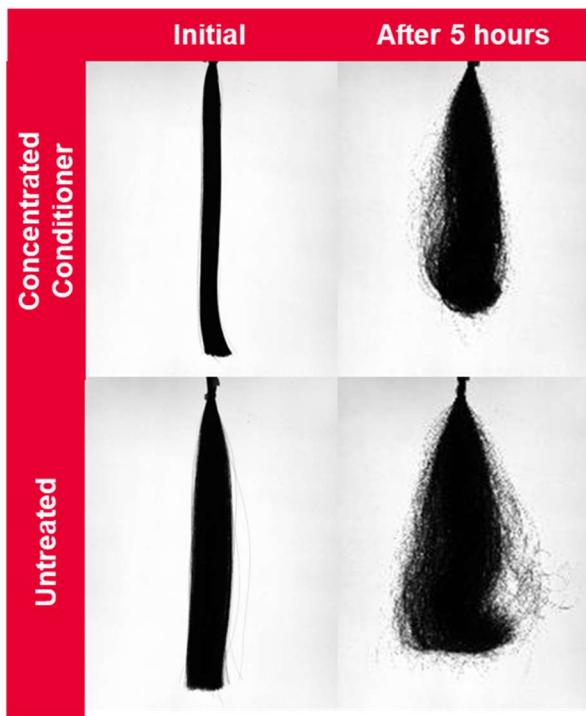


Figure 9. Tresses at time 0 and after 5 hours of exposure to high humidity.

Discussion.

The combination of PEG-12 Dimethicone and organic emulsifiers, namely Dicetyldimonium Chloride and Sorbitan Oleate, allows obtaining a high viscosity emulsion similar to traditional waxy hair conditioners, which relies on fatty alcohols to build viscosity. Without the need to have such waxes in the composition, a cold manufacturing process becomes possible, as demonstrated herein. The internal phase contains a combination of aminosilicones main contributors to the superior performance on hair (Bis-Diisopropanolamino-PG-Propyl Disiloxane/Bis-Vinyl Dimethicone Copolymer and Bis-Hydroxy/Methoxy Amodimethicone).

As a result, a formulation with three times higher active levels and cold processed, achieve an equivalent or superior performance compared to conventional conditioners while maintaining a comparable texture and minimizing product consumption. A concentrated formulation also offers sustainable benefits in terms of packaging and logistics. This formulation can be sold in two ways: in a package with a third of the volume with the same expected durability for consumers,

or in a conventional package size that takes longer to be fully consumed. Both strategies result in reduced plastics consumption throughout the value chain, either through smaller packaging or less frequent repurchasing. Also, as the conditioner has excellent performance both as a rinse-off and as a leave-on, it offers consumers the option of reducing the number of products purchased on the shelves.

In summary, the proposed formulation allows a better balance between sustainability and performance with an innovative approach to a conventional format in the hair care segment.

Conclusion.

This study demonstrates that performance does not have to be compromised to achieve sustainability goals and part of innovation process is to find the best ingredients and their respective balance to deliver performance and customer satisfaction, while aligning new developments in manufacturing process and energy savings. Silicones, particularly, prove to be valuable formulator's allies to achieve these goals.

The proposed hair conditioner leverages minimal product consumption with superior conditioning performance compared to standard commercial products. Produced via a cold process, it eliminates the need for heating and decreases energy consumption, distinguishing itself from traditional waxy conditioners that require heat in the manufacturing process. Additionally, the product formulation is three times more concentrated, resulting in lower usage levels and extended product use and a decrease in water consumption in the manufacturing. The formula is versatile, suitable for both rinse-off and leave-in applications, offering benefits such as volume and frizz control, high conditioning performance, alignment for straight hair, and curl definition for textured hair, even in high humidity conditions. Its multifunctionality meets diverse hair care needs, and its sustainability claims appeal to the eco-friendly-oriented market.

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Conflict of Interest Statement.

NONE

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