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ENVIRONMENTAL SCIENCE ARCHIVES
ISSN: 2583-5092
Volume V, Special Issue, 2026
Received: 1/244/2026 Accepted: 3/6/2026 Published: 3/10/2026
DOI: 10.5281/zenodo.18941040

RESEARCH PAPER OPEN ACCESS

Utilizing Laser Diffraction to Validate Green Chemical Alternatives: The Structural Impact of Organic Cleansers on Keratin Fibres

K Haritha[1], J Ishwarya[1], V Vani[1], R Omkar[1], B Naveen[1], S Krishnapriya[1] and NP Viraja[2]

[1]Department of Physics, Government Degree College, Malkajgiri, Hyderabad Telangana State, India
[2]Richardson Police Department, Texas
*Correspondence for materials should be addressed to KH (email: kadiriharita@gmail.com)

Abstract
This study develops a non-destructive, optomechanical sensor to evaluate the structural dynamics of human hair. By utilizing a 650 nm laser diffraction setup combined with mechanical resonance, we compared the effects of organic Sapindusmukorossi (Reetha) against three synthetic shampoos and a hydrogen peroxide (H_2O_2) chemical stressor. The results indicate that while synthetic cleansers and H_2O_2 alter the hair's internal "spring constant" and external diameter, Reetha maintains the fibre's natural physical signature. This methodology proves that laser-based frequency analysis is an effective biomarker for assessing the efficiency of organic treatments.

Keywords: Organic-cleancer, Reetha, Diffraction, Hair-diagnosis, Keratin, Hair-Health-Index

Introduction

The work (Halliday et al., 2013) provides a detailed, calculus-based explanation of diffraction, focusing on the far-field (Fraunhofer) approximation and the theoretical relationship between obstacles and apertures (Babinet's Principle). The research (Umul, 2011) demonstrates that Babinet's principle accurately predicts the Fraunhofer scattering patterns of a thin finite wire by evaluating Rayleigh-Sommerfeld integrals for both the wire and its complementary aperture. Hair is a sulphur-rich keratin fibre whose geometry determines key properties like elasticity, smoothness, and volume (Velasco, 2009). These characteristics are assessed using specialized techniques such as microscopy, mechanical resistance testing, and optical coherence tomography (OCT). The purpose of this study is to develop a non-destructive, high-precision method to evaluate the efficiency and structural impact of hair cleansers. This project utilizes laser diffraction and mechanical resonance to quantify how synthetic shampoos versus organic alternatives, specifically Reetha affects both the external diameter and internal elasticity of human hair.

Methodology

A narrow vertical slit is constructed using two razor blades, with a single hair strand fixed between them to create a double-slit diffraction setup. The blades are painted matte black to minimize reflection and scattering. The hair functions as a vibrating string fixed at both ends, with nodes at the contact points and an antinode at the centre. A red semiconductor laser (λ= 650 nm) is incident upon the slit, projecting a clear diffraction pattern onto a screen at a distance D. The fringe width, β is defined as the distance between adjacent dark fringes.

A frequency generator, placed within 1 cm of the hair, sweeps from 400 Hz to 1300 Hz. When the generator's frequency matches the natural frequency of the hair, resonance occurs, causing the hair to vibrate with maximum amplitude. This vibration causes the static diffraction pattern to blur. This resonant frequency, f, is recorded for each sample.

Each hair sample underwent a standardized treatment cycle defined as follows: Each sample is treated with the assigned cleaning agent for exactly 180 seconds per cycle, a controlled wash with the distilled water, and a subsequent drying period of 3–4 hours in the shade. This cycle is repeated four times for each sample to simulate cumulative exposure.

The study compared three leading synthetic shampoos against an organic Reetha extract. Additionally, the effects of hydrogen peroxide, a common bleaching agent found in hair dyes were analysed. After completing four such cycles, the samples were mounted across the slit setup.

For each of the six samples, the diameter (d) was determined using the recorded fringe width (β) and the slit-to-screen distance (D). Finally, the resonant frequency (f) for each sample was measured and the resulting data are tabulated for analysis.

S. No.	Sample	Treatment	Fringe width β	Calculated diameter d	Resonant Frequency f	Health Index f/d
1	Bleaching agent	Hydrogen Peroxide	3	100	527	5.27
2	Control	Plain water	3.2	96	605	6.30
3	Synthetic shampoo 1	X	3.1	94	565	6.01
4	Synthetic shampoo 2	Y	3.4	90	575	6.38
5	Synthetic shampoo 3	Z	3.6	85	635	7.47
6	Organic	Reetha	3.8	81	681	8.41

Key Findings

The Reetha Advantage: Reetha gave the best results. It resulted in the thinnest diameter (81µm) and the highest vibration frequency (681Hz). This means it cleans deeply without damaging the hair's inner strength.

Chemical Damage: Hydrogen Peroxide caused the most damage. The hair became thicker (100 µm) because it swelled up, and the frequency dropped (527Hz) because the internal protein bonds weakened.

Synthetic Shampoos: Commercial shampoos like Z performed well, but they could not match the natural efficiency of the organic Reetha.

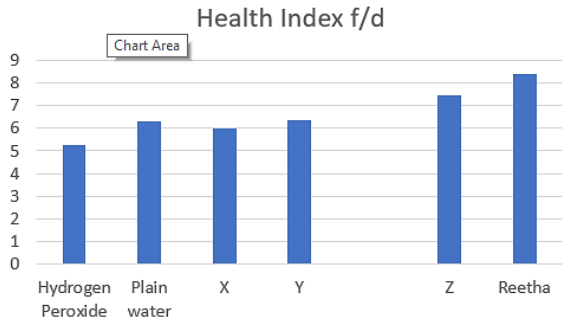

Fig. 1. Health Index

Discussion

The data prove that Reetha (*Sapindus mukorossi)* is a superior "Green" resource. In physics terms, a high resonant frequency means the hair is stiff and healthy. A lower diameter means the hair is clean and free of heavy residues. Because Reetha had the highest Hair Health Index (8.41), we can conclude that natural saponins protect the hair's structure better than synthetic chemicals. This experiment shows that we can use laser physics to prove that eco-friendly, plant-based products are just as effective—and often better—than commercially produced chemicals.

Conclusion

This study successfully used laser diffraction and mechanical resonance to compare organic and synthetic hair treatments. The data leads to the following conclusions:

1. Organic Superiority: Reetha achieved the highest Health Index (8.41), proving that natural cleansers preserve hair integrity better than synthetic alternatives.

2. Physics as a Diagnostic Tool: The inverse relationship between fringe width (β) and diameter (d) proved that non-destructive laser testing can accurately detect subtle changes in fibre thickness.

3. Structural Integrity: The high resonant frequency in organic samples indicates that plant-based cleansers maintain the internal keratin matrix, whereas chemical stressors like Hydrogen Peroxide significantly weaken it.

4. Sustainable Choice: The results provide scientific evidence that switching to "Green" resources is beneficial for both the environment and personal hair health.

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Author Contributions

All the authors conceived the concept, wrote and approved the manuscript.

Acknowledgements

Not applicable.

Funding

Not applicable.

Availability of data and materials

Not applicable.

Competing interest

The authors declare no competing interests.

Ethics approval

Not applicable.

Citation: Haritha K, Ishwarya J, Vani V, Omkar R, Naveen R, Krishnapriya S, Viraja NP (2026) Utilizing Laser Diffraction to validate Green Chemical Alternatives: The Structural Impact of Organic Cleansers on Keratin Fibres. Environmental Science Archives5 (Special Issue): 179-181.