IFSCC 2025 full paper (IFSCC2025-1793)

Quantifying Hair Damage: Bridging the Gap Between Subjective and Objective evaluations to Assess Hair Elasticity

Deborah Barros[1], Gabriela Tavares[1], Maria Gonçalves[1], Robert Gael[2], Andressa Matos[3], Nathalia Oliveira[4], Daiane Mercurio[4]

[1]Evaluation Intelligence, L'Oréal Research and Innovation, Rio de Janeiro, Brazil; [2]Evaluation Intelligence, L'Oréal Research and Innovation, Clichy, France; [3]Research and Innovation, L'Oréal Research and Innovation, Rio de Janeiro, Brazil;[4]Evaluation Intelligence, L'Oréal Research and Innovation, Chevilly-Larue, France.

1. Introduction

Hair damage presents distinct features depending on its hydration state. Dry damage manifests as split ends, stiffness, lack of shine, and thinning, while wet hair reveals damage through breakage and a "rubbery/gummy" texture. This rubbery texture is associated with increased hair deformation under longitudinal tension and the inability to return to its original state after the tensile force is removed [1,2].

Hairdressers employ a subjective pull test to assess hair elasticity as a safety precaution before applying chemical treatments like bleaching or straightening to a client's entire head. A small amount of the treatment is applied to a hair tress, and after a predetermined time, the hairdresser evaluates the tress's elasticity. Higher elasticity indicates compromised fiber integrity, influencing the decision of whether to proceed with the full treatment [2].

This subjective elasticity assessment, while practical, lacks standardization and quantifiable measurement [2]. Furthermore, it does not directly correlate with physical parameters measurable through tensile testing [3]. Highly elastic hair often exhibits compromised integrity to the extent that a well-defined elastic region is no longer discernible in tensile tests.

This study introduces a novel 6-level elasticity scale and a validated methodology with standardized parameters to objectively assess hair damage and repair efficacy, bridging the gap between subjective observation and quantifiable measurement.

2. Materials and Methods

This methodology was developed in a controlled environment (22 ± 2 °C and 55 ± 5 % relative humidity) using a three-stage process:

2.1 Scale Definition

Hair tresses (2.7g/27cm, type III curl pattern) underwent the chemical treatments (bleaching, straightening, and combined treatments) outlined in Table 1, with one tress prepared per condition. Two expert hairdressers performed pull tests on all treated tresses to establish elasticity levels and define a scale, which was then refined with feedback from eight additional hair-dressers.

Table 1. Chemical Treatment Protocols for Scale Definition

Condi-tion	Treatments Applied	Protocol
01	1x Bleaching (low-aggressive)	The hair fibers were submitted to 1 bleach application using a bleach mixture containing 9% hydrogen peroxide for 45 minutes in a 27 °C heat plate, the hair was washed with shampoo and dried naturally.
02	1x Bleaching (medium-aggressive)	The hair fibers were submitted to 1 bleach application using a bleach mixture containing 12% hydrogen peroxide for 45 minutes on a stove at 37°C, wrapped in aluminum paper. The hair was washed with shampoo and dried naturally.
03	1 x Bleaching (high-aggressive)	The hair fibers were submitted to 1 bleach application using a bleach mixture containing 12% hydrogen peroxide for 45 minutes on a stove at 55°C, wrapped in aluminum paper. The hair was washed with shampoo and dried naturally.
04	1x Bleaching (medium-agressive) + 1x 3% Acid Straightening treatment	After 1 bleach application, the hair fibers were submitted to 1 application of 3% acid straightening in a 27°C heat plate for 30 minutes pause time, then brushed 200 times with a hairdryer, in sequence 5 flat iron strokes, then the neutralizer was applied with 10 minutes pause time, and finally the hair was washed with shampoo and dried naturally.
05	1x Bleaching (médium-agressive) + 1x 8% Acid Straightening treatment	After 1 bleach application, the hair fibers were submitted to 1 application of 8% acid straightening in a 27°C heat plate for 30 minutes pause time, then brushed 200 times with a hairdryer, in sequence 5 flat iron strokes, then the neutralizer was applied with 10 minutes pause time, and finally the hair was washed with shampoo and dried naturally.
06	1x Bleaching (medium-agressive) + 3x Glyoxylic Acid	After 1 bleach application, the hair fibers were submitted to 3 applications of glyoxylic acid in a 27°C heat plate for 40 minutes pause time, 20 times with a hairdryer, in sequence 10 flat iron strokes, then the neutralizer was applied with 10 minutes pause time, and finally the hair was washed with shampoo and dried naturally.

2.2 Parameter Standardization and Operator Training

A representative tress for each scale level was prepared. To standardize the assessment, an expert hairdresser performed the pull test, evaluating:

- **Number of fibers:** Tresses containing 10, 30, and 50 fibers were tested.
- **Evaluation zones:** The tress was divided into root, mid-length, and tip (zones 1, 2 and 3), with the number of pulls defined for each zone.
- **Hydration method:** Tresses were hydrated using running water or a spray bottle.
- **Pause time:** Tresses were evaluated immediately after hydration or after a one-minute pause.

The selected parameters (30 fibers, three zones, spray hydration, and a one-minute pause) were documented.

The expert's gesture was recorded with a camera positioned at a 90° angle, alongside a ruler to measure fiber elongation. This established the target elongation for each scale level.

A training protocol was developed to standardize the applied force. Trainees practiced the gesture on training tresses attached to a support with a ruler, aiming for the predefined elongation for each level (Table 2), repeating the gesture 20 times for each level (excluding level 5). A new tress was used for each repetition.

Table 2. Approximate Elongation (cm) for Training

Approximate elongation (cm)					
Level 0	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
0.5	1.0	1.5	1.7	2.0	-

2.3 Validation

Phase 1 – Scale Level Assessment: Three trained operators evaluated nine replicates each, of each scale level (Table 1) on two separate days to assess inter-operator and inter-day reproducibility.

Phase 2 – Sensitivity to Repair Technologies: Hair tresses were damaged using a high-lift bleach (Table 1). Four repair treatments were applied: a negative control (non-repairing routine), a positive control (known repairing/bonding routine), and two test products. Table 3 details the protocols. Three operators evaluated nine replicates per condition (including an untreated reference) over two days. Inter-operator and inter-day reproducibility were assessed.

Table 3. Treatments Protocols for Sensitivity to Repair Technologies Evaluation

Condition	Treatments Applied	Protocol
High-Bleach	1 x Bleaching (high-aggressive)	The hair fibers were submitted to 1 bleach application using a bleach mixture containing 12% hydrogen peroxide for 45 minutes on a stove at 55°C, wrapped in aluminum paper. The hair was washed with shampoo and dried naturally for 24 hours in a climate-controlled environment.
Negative Control	1 x Bleaching (high-aggressive) + 5x [Shampoo + Conditioner]	After the bleaching application, the hair fibers were washed five times with a low-treatment shampoo and conditioner routine, pausing for 1 and 5 minutes, respectively.

		Finally, the hair swatches were naturally dried for 24 hours in a climate-controlled environment.
Positive Control	1x Bleaching (high-agressive) mixed with Bonding treatment + rinse-off post-treatment	A bond-building treatment was added to the bleach powder and developer mixture during the bleaching process. Afterward, a post-treatment was applied to the hair fibers and rinsed off after 10 minutes. The hair was then allowed to dry naturally for 24 hours in a climate-controlled environment.
Treatment 01	1x Bleaching (high-agressive) mixed with Bonding treatment + 5x [Shampoo + Bond repair mask]	After bleaching, the hair fibers were washed five times using a low-treatment shampoo and bond repair mask, pausing for 1 minute after the shampoo and 5 minutes after the mask. The swatches were then naturally dried for 24 hours in a climate-controlled environment.
Treatment 02	1x Bleaching (high-agressive) mixed with Bonding treatment + 5x [Bond Pre – Shampoo + Shampoo + Bond repair conditioner]	After bleaching, the hair fibers were washed five times using a complete repair routine consisting of a pre-treatment, shampoo, and conditioner, pausing for 5, 1, and 5 minutes respectively. The swatches were then naturally dried for 24 hours in a climate-controlled environment.

Operators were blinded throughout the validation process, and all samples were randomized. The Hair Damage Level (HDL) was calculated as the average score across the three zones: HDL = (Score zone 1 + Score zone 2 + Score zone 3) / 3. Statistical analysis (XLSTAT 2019.1.1) included t-tests, Mann-Whitney, Wilcoxon, and ANOVA based on data normality (Shapiro-Wilk test) and homogeneity. Significance was set at $p < 0.05$. Intraclass correlation coefficient (ICC) between operators was calculated [4].

3. Results

3.1 Scale Definition

The generated scale employs a 6-level video scale ranging from "no damage" (natural hair reference) to "very damaged" (immediate breakage). Level 0 refers to natural, undamaged hair, which exhibits no deformation when pulled. Levels 1 and 2 represent hair that has undergone some damage, demonstrating elastic behavior when tensioned but returning to its original state. From Level 3 onward, the hair is more damaged, exhibiting high elasticity when tensioned, with some fibers failing to return to their original state after the test. At the highest level (Level 5), the hair fibers are so severely damaged that they break during the test. Figure 1 presents the description and illustrative image of each level of the scale. For training and accreditation, the video scale must be used.

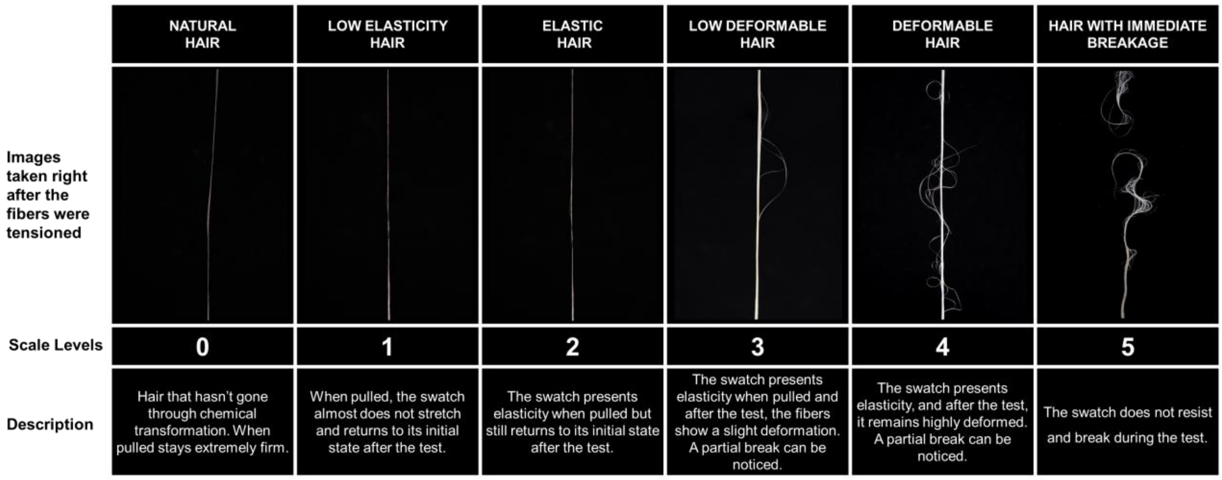

Figure 1. Scale Levels description

2.2 Parameter Standardization and Operator Training

The standardized assessment involves stretching a hydrated tress three times using a defined finger gesture, maintaining consistent force and speed. The roots, mid-length, and tips of the tress are evaluated. The observed elasticity during the test and the tress's appearance after the gesture determine the damage level according to the scale. The standardized protocol is described below.

Evaluation Swatch Preparation: A 30-fiber swatch will be used for the evaluation. This swatch should be prepared from the main swatch representing the condition being evaluated. Fibers should be counted from the tips of the main swatch (Figure 2a) to avoid including broken fibers in the evaluation swatch.

Evaluation Zones: The evaluation swatch is divided into three regions (zones 1, 2, and 3) where the stretching gesture will be performed. Zone 3 is always the region closest to the tips. Each region is approximately 5.0 cm (or 4 finger-widths) apart (Figure 2b).

Evaluation Protocol:

- **Pre-Gesture Standardization:** Spray the swatch with water 10 times, divided into two sets of 5 sprays along the length of the swatch. Distribute the sprays evenly to the tips, maintaining a distance of approximately 5 cm between the sprayer and the swatch. After a 1-minute pause, spray the swatch 5 more times with water. Immediately proceed with the evaluation gesture.
- **Evaluation Gesture:** Hold the top of the evaluation area firmly between the index finger and thumb of one hand. Maintain a 5.0 cm distance and hold the bottom of the assessment area with the thumb and forefinger of the other hand. Using the hand holding the lower portion, pull the swatch three times consecutively without pausing. Repeat this procedure for each assessment zone, always starting from zone 1 and progressing to zone 3. During the evaluation, a score is assigned to each zone based on the observed elasticity during and after the stretching gesture, according to the scale.

Operator Training: For training, follow the evaluation protocol and gesture described above. Perform the gesture, pulling the swatch three times until the point on the ruler corresponds to the final elongation for the respective damage level (Table 3). The training gesture is performed only in zone 1 of the swatch.

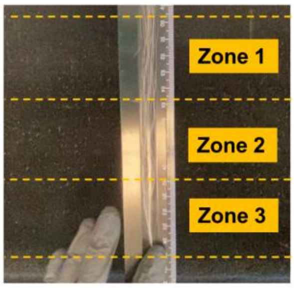

Figure 2. (a) Counting fibers for evaluation swatch preparation; (b) Definition of evaluation zones.

3.3 Validation

Phase 01 – Scale Levels assessment

Table 4 presents the inter-day reproducibility results for each operator. The statistical results presented below were calculated based on the calculated Hair Damage Level (HDL) values.

Table 4. Inter-day Reproducibility of Hair Damage Level (HDL) Scores

Operator	Condition	Mean Value Day 01	Mean Value Day 2	P-value based (Day 1 vs Day 2)
Operator 1	Condition 01	1	1	1,000
	Condition 02	1	1	1,000
	Condition 03	3,222222	3,296296	0,813
	Condition 04	2,888889	3,074074	0,554
	Condition 05	2,666667	3,481481	0,036
	Condition 06	3,925926	4,333333	0,005
Operator 2	Condition 01	1	1	1,000
	Condition 02	1,111111	1,333333	0,131
	Condition 03	3,888889	4,111111	0,373
	Condition 04	3,444444	3,666667	0,332
	Condition 05	3,111111	3,222222	0,471
	Condition 06	4,296296	4	0,169
Operator 3	Condition 01	1	1	1,000

Condition 02	1	1	1,000
Condition 03	3,444444	3,555556	0,670
Condition 04	3,37037	3,222222	0,618
Condition 05	3,148148	3,148148	0,833
Condition 06	4,333333	4,481481	0,206

Inter-operator reproducibility was assessed, with results detailed in Table 5.

Table 5. Inter-operator Reproducibility of Hair Damage Level (HDL) Scores (p-values)

Comparisons	**Condition**	**P-value (Day 1)**	**P-value (Day 2)**
Operator 1 vs Operator 2	Condition 01	1,000	1,000
	Condition 02	0,374	0,028
	Condition 03	0,056	0,001
	Condition 04	0,024	0,050
	Condition 05	0,115	0,232
	Condition 06	0,034	0,028
Operator 1 vs Operator 3	Condition 01	1,000	1,000
	Condition 02	1,000	1,000
	Condition 03	0,384	0,158
	Condition 04	0,216	0,653
	Condition 05	0,071	0,150
	Condition 06	0,012	0,032
Operator 2 vs Operator 3	Condition 01	1,000	1,000
	Condition 02	0,374	0,028
	Condition 03	0,837	0,019
	Condition 04	0,468	0,100
	Condition 05	0,886	0,468
	Condition 06	0,963	0,004

Only data from Operators 2 and 3 were included in this analysis due to the reproducibility issues observed with Operator 1 (Table 4 and 5). The intraclass correlation coefficient (ICC) between Operators 2 and 3 was 0.864. Mean scores for each zone, and the resulting HDL, were calculated for Operators 2 and 3. No statistically significant difference was found between the mean results of Day 1 and Day 2 for any condition. Figure 3 presents the calculated mean values for both operators on Days 1 and 2.

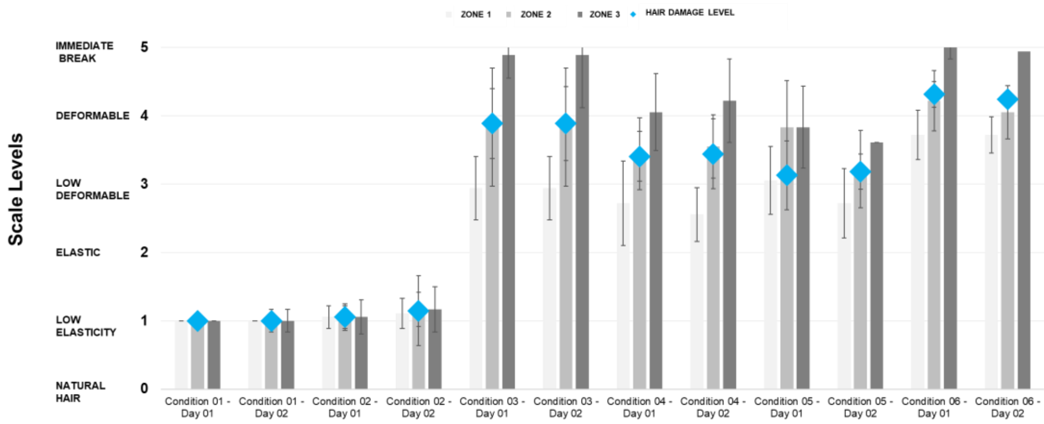

Figure 3. Mean Hair Damage Assessment Scores for Each Condition and Day (Operators 2 & 3 Averaged)

Phase 2 – Sensitivity to Repair Technologies

Only data from Operators 2 and 3 were included in this analysis due to the reproducibility issues observed with Operator 1 in the previous phase. Inter-day and inter-operator reproducibility were assessed and found to be satisfactory (no statistically significant differences observed). As in Phase 1, mean scores for each zone and the resulting HDL were calculated for Operators 2 and 3. No statistically significant difference was found between Day 1 and Day 2 for any condition. Figure 4 presents the calculated mean values.

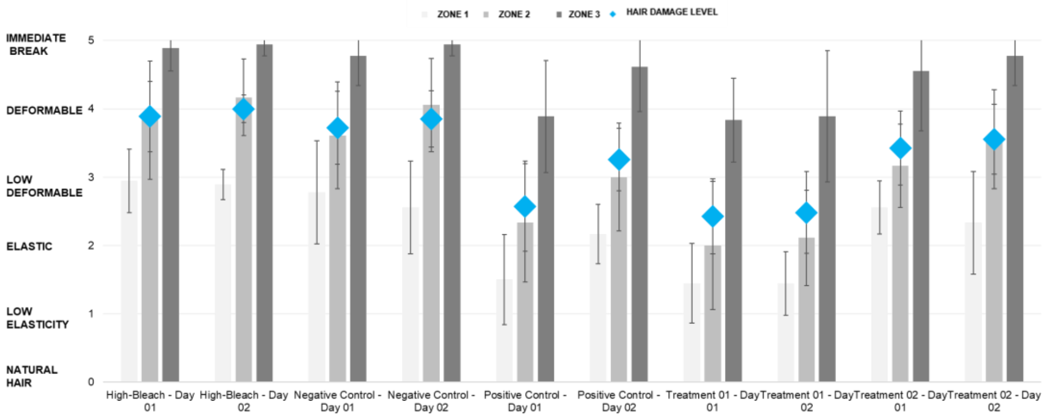

Figure 4. Mean Hair Damage Assessment Scores for Each Treatment Condition (Operators 2 & 3 Averaged)

To assess the methodology's ability to differentiate between repair technologies, statistical analysis was performed on the calculated mean values for each evaluated condition. Table 6 presents the statistical comparisons between the technologies for both evaluation days.

Table 6. P-values for Treatment Comparisons (Phase 2, Days 1 & 2)

Comparisons	P-value (Day 01)	P-value (Day 2)
High - Bleach vs Negative Control	0,509	0,348
High - Bleach vs Positive Control	0,000	0,001
High - Bleach vs Treatment 01	0,001	< 0,0001
High - Bleach vs Treatment 02	0,056	0,036
Negative Control vs Positive Control	0,001	0,011
Negative Control vs Treatment 01	0,002	< 0,0001
Negative Control vs Treatment 02	0,321	0,196
Positive Control vs Treatment 01	0,788	0,007
Positive Control vs Treatment 02	0,011	0,215
Treatment 01 vs Treatment 02	0,004	0,001

4. Discussion

The results of this study demonstrate the successful development and validation of a novel 6-level visual scale for assessing hair damage based on elasticity. Derived from observations of chemically treated hair tresses and refined with expert hairdresser feedback, the scale provides a standardized and objective approach to evaluating hair damage, addressing the limitations of current subjective methods. The eight hairdressers who reviewed the scale confirmed its practical relevance and alignment with their professional experience, suggesting its potential as a diagnostic tool in salons, enabling more precise communication about damage levels and personalized treatment recommendations for clients.

The standardized methodology, involving a controlled stretching gesture and pre-hydration protocol, was designed to minimize variability and enhance reproducibility. The validation study confirmed this (Tables 3 and 4), with Operators 2 and 3 demonstrating good inter-day and inter-operator reliability (p-values > 0.05). The inconsistencies observed on Day 2 regarding inter-operator reproducibility may be attributed to sample storage time prior to testing. As all samples were prepared concurrently, those assessed on Day 2 were stored for a longer duration than those assessed on Day 1. Indeed, operators reported changes in tress behavior despite being blinded to the conditions.

The inconsistent performance of Operator 1, evidenced by low inter-day reproducibility and discrepancies with the other operators (p-values < 0.05), highlights the importance of proper training and operator qualification before using the method. Some operators may require more extensive practice to achieve consistent results.

Mean scores between Operators 2 and 3 were used for analysis to improve data reliability (Figure 3). The high ICC value between these operators further supports the method's reproducibility when performed by trained and qualified assessors.

The method's sensitivity in differentiating the efficacy of repair treatments was clearly demonstrated in Phase 2. As shown in Table 6 and Figure 4, the Negative Control yielded statistically similar results to the High-Bleach condition ($p > 0.05$). The Positive Control, however, differed significantly from both the High-Bleach and Negative Control conditions ($p < 0.05$), indicating its repair efficacy. Treatments 1 and 2 also demonstrated damage reduction compared to the High-Bleach and Negative Control. While inter-day comparisons for each condition were

satisfactory, with no significant differences observed, the differentiation between the Positive Control and Treatments 1 and 2 varied between evaluation days (Table 6). Similar to Phase 1, operators reported changes in tress behavior despite being blinded to the conditions, further suggesting that sample storage time prior to evaluation influenced the observed results.
To ensure methodological validity, evaluations should be conducted one day after the final procedure by qualified operators demonstrating inter-day and inter-operator reproducibility. For robust statistical analysis, two qualified operators should perform blind evaluations on randomized samples, using the mean score for comparisons between test conditions. A minimum of six tresses per condition should be assessed by each operator.

5. Conclusion

This study successfully developed and validated a novel 6-level elasticity scale and standardized method for the objective assessment of hair damage. The method demonstrates good reproducibility when performed by trained operators and effectively differentiates the efficacy of various repair treatments. This objective approach offers a significant advancement over current subjective methods, providing a quantifiable and reproducible tool for evaluating both in vitro and in vivo hair damage and repair. In fact, following the validation stage, the methodology has already been employed in a clinical study with 40 volunteers with damaged hair to evaluate the efficacy of repair products, and the observed results were consistent with in vitro assessments of the same products, indicating good in vitro-in vivo reproducibility. The findings of this work will be published subsequently. This tool can enhance communication between hair care professionals and consumers, enabling more informed product development and personalized treatment strategies. Future research will investigate the correlation between this method and established biophysical measurements of hair fiber properties to enhance its scientific rigor and explore potential refinements to the protocol, such as optimizing storage conditions to minimize variability.

Conflict of Interest Statement.
L’Oréal Brazil provided the resources for this study.

References.

1. L'Oréal R&I. (2021). Consumer Insights on Damaged Hair (Unpublished internal report). Data collected from interviews with over 5,000 consumers across Brazil, France, United States, and China between December 2020 and January 2021.
2. L'Oréal R&I. (2022). Hair Damage & Evaluation Gestures (Unpublished internal report). Data collected from online desk research across Google, YouTube, Instagram, TikTok, and Facebook in Brazil, United States, and France.
3. Yu, Y., Yang, W., Wang, B., & Meyers, M. A. (2017). Structure and mechanical behavior of human hair. Materials Science and Engineering: C, 73, 152-163.
4. Ohyama, T. A comparison of confidence interval methods for the intraclass correlation coefficient based on the one-way random effects model. Jpn J Stat Data Sci (2025). https://doi.org/10.1007/s42081-025-00292-3
5. Benzarti, M., Pailler-Mattei, C., Jamart, J. et al. The Effect of Hydration on the Mechanical Behaviour of Hair. Exp Mech 54, 1411–1419 (2014).
6. Robbins, C. R., & Robbins, C. R. (2002). Chemical and physical behavior of human hair (Vol. 4). New York: Springer.