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Measurement of hair luster by diffuse reflectance spectrophotometry

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Synopsis

We studied the application of the diffuse reflectance spectrophotometry technique in order to obtain consistent hair-luster measurements. The influence on data quality of such experimental conditions as sample color, texture, geometry, and position, and of such instrumental operating conditions as viewing angle, viewing aperture, and inclusion or exclusion of the specular component, were established. The color-difference parameter (DE) appears as the best parameter to measure hair luster in CIELAB and FMCII systems of equations. Hair tresses submitted to several treatments, including shampooing and conditioning, were used to choose the best reference (zero-luster value) and hair-luster saturation (maximum-luster value). A luster scale was assembled from DE values, pointing out that diffuse reflectance spectrophotometry data allows measuring and quantifying hair luster.

INTRODUCTION

Luster is an essential quality for hair beauty. However, it is difficult to measure it by physical methods. The literature describes a few light-scattering measurements using goniophotometry (1–5), but usually visual evaluations are applied for describing hair luster. In fact, luster or gloss is an optical phenomenon that results from the specular reflection of light (referring to the mirrorlike reflection) from a smooth surface. As the surface becomes rougher, the luster is reduced and the diffuse reflection from the surface increases. A completely nonlustrous rough surface is a diffuse reflector (6,7). Therefore, diffuse reflectance spectrophotometry should be able to measure luster. This is a well known method for color measurements in opaque substances and surfaces, widely applied in the paint and paper industry (6); however, it has not been applied to luster measurements.

We have investigated the capacity of simple diffuse reflectance equipment to measure hair luster. From the spectra, an ordinary software calculated color parameters as defined by two color systems, CIELAB (Commission International on Illumination L*, a*, b*) and FMCII (Friele-MacAdam-Chickering), both based on just-perceptible differences of color. Lightness difference (DL), chromaticity difference (DC), and color difference

(DE) were used in order to characterize the hair color/luster alterations after cosmetic and other treatments.

EXPERIMENTAL

MATERIALS

Hair samples. Several tresses of virgin dark-brown and black hair were obtained from Ind. Com. de Cosméticos Natura Ltda, Itapecerica da Serra/SP, Brazil. Hair samples were cleaned by 8 h extraction in ethyl ether in a soxhlet and rinsed in distilled water prior to use. The tresses were oriented from root to tip end, and tied near the root end, combed, and stored in a desiccator. The tresses were kept in the instrument room 24 h before the measurements in order to attain humidity equilibrium. Table I shows some features of the tresses used.

Cosmetic products and formulations. The following commercial products and formulations were used in this work: Rexona® soap, Tabu® commercial brilliantine, Revlon Aquamarine® shampoo for dry hair, Neutrox® conditioner, Lóreal Elsève Multivitaminas® shampoo, and standard and PQ7 formulations. The manufacturers and composition of these products are shown in Appendix A.

Instrument. The diffuse reflectance measurements were made using a diffuse reflectance spectrophotometer, Macbeth Color-Eye 2020. The diffuse reflectance spectrophotometer viewing conditions involve an integrating sphere, a hollow metal sphere inches in diameter and painted white inside. An integrating sphere collects all light reflected from the surface of a sample placed against an opening in its side. Provision is usually made for including and excluding that part of the light reflected in a specular direction from a sample. The measurements were done while keeping the same tress region and turning the hair tress sample in the instrument sample holder. The instrument operation conditions were (a) configuration CRIIS (C: ceramic calibration, R: reflectance, I: ultraviolet waves, I: specular component, S: short viewing aperture) and (b) D65 illuminant. Spectra rendered values of L* (lightness of the color), a* (redness if positive coordinate or greenness if negative coordinate), b* (yellowness if positive coordinate or blueness if negative coordinate) from the CIELAB system and X (coordinate x), Y (coordinate y), Z (coordinate z) from the FMCII system. From these, the calculated parameters were DL*, DL (lightness difference), DC*, DC (chromaticity difference), and DE*, DE (color difference), for the CIELAB and FMCII systems of equations, respectively.

Table I
Virgin Hair Sample Characteristics as Visually Observed/Tress Sample Denomination and Correlated Experiment

Hair characteristics	Tress sample	Experiment
Less damaged dark-brown hair (25 cm)	D-B1, D-B2, D-B3	Experimental optimization, color-parameters evaluation
More damaged dark-brown hair (20 cm)	DD-B1, DD-B2, DD-B3	Cumulative treatments: standard and PQ7 formulations
Less damaged black hair (15 cm)	B1, B2, B3, B4, B5	Internal and external references, statistical analyses

METHODS

Experimental optimization. In order to evaluate the instrument sensibility and to get the better instrumental conditions for human hair samples, several equipments were performed as described.

Influence of position, viewing angle, and viewing aperture of the sample. This experiment was done by varying the position of a dark-brown tress (D-B) in the instrument, the viewing angle (2° and 10°), and the sample-viewing aperture (5 × 10 mm and 20 × 10 mm). The sample-viewing aperture readings were taken in two different ways: first, by changing the hair tress position, and second, by retaining the hair tress position in the instrument sample holder.

Influence of sample color, texture, and geometry. Diffuse-reflectance measurements were performed using a smooth plate with drops of "nanquim" black dye, a cylindrical capillary tube filled with "nanquim" black dye, a black hair tress (B) treated or not treated with brilliantine (cylindrical surfaces), and a smooth and a wrinkled surface of green paper.

Current and adapted holder. Figure 1 shows the design of the adapted holder, which allows a better arrangement of the hair fibers, avoiding hair entanglement that could cause an increase in error. The less damaged dark-brown hair tresses (D-B1, D-B2, and D-B3 cleaned with ethyl ether for 8 h) were used in this experiment. Measurements were done first with tresses using the current holder. After that, the instrument was calibrated with the adapted hair holder and the measurements were repeated with the same tresses.

Color parameter evaluation. This experiment was performed with 25-cm tresses of less damaged dark-brown hair (D-B), in order to verify the measurement reproducibility after treatments. The tress was divided into three samples (D-B1, D-B2, and D-B3), and the treatments were done in triplicate. The clean hair tresses were rinsed with 1 ml of the product for 2 min, immediately rinsed with distilled water at 35°–40°C for 1 min, and dried with a hair drier for 1 min. DE* and DE values were obtained between the reference hair tress (zero difference, cleaned with ethyl ether for 8 h) and the treated hair tress.

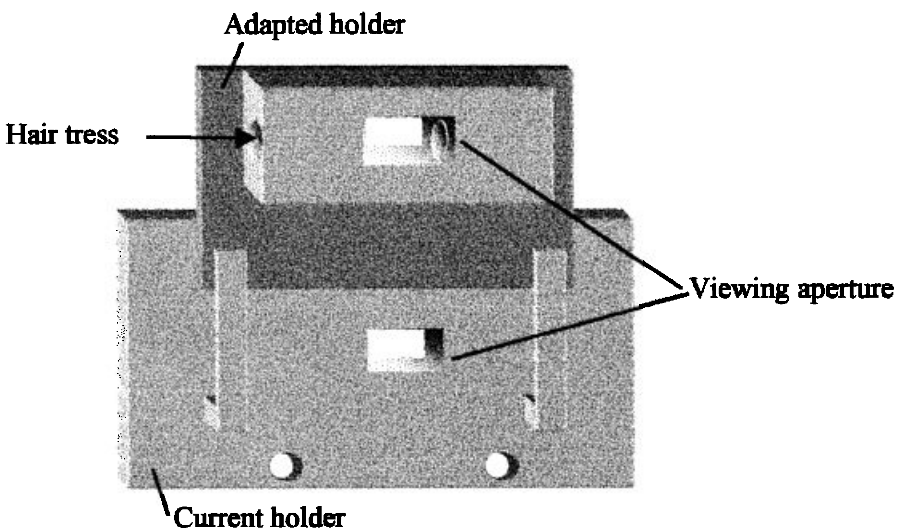

Figure 1. Illustration of the adapted holder used in the diffuse-reflectance measurements.

Cumulative treatments. In this experiment a more damaged dark-brown (DD-B) hair tress was treated with two different formulations obtained from Ind. Com. Cosméticos Natura Ltda., Itapecerica da Serra/SP, Brazil. The tress was divided into three samples (DD-B1, DD-B2, and DD-B3) and rinsed with 1 ml of the formulation for 2 min, washed with water at 40°C for 1 min, combed, and left to dry at room temperature for 3 h before the measurements. This procedure was repeated four times every two days. After thirty days the fifth washing and measurements were done. Treated hair was stored in a desiccator during the intervals.

Influence of reference (zero difference) and statistical analyses. The aim of this experiment was to evaluate the use of an external or an internal reference (zero difference) to calculate the color difference parameters. A less damaged black hair (B) tress was cleaned by extraction in ethyl alcohol for 8 h (external reference), divided into five samples of 2 g (B1, B2, B3, B4, and B5), and extracted again in commercial ethanol for 8 h. Table II shows the treatments that were done on the samples.

RESULTS AND DISCUSSION

EXPERIMENTAL OPTIMIZATION

Position, viewing angle, and viewing area of the sample. These measurements were done to find the better instrumental operating conditions for human hair samples. Table III shows the average results of L*, a*, and b* parameters obtained with different instrumental configurations. As observed in Table III, there is no significant difference among the average color values for sample position, viewing angle, and viewing aperture. Based on these results, the following instrumental conditions were chosen for the next experiments: horizontal position, a viewing angle of 10°, and a viewing aperture of 5 × 10 mm.

Influence of sample color, texture, and geometry. The next step was to evaluate the instrumental sensitivity for samples of different color, texture, and geometry, including or excluding the specular component, as shown in Table IV. As expected, the exclusion of

Table II
Treatments in Less Damaged Black Hair (B) Samples

Samples	Treatments
B1	Ethanol PA/8 h, ethanol commercial/8 h, and Neutrox® conditioner
B2	Ethanol PA/8 h, ethanol commercial/8 h (a), ethanol PA/8 h, and ethanol commercial/8 h (b)
B3	Ethanol PA/8 h, Neutrox® conditioner, ethanol commercial/40 min, shampoo + Neutrox® 1° (first wash), shampoo + Neutrox® 2° (second wash), and shampoo + Neutrox® 3° (third wash)
B4	Ethanol PA/8 h + Neutrox® conditioner
B5	Ethanol PA/8 h + Neutrox® conditioner

Operating conditions: D65 illuminant, 10° viewing angle, 5 × 10 mm viewing aperture, and adapted holder were used. Sets of ten diffuse reflectance measurements were done.
Internal reference was chosen among a set of ten readings, taking the closet L*, a*, b* (CIELAB) and X, Y, Z (FMCII) values to the average value in each treatment.

Table III
Color Values as a Function of Position, Viewing Angle, and Viewing Aperture of the Sample

		L*	a*	b*
Sample position	Vertical	23.04 ± 0.68	4.04 ± 0.28	4.72 ± 0.16
	Horizontal	22.48 ± 0.62	4.10 ± 0.16	5.13 ± 0.21
Sample viewing angle	2°	23.75 ± 1.19	3.82 ± 0.33	4.95 ± 0.44
	10°	23.59 ± 1.19	3.87 ± 0.33	4.76 ± 0.42
Reading reproducibility[1]	5 × 10 mm	22.72 ± 0.02	3.35 ± 0.03	3.85 ± 0.03
	20 × 10 mm	21.68 ± 0.02	4.28 ± 0.03	5.41 ± 0.03
Sample viewing aperture[2]	5 × 10 mm	23.59 ± 1.19	3.87 ± 0.33	4.73 ± 0.42
	20 × 10 mm	21.85 ± 0.31	4.07 ± 0.17	5.09 ± 0.38

Operation conditions not specified by second column were: horizontal sample position, D65 illuminant, 10° viewing angle and 5 × 10-mm viewing aperture. Averages and estimated standard deviation among a set of ten measurements. Dark brown hair (D-B).
[1] Hair tress remained in the same position during the readings.
[2] Hair tress position was changed during the readings.

Table IV
Color Values as a Function of Color, Texture, and Geometry of the Sample, Including and Excluding the Specular Component

Sample	Specular component	L*	a*	b*
Smooth surface: a slide with black "nanquim" dye	Included	25.95	−0.05	0.24
	Excluded	1.12	0.10	−0.96
Cylindrical surface: capillary tube filled with "nanquim"	Included	19.89	−0.08	−0.62
	Excluded	19.06	−0.08	−0.76
Cylindrical surface: black hair	Included	18.37	−0.05	−0.84
	Excluded	18.00	0.02	−0.91
Cylindrical surface: black hair treated with brilliantine	Included	20.67	−0.04	−0.96
	Excluded	20.17	0.02	−0.99
Smooth surface: smooth green paper	Included	46.75	−52.38	13.15
	Excluded	42.75	−65.83	17.51
Irregular surface: wrinkled green paper	Included	46.28	−50.84	12.59
	Excluded	45.28	−52.80	13.28

Operating conditions: horizontal sample position, D65 illuminant, 10° viewing angle, and 5 × 10-mm viewing aperture. Quintuplicate measurements.

the specular component had a significant influence on the color parameters when the surface was smooth. However, for cylindrical samples, this difference was in the experimental error range. This means that for hair samples, the specular component does not correlate with luster.

Current and adapted holder. As described above, an adapted holder was built in order to improve alignment and to avoid entanglement among hair fibers during the measurements, since a reduction in luster occurs when fibers are not sufficiently aligned (7). Table V shows the parameters of average values obtained with the current holder and the adapted holder for the CIELAB and FMCII systems. The L* value decreased by approxi-

Table V
CIELAB System Parameters L*, a*, and b* and FMCII System Parameters X, Y, and Z, Obtained for Three Dark-Brown Hair Tresses (D-B1, D-B2, D-B3; ethyl ether/8 h) With Current and Adapted Holder

		CIELAB			FMCII		
		L*	a*	b*	X	Y	Z
Current holder D-B1	Average	23.03	3.96	5.46	3.88	3.80	3.23
	Deviation	0.35	0.11	0.16	0.10	0.10	0.08
	% Deviation	1.52	2.88	2.89	2.59	2.66	2.56
Adapted holder D-B1	Average	21.14	3.89	5.34	3.35	3.28	2.71
	Deviation	0.20	0.16	0.33	0.06	0.05	0.04
	% Deviation	0.98	4.03	6.13	1.74	1.67	1.33
Current holder D-B2	Average	23.38	3.78	4.87	3.97	3.91	3.36
	Deviation	0.40	0.18	0.18	0.13	0.12	0.01
	% Deviation	1.75	4.99	3.89	3.25	3.10	2.87
Adapted holder D-B2	Average	20.79	3.84	5.47	3.25	3.19	2.61
	Deviation	0.20	0.12	0.24	0.06	0.05	0.02
	% Deviation	0.98	3.21	4.41	1.76	1.64	0.91
Current holder D-B3	Average	22.88	3.80	4.03	3.82	3.72	3.22
	Deviation	0.47	0.15	0.31	0.14	0.03	0.09
	% Deviation	2.08	4.07	7.59	3.73	3.69	2.81
Adapted holder D-B3	Average	21.31	3.72	4.99	3.38	3.32	2.81
	Deviation	0.44	0.16	0.22	0.12	0.12	0.11
	% Deviation	2.11	4.26	4.49	3.62	3.57	3.94

Operating conditions: horizontal sample position, D65 illuminant, 10° viewing angle and 5 × 10-mm viewing aperture. Averages and estimated standard deviation among quintuplicate measurements. CIELAB system parameters: L* (lightness coordinate), a* (red-green coordinate), and b* (blue-yellow coordinate). FMCII system parameters: X (coordinate x), Y (coordinate y), and Z (coordinate z).

mately 10% with the adapted holder, which means a sample darkening in relation to the data obtained with the current holder. The a* and b* values obtained with the adapted holder were in the error range of those with the current holder. The reproducibility was in the same range for the CIELAB system with the adapted holder. However, for the FMCII system, the values of X, Y, and Z decreased by approximately 12% to 22%, and the reproducibility decreased by an average of 25% (current holder deviation of 3.00% and adapted holder deviation of 2.24%). The adapted holder was used throughout the next experiments.

COLOR PARAMETER EVALUATION

Diffuse reflectance measurements were performed on the samples treated as described earlier in Methods. The following parameters were obtained: for CIELAB: L*, a*, b*, DL*, DC*, and DE*; and for FMCII: X, Y, Z, DL, DC, and DE. A reference (zero-difference) value was obtained from the average value of L*, a*, b*, or X, Y, Z of the quintuplicate measurements taken from ethyl ether 8-h treatment on the hair tress. Values of color differences (DL*, DC*, DE*, and DL, DC, DE) for the two systems were comparatives between the reference values and the respective values for each treatment.

Results obtained for the three samples (DB-1, DB-2, and D-B3) were reproducible. A maximum estimated standard deviation of 12% was observed in coordinate parameters (L*, a*, b* and X, Y, Z) except for L* (lightness), which was 4.5%. Table VI shows an example of quintuplicate measurements and averages obtained after soap treatment in the CIELAB system. Values of DC* (chromaticity difference) and DL* (lightness difference), for both systems, showed a high estimated standard deviation, hindering them in quantifying luster. DE* (color difference) showed the lowest error range among color parameter values.

Figure 2 shows DE, DE* (color difference) values obtained, after the treatments described in Methods, for the CIELAB and FMCII systems. These values were sensitive to the different treatments. The brilliantine treatment showed the highest DE (FMCII) value. Visual observation of the treated tresses and the reference (ethyl ether/8 h) tress showed a darkening and an increase in luster after brilliantine treatment, agreeing with the decrease observed in L*, L (lightness) values and the significant increase in the DE, DE* values. The overall data indicates DE*, DE as the most sensitive color parameter for means luster.

CUMULATIVE TREATMENTS

Diffuse reflectance measurements were done after every sequential treatment, as described in Methods. As an example of the data obtained, Figure 3 shows the average DE values in cumulative treatments with standard and PQ7 formulations (the graph shape is similar in the CIELAB system, although DE values were lower). As seen, DE values tend to increase after each treatment sequence. This was observed in every case, but especially with the PQ7 formulation, meaning that no luster saturation was attained. After 30 days (fifth wash), the color-difference values decreased, being lower than those obtained after the first wash. This may point to a hair-surface modification during storage. The color-difference parameter (DE) again showed the highest sensitivity to discriminate among the treatments.

Table VI

Quintuplicate Measurements of the CIELAB System Parameters L*, a*, and b* and the Calculated Parameters DL*, DC*, and DE*, Obtained With Sample D-B1 Treated With Commercial Soap

Readings	L*	a*	b*	DL*	DC*	DE*
1	22.49	4.09	4.75	-0.92	-0.21	1.04
2	23.27	4.19	4.97	-0.14	0.02	0.39
3	23.11	3.95	4.96	-0.30	-0.14	0.38
4	22.49	4.05	5.43	-0.92	0.30	0.97
5	22.31	4.07	5.23	-1.10	0.15	1.11
Average	22.73	4.07	5.07	-0.68	0.02	0.78
Estimated standard deviation	0.38	0.09	0.26	0.38	0.19	0.32
% Deviation	1.68	2.11	5.22	-56.43	776.66	41.64

Operating conditions: horizontal sample position, D65 illuminant, 10° viewing angle, 5 × 10-mm viewing aperture, and adapted holder.
CIELAB system parameters: L* (lightness coordinate), a* (red-green coordinate), b* (blue-yellow coordinate), DL* (lightness difference), DC* (chromaticity difference), and DE* (color difference).
Reference tress (ethyl ether/8 h) and sample D-B1 (dark-brown hair) were used.

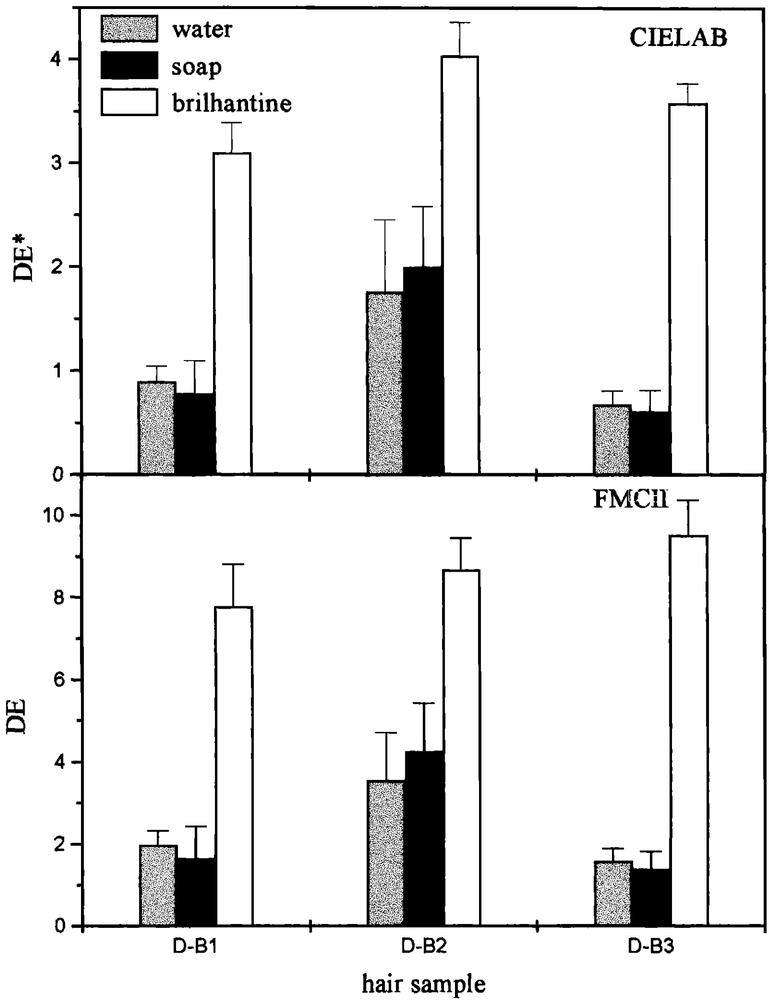

Figure 2. Average of color-difference values obtained after treatments in the dark-brown hair. Samples D-B1, D-B2, and D-B3. Treatments: water 35°–40° C (grey bar), commercial soap (black bar), and brilliantine (white bar). Quintuplicate measurements. D65 illuminant. 10° viewing angle. 5 x 10-mm viewing aperture. Reference tress: dark-brown hair treated with ethyl ether/8 h. CIELAB and FMCII systems.

ESTABLISHING THE LUSTER SCALE

Diffuse reflectance measurements were done in black hair tress (B) samples treated as described in Methods. Color differences (DL*, DC*, DE* and DL, DC, DE) were calculated using internal (color-parameter values measured for every sample before the treatments) and external (color-parameter values measured for the tress before the treatments) references. All samples came from the same tress. Internal and external references were chosen based on the L*, a*, b* (CIELAB) and X, Y, Z (FMCII) values. The internal reference data was chosen by taking the value closest to the average among a set of ten measurements. These values were taken from the diffuse reflectance data of each of the alcohol-treated samples of the tress. The external reference was chosen among the

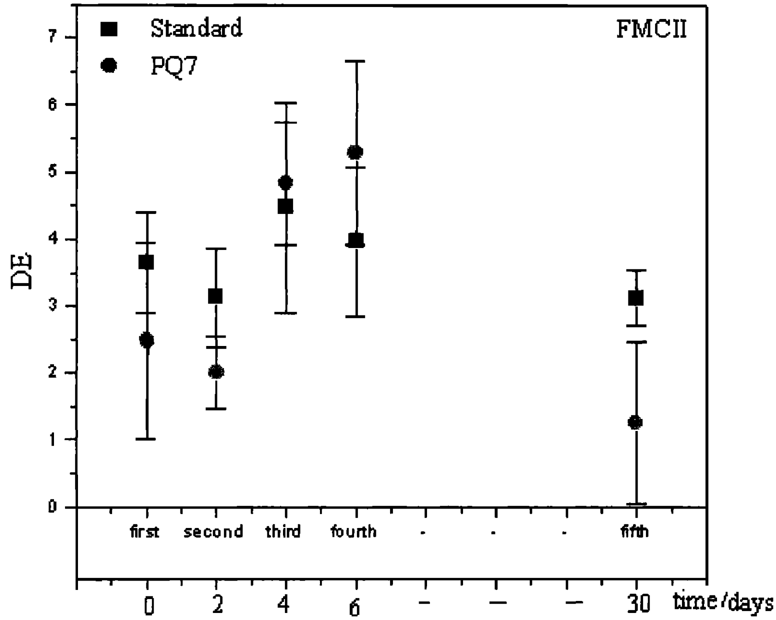

Figure 3. Average color-difference values obtained after sequential treatments in more damaged dark-brown hair tress. Treatments: standard and PQ7 Natura formulations. Quintuplicate measurements. D65 illuminant. 10° viewing angle. 5 × 10-mm viewing aperture. Reference tress: damaged dark-brown hair tress treated with ethyl ether/8 h. FMCII system.

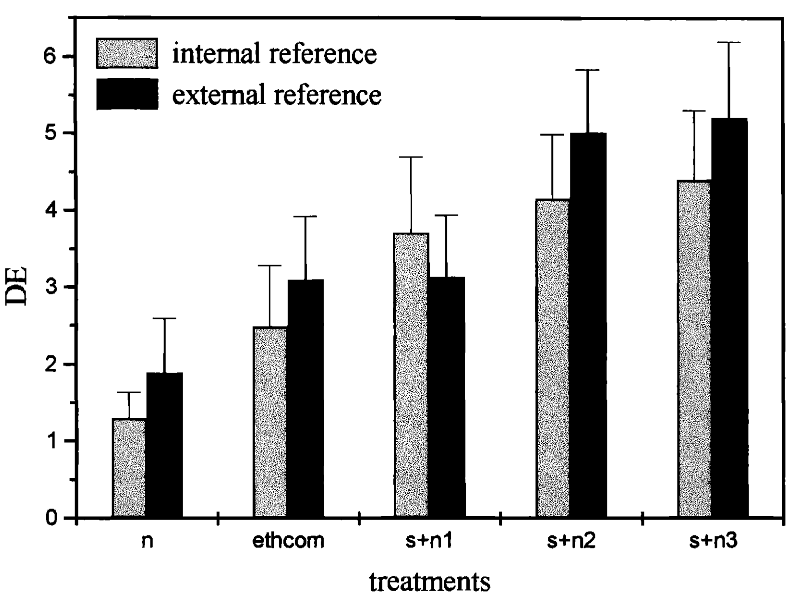

Figure 4. Average color-difference values obtained after sequential treatments in black hair sample using external and internal references. Sample B3. Treatments: n (Neutrox® conditioner), ethcom (ethanol commercial/40 min), s + nl (Élseve® shampoo + Neutrox®/first wash), s + n2 (Élseve® shampoo + Neutrox®/second wash), s + n3 (Élseve® shampoo + Neutrox®/third wash). Results of ten measurements. D65 illuminant. 10° viewing angle. 5 × 10-mm viewing aperture. Internal reference: ethanol PA/8 h treatment (fourth reading). External reference X = 3.27, Y = 3.32, Z = 3.23. FMCII system.

Table VII
Statistical Analysis of Color Difference (DE) Data Obtained Using External Reference for CIELAB and FMCII Systems

	Treatment	Sample	Equations	DE_m	S_2R	DE_M	S_2T
	Ethanol	B1		0.65	0.09		
1	PA/8 h	B2	CIELAB	1.31	0.32	0.89	1.30
		B3		0.73	0.03		
	Ethanol	B1		1.76	0.77		
2	PA/8 h	B2	FMCII	3.30	0.94	2.30	7.57
		B3		1.18	0.40		
		B1		0.84	0.07		
3	Commercial alcohol	B2 (a)	CIELAB	0.43	0.03	0.61	0.39
		B2 (b)		0.46	0.04		
		B3		0.70	0.08		
		B1		2.98	0.43		
4	Commercial alcohol	B2 (a)	FMCII	1.12	0.68	2.14	9.52
		B2 (b)		1.89	0.44		
		B3		3.10	0.82		
		B1		1.95	0.27		
		B2		2.94	0.25		
5	Neutrox® conditioner	B3	CIELAB	0.75	0.05	1.58	8.29
		B4		1.53	0.09		
		B5		1.78	0.16		
		B1		4.21	1.23		
6	Neutrox® conditioner	B2	FMCII	6.11	1.04	3.40	33.8
		B4		3.21	0.61		
		B5		1.59	0.79		
		B3-fw†		1.01	0.23		
7	shampoo + Neutrox®	B3-sw††	CIELAB	2.32	0.16	1.92	6.34
		B3-tw†††		2.45	0.23		
		B3-fw†		3.13	0.81		
8	shampoo + Neutrox®	B3-sw††	FMCII	5.01	0.82	4.44	13.09
		B3-tw†††		5.20	0.99		

DE_m = average color difference among a set of ten measurements; DE_M = average color difference among the samples; S_2R = variance within sample; S_2T = variance among the samples.
†fw (first wash); ††sw (second wash); †††tw (third wash).
Operating conditions: horizontal sample position, D65 illuminant, 10° viewing angle, 5 × 10-mm viewing aperture, and adapted holder.
Sets of ten measurements. Black hair samples (B1, B2, B3, B4, and B5).
External reference: FMCII (X = 3.27, Y = 3.32, and Z = 3.23) and CIELAB (L* = 21.04, a* = 1.76, and b* = 1.58).

diffuse reflectance data of a set of ten measurements for the alcohol-treated tress, as the one that presented the lower estimated standard deviation in color values. The data used as external reference were L* = 21.04, a* = 1.76, and b* = 1.58 (CIELAB) and X = 3.27, Y = 3.32, and Z = 3.23 (FMCII), for all samples.

Figure 4 shows the average DE values (FMCII) obtained after sequential treatments in sample B3, using the external and the internal reference. Internal reference data for sample B3 were obtained from ethanol commercial/40-min treatment (sixth reading) for

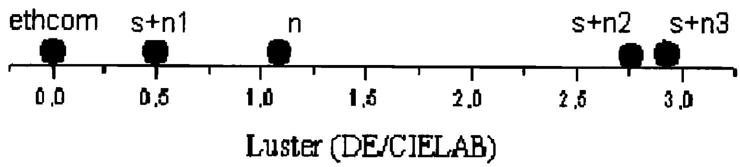

Figure 5. Luster scale using color-difference values obtained for black hair tress. Sample B3. Treatments: ethcom (commercial ethanol/8 h), n (Neutrox® conditioner), s + n1 (Élseve® shampoo + Neutrox®/first wash), s + n2 (Élseve® shampoo + Neutrox®/second wash), s + n3 (Élseve® shampoo + Neutrox®/third wash). Results of ten measurements. D65 illuminant. 10° viewing angle. 5 × 10-mm viewing aperture. Internal reference. CIELAB system.

Table VIII
Values of Color Difference (DE) Obtained Using Internal Reference for CIELAB and FMCII Systems After the Described Treatments

Treatments	DE/FMCII	DE*/CIELAB
Commercial alcohol	2.49 ± 0.8	0.50 ± 0.3 zero–luster value
Ethanol PA/8 h	1.48 ± 0.9 zero–luster value	0.81 ± 0.4
Neutrox® conditioner	1.29 ± 0.3	1.18 ± 0.3
Shampoo + Neutrox®†	3.71 ± 0.9	0.61 ± 0.4
Shampoo + Neutrox®††	4.16 ± 0.8	2.77 ± 0.4
Shampoo + Neutrox®†††	4.40 ± 0.9	2.89 ± 0.5

†fw (first wash), †† sw (second wash), and ††† tw (third wash).
Operating conditions: horizontal sample position, D65 illuminant, 10° viewing angle, 5 × 10-mm viewing aperture, and adapted holder. Black hair sample B3.
Averages and estimated standard deviation among a set of ten measurements.
Internal reference: CIELAB (commercial alcohol: L* = 21.55, a* = 1.73, and b* = 1.67) and FMCII (X = 3.13, Y = 3.19, and Z = 3.08).

CIELAB and from ethanol PA/8-h treatment (fourth reading) for FMCII. As observed, the choice of the reference produces significant differences in the results. However, in both cases, the data show the same profile. After the treatments with shampoo plus Neutrox®, there was a consistent increase in DE values, which demonstrates a cumulative luster effect on hair.

Analysis of variance (ANOVA) was performed in order to select the best reference (8,9). Table VII shows the results of statistical analysis, where DE_m is the average color difference among a set of ten measurements for each sample, DE_M is the average color difference among the samples, S_2R is the variance within the sample, and S_2T is the variance among the samples, always using the external reference. As observed, $S_2T \gg S_2R$ in every case. This means that each sample is statistically different from the others. Therefore, it is not reasonable to calculate the parameters of color difference using an external reference. The color-difference calculations should be done, using as reference the sample that will be afterwards treated, in order to build the luster scale. Note that all the "samples" come from a single "tress." These results agree with those of Bustard and Smith, who used an internal reference to make sure that any changes between the light-scattering properties of the reference and the treated hair were attributed only to the effects of the treatment (5).

The cumulative effect of luster can also be observed in Table VII. Color-difference (DE) values increased after each treatment, especially after sequential shampoo-plus-conditioner treatments. Therefore, in order to build a scale, the luster should be saturated.

Table VII shows the DE and DE* values obtained after sequential treatments in sample B3. As seen before, in both cases the data show the same profile. The treatments with shampoo plus Neutrox® produce an increase in DE and DE* values, which demonstrates a cumulative luster effect on hair.

Figure 5 shows the luster scale built with Table VIII DE*/CIELAB data. The luster scale was built from 0 (zero luster value as internal reference) to 3 (maximum luster value) for the CIELAB system. The DE* estimated standard deviation was about 0.5, as calculated for each sample from a set of DE* values using the internal reference. In the FMCII system the luster scale ranged from 0 (zero luster value as internal reference) to 6 (maximum luster value). In this case, the DE estimated standard deviation was about 1.5. Visual luster observations of the treated samples agree with the DE and DE* data.

CONCLUSIONS

We have show that diffuse reflectance is a suitable technique for the measurement of hair luster. Being a spectrophotometric technique, it avoids the subjective factor that is associated with human perception. This can be an advantage in cases in which a quick check is needed.

As expected, the cylindrical geometry of human hair hindered the use of the specular component as the main luster variable. The overall color difference is the best parameter both in CIELAB and in FMCII color equation systems. From this, the luster scale is not an absolute scale, since it depends on hair color characteristics. The luster scale should be built using as zero-luster the color values of the sample before applying the luster treatment.

Diffuse reflectance equipment is relatively cheap and easy to handle. The luster scale has enough sensitivity to discriminate among treatments, although the estimated standard deviation of luster between measurements is somewhat high, in the range of 20%. This error range forces one to do a relatively high number of measurements on each sample, but since the measurements are taken just by moving the sample in the sample holder, this takes no more than one minute per replicate.

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Appendix A
Commercial Names, Manufacturers, and Composition of Products Used to Rinse Hair Tresses for Diffuse Reflectance Measurements in This Work

Commercial name	Manufacturer	Composition
Tabu® commercial brilliantine	Perfumens Dana do Brasil S.A.	Petroleum jelly, mineral oil, paraffin, and essence
Revlon Aquamarine® shampoo for dry hair	Ceil Comércio Exportação e Indústria Ltda.	Water, sodium lauryl ether sulfate, coconut diethanolamine, sodium chloride, methylchloroisothiazolinone, methylparaben, propylparaben, colorant, fragrance, marine algae extract (5 mg/g), and animal protein (1 mg/g)
Rexona® soap	Insdústrias Gessy Lever Ltda—Divisão Elida Gibbs	Water, sodium soap, EDTA, thickeners, glycerol, titanium dioxide, colorants, and fragrance
Lóreal Elsève Multivitamina® shampoo	Procosa Produtos de Beleza Ltda.	Water, sodium lauryl ether sulfate, nicotinamide, sodium cetyl stearyl sulfate, pantenol, coconut betaine, tocoferol acetate, chloride guarhydroxypropyl, dimethicone, hydroxy stearyl cetyl ether, cetyl alcohol, propylene glycol, coconut isopropanolamide, sodium methylparaben, hydantoine, phenoxyethanol, methylparaben, ethlyparaben, propylparaben, butylparaben, and fragrance
Standard formulation	Indústria e Comércio de Cosméticos Natura Ltda.	Water, sodium lauryl ether sulfate, coconut diethanolamine, EDTA, citric acid (pH 5.5), and fragrance
PQ7 formulation	Indústria e Comércio de Cosméticos Natura Ltda.	Water, sodium lauryl ether sulfate, coconut diethanolamine, polyquartenium 7, EDTA, citric acid (pH 5.5), and fragrance
Neutrox 1® conditioner	Indústria de Cosméticos Coper Ltda.	Water, cetyl stearyl alcohol, glyceryl stearate, isopropyl palmitate, alquil trimethyl ammonium chloride, mineral oil, colorants, and fragrance

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