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Assessment of the photoprotection properties of hair cosmetics using the hemispherical directional reflectance method

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Abstract

Background: Solar radiation is responsible for changes in the structure of human hair, the damages include proteins (65%–95%), lipids, and melanin. The aim was to examine the effectiveness of sunscreen in hair cosmetics and whether hair color affects it.

Materials and Methods: The study included nine women, divided according to hair color to three groups: light, dark, and gray hair. The 410-Solar reflectometer was used in five time points. The hair was divided into three strands, one product applied to each.

Results: Dark hair showed the highest absorption of radiation in all wavelength ranges, the reflectance before products application was significantly higher than the hair reflectance immediately after application. The effect of sunscreens on light hair reflectance was found at wavelengths 400 and 720 nm and between 1000 and 2500 nm, the reflectance before application was significantly higher than the reflectance after. The use of products on gray hair did not have a significant effect on hair reflectance at wavelengths 400–1100 nm, the effect of sunscreens on the gray hair reflectance was observed in the UV and infrared range, the reflectance before application was significantly higher than immediately after.

Conclusions: The results showed that the 410-Solar reflectometer is useful to assess the effectiveness of hair sunscreens. All three tested hair products do not show the expected protection properties. Dark hair showed the highest absorption of radiation in all wavelength ranges, suggesting that dark hair should be more protected against radiation than light and gray hair.

KEYWORDS
hair, hair cosmetics, hemispheric directional reflectance, photoprotection, qualitative assessment

1 | INTRODUCTION

Exposure to UV radiation is associated with the formation of undesirable skin lesions. The negative effects include primarily: photoaging, photodermatoses, sunburn, hyperpigmentation, precancerous conditions and skin cancers.[1] Solar radiation is also responsible for changes in the structure of human hair, the damages include proteins (65%–95%), lipids, and melanin. It leads to undesirable effects such as color change, loss of gloss, and loss of mechanical strength.[2] Gray hair is exposed to the negative effects of sunlight the most, because it does not have a photoprotective dye in its structure. Colored hair is damaged more quickly than natural hair. The influence of radiation on hair may be different, due to the individual quantitative content of particular melanin types.[3]

The melanins present in the cortex, in the middle of the hair shaft, are responsible for the color of the hair, among which we distinguish two forms: pheomelanin—a yellow to red pigment, and eumelanin—brown or black. Melanins are synthesized in melanocytes.[4]

The content of different types of melanin in the hair is an individual feature.[4,5] Melanin is a natural protection against the negative effects of UV rays. The protective effect of melanin is based on the principle of absorbing UV rays and protecting against free radicals. Dark hair is more resistant to UV damage than light hair. Dyed hair, due to the use of synthetic pigments, does not protect against solar radiation. Sun-exposed hair often bleaches. That is why it is so important to properly protect the hair. For this purpose, products containing sunscreens are used. These should be left-on products so that it stays on the surface of the hair and protect it from UV rays penetrating the cuticle.[5] Biological changes in hair pigment include its darkening or lightening observed occasionally at a very young age, or graying.[4,6] In the course of particular diseases, there might be also a change in hair color. Here the specific disease is vitiligo.[7] Hair is regularly exposed to destructive mechanical, thermal, and chemical factors. One of the curtail irritants leading to the hair structure damage is UV radiation, which affects the hair, especially wet hair, causing reactions related to the formation of free radicals. It leads to the keratin denaturation. The hair becomes less resistant to mechanical damage and becomes brittle.[5] Exposure to UV radiation leads to the oxidation of lipid and protein components of the hair. Although melanin provides some protection against the oxidation process, the hair becomes lighter and lighter, due to the oxidation of the hair dyes.

Human skin is a barrier that protects against external factors, including radiation. Darkening of the skin is a defense against the sun, melanin is a natural protective filter. Hyperkeratosis, that is, thickening of the stratum corneum, is also a basic defense mechanism against radiation. What's more, lipids in the epidermis together with transurocanic acid have the ability to absorb and scatter radiation.[8,9]

Considering all the harmful effects of solar radiation, the use of protective products is an important element preventing against the development of erythema or sunburn, as well as the formation of reactive oxygen species responsible not only for photoaging, but also for skin cancer.[10,11] The hair should also be protected from the harmful rays so that it maintains its proper condition. Products containing UV filters absorbing ultraviolet radiation, as well as antioxidants are used.[11,12] The organic filters, silicones and antioxidants are the most commonly used. Usually used product types are ones that remain on the hair, the so-called "leave-on," for example, sprays, gels. Protective substances can also be found in shampoos or conditioners. An important problem is to obtain a layer that will protect all the hair evenly along the entire length. The type of substance used as a filter in sunscreen products is also important. Unfortunately, many organic filters do not adhere precisely to the surface of the hair, making them susceptible to wiping off. Thus, shows poor protection against radiation.[3]

2 | OBJECTIVE

The aim of the study was to examine the effectiveness of sunscreen in hair cosmetics. It was also decided to find an answer whether hair color affects the protective function of such products.

3 | MATERIAL AND METHODS

3.1 | Hemispheric directional reflectance

The directional reflectance (DR) of a surface is the ratio of the total energy reflected to the intermediate half-space to the incident energy on the analyzed surface.[13]

The 410-Solar reflectometer is a device used to measure reflected radiation: total, specular, and diffuse. The device emits radiation in the spectral range of 330–2500 nm. Determines the light reflectance for an angle of incidence of 20° and seven wavelength bands in the UV, visible and near infrared range. The basic parts of the reflectometer construction include: the measuring head and the control module.[14]

3.2 | Study group

The study included a group of nine women. The numerical code from 1 to 9 was assigned to each volunteer. Hair that was varied in color was subjected to the study. On the day of the examination, the hair was freshly washed, no cosmetics were applied. The research was conducted at the Medical University of Silesia, in the Department and Department of Basic Biomedical Sciences. All volunteers agreed to participate in the study.

The study involved two people with natural blond hair, which was classified as "Light" (Figures 1 and 2), two people with light hair obtained by oxidizing dark hair (Figures 3 and 4), which was also classified as "Light," two people with dark natural hair color "Dark" (Figures 5 and 6), one person with dark hair, dyed from light hair classified as "Dark" (Figure 7) and two people with gray hair—"Grey" (Figures 8 and 9) . As a result, a 3-fold measurement (one measurement cycle before the application of each of the three products) was used to compare the reflectance of hair of different colors with each other in four people with light hair (Bright, $N = 12$), 3-fold measurement in three people with dark hair (Dark, $N = 9$) and a 3-fold measurement in two people with gray hair (Gray, $N = 6$). Similarly, to assess the effect of hair color on the effectiveness of sunscreen products, the following groups were used: Light, $N = 12$; Dark, $N = 9$; Gray, $N = 6$, at time points from t0 to t5. The photos of hair colors are presented below. Figures 1–9 show photos taken with the OLYMPUS Tough F 2.0 camera using a lighting system with flat linear characteristics, high CRI (color rendering

FIGURE 1 Natural light hair no. 1.

FIGURE 2 Natural light hair no. 2.

FIGURE 3 Light hair obtained by oxidizing dark hair no. 1.

FIGURE 4 Light hair obtained by oxidizing dark hair no. 2.

index). The flash energy of the lamps was current-controlled, the photos were taken on a white background, which was a reference pattern for identification and white balance averaging.

4 | MATERIALS AND METHODS

During the study, three products characterized by the protection against radiation were used.

ANWEN—SUMMER PROTECT—HAIR MIST WITH UV FILTERS, SPF 10

Ingredients (INCI): Aqua, Dicaprylyl Ether, C12-C15 Alkyl Benzoate, PEG/PPG-20/20 Phenylisopropyl Caprylyl Dimethicone, Octocrylene, Butyl Methoxydibenzoylmethane, Ethylhexyl Triazone, Rubus Idaeus (Raspberry) Seed Oil, Triticum Vulgare (Wheat) Germ Oil, Benzophenone-4, Diethylhexyl Malate, Homosalate, Hydroxypropyltrimonium Hyaluronate, Aloe Barbadensis Leaf Juice Powder, Tocopheryl Acetate, Panthenol, Parfum, Sodium Hydroxide, Citric Acid, Phenoxyethanol, Ethylhexylglycerin, Hexyl Cinnamal, Limonene, Linalool.

ELEMENT—PROTECTIVE HAIR SPRAY, ANTIOXIDANTS + UV FILTERS

Ingredients (INCI): Aqua, Maltooligosyl Glucoside, Hydrogenated Starch Hydrolysate, Lepidium Sativum Sprout Extract, Pullulan, Sodium Carboxymethyl Betaglucan, Caesalpinia Spinosa Gum, Maltodextrin,

FIGURE 5 Natural dark hair no. 1.

FIGURE 6 Natural dark hair no. 2.

FIGURE 7 Dark hair, dyed from light hair no. 1.

FIGURE 8 Gray hair no.1.

Acrylates/Beheneth-25 Methacrylate Copolymer, Butyl Methoxydibenzoylmethane, Octocrylene, Ethylhexyl Methoxycinnamate, Phospholipids, Hydrolyzed Keratin, Argania Spinosa Kernel Oil, Sodium Laureth Sulfate, Butylene Glycol, Parfum, Sodium Hydroxide, Sodium Benzoate, Potassium Sorbate, Caprylyl Glycol, Phenoxyethanol, Benzyl Salicylate, Butylphenyl Methylpropional, Citral, Citronellol, Coumarin, Hexyl Cinnamal, Geraniol, Limonene, Linalool

VIS PLANTIS PROFESSIONAL SPRAY FOR CURLY HAIR WITH UV FILTERS

Ingredients (INCI): Aqua, 1.2-Hexanediol, Inulin, Betaine, Hydrolyzed Jojoba Esters, Hydrolyzed Lupine Seed Extract, Humulus Lupulus (Hops) Cone Extract, Linum Usitatissimum (Linseed) Seed Extract, Maltooligosyl Glucoside, Hydrogenated Starch Hydrolysate, Argania Spinosa (Argan) Kernel Oil, Ethylhexyl Methoxycinnamate,Octocrylene, Butyl Methoxydibenzoylmethane, Phospholipids, Butylene Glycol, Undecane, Tridecane, Glycerin, Tocopherol, Parfum, Acrylates/Beheneth-25 Methacrylate Copolymer, Caprylyl Glycol, Sodium Benzoate, Potassium Sorbate, Phenoxyethanol, Sodium Hydroxide, Benzoic Acid

4.1 | Procedure

Each person's hair was examined with a 410-Solar reflectometer. Measurements were performed before applying the sunscreen (t0), immediately after applying the product (t1), 20 min after (t2), 1 h after

FIGURE 9 Gray hair no.2.

(t2), 1.5 h after (t4), and 2 h (t5) from product application. The selected time points accurately reflect the manufacturer's recommendations for the initial application and subsequent sunscreen applications during exposure to radiation. In our research, time intervals were practical for a customer who follows the application recommendations on the product packaging.

The hair of each person was divided into three strands of similar thickness. One product was applied to each. Measurements were performed in the supine position, so that the strands did not stick to each other. Before measurements, the hair was photographed using an OLYMPUS Tough F2.0 camera.

The tested products were applied to the hair in the amount of 2 mg/cm^2. Cosmetic standards do not specify the amount of the product that should be applied to the hair, so the amounts for skin products, in accordance with the COLIPA standard (The European Cosmetic and Perfumery Association), was applied.

Prior to testing, the 410-Solar reflectometer was enabled and properly calibrated using two calibration coupons. Next, a folder had to be created and the samples had to be named in an understandable way.

During the measurements, the measuring head had to be in close contact with the tested hair. Then, to take the measurement, the trigger had to be pressed. This procedure was performed three times for each strand of hair to standardize the results obtained, which were recorded in seven spectral bands.

4.2 | Statistical analysis

For results analysis Microsoft Excel 2016 was used. Statistical analysis was carried out using the STATISTICA 13 software. Due to the lack of normal distribution, the analysis was carried out using non-parametric tests. Friedman's ANOVA test was used to evaluate the effect of applying particular hair product on reflectance at different time points. The Kruskal–Wallis test was used to compare the reflectance of different hair colors before applying the products. Friedman's ANOVA test was used to assess the effect of hair products on reflectance of the hair in different color, at different time points after application. The statistical significance was set for $p < 0.05$.

5 | RESULTS

5.1 | The influence of various sunscreens on hair reflectance

The reference point for the tested coefficients was clean hair without the application of sunscreens. The lack of information on how the applied cosmetics protect against radiation results from the intention of the research. Testing on a different surface was deliberately not performed, so as to reproduce the most reliable in vivo conditions.

The use of ANWEN product did not have a statistically significant effect on hair reflectance at wavelengths of 335–380 nm, 400–540 nm, 480–600 nm, 590–720 nm, and 700–1100 nm (Table 1).

At the wavelength of 1000–1700 nm, ANWEN had a significant effect on hair reflectance ($p < 0.001$). Clean hair (t0) in this wavelength range showed higher reflectance than hair just after application of ANWEN mist (t1) ($p < 0.05$) and 20 min after its application (t2) ($p < 0.05$).

Hair reflectance at the wavelength of 1700–2500 nm changed in a statistically significant way after using the ANWEN mist ($p < 0.001$). The hair before the product application (t0) at the wavelength of 1700–2500 nm showed a higher reflectance than the hair immediately after the application of the ANWEN mist (t1) ($p < 0.05$) and 20 min after its application (t2) ($p < 0.05$). Compared to the reflectance at time point t1 – just after application, the value of reflectance at t4 – 1.5 h later, was statistically significantly higher ($p < 0.05$).

The effect of the ELEMENT protective spray on the hair reflectance was observed at all tested wavelengths, with the weakest at the range of 335–380 nm and 590–720 nm, on the borderline of statistical significance (respectively $p = 0.051$ and $p = 0.59$) and the strongest at wavelengths above 1000 nm ($p < 0.001$) (Table 3).

At the wavelength of 335–380 nm, it can be observed that the highest reflectance values occurred right after applying the ELEMENT spray (t1), and the lowest values occurred at t0 and t2, but the differences described did not reach statistical significance.

For the other wavelength ranges, opposite relations were observed, that is, clean hair was characterized by the highest reflectance values (t0), while immediately after applying the ELEMENT spray on the hair (t1) the reflectances were the lowest. Moreover after leaving the ELEMENT spray on the hair, their reflectance increased. Detailed reflectance values, with an indication of statistically significant differences between reflectance at individual time points, are presented in the Table 2.

The use of VIS PLANTIS hair spray had a statistically significant effect on the hair reflectance in all tested wavelength ranges, except for the 335–380 nm range (Table 3). At the wavelength ranges of 400–540 nm, 480–600 nm, 590–720 nm, 700–1100 nm,

TABLE 1 Hair reflectance at seven wavelength ranges, before application of ANWEN—SUMMER PROTECT—HAIR MIST WITH UV FILTERS, SPF 10 (t0), immediately after its application (t1), 20 min after (t2), 1 h after (t3), 1.5 h after (t4), and 2 h after (t5) application; Med- median, Q1- first quartile, Q3- third quartile, Min- minimum, Max- maximum, *p*- level of significance, ns- not significant.

Wavelength	Measurement	Med	Q1	Q3	Min	Max	p	post-hoc p<0.05
335-380 nm	t0	0.014	0.011	0.069	0.008	0.278	ns	ns
	t1	0.014	0.012	0.034	0.009	0.113		
	t2	0.016	0.011	0.049	0.007	0.120		
	t3	0.014	0.013	0.025	0.008	0.089		
	t4	0.026	0.014	0.038	0.007	0.093		
	t5	0.012	0.008	0.028	0.006	0.100		
400-540 nm	t0	0.178	0.081	0.237	0.063	0.494	ns	ns
	t1	0.172	0.080	0.206	0.056	0.450		
	t2	0.183	0.094	0.224	0.063	0.477		
	t3	0.153	0.085	0.252	0.062	0.511		
	t4	0.161	0.087	0.212	0.073	0.528		
	t5	0.161	0.087	0.235	0.073	0.475		
480-600 nm	t0	0.147	0.057	0.197	0.021	0.489	ns	ns
	t1	0.138	0.054	0.168	0.023	0.438		
	t2	0.148	0.058	0.183	0.049	0.471		
	t3	0.121	0.054	0.208	0.049	0.510		
	t4	0.129	0.055	0.173	0.048	0.531		
	t5	0.123	0.049	0.191	0.046	0.474		
590-720 nm	t0	0.213	0.049	0.317	0.030	0.525	ns	ns
	t1	0.201	0.037	0.252	0.032	0.481		
	t2	0.220	0.050	0.285	0.035	0.507		
	t3	0.177	0.063	0.323	0.033	0.550		
	t4	0.185	0.077	0.262	0.028	0.570		
	t5	0.184	0.067	0.297	0.031	0.515		
700-1100 nm	t0	0.475	0.293	0.616	0.223	0.707	ns	ns
	t1	0.461	0.231	0.601	0.201	0.678		
	t2	0.464	0.243	0.565	0.224	0.697		
	t3	0.409	0.244	0.631	0.211	0.681		
	t4	0.430	0.259	0.541	0.223	0.692		
	t5	0.418	0.282	0.597	0.215	0.640		
1000-1700 nm	t0	0.587	0.513	0.607	0.457	0.660	<0.001	t0 vs t1 t0 vs t2
	t1	0.514	0.467	0.537	0.387	0.637		
	t2	0.521	0.477	0.559	0.446	0.632		
	t3	0.539	0.462	0.559	0.456	0.652		
	t4	0.520	0.483	0.566	0.454	0.655		
	t5	0.542	0.514	0.568	0.448	0.622		
1700-2500 nm	t0	0.265	0.248	0.288	0.219	0.319	<0.001	t0 vs t1 t0 vs t2 t1 vs t4
	t1	0.175	0.145	0.227	0.124	0.260		
	t2	0.236	0.214	0.239	0.113	0.259		
	t3	0.231	0.219	0.240	0.167	0.267		
	t4	0.239	0.223	0.246	0.184	0.267		
	t5	0.231	0.223	0.253	0.207	0.301		

the lowest hair reflectance occurred just after application (t1) and was significantly lower than the reflectance measured 2 h after application (t5). At the wavelength of 1000–1700 nm, the highest reflectance was shown for clean hair (t0), significantly higher than for hair with VIS PLANTIS immediately after application (t1) ($p < 0.05$) and 20 min after application (t2). In addition, it was found that at the wavelength of 1000–1700 nm immediately after the application of VIS PLANTIS (t1), the reflectance was significantly lower than after 1.5 h (t4, $p < 0.05$) and 2 h (t5, $p < 0.05$). At the wavelength of 1700–2500 nm, statistically significant differences in reflectance were analogous to those at the wavelength of 1000–1700 nm, additionally it was shown that the reflectance 2 h after product application (t5) was significantly higher than 20 min after (t2) ($p < 0.05$).

TABLE 2 Hair reflectance at seven wavelength ranges, before application of ELEMENT—PROTECTIVE HAIR SPRAY, ANTIOXIDANTS + UV FILTERS (t0), immediately after its application (t1), 20 min after (t2), 1 h after (t3), 1.5 h after (t4), and 2 h after (t5) application; Med- median, Q1-first quartile, Q3- third quartile, Min- minimum, Max- maximum, *p*- level of significance, ns- not significant.

Wavelength	Measurement	Med	Q1	Q3	Min	Max	p	post-hoc p<0.05
335-380 nm	t0	0.016	0.010	0.058	0.007	0.271	=0.051	ns
	t1	0.032	0.015	0.042	0.006	0.131		
	t2	0.014	0.010	0.044	0.006	0.098		
	t3	0.017	0.012	0.037	0.007	0.100		
	t4	0.019	0.012	0.050	0.009	0.135		
	t5	0.022	0.011	0.034	0.008	0.090		
400-540 nm	t0	0.212	0.081	0.234	0.065	0.495	<0.01	t0 vs t1 t1 vs t5
	t1	0.135	0.075	0.229	0.054	0.405		
	t2	0.159	0.076	0.234	0.051	0.449		
	t3	0.177	0.091	0.241	0.071	0.385		
	t4	0.187	0.101	0.201	0.065	0.483		
	t5	0.188	0.092	0.278	0.084	0.482		
480-600 nm	t0	0.184	0.058	0.197	0.021	0.483	<0.05	t0 vs t1 t1 vs t5
	t1	0.107	0.057	0.184	0.023	0.383		
	t2	0.125	0.060	0.191	0.047	0.435		
	t3	0.136	0.065	0.190	0.048	0.364		
	t4	0.151	0.070	0.162	0.050	0.476		
	t5	0.146	0.066	0.244	0.044	0.479		
590-720 nm	t0	0.266	0.056	0.296	0.028	0.535	=0.059	t1 vs t5
	t1	0.136	0.050	0.305	0.033	0.435		
	t2	0.186	0.060	0.295	0.027	0.484		
	t3	0.178	0.083	0.311	0.030	0.422		
	t4	0.221	0.100	0.252	0.032	0.522		
	t5	0.220	0.093	0.373	0.033	0.526		
700-1100 nm	t0	0.489	0.297	0.616	0.228	0.682	<0.01	t0 vs t1 t1 vs t5
	t1	0.384	0.281	0.579	0.213	0.614		
	t2	0.431	0.258	0.589	0.204	0.635		
	t3	0.356	0.314	0.595	0.259	0.654		
	t4	0.487	0.321	0.488	0.238	0.649		
	t5	0.476	0.307	0.639	0.253	0.684		
1000-1700 nm	t0	0.569	0.513	0.612	0.457	0.694	<0.001	t0 vs t1 t1 vs t3 t1 vs t5
	t1	0.426	0.396	0.454	0.378	0.533		
	t2	0.457	0.450	0.517	0.332	0.554		
	t3	0.511	0.506	0.549	0.402	0.606		
	t4	0.514	0.502	0.594	0.388	0.613		
	t5	0.529	0.501	0.589	0.464	0.628		
1700-2500 nm	t0	0.269	0.249	0.316	0.236	0.339	<0.001	t0 vs t1 t0 vs t2 t1 vs t5 t2 vs t5
	t1	0.146	0.086	0.157	0.042	0.218		
	t2	0.174	0.152	0.196	0.052	0.264		
	t3	0.240	0.160	0.254	0.101	0.275		
	t4	0.251	0.203	0.261	0.096	0.302		
	t5	0.260	0.251	0.275	0.145	0.311		

5.2 | Reflectance of different hair colors and the influence of hair color on the sunscreens effectiveness

It was shown that before applying sunscreen products hair reflectance differed in a statistically significant way depending on their color in all wavelength ranges from 335 to 1700 nm (Table 4). Only in the highest range (1700–2500 nm) no statistically significant differences between different hair colors were found. Dark hair was characterized by the lowest reflectance, significantly lower than light hair reflectance at wavelengths of 400–540 nm, 480–600 nm, 590–720 nm, 700–1100 nm, and 1000–1700 nm. Dark hair was also characterized by significantly lower reflectance than gray hair at wavelengths of 335–380 nm, 400–540 nm, 480–600 nm and 590–720 nm. Gray hair had significantly higher reflectance than light hair at wavelength of 335–380 nm.

TABLE 3 Hair reflectance at seven wavelength ranges, before application of VIS PLANTIS PROFESSIONAL SPRAY FOR CURLY HAIR WITH UV FILTERS (t0), immediately after its application (t1), 20 min after (t2), 1 h after (t3), 1.5 h after (t4), and 2 h after (t5) application; Med- median, Q1- first quartile, Q3- third quartile, Min- minimum, Max- maximum, *p*- level of significance, ns- not significant.

Wavelength	Measurement	Med	Q1	Q3	Min	Max	p	post-hoc p<0,05
335-380 nm	t0	0.023	0.011	0.060	0.009	0.260	ns	ns
	t1	0.017	0.011	0.038	0.005	0.161		
	t2	0.025	0.012	0.048	0.007	0.190		
	t3	0.025	0.012	0.039	0.007	0.155		
	t4	0.024	0.018	0.049	0.008	0.178		
	t5	0.023	0.017	0.041	0.008	0.140		
400-540 nm	t0	0.219	0.094	0.242	0.085	0.514	<0.05	t1 vs t5
	t1	0.140	0.054	0.244	0.045	0.522		
	t2	0.165	0.071	0.236	0.067	0.551		
	t3	0.191	0.090	0.226	0.063	0.519		
	t4	0.164	0.104	0.282	0.064	0.528		
	t5	0.163	0.097	0.222	0.026	0.560		
480-600 nm	t0	0.198	0.065	0.218	0.022	0.514	<0.01	t1 vs t5
	t1	0.100	0.051	0.200	0.006	0.521		
	t2	0.137	0.060	0.188	0.044	0.552		
	t3	0.162	0.060	0.177	0.047	0.519		
	t4	0.139	0.063	0.244	0.042	0.530		
	t5	0.152	0.061	0.226	0.050	0.564		
590-720 nm	t0	0.282	0.079	0.322	0.031	0.566	<0.01	t1 vs t5
	t1	0.150	0.036	0.312	0.012	0.573		
	t2	0.164	0.057	0.310	0.030	0.593		
	t3	0.220	0.062	0.281	0.026	0.578		
	t4	0.177	0.081	0.379	0.030	0.581		
	t5	0.182	0.091	0.349	0.037	0.604		
700-1100 nm	t0	0.522	0.316	0.574	0.276	0.710	<0.05	t1 vs t5
	t1	0.385	0.222	0.582	0.191	0.709		
	t2	0.376	0.264	0.579	0.233	0.712		
	t3	0.484	0.311	0.564	0.216	0.722		
	t4	0.425	0.318	0.632	0.231	0.711		
	t5	0.423	0.329	0.631	0.259	0.713		
1000-1700 nm	t0	0.566	0.553	0.618	0.513	0.677	<0.001	t0 vs t1 t0 vs t2 t1 vs t4 t1 vs t5
	t1	0.406	0.373	0.554	0.345	0.616		
	t2	0.481	0.459	0.596	0.379	0.622		
	t3	0.527	0.450	0.593	0.437	0.651		
	t4	0.563	0.509	0.602	0.416	0.644		
	t5	0.569	0.538	0.618	0.513	0.643		
1700-2500 nm	t0	0.278	0.271	0.296	0.219	0.310	<0.001	t0 vs t1 t0 vs t2 t1 vs t4 t1 vs t5 t2 vs t5
	t1	0.121	0.105	0.202	0.033	0.205		
	t2	0.208	0.198	0.222	0.070	0.271		
	t3	0.240	0.237	0.244	0.102	0.266		
	t4	0.273	0.240	0.289	0.141	0.297		
	t5	0.271	0.245	0.293	0.201	0.328		

A statistically significant effect of sunscreen products on light hair reflectance was observed at wavelengths between 400 and 720 nm and between 1000 and 2500 nm (Table 5). At all the wavelength ranges mentioned above, the reflectance of light hair before products application (t0) was statistically significantly higher than the reflectance of hair immediately after application (t1). In addition, at wavelengths of 1000–1700 nm and 1700–2500 nm, the reflectance of light hair before application (t0) was higher than 20 min after application (t2). At these ranges, it was also observed that just after application (t1), the reflectance of light hair was significantly lower than 1.5 h (t4) and 2 h after application (t5). At the wavelength of 1700–2500 nm there were also significant differences between the reflectance at time points t0 and t3.

The use of sunscreen products on dark hair resulted in statistically significant differences in reflectance at all wavelength ranges, starting from 400 nm (Table 6). At the wavelength of 400–540 nm, the lowest reflectance occurred just after applying the products (t1) and it was significantly lower than the reflectance after 1.5 h (t4) and 2 h (t5)

TABLE 4 Reflectance of different hair colors at seven wavelength ranges, before application of protective products; Med- median, Q1- first quartile, Q3- third quartile, Min- minimum, Max- maximum, *p*- level of significance, ns- not significant.

Wavelength	Measurement	Med	Q1	Q3	Min	Max	p	post-hoc p<0,05
335-380 nm	Light	0.027	0.013	0.055	0.009	0.069	<0.001	S vs J S vs C
	Dark	0.010	0.009	0.011	0.007	0.016		
	Grey	0.188	0.093	0.271	0.092	0.278		
400-540 nm	Light	0.235	0.219	0.256	0.178	0.322	<0.001	C vs J C vs S
	Dark	0.081	0.069	0.085	0.063	0.094		
	Grey	0.329	0.162	0.495	0.154	0.514		
480-600 nm	Light	0.198	0.190	0.228	0.147	0.312	<0.001	C vs J C vs S
	Dark	0.055	0.022	0.058	0.021	0.065		
	Grey	0.313	0.137	0.489	0.130	0.514		
590-720 nm	Light	0.294	0.281	0.346	0.213	0.443	<0.001	C vs J C vs S
	Dark	0.041	0.031	0.056	0.028	0.079		
	Grey	0.347	0.162	0.535	0.153	0.566		
700-1100 nm	Light	0.565	0.517	0.642	0.475	0.707	<0.01	C vs J
	Dark	0.276	0.240	0.322	0.223	0.352		
	Grey	0.477	0.293	0.682	0.289	0.710		
1000-1700 nm	Light	0.610	0.587	0.619	0.553	0.636	<0.01	C vs J
	Dark	0.513	0.513	0.549	0.457	0.566		
	Grey	0.589	0.497	0.677	0.486	0.694		
1700-2500 nm	Light	0.274	0.246	0.295	0.219	0.316	ns	ns
	Dark	0.265	0.236	0.310	0.219	0.339		
	Grey	0.280	0.271	0.286	0.265	0.334		

after application. At the wavelength of 480–600 nm, the reflectance at t1 – just after product application was significantly lower than at t3 – after 1 h. At the wavelength of 590–720 nm, the reflectance at t1 – was significantly lower than at t5. At the wavelength of 700–1100 nm, the lowest reflectance occurred just after applying the hair products (t1) and it was significantly lower than the reflectance of clean dark hair (t0), and the reflectance 1 h (t3) and 1.5 h (t4) after application. The reflectance of clean dark hair at the wavelength of 1000–1700 nm was significantly higher than its reflectance just after (t1) and 20 min after application (t2), moreover, the reflectance of dark hair immediately after application (t1) was significantly lower than their reflectance 1 h (t3) and two hours later (t5). The reflectance of clean hair at the wavelength of 1700–2500 nm was the highest (t0), significantly higher than the reflectance just after (t1) and 20 min after applying the products (t2), and the reflectance at time point t1 was significantly lower than reflectance at t4 and t5.

A statistically significant effect of sunscreen products on the reflectance of gray hair occurred in the extreme wavelength ranges used in the study (Table 7). At the wavelength of 335–380 nm, the reflectance of clean gray hair (t0) was significantly higher than the reflectance of hair immediately after application (t1) and 2 h after application (t5). At wavelengths of 1000–1700 nm and 1700–2500 nm hair gray without the applied product (t0) showed a higher reflectance than the hair immediately after application (t1), additionally, at the wavelength of 1700–2500 nm statistically significant differences occurred at the time points t0 and t2.

The study analyzed the reflectance of hair in a wide range from 335 to 2500 nm. But a separate graphical presentation of the results in the 335–380 nm spectral range was not presented because the results were not statistically significant.

6 | DISCUSSION

Solar radiation brings many negative effects on the structure of the hair, especially within the hair shaft.[15] The hair of the head is the most vulnerable to sun damage. Frequent and prolonged exposure to sunlight causes changes in the hair, such as decreased tensile strength, dulling, split ends and changes in color. UV radiation initiates the formation of free radicals.[16] The consequence of which is the lipid, protein and melanin oxidation in the hair.

The hair melanin, despite its radiation-protective properties, is not able to fully protect the hair from the negative effects of radiation. Therefore, it is recommended to use UV filters not only for the skin, but also for the hair. Such products usually contain silicones, which are responsible for the even filters distribution on the hair surface, antioxidants to neutralize free radicals, and organic filters. Despite the use of coating substances, such as silicones, products in the form of aerosols and mists are not evenly distributed on the surface of the hair shafts. Unfortunately, the inability to cover every millimeter of hair thoroughly, limits the effectiveness of the cosmetics. The lack of standards for evaluating the effectiveness of hair products makes it difficult to analyze the results in the literature. It seems important to establish appropriate conditions, similar to those during the sun exposure. These are irradiation time, humidity, temperature, and radiation intensity.[2,3,12]

TABLE 5 Reflectance of light hair at seven wavelength ranges, before the application of protective products (t0) and immediately after its application (t1), 20 min after (t2), 1 h after (t3), 1.5 h after (t4), and 2 h after (t5) application; Med- median, Q1- first quartile, Q3- third quartile, Min- minimum, Max- maximum, *p*- level of significance, ns- not significant.

Wavelength	Measurement	Med	Q1	Q3	Min	Max	p	post-hoc p<0.05
335-380 nm	t0	0.027	0.013	0.055	0.009	0.069	ns	ns
	t1	0.029	0.014	0.038	0.005	0.042		
	t2	0.023	0.014	0.041	0.008	0.049		
	t3	0.025	0.013	0.034	0.009	0.039		
	t4	0.027	0.021	0.040	0.010	0.050		
	t5	0.023	0.014	0.029	0.008	0.041		
400-540 nm	t0	0.235	0.219	0.256	0.178	0.322	<0.05	t0 vs t1
	t1	0.206	0.164	0.240	0.135	0.319		
	t2	0.225	0.184	0.252	0.138	0.320		
	t3	0.222	0.180	0.265	0.136	0.293		
	t4	0.202	0.183	0.259	0.161	0.284		
	t5	0.215	0.166	0.276	0.026	0.299		
480-600 nm	t0	0.198	0.190	0.228	0.147	0.312	<0.05	t0 vs t1
	t1	0.154	0.128	0.195	0.095	0.290		
	t2	0.181	0.151	0.211	0.098	0.286		
	t3	0.175	0.144	0.224	0.101	0.265		
	t4	0.157	0.146	0.217	0.119	0.254		
	t5	0.194	0.140	0.238	0.121	0.262		
590-720 nm	t0	0.294	0.281	0.346	0.213	0.443	<0.05	t0 vs t1
	t1	0.248	0.190	0.310	0.133	0.419		
	t2	0.281	0.221	0.330	0.148	0.427		
	t3	0.273	0.212	0.342	0.135	0.394		
	t4	0.247	0.216	0.334	0.177	0.381		
	t5	0,289	0.207	0.364	0.179	0.390		
700-1100 nm	t0	0.565	0.517	0.642	0.475	0.707	ns	ns
	t1	0.544	0.432	0.608	0.384	0.678		
	t2	0.547	0.474	0.612	0.376	0.697		
	t3	0.542	0.462	0.642	0.356	0.654		
	t4	0.503	0.478	0.613	0.425	0.676		
	t5	0.566	0.465	0.640	0.418	0.684		
1000-1700 nm	t0	0.610	0.587	0.619	0.553	0.636	<0.001	t0 vs t1 t0 vs t2 t1 vs t4 t1 vs t5
	t1	0.507	0.401	0.546	0.389	0.557		
	t2	0.520	0.474	0.567	0.403	0.608		
	t3	0.552	0.488	0.585	0.402	0.606		
	t4	0.568	0.527	0.597	0.388	0.631		
	t5	0.575	0.565	0.604	0.502	0.628		
1700-2500 nm	t0	0.274	0.246	0.295	0.219	0.316	<0.001	t0 vs t1 t0 vs t2 t0 vs t3 t1 vs t4 t1 vs t5
	t1	0.144	0.092	0.204	0.033	0.228		
	t2	0.202	0.133	0.241	0.056	0.271		
	t3	0.222	0.164	0.258	0.101	0.269		
	t4	0.240	0.198	0.272	0.096	0.297		
	t5	0.253	0.224	0.279	0.145	0.328		

The results obtained using the 410-Solar reflectometer allow to determine the effectiveness of the hair filters in vivo. The hemispheric directional reflectance of the hair before and after the use of sunscreen products showed the lack of effectiveness of the used cosmetics with filters for most wavelength ranges. Immediately after using each product, an increase in radiation absorption was noticed compared to clean hair, which was a surprising result of the study. The ANWEN product did not significantly effect the reflectance of the hair in the wavelength ranges of 335–380 nm, 400–540 nm, 480–600 nm, 590–720 nm, and 700–1100 nm. In the infrared range (1000–17000 nm, 1700–2500 nm), the reflectance of the hair after product application was lower than the reflectance of clean hair. The use of the ELEMENT product increased the reflectance immediately after application at the wavelength of 335–380 nm. In other waveranges, the hair reflectance after application was lower than the reflectance of clean hair.

TABLE 6 Reflectance of dark hair at seven wavelength ranges, before the application of protective products (t0) and immediately after its application (t1), 20 min after (t2), 1 h after (t3), 1.5 h after (t4), and 2 h after (t5) application; Med- median, Q1- first quartile, Q3- third quartile, Min- minimum, Max- maximum, *p*- level of significance, ns- not significant.

Wavelength	Measurement	Med	Q1	Q3	Min	Max	p	post-hoc p<0.05
335-380 nm	t0	0.010	0.009	0011	0.007	0.016	ns	ns
	t1	0.011	0.008	0.014	0.006	0.022		
	t2	0.010	0.007	0.011	0.006	0.013		
	t3	0.012	0.008	0.014	0.007	0.019		
	t4	0.011	0.008	0.014	0.007	0.018		
	t5	0.009	0.008	0.012	0.006	0.017		
400-540 nm	t0	0.081	0.069	0.085	0.063	0.094	<0.001	t1 vs t3 t1 vs t4 t1 vs t5
	t1	0.056	0.054	0.062	0.045	0.080		
	t2	0.070	0.067	0.072	0.051	0.094		
	t3	0.082	0.071	0.090	0.062	0.094		
	t4	0.085	0.073	0.096	0.064	0.104		
	t5	0.088	0.085	0.094	0.073	0.111		
480-600 nm	t0	0.055	0.022	0.058	0.021	0.065	<0.05	t1 vs t3
	t1	0.048	0.023	0051	0.006	0.057		
	t2	0.051	0.047	0.058	0.044	0.060		
	t3	0.054	0.049	0.060	0.047	0.065		
	t4	0.053	0.050	0.057	0.042	0.070		
	t5	0.049	0.047	0.059	0.044	0.066		
590-720 nm	t0	0.041	0.031	0.056	0.028	0.079	<0.01	t1 vs t5
	t1	0.036	0.033	0.036	0.012	0.050		
	t2	0.036	0.035	0.050	0.027	0.060		
	t3	0.040	0.033	0.062	0.026	0.083		
	t4	0.042	0.032	0.078	0.028	0.100		
	t5	0.066	0.037	0.087	0.031	0.093		
700-1100 nm	t0	0.276	0.240	0.322	0.223	0.352	<0.01	t0 vs t1 t1 vs t3 t1 vs t4
	t1	0.213	0.202	0.222	0.191	0.313		
	t2	0.243	0.233	0.258	0.204	0.318		
	t3	0.292	0.244	0.311	0.216	0.318		
	t4	0.259	0.238	0.302	0.231	0.344		
	t5	0.260	0.255	0.307	0.215	0.333		
1000-1700 nm	t0	0.513	0.513	0.549	0.457	0.566	<0.001	t0 vs t1 t0 vs t2 t1 vs t3 t1 vs t5
	t1	0.387	0.373	0.396	0.345	0.510		
	t2	0.457	0.446	0.464	0.332	0.521		
	t3	0.458	0.456	0.515	0.450	0.539		
	t4	0.499	0.469	0.502	0.416	0.538		
	t5	0.502	0.473	0.530	0.448	0.542		
1700-2500 nm	t0	0.265	0.236	0.310	0.219	0.339	<0.001	t0 vs t1 t0 vs t2 t1 vs t4 t1 vs t5
	t1	0.129	0.105	0.146	0.056	0.215		
	t2	0.214	0.188	0.219	0.052	0.264		
	t3	0.240	0.237	0.247	0.135	0.275		
	t4	0.246	0.223	0.273	0.141	0.302		
	t5	0.251	0.223	0.301	0.178	0.311		

TABLE 7 Reflectance of gray hair at seven wavelength ranges, before the application of protective products (t0) and immediately after its application (t1), 20 min after (t2), 1 h after (t3), 1.5 h after (t4), and 2 h after (t5) application; Med- median, Q1- first quartile, Q3- third quartile, Min- minimum, Max- maximum, p- level of significance, ns- not significant.

Wavelength	Measurement	Med.	Q1	Q3	Min	Max	p	post-hoc p<0.05
335-380 nm	t0	0.188	0.093	0.271	0.092	0.278	<0.01	t0 vs t1 t0 vs t5
	t1	0.083	0.045	0.131	0.034	0.161		
	t2	0.089	0.057	0.120	0.054	0.190		
	t3	0.084	0.068	0.100	0.044	0.155		
	t4	0.078	0.051	0.135	0.050	0.178		
	t5	0.070	0.039	0.100	0.036	0.140		
400-540 nm	t0	0.329	0.162	0.495	0.154	0.514	ns	ns
	t1	0.270	0.112	0.450	0.098	0.522		
	t2	0.307	0.123	0.477	0.109	0.551		
	t3	0.288	0.178	0.511	0.085	0.519		
	t4	0.323	0.159	0.528	0.095	0.528		
	t5	0.326	0.174	0.482	0.131	0.560		
480-600 nm	t0	0.313	0.137	0.489	0.130	0.514	ns	ns
	t1	0.245	0.084	0.438	0.066	0.521		
	t2	0.286	0.093	0.471	0.077	0.552		
	t3	0.263	0.143	0.510	0.054	0.519		
	t4	0.308	0.122	0.530	0.063	0.531		
	t5	0.313	0.142	0.479	0.098	0.564		
590-720 nm	t0	0.347	0.162	0.535	0.153	0.566	ns	ns
	t1	0.286	0.106	0.481	0.090	0.573		
	t2	0.324	0.116	0.507	0.101	0.593		
	t3	0.308	0.178	0.550	0.076	0.578		
	t4	0.345	0.157	0.570	0.085	0.581		
	t5	0.349	0.177	0.526	0.125	0.604		
700-1100 nm	t0	0.477	0.293	0.682	0.289	0.710	ns	ns
	t1	0.444	0.238	0.636	0.231	0.709		
	t2	0.475	0.264	0.641	0.243	0.712		
	t3	0.476	0.350	0.681	0.211	0.722		
	t4	0.493	0.318	0.692	0.223	0.711		
	t5	0.495	0.329	0.653	0.282	0.713		
1000-1700 nm	t0	0.589	0.497	0.677	0.486	0.694	<0.01	t0 vs t1
	t1	0.500	0.426	0.616	0.409	0.637		
	t2	0.511	0.475	0.622	0.457	0.632		
	t3	0.542	0.511	0.651	0.462	0.652		
	t4	0.565	0.509	0.644	0.483	0.655		
	t5	0.576	0.519	0.626	0.514	0.643		
1700-2500 nm	t0	0.280	0.271	0.286	0.265	0.334	<0.001	t0 vs t1 t0 vs t2
	t1	0.180	0.152	0.227	0.147	0.260		
	t2	0.212	0.196	0.238	0.164	0.259		
	t3	0.240	0.231	0.243	0.193	0.267		
	t4	0.254	0.240	0.267	0.240	0.267		
	t5	0.254	0.251	0.255	0.245	0.261		

The VIS PLANTIS product did not significantly affect the hair reflectance at the wavelength range of 335–380 nm (UVA). In the other waveranges, the hair reflectance after application was lower than the reflectance of clean hair. UV radiation damages the hair structure. However, wet hair is more vulnerable. A humid environment contributes to the increased free radicals and reactive oxygen species formation, which affect keratin by oxidizing disulfide bonds, which reduces the hair's mechanical resistance.[12] In the article entitled "UV damage to hair and the effect of antioxidants and metal chelators" by K.R. Millington and J.M. Marsh, special techniques to detect the presence of free radicals in the hair after exposure to UV radiation and to assess the effectiveness of UV protecting treatments were used. The techniques used are electron paramagnetic resonance (EPR) spectroscopy and a terephthalate probe for hydroxyl radicals detection. Studies have shown that irradiation of wet hair leads to increased production of hydroxyl radicals. The presence of copper ions in the hair, caused by the use of tap water, also contributes to the increased hydroxyl radicals formation in a humid environment.[12]

So far, the directional reflectance method has not been used to test the effectiveness of hair sunscreens in any research project before.

All three tested products contained water in the first place in the list of ingredient. It brings to the hypothesis whether a water-based products do not cause the opposite effect to the intended radiation protection properties. The melanin in the hair helps to protect against solar radiation. Light and gray hair is more susceptible to radiation damage than dark hair. Dyeing the hair also lowers its protection.[5]

Dark hair showed the highest absorption of radiation in all wavelength ranges, which is a consequence of the highest eumelanin concentration.

In the spectral range of 1700–2500 nm, no statistically significant differences in the reflectance of different hair colors were obtained. Presumably, the radiation absorbed by melanins (eumelanin and pheomelanin) decreases along with increasing wavelength, because the radiation energy depend of the wavelength. The higher the wavelength the lower the radiation energy, and thus the protection does not have to be as effective. In the other ranges, dark hair was characterized by the lowest reflectance compared to light and gray hair. In terms of UV and visible light, gray hair was characterized by the highest reflectance. In the wavelength ranges of 700–1100 nm and 1000–17000 nm, light hair had the highest reflectance.

The effect of used sunscreens on the light hair reflectance was found at wavelengths between 400 and 720 nm and between 1000 and 2500 nm. For all the wavelengths mentioned above, the light hair reflectance before products application was significantly higher than the reflectance after the application. The use of the products on light hair did not have a statistically significant effect on hair reflectance at wavelengths in the 335–380 nm and 700–1100 nm ranges. The use of products on dark hair did not have a statistically significant effect on hair reflectance at the wavelength range of 335–380 nm. The effect of sunscreens on the dark hair reflectance was observed at wavelengths between 400 and 2500 nm. For all the wavelength mentioned above, the dark hair reflectance before products application was significantly higher than the hair reflectance immediately after application.

The use of products on gray hair did not have a statistically significant effect on hair reflectance at wavelengths between 400 and 1100 nm. The effect of sunscreens on the gray air reflectance was observed in the UV and infrared range, the reflectance of gray hair before products application was significantly higher than the hair reflectance immediately after the applications.

During the research, hair with a natural blond color and those dyed light from dark colors were classified as "light" hair. Natural dark hair and those dyed dark from light colors were assigned to "dark" hair. The hair coloring procedure may have influenced the obtained results, same as the number of washing procedures after dying. Assessing the effectiveness of protection against radiation in hair cosmetics, the daily hair care, lifestyle or respondents diet were not analyzed, although it is widely known that these factors affect the physiology of the hair.[17–19] Such correlations require further research in this area. There are constantly newer products on the market appearing, characterized by different ingredients and formulation. Hopefully, the effective product that protects hair from solar radiation will appear soon.

7 | CONCLUSIONS

1. The 410-Solar reflectometer is useful to assess the effectiveness of hair sunscreens in vivo and ex vivo .
2. The obtained results indicate that all three tested hair products do not show the expected protection properties.
3. When analyzing the reflectance of each hair color, dark hair showed the highest absorption of radiation in all wavelength ranges, suggesting that dark hair should be more protected against radiation than light and gray hair.

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CONFLICT OF INTEREST STATEMENT

The author reports no conflicts of interest in this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICAL STATEMENT

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Bioethics Committee of the Medical University of Silesia (PCN/CBN/0052/KB1/62/22).

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