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"Synergy between a food supplement and a cosmetic care for hair longevity: effects on protein carbonylation, hair pigmentation and texture"

Elsa Renzacci [1], Emilie Cecconi-Roman [1], Jessica Magand [1], Karine Ancolio-Morcq [1], Stella Ricois [1], Aurélie Guyoux [1, *]

[1] R&D, Laboratoires Arkopharma, Carros, France

1. Introduction

Hair aging manifests progressively as changes in fiber integrity, pigmentation loss, and diminished follicular activity, resulting from the cumulative impact of genetic predisposition, hormonal shifts, and environmental oxidative damage [1], [2], [3]. Protein carbonylation, keratin fiber weakening, and melanocyte depletion underlie the visible hallmarks of aging hair [4], [5]. Concomitantly, deterioration of hair follicle stem cell niches and impaired vascularization further contribute to reduced hair density and delayed growth cycles [6], [7].

We performed a monocentric, single-blind, controlled clinical study in order to clinically validate the efficacy of a combined nutraceutical and cosmetic care regimen, specifically formulated to address structural deterioration, oxidative damage, melanocyte dysfunction, and hydration loss — the principal biological pathways implicated in hair aging.

Conventional hair care products often target individual manifestations of aging, lacking an integrated, mechanistically grounded approach. Nutraceuticals, on the other hand, offer systemic support for cellular pathways associated with oxidative stress, melanin biosynthesis, and microcirculatory function. The present study evaluates a novel synergistic strategy combining a food supplement and a topical cosmetic product to counteract the multifactorial aspects of hair aging.

The synergistic efficacy observed in this study is underpinned by the scientifically designed composition of the food supplement and the topical cosmetic care, each contributing distinct but complementary actions.

The oral food supplement contains a selection of actives targeting internal pathways critical for hair vitality (see Figure 1). L-Tyrosine serves as a key substrate for melanin biosynthesis,

acting as a precursor for the enzymatic cascade leading to hair pigmentation [8]. Copper, an essential cofactor for tyrosinase, enhances the enzymatic conversion of tyrosine to melanin, thus promoting melanogenesis [9]. Catalase provides antioxidant protection by decomposing hydrogen peroxide, thereby preventing oxidative damage to hair follicles and protecting against premature greying [10]. Blueberry extract (Vaccinium myrtillus) delivers potent anthocyanins, enhancing scalp microcirculation and improving nutrient delivery to hair follicles [11],[12]. Vitamins B5, B6, B8, and B9 contribute to optimal keratin synthesis, follicular metabolism, and maintenance of hair structure integrity. Zinc plays a critical role as a cofactor for numerous enzymatic processes essential for protein structure stabilization and follicular defense against oxidative injury.

In parallel, the topical cosmetic product offers direct action on the hair shaft and scalp environment through targeted botanicals and hydration agents (see Figure 1). Spiny restharrow (*Ononis spinosa* L.) and black oats (*Avena strigosa* Schreb.) stimulate melanin production locally and protect melanocytes from oxidative stress, supporting pigmentation maintenance . Ginkgo biloba extract improves scalp microcirculation, boosts oxygen and nutrient supply to follicles, and exerts a strong antioxidant action that protects against cellular aging [13],[14],[15]. Hyaluronic acid acts as a hygroscopic molecule, attracting and retaining water within the hair shaft, thus improving fiber hydration and mechanical resilience [16]. Sodium PCA complements this moisturizing effect by enhancing water retention within the stratum corneum of the scalp, optimizing scalp barrier function and comfort [17],[18]. Topically delivered B vitamins (B5, B6, B8) further promote keratinization processes and balance sebaceous gland activity, contributing to improved scalp and hair quality.

Mechanistically, the intervention targets four fundamental biological pathways. First, stimulation of melanogenesis is achieved through the tyrosine-copper synergy and the pigmentation support of botanical extracts. Second, antioxidant defenses are reinforced via catalase, zinc, and phytochemical antioxidants, reducing oxidative damage to the hair structure and melanocytes. Third, vascular support is enhanced by blueberry and Ginkgo biloba extracts, ensuring an optimal supply of nutrients and oxygen to the hair follicle microenvironment. Fourth, structural reinforcement and hydration maintenance are promoted by the combined actions of B vitamins, sodium PCA, and hyaluronic acid, contributing to scalp health and fiber resilience (see Figure 1).

This multi-targeted approach is hypothesized to provide superior protection against the multifactorial processes driving hair aging, resulting in visible and measurable improvements in hair structure, pigmentation, and texture .

Study Objective

Therefore, the aim of the present study was to clinically evaluate the efficacy and safety of a combined oral nutraceutical and topical cosmetic regimen in counteracting the structural, pigmentary, and textural hallmarks of hair aging. Specifically, the study sought to assess the impact of this synergistic intervention on protein oxidation levels, hair pigmentation dynamics, hair fiber hydration, density, and the hair growth cycle. The objective was to demonstrate that

targeting multiple biological pathways simultaneously could provide superior and measurable benefits for hair longevity compared to monotherapies.

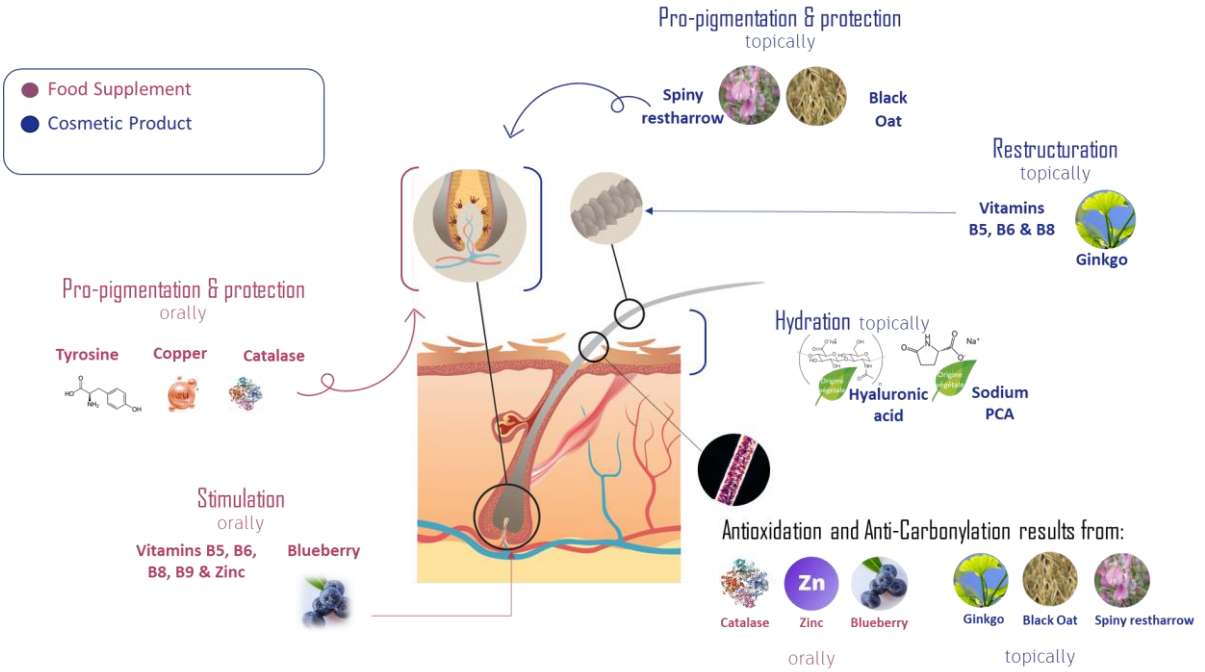

Figure 1 : Mechanistic pathways targeted by the combined nutraceutical and cosmetic intervention for hair longevity.

Schematic representation of biological pathways involved in hair aging and targeted by the synergistic regimen. Ingredients from the oral supplement are shown in purple (systemic actions: antioxidation, melanogenesis support, vascularization), and ingredients from the topical cosmetic product are shown in blue (local actions: hydration, melanocyte protection, structural reinforcement). The combined intervention leverages a food supplement rich in substrates for melanogenesis, antioxidants, and vascular support factors, alongside a topical cosmetic product targeting hair fiber integrity, scalp hydration, and local antioxidative protection. Mechanistically, the combined intervention addresses stimulation of melanogenesis, reinforcement of antioxidant defenses, enhancement of vascular supply, and structural rehydration and repair.

2. Materials and Methods

A monocentric, single-blind, controlled clinical study was conducted under dermatological supervision to investigate the synergistic anti-aging effects of a combined oral nutraceutical and topical cosmetic regimen on hair structure, pigmentation, and texture. The study was performed in compliance with the Declaration of Helsinki and Good Clinical Practice guidelines.
Sixty-six healthy subjects, aged over 40 years, with Fitzpatrick skin phototypes I–IV and 20–30% visible grey hair (but not predominantly white hair), were initially recruited.
After minor attrition, 60 subjects completed the study. Participants were randomized into three equal groups (n= 20 each) : Group 1 received both the food supplement and the topical cosmetic product; Group 2 received the food supplement only; Group 3 applied the cosmetic product only.

The primary endpoint of the study was the assessment of hair structure through the quantification of protein carbonylation levels, using a patented proteomics approach designed to detect oxidative damage in hair proteins. For this, hair shafts (approximately 1 cm from the root) were collected at D0, D30, D60, and D120 and analyzed for carbonylated proteins.

Secondary endpoints included pigmentation and texture parameters.
Hair pigmentation was evaluated through two complementary methods: (1) calculation of the white hair to total hair ratio using trichoscopy (Trichoscan® HD system), and (2) clinical assessment of grey hair extent by a dermatologist using a validated 5-point scale: Score 0 (no grey hair), Score 1 (few grey hairs, <5%), Score 2 (trace grey hairs, 5–20%), Score 3 (diffuse grey hairs, up to 30%), and Score 4 (generalized grey hairs, >30%).
Hair texture was evaluated through objective hydration measurements using the Visioscan® VC 20 Plus, and by assessing hair density and the anagen/telogen ratio via trichoscopy (Trichoscan® HD system).
For hair Hydration, Visioscan® VC20 Plus (Courage+Khazaka Electronic GmbH, Germany) was used to assess the homogeneity parameter on a fixed hair area, specifically in Group 1 participants.
For Hair Growth and Density Parameters: Trichoscan HD technology assessed total hair density (hairs/cm^2), and the anagen/telogen phase ratio. A small scalp area was shaved two days prior to measurement for optimized assessment.

Assessments were performed at baseline and at 30, 60, and 120-day intervals. Tolerance to the interventions was evaluated using participant self-reports and clinical dermatological examinations.

Statistical Analysis
All continuous variables were subjected to paired Student's t-tests or Wilcoxon signed-rank tests for intra-group comparisons. Inter-group differences were analyzed using appropriate nonparametric tests where applicable. Statistical significance was considered at $p<0.05$. All calculations were performed using SPSS version 23 (IBM, USA).

Subjects were instructed to apply the assigned treatments under standardized conditions replicating normal consumer use. The topical cosmetic product was applied directly to the scalp once daily, and the nutraceutical food supplement was ingested daily in accordance with manufacturer recommendations.
Product compliance was monitored through subject questionnaires administered during and at the end of the study and by tracking product consumption.

3. Results

Hair Structure

Significant structural improvements were observed through the reduction of oxidized proteins in hair shafts. In situ visualization by specific fluorescence labeling showed a progressive decrease in protein carbonylation intensity from baseline (D0) to Day 120 with the combined use of the food supplement and the cosmetic care (Figure 2).

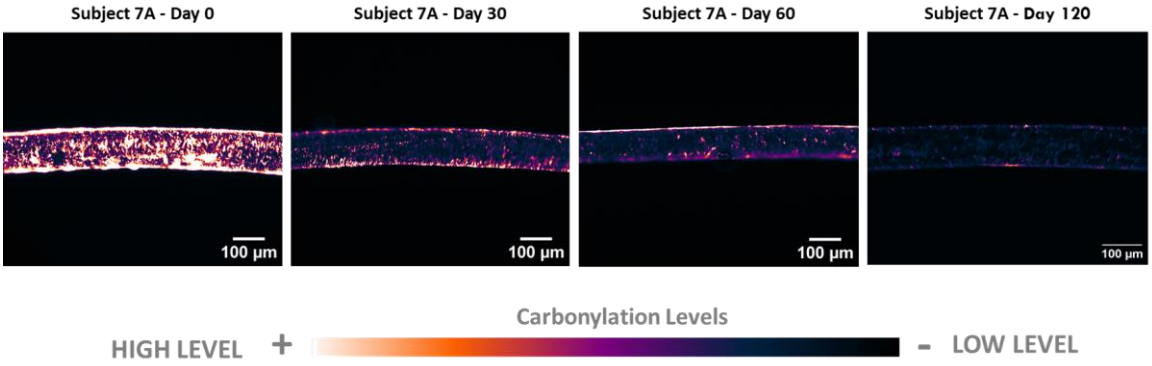

Figure 2 : Progressive reduction of oxidized proteins in hair shafts over 120 days of combined treatment.

In situ fluorescence visualization of carbonylated proteins on hair shafts from a representative subject in Group 1 (Subject 7A). Sequential images taken at D0, D30, D60, and D120 demonstrate gradual reduction in oxidative damage following combined oral and topical intervention.

A quantification of carbonylated proteins (Figure 3) confirmed a 15% decrease as early as Day 30 ($p < 0.05$), and a 47% reduction at Day 120 ($p < 0.001$). These reductions were markedly more substantial in the combined treatment group (food supplement and cosmetic care) compared to either monotherapy, highlighting the potentiation of the cosmetic care effect by the food supplement.

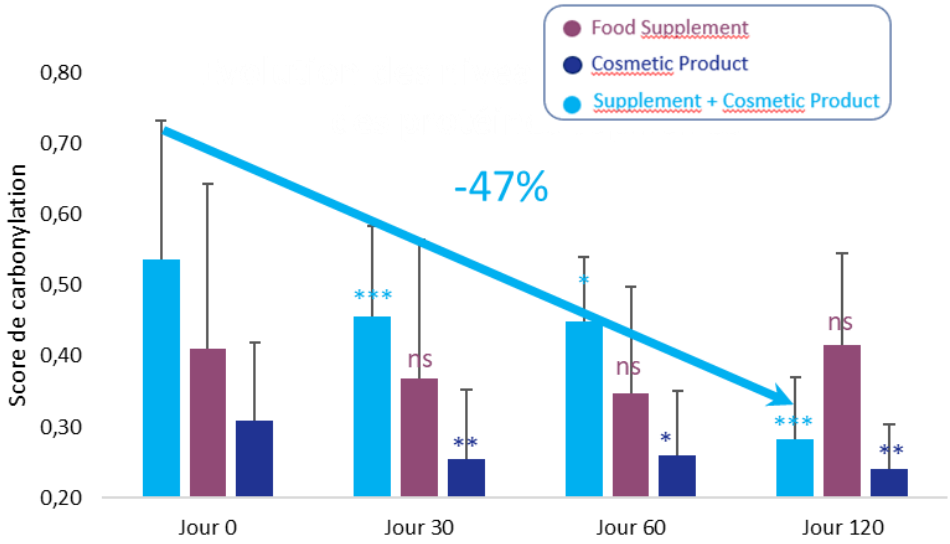

Figure 3 : Quantification of carbonylated protein levels over time across study groups.

Light blue bars: combined use; dark blue bars: cosmetic care only; purple bars: food supplement only. Statistical significance: ***p<0.001, **p<0.01, *p<0.05, ns: not significant.

Hair pigmentation

Hair pigmentation parameters demonstrated notable improvements under the combined intervention. After two months, the food supplement alone showed a trend towards a 9.6%

reduction in the white hair ratio (Figure 4). In contrast, the combined use of the food supplement and the regenerating topical treatment significantly decreased the proportion of grey hairs, with a 20% reduction observed at Day 60 ($p<0.05$) (Figure 5).

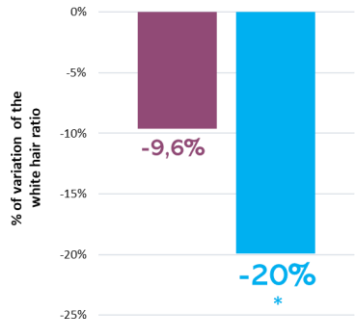

Figure 4 : % of variation of the white hair ratio between Day 60 and D0 following nutritional and combined interventions.
Percentage change in white hair/total hair ratio at Day 60 compared to baseline. Purple bars: food supplement only; light blue bars: combined use. *p<0.05 vs baseline.

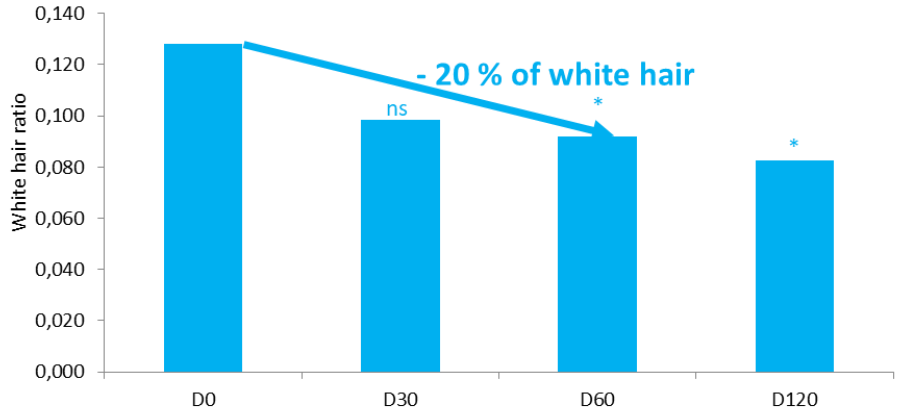

Figure 5 : Longitudinal analysis of white hair ratio by trichoscopy following combined use.
Evolution of the white hair/total hair ratio measured by trichoscopy at multiple time points under combined oral and topical treatment. *p<0.05 vs baseline ; ns: not significant.

Additionally, the clinical dermatological score for grey hair significantly improved from Day 30 onwards under the combined use (Figure 6).

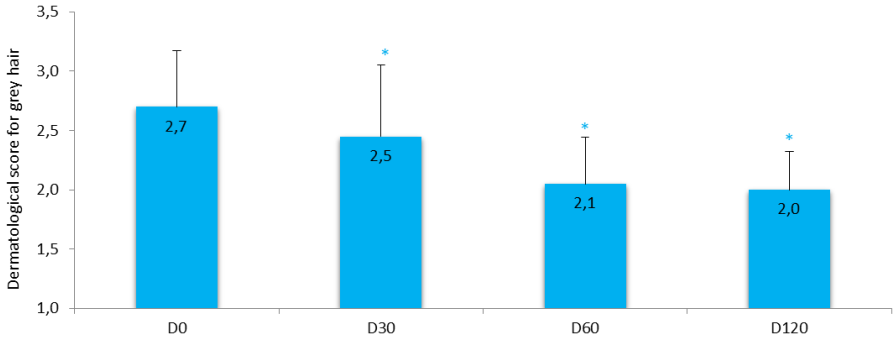

Figure 6 : Dermatologist-assessed improvement in grey hair clinical score with combined use.
Reduction in clinical greying score as assessed by a dermatologist, using g a 0–4 scale [Score 0 (no grey hair), Score 1 (few grey hairs, <5%), Score 2 (trace grey hairs, 5–20%), Score 3 (diffuse grey hairs, up to 30%), and Score 4 (generalized grey hairs, >30%)], over 120 days under combined treatment. *p<0.05 vs baseline.

These findings highlight the complementary action of internal and topical interventions on melanogenesis restoration and visible pigmentation recovery.

Hair texture

Significant improvements in hair texture parameters were observed with combined use:

- Anagen/telogen ratio, reflecting follicular vitality, increased by 25.1% at Day 60 and by 46.5% at Day 120 compared to baseline (Figure 7).

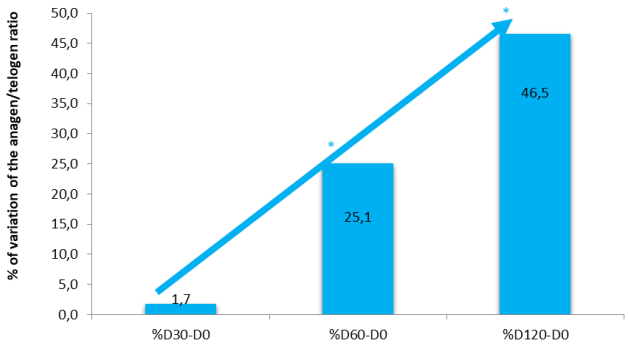

Figure 7: Increase in anagen/telogen ratio following combined intervention.
Percentage change in anagen/telogen ratio from baseline at each time point. (*p<0.05)

- Hair density increased progressively with combined intervention, showing significant gains of 11.7%, 13.8%, and 15.4% at Days 30, 60, and 120, respectively (Figure 8).

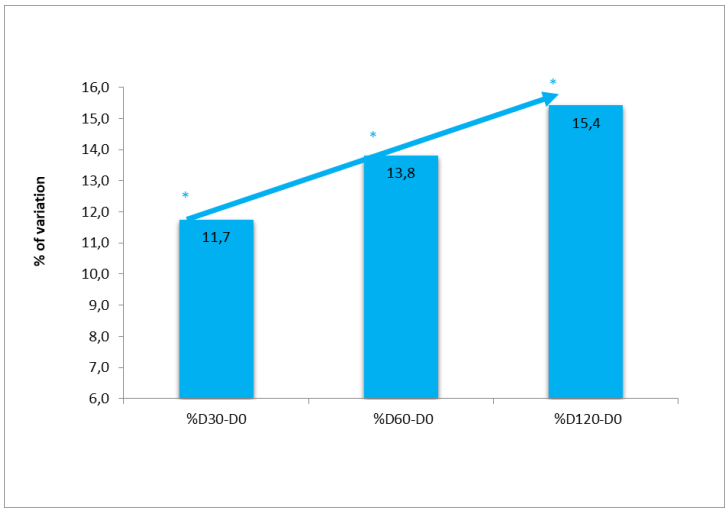

Figure 8: Enhancement in hair density variation under combined treatment
Variation in hair density (hairs/cm²) over time in subjects receiving the combined oral and topical intervention. *p<0.05 vs baseline.

Moreover, scalp and hair hydration significantly improved from Day 60 (Figure 9).

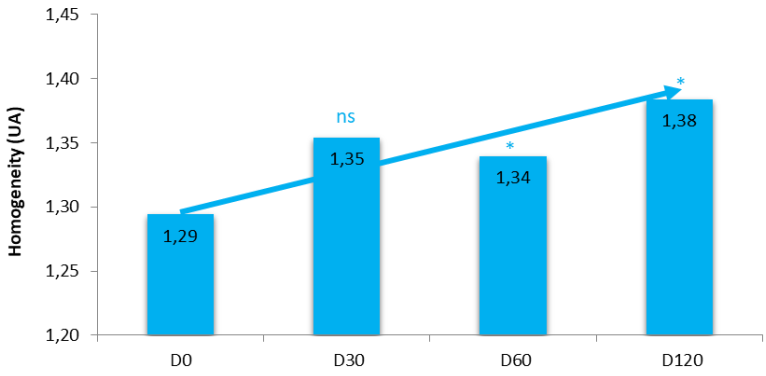

Figure 9: Improvement in moisturization with combined use.
Assessment of hydration changes using the Visioscan® VC20 Plus system. Increase in hydration observed from Day 60 onward. *p<0.05 vs baseline; ns: not significant.

These improvements reflect the structural and functional recovery of the scalp environment under combined nutraceutical and cosmetic intervention.

Safety

Throughout the 120-day study, no adverse dermatological events were reported in any group, confirming the excellent safety and tolerance profile of both the food supplement and cosmetic product.

4. Discussion

This study demonstrates the efficacy of a dual-modality approach in countering age-related hair deterioration. The significant reduction in protein carbonylation with combined treatment suggests robust protection against oxidative stress at the structural protein level. This preservation of keratin integrity may directly contribute to improved fiber resilience and quality.

Simultaneous improvements in pigmentation — specifically the reduced white hair ratio and clinical greying scores — point to reactivation or preservation of melanogenic activity.

Moreover, the observed enhancements in density, hydration, and growth phase ratios indicate improved follicular health and microenvironment, likely attributable to systemic improvements in nutrient delivery and localized stimulation of cellular activity.

Overall, the synergy observed between oral and topical interventions supports a comprehensive model for hair anti-aging care, one that simultaneously targets intracellular stress, pigmentation dynamics, and follicular vitality.

This study confirms that a synergistic nutraceutical and cosmetic regimen can effectively counteract key mechanisms underlying hair aging. The marked decrease in protein carbonylation aligns with the reversal of oxidative damage pathways described by Cavagnino et al. (2022) [2] and Liang et al. (2023) [3]. Improved pigmentation restoration resonates with residual melanogenic potential documented by Fernandez-Flores et al. (2019) [4] and Tobin (2008) [5]. Enhancements in follicular density and vitality suggest a partial recovery of the aging hair follicle microenvironment, consistent with Jang et al.'s findings (2023) [6] . The present intervention thus addresses structural integrity, melanocyte functionality, vascularization, and hydration, representing a holistic anti-aging hair strategy.

5. Conclusion

The combination of a targeted food supplement and a topical cosmetic product exerts a multidimensional, synergistic effect on the hallmarks of hair aging. It significantly reduces oxidative damage, restores pigmentation, improves hydration, and supports healthy hair cycling. These findings provide strong evidence for the potential of integrated nutraceutical-cosmeceutical strategies in hair longevity science.

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