Bio-Inspired Photo-Crosslinking of Casein with Riboflavin Phosphate and Tannic Acid for Enhanced Colorant Retention in Sustainable Cosmetic Applications

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With increasing consumer demand for sustainable cosmetics, developing eco-friendly systems that maintain performance remains challenging. This research introduces a novel approach utilizing photo-responsive biopolymers to enhance water-soluble colorant stability in cosmetic applications. We developed an innovative platform based on casein protein films crosslinked through a riboflavin phosphate (RFP)-mediated photoreaction, with tannic acid (TA) as a natural polyphenolic reinforcement agent [1].

The fabrication process involved a systematic optimization of casein concentration, RFP content, and TA incorporation, followed by blue light irradiation (450-490 nm) to induce protein crosslinking. Structural characterization through FTIR spectroscopy confirmed successful crosslinking via formation of dityrosine bonds, while SEM analysis revealed a networked porous architecture conducive to controlled dye retention. Rheological assessment demonstrated that TA-modified films exhibited significantly improved mechanical properties, with up to 40% increase in storage modulus compared to unmodified counterparts.

The biocompatibility of these films was validated using NIH/3T3 fibroblasts, with cell viability consistently above 90% at all tested concentrations. When applied to human skin models, the photo-crosslinked films containing a model water-soluble red dye demonstrated remarkable color retention under standardized wash conditions, maintaining 85% of original color intensity after 8 hours compared to 32% for non-irradiated controls. The addition of TA provided supplementary improvement in durability through secondary interactions with both the protein matrix and encapsulated colorants.

This study establishes a foundation for development of next-generation sustainable color cosmetics by bridging principles from biomaterials science with cosmetic technology. The versatility of this platform allows for potential expansion to various colorants and active ingredients, offering promising opportunities for dermal delivery systems beyond decorative cosmetics. Our findings demonstrate that biomimetic, photo-responsive protein films represent an effective and environmentally conscious approach to addressing the persistent challenge of water-soluble dye retention in cosmetic applications.

Keywords: Photo-crosslinked casein, Riboflavin phosphate, Sustainable color cosmetics

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References

[1] Hong, M.J.; Lee, Y.; Kyung, S.J.; Choi, J.; Lee, H.J. Sustainable and durable color cosmetics: riboflavin phosphate-mediated photo-crosslinked casein films with tannic acid. *Biomaterials Science* **2024**, *12*, 6136-6147.