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Advanced Makeup Performance with Cationic Polymer-Infused Skincare Formulations

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1. Introduction

Recent market reviews increasingly highlight consumer complaints regarding makeup lifting, darkening, clumping, and radiance loss [1]. Particularly among consumers sensitive to skin appearance, there is a growing demand for solutions targeting adhesion, sebum control, and skin texture enhancement. However, conventional makeup products often fall short of fulfilling these needs. Primers and base products bridge the gap between skincare and makeup, serving as a pivotal step for improving overall makeup durability and finish.

As consumers become more knowledgeable, expectations for primer performance have expanded beyond basic functions. There is now a clear demand for hybrid products that combine skincare benefits with makeup-enhancing properties. In particular, improvements in adhesion, radiance retention, and texture refinement are prioritized when evaluating primer efficacy.

Consumers now expect primers to offer multifunctionality beyond simple skin smoothing, including radiance enhancement, sebum regulation, and prevention of darkening. Consequently, technological approaches that strengthen both skincare functionality and makeup performance have become essential.

In this study, we explored the application of cationic polymers within skincare primers to leverage the natural negative charge of the skin for enhanced adhesion. Additionally, a radiance-enhancing technology was incorporated to develop a hydrating, hybrid primer. Objective experimental validation was conducted to confirm the efficacy of the developed formulation.

2. Materials and Methods

2.1 Experimental Formulation Preparation

Base formulations were prepared as detailed in Table. I to investigate the effects of cationic polymers, film formers, oils, and humectants. The water phase was heated to 80 °C, followed by the addition of a thickener and the heated oil phase. Emulsification was performed at 3,500 rpm for 5 minutes, and the batch was then cooled to form a stable emulsion. Five variations (A–E) were created to evaluate the role of each component.

Table I. Manufacture Formulation of Base

ICID Name	A Contents	B Contents	C Contents	D Contents	E Contents
Water	q.s to 100	q.s to 100	q.s to 100	q.s to 100	q.s to 100
Disodium EDAT	0.10	0.10	0.10	0.10	0.10
Glycerim	15.00	15.00	15.00	15.00	-
Butylene Glycol	5.00	5.00	5.00	5.00	-
Humectant	-	-	-	-	20.0
1,2-Hexanediol	2.00	2.00	2.00	2.00	2.00
Hydroxyethylcellulose	0.20	0.20	0.20	0.20	0.20
Carbomer	0.10	-	-	-	-
Cationic polymer	-	q.s	q.s	q.s	q.s
Polyglyceryl-3 Distearate, Glyceryl Stearate Citrate	1.20	1.20	1.20	1.20	1.20
Glyceryl Stearate	0.30	0.30	0.30	0.30	0.30
Cetearyl Alcohol	0.50	0.50	0.50	0.50	0.50
Caprylic/Capric Triglyceride	1.00	1.00		1.00	1.00
Oil	-	-	q.s	-	-
Film Former	-	-	-	q.s	-
Tromethamine	q.s	q.s	q.s	q.s	q.s

* q.s : quantum sufficit

2.1.1 Preparation with Cationic Polymers

Cationic polymers demonstrating an optimal balance between viscosity enhancement, low irritation potential, and stability were selected (Table. II) and incorporated into the base formulation (Table I. B) for experimental evaluation. [2-7]

Table II. Cationic Polymers: Function, Structure, and Electrostatic Profile Comparison

INCI	Function	Backbone Structure	Charge Density
Polyquaternium-7	Moisturization, conditioning effect, broad applicability	Acrylamide-based	Medium
Polyquaternium-10	Moisturization, skin protection, soft texture	Hydroxyethylcellulose-based	Low
Polyquaternium-22	Long-lasting hydration, contains both anionic and cationic moieties	Acrylic acid-based	Medium
Polyquaternium-37	Excellent moisturization, strong film-forming properties	Methacrylate-based	High
Polyquaternium-39	Skin protection, conditioning, pH stability, superior long-wear performance	Based on three monomer-based	Medium
Polyquaternium-67	Soft texture, radiance enhancement	Quaternized polyvinyl-pyrrolidone-based	Low
Guar Hydroxypropyl-trimonium Chloride	Hydration retention, film-forming, conditioning	Guar gum-based (natural polysaccharide)	High

2.1.2 Preparation with Different Oils
To enhance immediate radiance, high-refractive-index oils were evaluated. Acrylates Copolymer, Amodimethicone, Squalane, Phenyl Trimethicone, Diphenylsiloxy Phenyl Trimethicone (DPTM), Diphenyl Dimethicone (DDM), PCA Dimethicone, Propylene Glycol Dibenzoate, and Trimethylsiloxysilicate were incorporated at 1 % - 3 % into Table I. C formulations, and their effects on radiance were observed.

2.1.3 Preparation with Film Formers
To maintain sustainable radiance and improve stability, film formers such as Polyether-1, Polyester-5, PVM/MA Copolymer, Polyurethane-15, PVP, Pullulan, Polyurethane-59, and Polyquaternium-51 were added at 0.1 % - 0.5 % into Table I. D formulations for evaluation.

2.1.4 Preparation with Humectant Blends
For fast absorption and reduced stickiness while maintaining approximately 20 % humectant content, various blends of Methyl Gluceth-20, Glycereth-26, Polyglycerin-3, Diglycerin, Glyceryl Polyacrylate, Trehalose, and Erythritol were formulated into Table I. E samples.

2.1.5 Final Optimal Sample Preparation
The most effective ingredients from each category were combined to prepare the final sample.

2.2 Testing Methods
All tests were performed three times, and the average values were used for evaluation.
2.2.1 Cationic Polymer Adhesion Performance
Adhesion Test — Adhesion was evaluated via a tape test. Samples were applied to artificial leather (5 cm × 5 cm), dried for over 10 minutes, then covered with foundation using a puff and dried again for 20 minutes. Adhesion tape was pressed twice with consistent pressure, and ΔL values were measured using a chromameter (Minolta Chroma Meter CR-210).
Absorption Test — For absorption, 0.2 g of each sample was applied to a 5 cm × 5 cm area on the inner forearm and rubbed 50 times. Residual transfer was measured by pressing with a clean pad under constant force, followed by chromameter analysis.

2.2.2 Oil Gloss and Refractive Index
Radiance and Refractive Index Measurements - Radiance was evaluated visually by applying samples to the skin and additionally applying a makeup foundation layer. Refractive index was measured using an RI meter to assess the optical properties of each formulation.

2.2.3 Water Resistance of Film Former
Film Strength Test - Film stability was assessed through two methods: Spreading and water resistance. For Spreading, samples were dried on artificial leather, makeup was applied, and the samples were incubated at 40 °C for 4 hours to observe oil and pigment spreading. For water resistance, samples with added colorant were dried on PMMA plates, immersed in water for 5 seconds, and observed visually.

2.2.4 Humectant Residual Stickiness
Stickiness and Moisture Retention Test - Stickiness was quantified by measuring the residual weight of foam residue after application. Moisture retention was evaluated using a Corneometer(Cutometer® MPA 580, Courage+Khazaka electronic GmbH, Germany) to assess hydration levels before and after product application.

2.2.5 Formulation Development and Validation through Panel Testing

Based on the above experiments, the optimal conditions were determined, a product was formulated, and product satisfaction was evaluated through a panel test. Consumer satisfaction was evaluated after applying the product to the skin followed by the use of a foundation. The panel consisted of 20 female participants aged between 25 and 40.

3. Results

3.1 Cationic Polymer Adhesion Performance

Cationic polymers were tested at 0.05 %, 0.1 %, and 0.2 %, showing improved performance with increasing concentration, but higher levels caused aggregation and instability. Due to poor emulsification compatibility of Polyquaternium-37, 0.1 % was selected for further studies. Adhesion and absorption tests confirmed that cationic polymers significantly improved both adhesion and absorption compared to anionic polymers. In adhesion testing, approximately 30 % enhancement was observed, with Polyquaternium-10 showing strong performance(Fig.1). Absorption tests further revealed about 79.1 % improvement for Polyquaternium-10 after blank adjustment, indicating faster penetration and lower residue(Fig.2).

	ST	PQ-7	PQ-10	PQ-22	PQ-39	PQ-67	GUAR
L	67.24	87.44	87.86	88.12	88.28	87.26	87.18
A	+0.29	-1.22	-0.95	-1.02	-0.95	-0.67	-0.90
b	10.31	+1.15	+1.95	+1.57	+1.04	+4.20	+2.95

Figure 1. Adhesion Performance of Cationic Polymers Evaluated by Tape Test

Blank	ST	PQ-7	PQ-10	PQ-22	PQ-39	PQ-67	GUAR
L (90.14)	85.07	89.08	88.30	87.64	87.32	86.71	87.26
A	14.95	1.55	5.20	8.46	8.52	12.44	10.26
b	-7.41	-1.90	-3.19	-4.27	-4.09	-4.82	-3.80

Figure 2. Absorption Test According to Cationic Polymer Type

The differences in performance among cationic polymers were attributed to variations in molecular structure and charge density [8]. Higher charge density resulted in stronger adhesion but also increased the risk of skin irritation. Polyquaternium-7 and Polyquaternium-10 exhibited excellent adhesion and absorption performance; however, skin irritation tests showed that Polyquaternium-10 had significantly lower irritation potential.

Additionally, although Polyquaternium-22 and Polyquaternium-7 provided strong adhesion, they displayed instability risks under preservative stress and acidic conditions. Polyquaternium-10, due to its lower charge density, flexible molecular structure, and superior stability, was determined to be the most suitable polymer for this formulation.

3.2 Oil Gloss and Refractive Index

High-refractive-index oils generally enhanced gloss, and gloss increased proportionally with higher oil content(Fig.3).

However, increased oil concentration delayed absorption, and thus the oil content was optimized to 1 %. Additionally, ingredients such as Acrylates Copolymer, Amodimethicone, and Diphenyl Dimethicone (DDM) were excluded due to poor usability and formulation instability. Visual observation revealed that despite its high refractive index, Diphenylsiloxy Phenyl Trimethicone (DPTM) exhibited relatively low visible radiance [9].

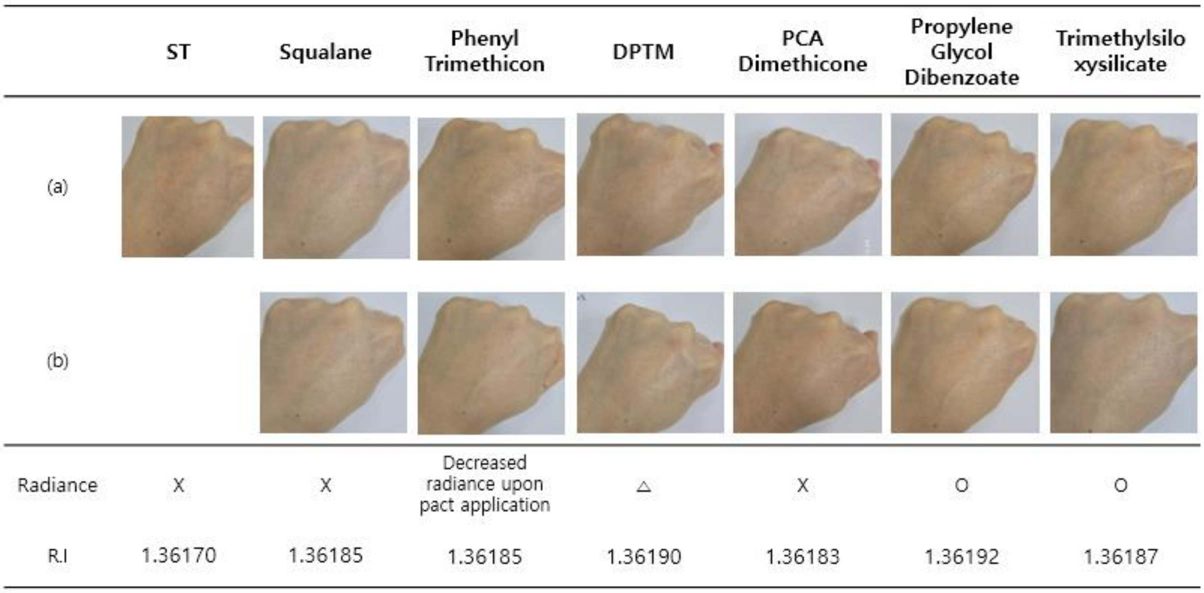


Figure 3. Effect of Oil Type on Formulation Gloss and Refractive Index (a) Application of only the formulated sample; (b) Application of foundation following the formulated sample

In contrast, Trimethylsiloxysilicate formed a strong, flexible film on the skin surface, enhancing both radiance and surface smoothness. These results suggest that perceived radiance is influenced not only by refractive index but also by film-forming ability.

3.3 Water Resistance of Film Former

In the case of film formers, increasing the concentration improved film formation but delayed absorption, with 0.2 % identified as the optimal level. Water-soluble ingredients adhered faster to the skin compared to oil-soluble ones.

As shown in Figure 4, water-soluble ingredients demonstrated superior initial performance compared to the untreated group but tended to clump after water exposure. Among them, Polyquaternium-51 and Polyurethane-15 exhibited the best results.

Spreading tests also confirmed that film formers reduced foundation and oil spreading. Overall, Polyquaternium-51(water-soluble) and Polyurethane-15(oil-soluble) showed the highest performance(Fig. 5).

Polyquaternium-51, with a phospholipid-like structure and low reactivity despite its cationic chain, likely contributes to strong adhesion while maintaining water solubility[10]. Polyurethane-15, containing both hydrophilic and lipophilic segments, forms a hydrophobic surface layer that enhances makeup adherence [11].

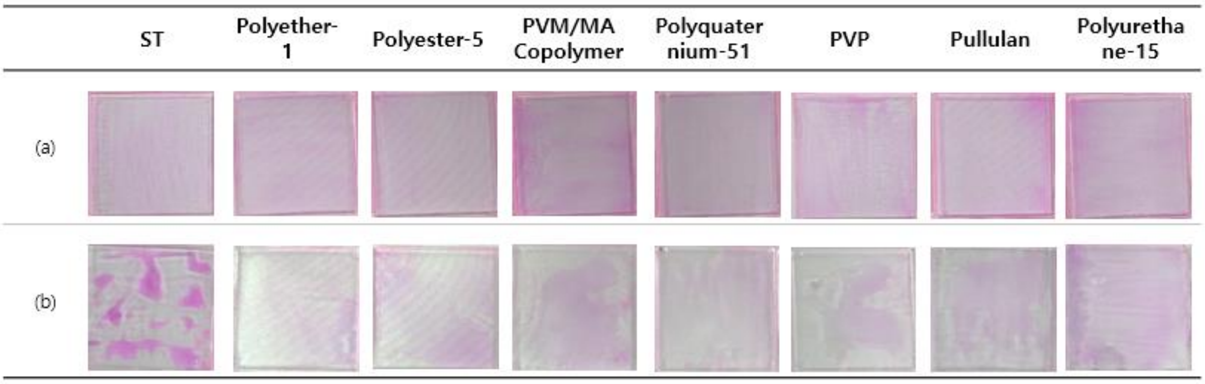
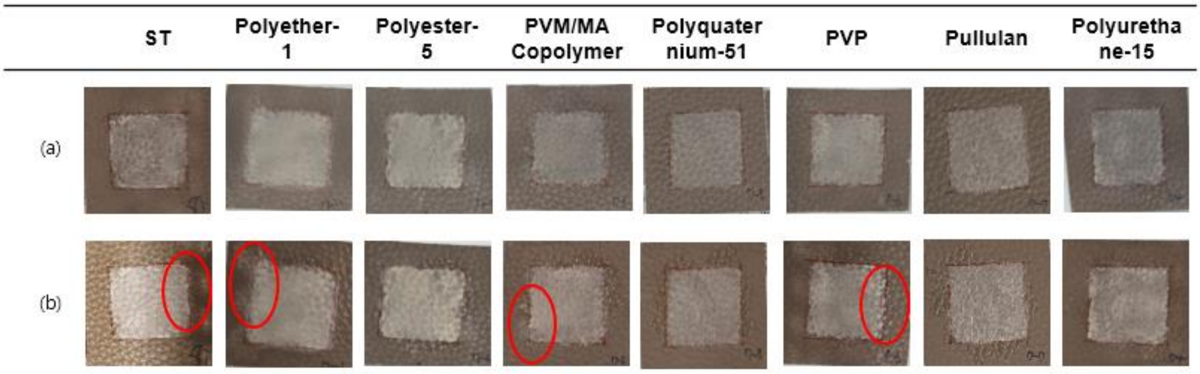


Figure 4. Film Strength Test of Film Formers (a) Plate applied with the formulated sample only; (b) Plate following the Water Resistance Test



	ST	Polyether-1	Polyester-5	PVM/MA Copolymer	Polyquaternium-51	PVP	Pullulan	Polyurethane-15
(c)	O	O	X	O	X	O	X	X
(d)	O	O	O	O	△	△	O	△

Figure 5. Spreading Test of Film Formers (a) Foundation applied over the formulated sample; (b) Plate after storage at 40 °C for 4 hours; (c) Evaluation of foundation spreading; (d) Evaluation of oil spreading

3.4 Humectant Residual Stickiness

Humectants were optimized to maintain hydration while minimizing stickiness. PEG-based humectants such as Methyl Gluceth-20 and Glycereth-26 offered low stickiness but sometimes felt heavy. Glycerin derivatives like Polyglycerin-3 and Diglycerin improved moisture retention but increased stickiness.

By blending Dipropylene Glycol, Methyl Gluceth-20, Polyglycerin-3, Glyceryl Polyacrylate, and Trehalose, stickiness was reduced by 89.6 %(Fig. 6), while skin hydration improved by 35 % compared to single humectants.

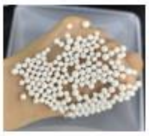
	ST	1	2	3	4	5	6
After							
Residual mass	0.11	0.40	0.22	0.25	0.28	0.26	0.45
Rubbing count	15	25	16	16	20	23	15

Figure 6. Stickiness and Absorption Test of Humectants

3.5 Formulation Development and Validation through Panel Testing

The final formulation combined Polyquaternium-10 for improved adhesion and absorption, Trimethylsiloxysilicate for sustained radiance, Polyquaternium-51 and Polyurethane-15 for enhanced film stability, and an optimized humectant blend for quick absorption and moisturization. Overall, these ingredients delivered a primer that outperformed the control in all measured parameters, including adhesion, radiance, stability, absorption rate, and user comfort (Fig.7).

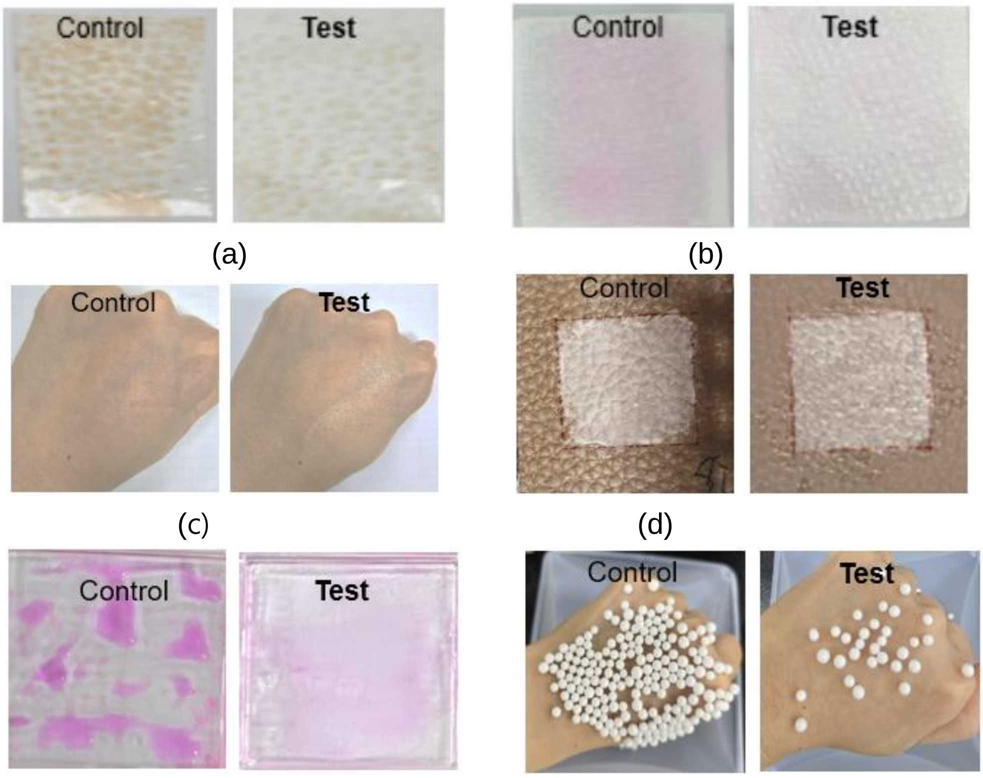


Figure 7. Formulation Application Test. (a) Adhesion Test: Control ΔL: 67.24, Test ΔL: 88.72; (b) Absorption Test: Control ΔL: 85.07, Test ΔL: 89.46; (c) Radiance Test Control R.I: 1.3617, Test R.I: 1.36198, (d) Spreading Test; (e) Water Resistance, (f) Stickiness Test: Control 0.11 g, Test 0.47 g

In the consumer satisfaction test, Participants who applied the experimental formulation reported significantly higher satisfaction compared to those using the control formulation.

In particular, satisfaction regarding makeup sliding was notably higher in the experimental group, with a mean score of 4.2 compared to 3.1 in the control group. Additionally, some participants mentioned experiencing a light, film-like sensation on the skin and noted that makeup wore off more evenly.These results demonstrate a clear consumer preference for the developed product and support its multifunctional benefits.

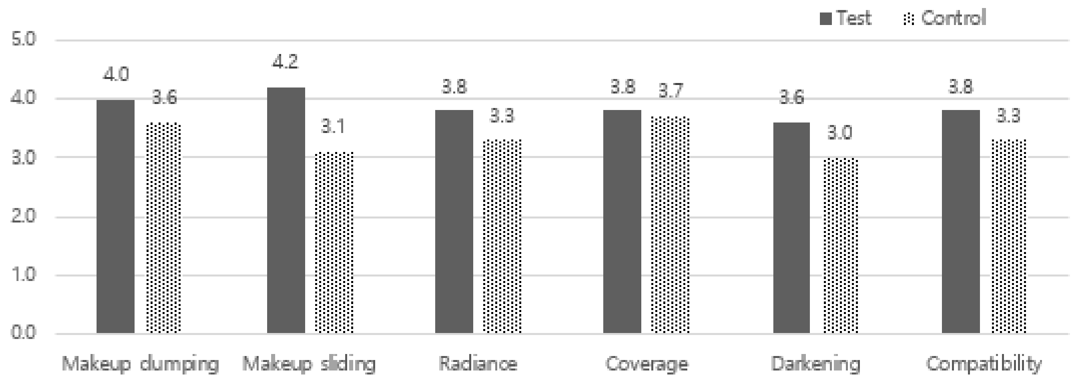


Fig 8. Product satisfaction after makeup application

4. Discussion

This study demonstrated that careful selection and optimization of cationic polymers, film formers, oils, and humectants can effectively enhance primer performance across multiple dimensions.

Among cationic polymers, Polyquaternium-10 offered a favorable balance between adhesion enhancement and formulation stability, while Trimethylsiloxysilicate contributed not only to optical radiance but also to surface smoothness through strong film formation.

Furthermore, the combination of Polyquaternium-51 and Polyurethane-15 provided improved film integrity, reducing pigment migration and enhancing water resistance.

The optimized humectant blend minimized stickiness while maintaining hydration, leading to better user comfort without sacrificing efficacy.

These results indicate that improving primer performance requires a holistic approach that balances adhesion, radiance, absorption, and stability simultaneously. Incorporating material properties such as charge interaction, refractive behavior, and film robustness was critical to meeting both instrumental performance standards and consumer expectations.

Although the developed formulation showed significant improvements under controlled conditions, this study was limited by relatively short-term evaluations and a small panel size. Future research should explore long-term wear performance, extended durability under environmental stress, and the effects on diverse skin types to further validate the applicability of this hybrid primer technology.

5. Conclusion

This study demonstrated that a skincare primer infused with optimized cationic polymers and gloss-enhancing technologies can significantly improve makeup adhesion, absorption, and radiance. Polyquaternium-10 effectively balanced adhesion and skin tolerance. Polyquaternium-51 and Polyurethane-15 jointly enhanced film stability, while Trimethylsiloxysilicate contributed to long-lasting radiance. Carefully blended humectants reduced stickiness while maintaining hydration.

The resulting hybrid primer represents a significant advancement over conventional water-based primers and establishes a foundation for next-generation skincare-makeup hybrid formulations.

6. Acknowledgments
None

7. Conflict of Interest Statement
None

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