# Supporting Information

## Dual-function Supramolecular System of α-Hydroxy Acid-based Ionic Liquids and Peptides for Enhanced Anti-aging Transdermal Delivery

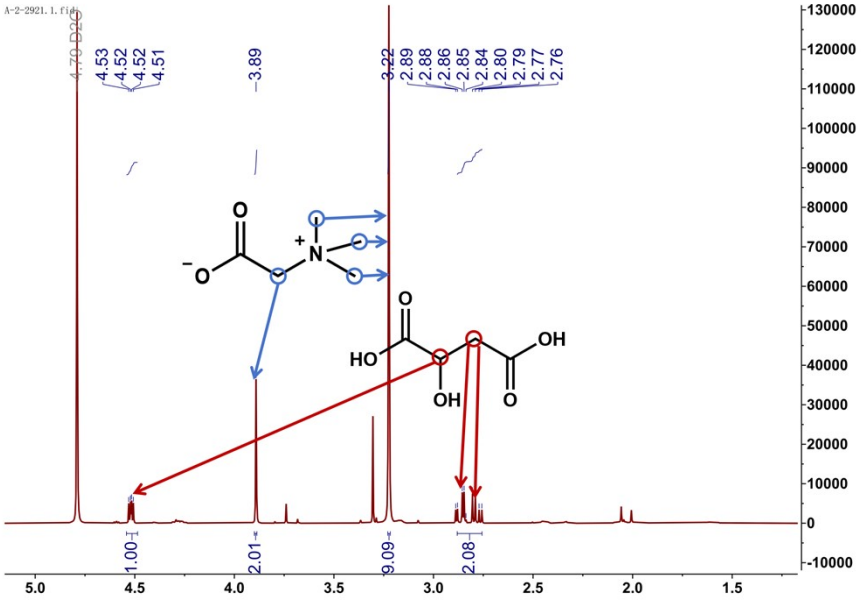


**Fig. S1** $^{1}$H NMR spectra of BMa.

To verify whether Bet and MA in BMa still exist in a 1:1 ratio, BMa was analyzed by nuclear magnetic resonance hydrogen spectrum, and its $^{1}$H NMR spectrum diagram is shown in Fig. S1, $^{1}$H NMR (500 MHz, deuterium oxide) δ 4.44 (DD, j=7.1, 4.5 Hz, 1H), 3.81 (s, 2H), 3.14 (s, 9H), 2.79 (DD, j=16.4, 4.5 Hz, 1H), 2.70 (DD, j=16.4, 4.5 Hz, 1H), 2.70 (DD, 2H). J=16.4, 7.1 Hz, 1H). The chemical signal results showed that the Bet and MA characteristic peaks existed, except for the MA active hydrogen, and the total hydrogen ratio of Bet and MA was 11:3; that is, the molar ratio of Bet and MA is 1:1. Therefore, it can be concluded that Bet and MA still exist in a 1:1 ratio in the BMa.

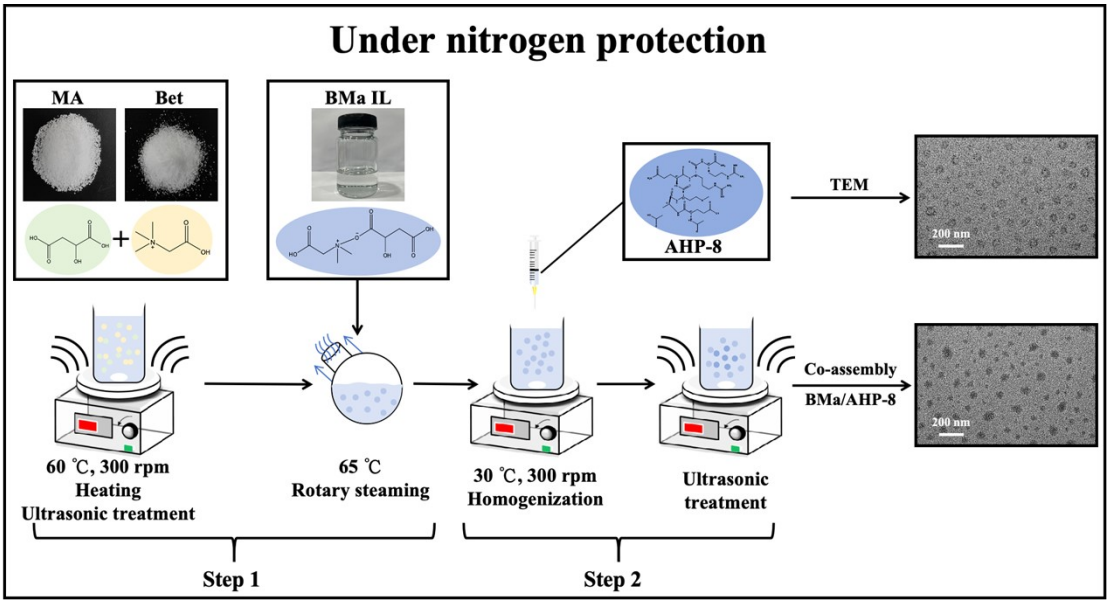


**Fig. S2** BMa/AHP-8 preparation process.

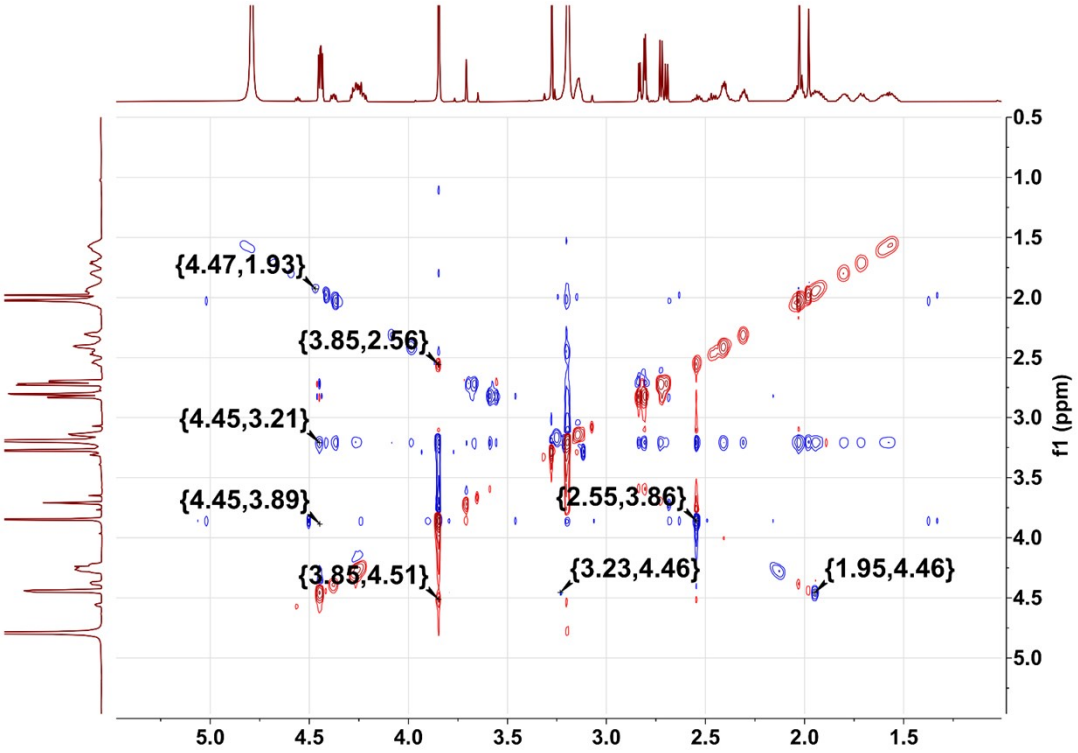


**Fig. S3** The BMa/AHP-8 NOESY spectrum.

Hydrogen-hydrogen correlation points were observed between MA and Bet at (4.45, 3.22), (3.22, 4.45), (4.45, 3.85), and (3.85, 4.45). Similar correlations were observed between Bet and AHP-8 at (3.85, 2.55), (2.55, 3.85), and others. The correlations between MA and AHP-8 included (4.45, 1.94), (1.94, 4.45), and more. These correlations suggest that hydrogen bonds exist between Bet, MA, and AHP-8, allowing them to form a more compact supramolecular structure.

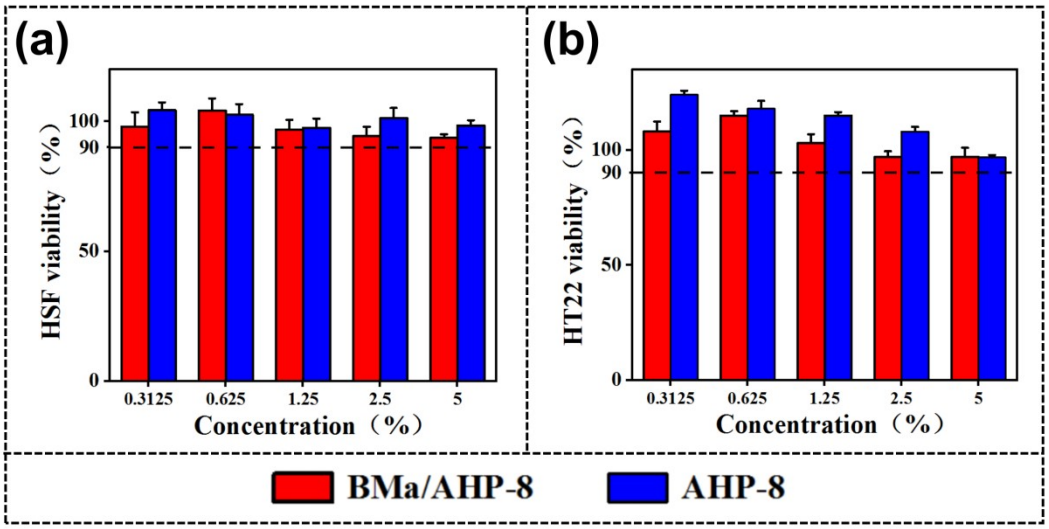


**Fig. S4** BMa/AHP-8 and AHP-8 cell toxicity assays. BMa/AHP-8 and AHP-8 toxicity testing against HSF (a) and HT22 (b).

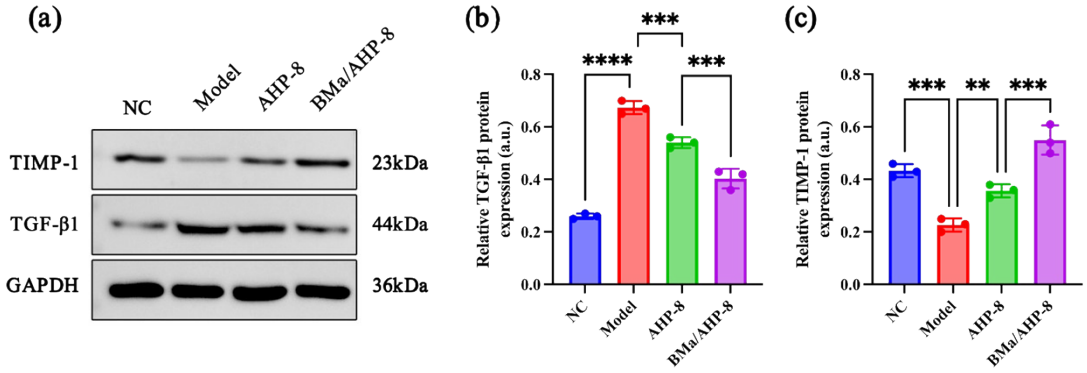


**Fig. S5** Western blot analysis of TGF-β1 and TIMP1 proteins in HSF cells treated with AHP-8 or BMa/AHP-8. Western blot images (a) and semi-quantitative analysis (b-c). Results are shown as mean ± SD for n = 3. **p < 0.01, ***p < 0.001.

A photoaging model of HSF cells was established via UV irradiation. The results demonstrated that UV irradiation significantly upregulated the expression of TGF-β1 while downregulating TIMP-1 expression, thereby promoting MMPs production and accelerating collagen degradation. In contrast, treatment with AHP-8 or BMa/AHP-8 significantly mitigated the UV-induced upregulation of TGF-β1 and downregulation of TIMP-1, thereby reducing MMPs production and promoting collagen synthesis.

**Table S1.** The stability of BMa/AHP-8 at 5 ℃ in darkness.

| Sample | Project | Day 0 | Day 30 | Day 60 | Day 90 |
|---|---|---|---|---|---|
| BMa/AHP-8 | pH | 2.60 | 2.62 | 2.61 | 2.62 |
| | Size（nm） | 56.4 | 57.3 | 55.7 | 60.2 |
| | PDI | 0.18 | 0.21 | 0.19 | 0.23 |
| | AHP-8 retention（%） | 100 | 98.1 | 97.95 | 96.83 |
| | Color | colorless | colorless | colorless | colorless |
| | Sediment | no | no | no | no |
| | Appearance |  |  |  |  |

The formula of BMa/AHP-8 shows excellent stability, with little changes in various parameters after 90 days storage.

**Table S2.** Formula of the BMa/AHP-8 facial cream.

| No | Component | Material | Composition | Ratio |
|---|---|---|---|---|
| 1 | A | Water | Water | TO 100 |
| 2 | | Butanediol | Butanediol | 4 |
| 3 | | Glycerol | Glycerol | 3 |
| 4 | | GL-26 | Glycerol polyether-26 | 2 |
| 5 | | Betaine | Betaine | 0.5 |
| 6 | | HA | Sodium hyaluronate | 0.05 |
| 7 | | EDTA-2Na | EDTA-2Na | 0.03 |
| 8 | | Transparent Hansheng adhesive | Xanthan gum | 0.2 |
| 9 | | ZEN | Polyacrylate cross-linked polymer-6<br>Water<br>Tert butanol | 0.4 |
| 10 | B | p-Hydroxyacetophenone | p-Hydroxyacetophenone | 0.5 |
| 11 | | 1,2-Hexanediol | 1,2-Hexanediol | 0.5 |
| 12 | C | Emulium Delta MB | Cetyl alcohol<br>Glyceryl stearate<br>PEG-75 stearate<br>Whale wax alcohol polyether-20<br>Stearyl alcohol polyether-20 | 2.5 |
| 13 | | A165 | Glyceryl stearate<br>PEG-100 stearate | 2 |
| 14 | | C16/18 alcohol | Cetearyl alcohol | 2 |
| 15 | | DC200/10CS | Polydimethylsiloxane | 2 |
| 16 | | Synthetic squalane | Hydrogenated Polyisobutene | 3 |
| 17 | | Golden jojoba oil | Simmondsia Chinensis Seed Oil | 2 |
| 18 | D | Dipotassium Glycyrrhizinate | Dipotassium Glycyrrhizinate | 0.1 |
| 19 | | VE | Tocopheryl acetate | 0.5 |
| **20** | | **BMa/AHP-8** | **BMa/AHP-8** | **2.25** |
| 21 | | SHINE+ Repairing Glycosides（α+β） | Water<br>Glycerol glucoside<br>1,2-Pentanediol<br>β - Glucan<br>Hexanediol<br>p-Hydroxyacetophenone<br>Xylitol glucoside | 1 |
| 22 | | AQUAXYL | Anhydroxylitol<br>Xylitol<br>Water<br>Glucose | 0.5 |
| 23 | | Tightening and wrinkle-reducing agent | *Euglena gracilis* polysaccharide<br>hydrolyzed collagen | 0.3 |
| 24 | E | NaOH | Sodium hydroxide | moderation |
| 25 | F | DMI | Isosorbitan dimethyl ether | 0.5 |

The formula of BMa/AHP-8 facial cream is shown in Table S2. The formula of AHP-8 facial cream was consistent except that ingredient No. 20 was replaced by AHP-8 in the AHP-8 cream and with water in the placebo cream.

**Table S3.** Grading criteria for skin reactions in the enclosed skin patch test.

| Extent | Grade | Skin reactions |
|---|---|---|
| - | 0 | Negative reaction |
| ± | 1 | Suspicious reaction: only weak erythema |
| + | 2 | Weak positive reaction (erythema reaction): erythema, infiltration, edema, possible papules |
| ++ | 3 | Strong positive reaction (vesicular reaction): erythema, infiltration, edema, papules, vesicles, reaction may extend beyond the test area |
| +++ | 4 | Extremely strong positive reaction (fused vesicular reaction): obvious erythema, severe infiltration, edema, fused vesicles, reaction beyond the test area |

**Table S4.** Summary of results of the enclosed skin patch test.

| Group | Number of participants | Observation time | Number of people with different levels of skin reactions | | | | |
|---|---|---|---|---|---|---|---|
| | | | **0** | **1** | **2** | **3** | **4** |
| MAB/AHP-8 facial cream | 31 | 0.5 h | 31 | 0 | 0 | 0 | 0 |
| | | 24 h | 31 | 0 | 0 | 0 | 0 |
| | | 48 h | 31 | 0 | 0 | 0 | 0 |
| AHP-8 facial cream | 31 | 0.5 h | 31 | 0 | 0 | 0 | 0 |
| | | 24 h | 31 | 0 | 0 | 0 | 0 |
| | | 48 h | 31 | 0 | 0 | 0 | 0 |
| Placebo facial cream | 31 | 0.5 h | 31 | 0 | 0 | 0 | 0 |
| | | 24 h | 31 | 0 | 0 | 0 | 0 |
| | | 48 h | 31 | 0 | 0 | 0 | 0 |
| Negative control Blank + Filter | 31 | 0.5 h | 31 | 0 | 0 | 0 | 0 |
| | | 24 h | 31 | 0 | 0 | 0 | 0 |
| | | 48 h | 31 | 0 | 0 | 0 | 0 |

Among the 31 subjects, no adverse reactions occurred, indicating that the above three kinds of facial cream had low irritation and did not cause irritation to human skin, so they could be safely used in daily products.