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“A Novel Biomimetic Approach Focused on Branched Alkyl Chains”

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1. Introduction

People of all ages often have hair problems, such as dryness due to lack of moisture retention and frizz caused by humidity. However, solving both problems is still one of the major challenges in hair care This is because moisture retention and humidity resistance can sometimes require opposing functional characteristics. To retain moisture, hydrophilic ingredients are needed, while to prevent moisture absorption from the air, hydrophobic approaches are required. Balancing these effects is not easy.

Hydrophilic moisturizing ingredients help keep hair moist, but in humid conditions, they can also cause frizz by absorbing too much moisture. On the other hand, Hydrophobic ingredients help reduce frizz from humidity, but they don't keep moisture in, so hair can become dry and brittle. Therefore, new materials or formulations that can combine both hydrophilic and hydrophobic properties are needed.

In this study, we focused on uropygial gland secretions, which waterfowl apply to their feathers during preening. These secretions contain oils with multiply branched alkyl structures, which help maintain feather gloss, water resistance, and health［1, 2］. Inspired by this, we explored the application of oils with multiply branched alkyl structures in hair care and examined their effects on water content and moisture absorption.

2. Materials and Methods

2. 1. Preparation of Test Hair Samples

In this study, commercially available Asian hair tresses were used as the test hair samples after being chemically damaged. The damage treatment involved bleaching using a formulation containing persulfate and hydrogen peroxide at room temperature for 25 minutes. This was followed by a perm treatment using a two-step formulation containing thioglycolic acid and bromate, applied for 10 minutes each at room temperature. Finally, the hair was shampooed to complete the damage process.

2. 2. Preparation of Hair Treatments Containing Various Branched Alkyl Chains

For the experiment, hair treatments were prepared using linear stearyl alcohol and four structural isomers of isostearyl alcohol (Fig. 1). Each treatment was based on a formula containing 5% linear stearyl alcohol, with an additional 2% of a C18 fatty alcohol isomer added (Table 1).

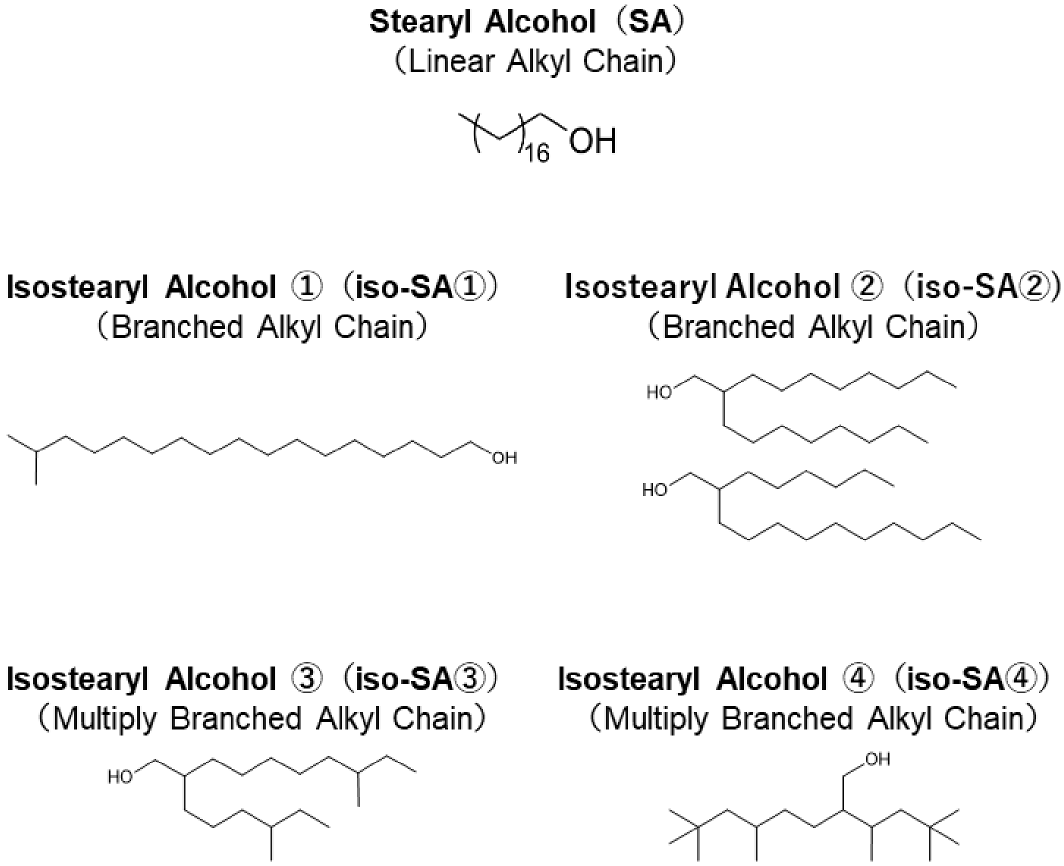

Figure 1. Structural isomers of C18 fatty alcohols used in this study.

Table 1. Treatment formulations

Ingredient	Formulation A	Formulation B	Formulation C	Formulation D	Formulation E
SA	7	5	5	5	5
iso-SA①	—	2	—	—	—
iso-SA②	—	—	2	—	—
iso-SA③	—	—	—	2	—
iso-SA④	—	—	—	—	2
Stearamidopropyl Dimethylamine	2	2	2	2	2
Lactic acid	0.75	0.75	0.75	0.75	0.75
pH	3.588	3.513	3.513	3.535	3.540
Viscosity (mPa・s)	10,590	14,470	8,470	1,3480	11,770

2. 3. Measurement of Water Content of Hair

After shampooing the damaged hair tresses in section 2.1., treatment was applied to the wet hair, rinsed off, and then air-dried. The hair was then left under controlled humidity conditions (75.3% RH using saturated salt solution) for 24 hours.

Next, the hair was heated at 65°C for 45 minutes to measure primary water loss, and then at 180°C for 30 minutes to measure secondary water loss. The total of these two values was defined as water content of the hair.

2. 4. Measurement of Moisture Absorption of Hair

After the measurements in section 2.3, the hair tresses were placed under controlled humidity conditions (75.3% RH using saturated NaCl solution) for 24 hours. The increase in weight was measured and defined as the moisture absorption of the hair.

2. 5. Quantification of Residual Treatment Ingredients on Hair

After shampooing the damaged hair tresses in section 2.1., treatment was applied to the wet hair, rinsed off, and air-dried. The hair was then immersed in hexane for 1 hour to obtain the extract.

Each extract was concentrated to the same volume, and gas chromatography (GC) was used to quantify SA and the iso-SA isomers (iso-SA① - ④) remaining on the hair. A flame ionization detector (FID) was used for detection.

2. 6. Measurement of Surface Properties of Adsorbed Layer on Mica

As a model for the hydrophilic surface of damaged hair, mica sheets were used because they have the same anionic charge and a relatively smooth surface. After each treatment was applied to the mica sheets, they were rinsed with water and air-dried. The surface topography of the samples was then observed using atomic force microscopy (AFM).

3. Results

3. 1. Measurement of Water Content of Hair

As shown in Figure 2, the treatments containing iso-SA showed higher water content in hair tresses compared to the treatment containing only SA (*). In addition, differences in branching structure also affected water content: as the alkyl chain became more multiply branched, the treated damaged hair tended to retain more water (**)(***).

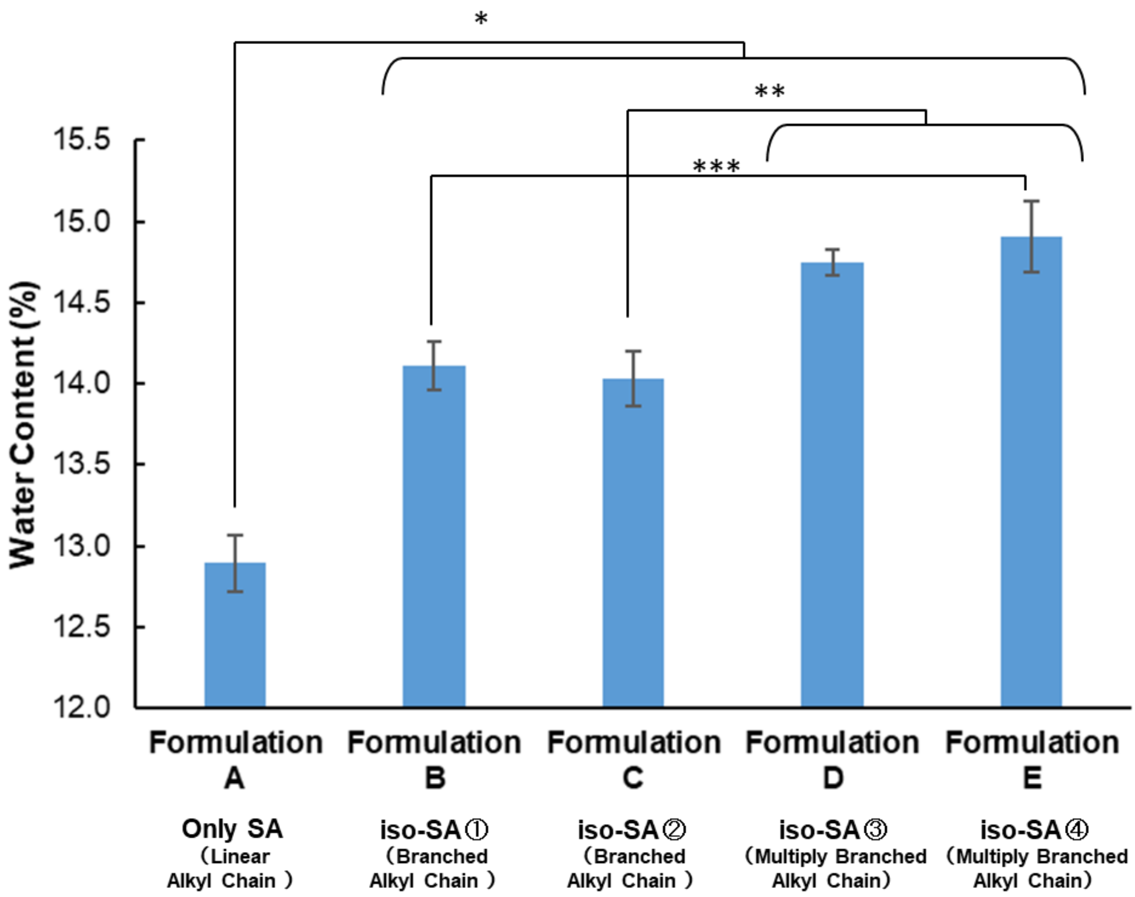

Figure 2. Water content (%) of damaged hair tresses treated with each formulation (A–E). Data are presented as mean ± standard deviation (N = 4). Asterisks indicate statistically significant differences ($p < 0.05$).
The number of asterisks (*, **, *) is used to distinguish between comparison groups and does not represent the degree of statistical significance.**

3. 2. Measurement of Moisture Absorption of Hair

As shown in Figure 3, the treatments containing iso-SA③ and ④ resulted in significantly lower moisture absorption in the treated damaged hair compared to the treatments containing only SA or iso-SA① and ② (****).

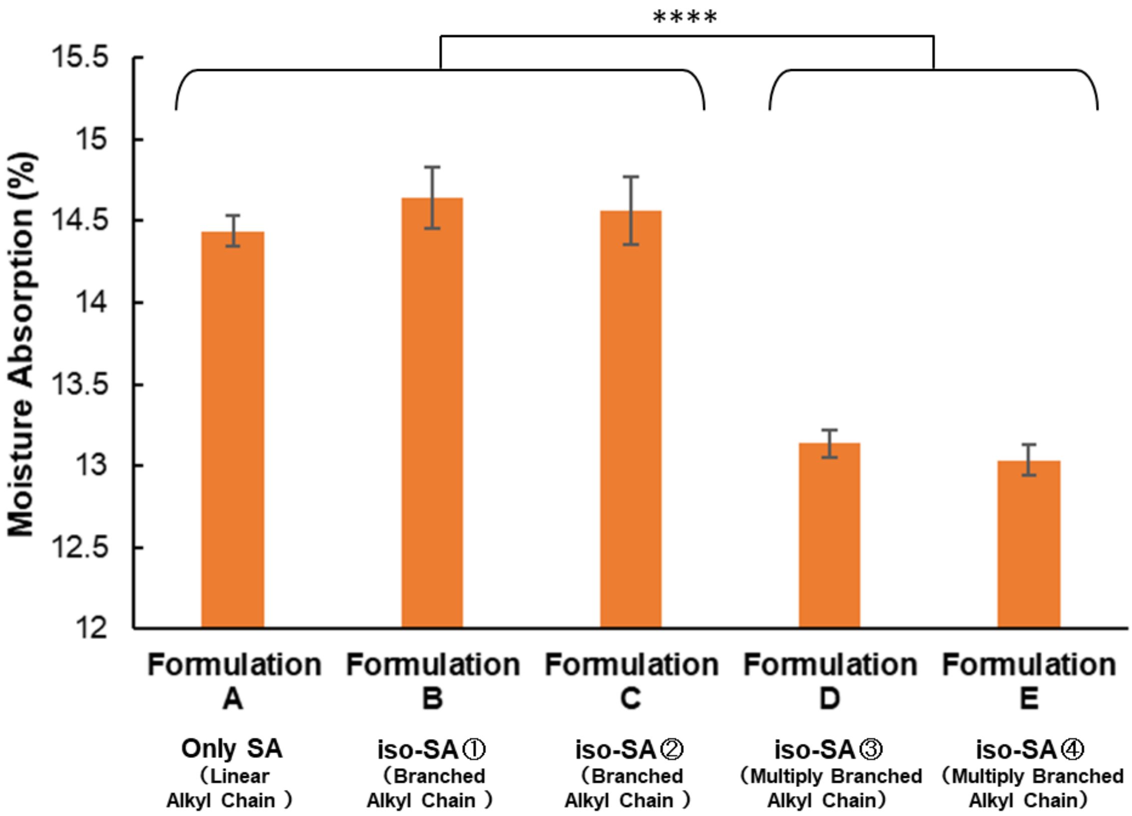

Figure 3. Moisture absorption (%) of damaged hair tresses treated with each formulation (A–E). Data are presented as mean ± standard deviation (N = 4). Asterisks indicate statistically significant differences ($p < 0.05$).
The number of asterisks (****) is used to distinguish between comparison groups and does not represent the degree of statistical significance.

3. 3. Quantification of Residual Treatment Ingredients on Hair

As shown in Table 2(a), the detected amounts of iso-SA①-④ remaining on the damaged hair tresses were lower than that of SA.

As shown in Table 2(b), the amount of SA detected in the hair tresses treated with Formulations B–E was approximately twice as high as that in the tresses treated with Formulation A. On the other hand, the differences in SA levels among the hair tresses treated with Formulations B–E were around 10 ppm.

Table 2. (a)
Concentration of each formulation ingredient extracted with hexane from damaged hair tresses.

Formulation	Target residue	Concentration (ppm)
Formulation A	SA	14※1
Formulation B	Iso-SA①	6
Formulation C	Iso-SA②	6
Formulation D	Iso-SA③	—（Not detected）
Formulation E	Iso-SA④	—（Not detected）

※1：Calculated from measured concentration × 2/7.

Table 2. (b)
Concentration of stearyl alcohol (SA) extracted with hexane from damaged hair tresses.

Formulation	Target residue	Concentration (ppm)
Formulation A	SA	31※2
Formulation B	SA	62
Formulation C	SA	71
Formulation D	SA	67
Formulation E	SA	60

※2：Calculated from measured concentration × 5/7.

3. 4. Measurement of Surface Properties of Adsorbed Layer on Mica

Figure 4(a) shows AFM images of the adsorption layers formed on mica sheets after treatment. In the images, dark areas indicate mica with no adsorption, while bright areas indicate the presence of a treatment-derived adsorption layer (Figure 4(b)).

When treatments contained alkyl chains with more branches, the adsorption area increased and the layer appeared more uniform.

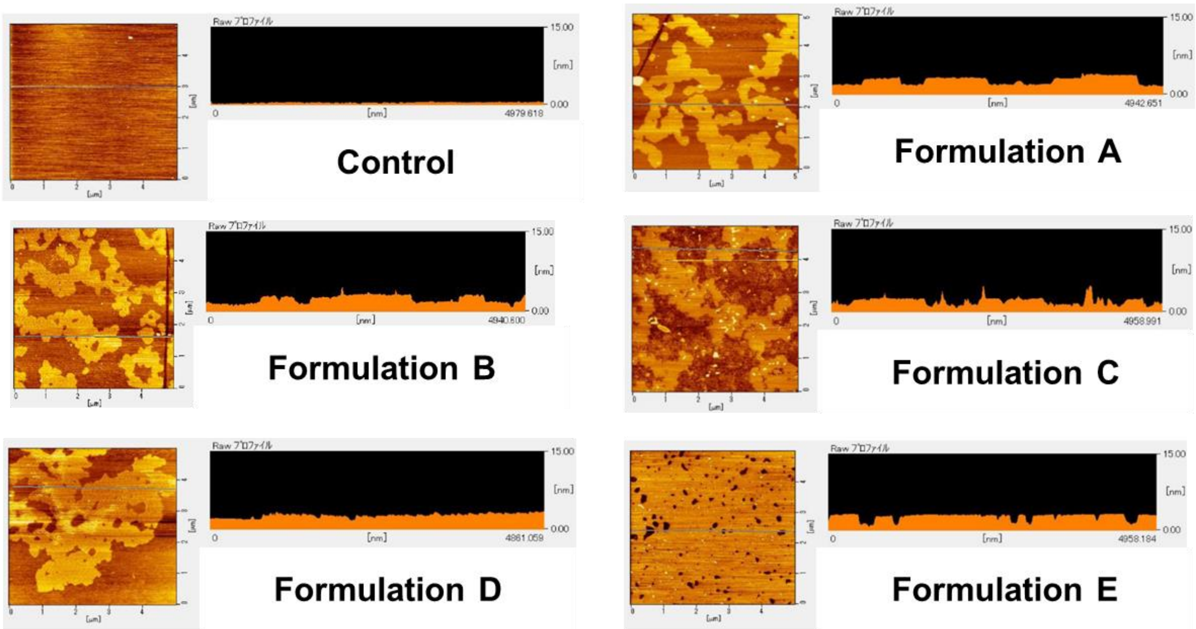

Figure 4(a). AFM images of the adsorption layer on the mica surface.

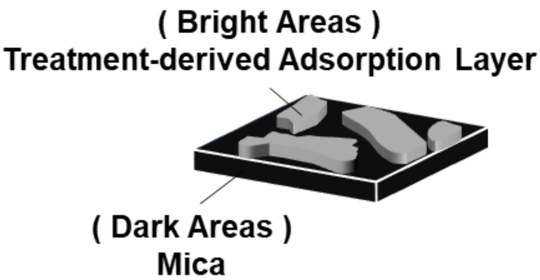

Figure 4(b). Dark areas indicate mica with no adsorption, while bright areas indicate the presence of a treatment-derived adsorption layer.

4. Discussion

Based on the results of sections 3.1 and 3.2, it was found that even isostearyl alcohols with the same INCI name, molecular weight, and molecular formula showed different effects depending on the degree of branching. Formulations containing multiply branched structures improved water content and reduced moisture absorption in damaged hair. This indicates that differences in branching structure can influence treatment performance.

In section 3.3, it was observed that isostearyl alcohol itself remained very little on the hair, while another ingredient, SA, was retained in larger amounts. This suggests that isostearyl alcohol may not easily adsorb onto the hair but may help support the adsorption or retention of SA. This effect was similar across different branching structures, showing no significant variation depending on the degree of branching.

On the other hand, AFM observations in section 3.4 showed that more multiply branched isostearyl alcohol led to adsorption layers that were more extensive and uniform on the hair surface. This suggests that even when SA retention is similar, differences in branching structure affect how evenly the layer spreads on the hair. In other words, higher branching seems to improve the spreading of the formulation and helps SA distribute more uniformly. As a result, the hair surface is covered with a continuous and uniform oily film, blocking moisture pathways. Such a structure helps prevent water evaporation from inside the hair and also blocks humidity from entering. These effects work together to improve water content while reducing moisture absorption—two effects that are usually difficult to achieve simultaneously (Figure 5).

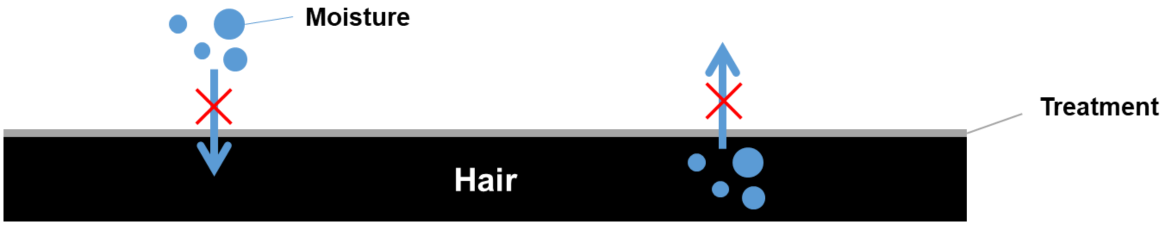

Figure 5. Schematic illustration of improved water retention and reduced moisture absorption in hair due to uniform film formation by the treatment.

These findings suggest that isostearyl alcohol acts as a "functional matrix" in the formulation. It temporarily helps other ingredients spread and adsorb, but is rinsed off without remaining on the hair. In particular, a more multiply branched structure makes the molecule bulkier, which likely helps other ingredients like SA spread better during application. However, due to its low affinity for damaged, hydrophilic hair, isostearyl alcohol is unlikely to adsorb and is rinsed off. This interpretation is consistent with the results obtained in this study. This behavior may be beneficial by reducing residue and stickiness after use.

However, this is just one interpretation, and others are possible. For example, it is also possible that isostearyl alcohol strongly adsorbs onto the hair, or that it forms stable complexes with other surfactants and thus is not easily extracted into hexane. Further investigation is required to clarify these possibilities. To test these hypotheses, alternative extraction methods or additional analyses of complex formation may be needed.

5. Conclusion

Improving hair moisture retention and reducing humidity-induced frizz may seem like conflicting goals. However, this study shows that both can be achieved by adding oil-based ingredients with branched alkyl structures, inspired by waterfowl uropygial gland secretions.

The results suggest that selecting and designing the branching structure appropriately can improve both water retention and humidity resistance. Especially, ingredients with more multiply branched alkyl chains tend to form better adsorption layers on the hair surface. This may also enhance hair shine, feel, and protection from external factors.

This study also found that even ingredients with the same INCI name, molecular weight, and molecular formula can perform differently depending on their branching structure. This highlights the potential of structure-based approaches to reveal functions that may be overlooked by traditional cosmetic development.

These findings could apply not only to hair care, but also to skincare, waterproofing, and broader cosmetic or material design, emphasizing the importance of molecular structure in formulation.

6. References

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