Introduction

Ultraviolet (UV) filters, an active ingredient in sunscreens, often cause skin irritation or skin sensitization when topically applied in amounts exceeding a certain limit. Thus, most countries have limited the content of UV filters in sunscreens to prevent the risk of sunscreen-induced skin irritation and skin sensitization. Therefore, it is essential to achieve more efficient UV protection with the lowest possible UV filter content.

The UV protection ability, expressed as sun protection factor (SPF), and UVA protection factor of sunscreens have been evaluated using in vivo SPF test methods (ISO 24444: 2010 and ISO 24442: 2010). Despite having the same UV filter composition, the SPF values of sunscreens often considerably vary depending on the vehicle used. The application amount and application method are defined in all SPF test methods. Therefore, parameters other than the chemical properties of the UV filter and the application method of the sunscreen must be responsible for the varying results. However, limited systematic information is available about the parameters of vehicles that influence the effective performance of UV filters.

Recent studies have revealed that the following parameters affect UV protection: photostability and skin penetration of UV filters, uneven dispersion of UV filters in sunscreens, and uneven film formation after the topical application. Some of these studies have reported that the film formed by the sunscreen on the skin must be even for the UV filters to effectively function. As the human skin has an uneven surface composed of hills and grooves, it is difficult to cover the hill area with sunscreen film, as the sunscreen eventually flows into the grooves. In fact, it has been reported that a thin film in the hill area facilitates the transmission of UV light into the skin and that the UV absorption is significantly reduced.

Abstract: The performance of sunscreen products depends on their ultraviolet (UV) absorption ability through the film formed on the skin surface upon their application. Therefore, it is important that a uniform film is formed on the uneven skin surface for effective sunscreen performance. Because most UV filters are oil soluble, we hypothesized in this study that increasing the viscosity of the oil phase of a sunscreen product can improve the performance of the sunscreen. We first examined the association between the concentration of the oil thickener and the UV absorption ability of the sunscreen product using a skin-mimicking substrate (SMS). Among all thickeners examined (petrolatum, dextrin palmitate, silica silylate, and organoclay), organoclay and silica silylate significantly increased the UV absorbance of sunscreen on the SMS in a concentration-dependent manner. Thereafter, we examined film uniformity to elucidate the mechanism underlying the observed increase in UV absorption. The uniformity of film thickness on the SMS increased with increasing organoclay content, based on decreased standard deviations of film thickness. Our results showed that increasing the viscosity of the oil phase with organoclay resulted in the formation of a uniform film by preventing the sunscreen from flowing into the grooves when applied on the SMS, thereby increasing UV absorbance by more than two-fold that of sunscreen without organoclay. Thus, the use of thickeners, such as organoclay, increases the viscosity of the oil phase at a low shear rate after the high shear of application. This is an effective strategy for improving the overall quality and performance of sunscreen products.

Key words: film thickness uniformity, oil thickener, organoclay, skin-mimicking substrate, sunscreen

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The protection ability of sunscreen products is strongly influenced by the extent to which the sunscreen screens into the grooves\(^8\). Furthermore, oil-in-water vehicles with low viscosity, owing to the absence of water-soluble thickeners such as xanthan gum, have a negative effect on the SPF values\(^7,10\). Therefore, the physical properties of sunscreen vehicles, especially viscosity, affect the UV protection ability of sunscreens.

Organic UV filters, widely used lipophilic molecules, are usually solubilized in the oil phase of sunscreens. Therefore, we hypothesized that increasing the viscosity of the oil phase, rather than that of the water phase, might lead to more effective UV protection. Although a patent document has described that the addition of dextrin palmitate to the oil layer facilitates uniform application\(^9\), systematic studies are lacking on the relationship between oil-phase viscosity and UV protection or the uniformity of the sunscreen film formed on the skin surface. This can be attributed to the difficulty in measuring the uniformity of the film formed on the skin surface.

A skin-mimicking substrate (SMS) can simulate the human skin surface with grooves of 75-µm depth, and it has been developed using polymethyl methacrylate to estimate the SPF value in vitro\(^5,20,21\). Therefore, the SMS is a suitable substrate for evaluating the evenness of the film formed upon the application of sunscreen in vitro. In this study, we aimed to determine how oil thickening affects the uniformity of sunscreen film thickness and alters UV absorbance. Our results may contribute to the development of effective sunscreen vehicles.

2 Experimental Procedures

2.1 Reagents

The following reagents and compounds were used in the present study: 2-(4-diethylamino-2-hydroxybenzoyl)-benzoic acid hexyl ester (DHHB; Uvinul A plus; BASF Japan, Tokyo, Japan), quaternium-18 hectorite (an ion-exchange addition product, dimethyldioctadecylammonium chloride with hectorite clays, organoclay; BENTONE® 38V CG; Elementis Specialties, East Windsor, NJ, USA), silica silylate (amorphous silica, reaction products with trimethylsilylamine; DOWSIL™ VM-2270; Dow Corning, Midland, MI, USA), petrolatum (Koshiro, Osaka, Japan), dextrin palmitate (Rheopearl KL2; Chiba Flour Milling, Chiba, Japan), polyethylene glycol (PEG)-10 dimethicone (silicones and silicones, dimethyl, hydropropoxy[oxy-1,2-ethanediyl]methyl, and trimethylsilyl terminated [10 mol ethylene oxide average molar ratio]; KF6017; Shin-Etsu Chemical, Tokyo, Japan), decamethyldicyclopentasiloxane (Shin-Etsu Chemical, Tokyo, Japan), triethylenediamino (Nikkol Trifat S-308; Nikko Chemicals, Tokyo, Japan), and sodium chloride (Nacalai Tesque, Kyoto, Japan).

2.2 Preparation of the thickened oil phase and sunscreen samples

DHHB was selected as the UV filter considering its photosstability\(^7\). Oils containing thickeners, which are generally used as cosmetic ingredients, were used to prepare samples. Dextrin palmitate (an amphiphilic compound), petrolatum (an organic nonpolar polymer), silica silylate (fine solid particle), and organoclay (a clay mineral) were examined as thickeners.

The oil phase, thickened by the addition of each thickener, was prepared as follows: 18 g triethylhexanoin containing 2 g DHHB, and 4 g PEG-10 siloxane were mixed with 0.5, 1.0, or 2.0 g of each thickener, and dispersed at 80°C for 3 min using an HM-300 homomixer (AS ONE, Tokyo, Japan). In addition, organoclay-containing oil without a UV filter was prepared to confirm the absorbance measurements.

Ten types of sunscreen samples containing DHHB in water-in-oil emulsions were prepared. The formulations are listed in Table 1. Triethylenediamino, DHHB, PEG-10 dimethicone, and each thickener were mixed and solubilized by heating at 80°C for 2 min. After the addition of decamethyldicyclopentasiloxane and ion-exchanged water containing sodium chloride, the resulting mixture was homogenized using HM-300.

2.3 Measurement of the viscosity of oils containing thickeners

The shear rate–dependent rheology of the oils containing thickeners was measured with a parallel-plate rotational rheometer (MCR 102; Anton Paar GmbH, Graz, Austria; 50-mm parallel plate, gap size = 0.5 mm) at a shear rate of 0.01–1000 s\(^{-1}\) and temperature of 25°C ± 0.1°C, after steady shearing (shear rate 100 s\(^{-1}\) ) for 60 s.

2.4 Measurement of absorbance

The UV absorbance of the sunscreen samples was measured after their application on the SMS (SPF MASTER® PA-01, 50 mm × 50 mm × 0.8 mm; Shiseido Irica Technology, Kyoto, Japan). The SMS was made of polymethyl methacrylate and was permeable to >80% of visible and UV light. V-grooves, based on the shape of the skin surface of the human back, were molded on one side. The width and depth of the V-grooves were 300 and 75 µm, respectively\(^9\).

The sunscreen, which was used at final amounts of 0.5, 1.0, 1.5, and 2.0 mg/cm\(^2\), was immediately spotted on the surface of the SMS using a microsyringe, and the spots were spread over the uneven surface with a fingertip covered by a finger sack. The SMS was allowed to dry for 30 min at room temperature, according to the International SPF Test Method 2006. The evaporation of volatile components in the sunscreen was confirmed by the change in the weight. We confirmed that a drying time of 30 min was sufficient, as there was no further change in the weight.
Organoclay Enhances the UV Absorption Ability of Sunscreen

2.5 Comparison of sunscreen film thickness on the SMS

The sample was applied to the SMS, which was placed on a fluorescent board and irradiated with 27-W black light (FPL27BLB; Sankyo Denki, Kanagawa, Japan), and an image of the reflected fluorescence was obtained using a digital microscope (VHX-7000; Keyence, Tokyo, Japan). The reflected fluorescence brightness value (5-point average) of the groove area and hill area was obtained from the digital microscope image, and the brightness ratio of the groove and hill was calculated using the following formula:

Brightness ratio of the hills and grooves = average brightness of the groove area / average brightness of the hill area

Owing to light scattering on an uneven plate, the brightness ratio is not as quantitative as quantification using the x-ray fluorescence method. However, the film thickness in the groove and hill can be compared.

2.6 Measurement of sunscreen film thickness by confocal laser microscopy

To calculate the film thickness of the sunscreen applied to the SMS, images were obtained using a three-dimensional laser scanning confocal microscope (VK-9700; Keyence, Osaka, Japan) with the following settings: laser wavelength, 408 nm; output power, 0.9 mW; magnification of the objective lens, 50×; and resolution for depth, 10 nm. Images of the SMS were captured 30 min after the application of the sunscreen. Seventeen images were obtained, measuring 4 mm in length from the center of the SMS, and were subsequently combined using an image combiner application (VK-Assembler; Keyence, Osaka, Japan) to calculate the film thickness and obtain a cross-sectional profile of the SMS surface with or without the application of sunscreen. The film thickness of the sunscreen was determined as the difference in the cross-sectional profile of the SMS surface with and without sunscreen application.

2.7 Statistical analysis

Comparisons between groups were performed using Student’s t-test. Results with a p value of <0.05 were considered statistically significant (*p<0.05, **p<0.01, NS: not significant).

Table 1 Sunscreen formulations used in this study.

| Ingredient                  | Composition (wt%) | Sample without UV-filter |
|-----------------------------|-------------------|--------------------------|
| Organoclay                  | - 0.5 1.0 2.0     | -                        |
| Silica Silylate             | - - 1.0 2.0      | -                        |
| Petrolatum                  | - -              | -                        |
| Dextrin palmitate           | - -              | -                        |
| DHBB                        | 2.0              | 2.0 2.0 2.0 2.0 2.0 2.0 2.0 1.0 1.0 - |
| PEG-10 dimethicone          | 4.0              | 4.0 4.0 4.0 4.0 4.0 4.0 4.0 4.0 4.0 4.0 4.0 |
| Trichlyhexanoin             | 18.0             | 18.0 18.0 18.0 18.0 18.0 18.0 18.0 18.0 18.0 18.0 19.0 19.0 20.0 |
| Decamethyclopenta siloxane  | 37.0             | 36.5 36.0 35.0 36.0 35.0 36.0 35.0 36.0 35.0 37.0 35.0 72.0 |
| Deionized water             | 38.5             | 38.5 38.5 38.5 38.5 38.5 38.5 38.5 38.5 38.5 38.5 - |
| Sodium chloride             | 0.5              | 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 - |

The sample without UV filter was confirmed to have an absorbance of 0.01 or less, and no absorption was observed in materials other than DHBB, such as organoclay.

of the SMS after 30 min.

The absorbance at 352 nm was measured using a UV-visible spectrophotometer (V-550; Jasco, Tokyo, Japan). The absorbance of sunscreen was determined by subtracting the baseline absorbance of the SMS from the absorbance of the SMS applied with sunscreen, at six different sites, and the mean value was obtained.
3 Results

3.1 Selection of an appropriate thickener

First, the thickener to be used in the sunscreen was selected. The results of shear rate-dependent rheology of the oils containing thickeners revealed that the use of organoclay and silica silylate resulted in a higher viscosity of the oil phase at low shear rates than petrolatum and dextrin palmitate (Fig. 1). The thickener concentration in the 26.0 wt% oil phase of a film of sunscreen with 2.0 wt% thickener in the formulation was 7.7 wt%. When compared at 7.7 wt% thickener concentration, the viscosity difference was small at a high shear rate but was up to 198 times (organoclay relative to petrolatum) at a low shear rate (Fig. 1).

The absorbance of 2.0 wt% DHHB sunscreen containing various thickeners (1.0 or 2.0 wt%), applied immediately after production, is shown in Fig. 2. A slight increase was observed in the absorbance of sunscreen samples containing petrolatum or dextrin palmitate. However, the absorbance of sunscreen containing organoclay or silica silylate was generally lower than that of petrolatum or dextrin palmitate.

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Fig. 1  Thickening efficiency of oil thickeners. The viscosity of the oil-phases containing 2.0, 4.0, and 7.7 wt% of each thickener (0.5, 1.0, and 2.0 g of each thickener, respectively, with 2.0 g DHHB, 18.0 g triethylhexanoin, and 4.0 g PEG10 dimethicone) was compared using a parallel-plate rotational rheometer. The shear rate-dependent rheology of the oil phase containing thickeners was measured at a shear rate of 0.01–1000 s⁻¹ under 25°C ± 0.1°C, after steady shearing (shear rate 100 s⁻¹) for 60 s.

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Fig. 2  Absorbance of sunscreen with various thickeners on the skin-mimicking substrate (SMS). Vertical axis: 352 nm absorbance of each sample measured spectrophotometrically after 30 min of drying. Student’s t-test *: p < 0.05, **: p < 0.01, NS: not significant.

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bance of sunscreen containing organoclay or silica silylate significantly increased as the amount of thickeners increased to 1.0 and 2.0 wt %.

The absorbance of sunscreen film containing 1.0 wt % organoclay, 2.0 wt % organoclay, 1.0 wt % silica silylate, and 2.0 wt % silica silylate increased to 1.24, 1.64, 1.20, and 1.58, respectively, compared with that of sunscreen without organoclay (0.80).

On the basis of these results, we concluded that organoclay is a suitable oil thickener for sunscreen emulsions. Therefore, we examined the relationship between the UV absorbance and oil-phase viscosity of sunscreen samples formulated with organoclay.

3.2 Absorbance of sunscreen samples with varying concentrations of organoclay

The results of absorbance measurements after the application of 2 mg/cm² sunscreen are presented in Table 3. As the concentration of organoclay increased (0.0, 0.5, 1.0, and 2.0 wt %), the absorbance of sunscreen increased (0.80, 1.00, 1.24, and 1.63, respectively). Sunscreen containing 2.0 wt % organoclay presented a 2.04-fold higher absorbance than sunscreen without organoclay.

3.3 Film thickness and cross-sectional profiles

The cross-sectional profiles of SMS with and without sunscreen and the profile of film thickness are shown in Fig. 3. Compared with sunscreen containing 2.0 wt % organoclay, sunscreen without organoclay accumulated in the grooves of the SMS, and a thin film was formed in the

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**Fig. 3** Film formation of sunscreen on the skin-mimicking substrate (SMS).

a) Cross-sectional curve of the sunscreen film without organoclay on the skin-mimicking substrate (SMS).

b) Film thickness of sunscreen without organoclay on the SMS.

c) Cross-sectional curve of the sunscreen film containing 2.0 wt % organoclay on the SMS.

d) Film thickness of sunscreen containing 2.0 wt % organoclay on the SMS.

Surface cross-sectional curves of the SMS and the sunscreen films are shown. Black line: surface cross-sectional curves of the sunscreen film. Gray line: surface cross-sectional curves of the SMS. The film thickness was calculated from the height of the SMS surface obtained by confocal laser microscopy and the surface height of the sunscreen film. The dashed line is the mean film thickness.
hill area of the SMS. Additionally, some parts had a film thickness ranging from zero to negative values (Figs. 3b and 3d). The negative thickness of the film caused an error in the measurement and calculation by laser microscopy. Thus, it was assumed that parts with a negative value were not covered by the sunscreen film.

3.4 Comparison of film thickness in the hill and groove areas on the SMS

The brightness ratio of the samples with 2.0 wt% organoclay, 2.0 wt% silica silylate, 2.0 wt% petrolatum, and 2.0 wt% dextrin palmitate was 0.87, 0.85, 0.75, and 0.77, respectively (Table 2). A low brightness ratio indicates nonuniform thickness, and a high brightness ratio of close to 1.0 indicates a relatively uniform thickness. This suggested that samples containing organoclay or silica silylate had a more uniform film thickness on SMS than samples containing petrolatum or dextrin palmitate.

3.5 Film thickness and UV absorbance of sunscreen applied on the SMS

The means and standard deviations of the film thickness and UV absorbance of sunscreen samples containing 0, 0.5, 1.0, and 2.0 wt% organoclay are shown in Table 3. Although the mean values of the film thickness of sunscreen samples containing different concentrations of organoclay showed no difference, the standard deviations of the film thickness decreased to 3.33, 2.66, 2.50, and 2.31 µm, respectively, in an organoclay concentration-dependent manner.

In contrast, the UV absorbance decreased as the standard deviation of the film thickness increased, suggesting that the nonuniformity of the film thickness was greater. This negative correlation was observed by linear approximation with the standard deviations of absorbance and thickness, with a multiple correlation coefficient of 0.78. This indicated a relationship between UV absorbance and

| Table 2 | Brightness ratio of the hills and the groove. |
|---------|----------------------------------------------|
| Thickener | Sample1 | Sample4 | Sample 6 | Sample 8 | Sample 10 |
| Absorbance | No thickener | Organoclay 2.0wt% | Silica silylate 2.0wt% | Petrolatum 2.0wt% | Dextrin palmitate 2.0wt% |
| 0.80±0.032 | 1.63±0.121 | 1.58±0.078 | 0.86±0.046 | 0.93±0.075 |
| Brightness ratio of the hills and the groove | 0.69±0.013 | 0.87±0.036 | 0.85±0.015 | 0.75±0.032 | 0.77±0.032 |
| Significance | - | ** | ** | N.S. | * |

Brightness ratio of the hills and the groove
= Average brightness of the groove area / Average brightness of the hill area
The low brightness ratio indicates non-uniform thickness, and the high brightness ratio close to 1.0 indicates relatively uniform thickness in the table.
The data are expressed as mean ± standard deviation. Significance: *: p < 0.05; **: p < 0.01; N.S.: not significant.

| Table 3 | Absorbance and film thickness of sunscreen containing different amounts of organoclay. |
|---------|---------------------------------------------------------------|
| Organoclay content | Sample 1 | Sample 2 | Sample 3 | Sample 4 |
| Absorbance | 0 wt% | 0.5 wt% | 1.0 wt% | 2.0 wt% |
| 0.80±0.032 | 1.00±0.007 | 1.24±0.04 | 1.63±0.121 |
| Mean thickness | 3.97 µm | 4.09 µm | 4.01 µm | 4.13 µm |
| Standard deviation of thickness | 3.33 µm | 2.66 µm | 2.50 µm | 2.31 µm |

Absorbance: absorbance of each sample at 352 nm and absorbance measured spectrophotometrically after drying for 30 min.
Mean thickness: The mean film thickness at 4,825 points in the range of 0–4,000 µm, as obtained by measurement using a confocal laser microscope.
Standard deviation of thickness: Standard deviation of film thickness at 4,825 points.
the thickness of the film formed by the application of sunscreen.

3.6 Comparison of the absorbance of sunscreen samples with and without thickeners at different application amounts

The effects of the amount of sunscreen application on UV absorbance were examined using sunscreen samples no. 1, 4, 9, and 10 (Table 1). The UV absorbance of sunscreen without organoclay gradually increased with an increase in the application amount (0, 0.5, 1.0, and 2.0 mg/cm²) (Fig. 4). However, sunscreen containing organoclay showed a higher increase in absorbance with increasing application amount than sunscreen without organoclay. The results indicated that organoclay enhanced the UV absorbance at the same amount of sunscreen.

4 Discussion

The human skin has an uneven topology consisting of hills (crista cutis) and grooves (sulcus cutis), referred to as “kime” in Japanese. Thus, when applying a sunscreen product, it is difficult to form a uniform film on the skin surface, which minimizes the protective effect of sunscreen against UV radiation. The process of film formation after sunscreen application is illustrated in Fig. 5a. The film is formed after the evaporation of water and volatile compounds. To form a film of uniform thickness, it is essential that UV filters, which are contained in oil, do not flow into the grooves of the skin. In this study, we hypothesized that increasing the viscosity of nonvolatile compounds (i.e., the oil phase) in sunscreen products is an effective strategy to create a UV filter-containing film of uniform thickness, by preventing the sunscreen from flowing into the skin grooves. According to a simple model calculations, the UV transmittance of an evenly distributed film is 3.7 times lower than that of an unevenly distributed film, which supports this hypothesis (Figs. 5b and 5c).

We first examined the UV absorption ability of sunscreen samples formulated with different oil-phase thickeners (organoclay, silica silylate, petrolatum, and dextrin palmitate), to determine the association between oil-phase viscosity and UV absorption. We found that thickening with organoclay and silica silylate significantly restored oil-phase viscosity at a low shear rate after the high shear of application, thereby increasing UV absorption (Figs. 1 and 2). Although petrolatum and dextrin palmitate slightly increased the oil viscosity of the sunscreen at a concentration of 2.0 wt%, both of them failed to increase UV absorption (Figs. 1 and 2). This failure could be due to the lack of ability to restore thickening at 25°C after the high shear of application. In contrast, both organoclay and silica silylate exhibited shear-thinning behavior in the oil phase even after the high shear of application (Fig. 1). Therefore, they provided higher viscosity to the oil phase than petrolatum and dextrin palmitate at a low shear rate even after the application. This, in turn, may have prevented the oil from flowing on the SMS plates, resulting in a more uniform film thickness (Table 2). The sunscreen film with organoclay

![Absorbance of sunscreen at various application amounts of sunscreen on the skin-mimicking substrate (SMS).](image-url)

Vertical axis: 352 nm absorbance measured spectrophotometrically following 30 min of drying of sunscreen applied at amounts 0.5, 1.0, 1.5, and 2.0 mg/cm² on the SMS.

Student’s t-test *: p<0.05, **: p<0.01, NS: not significant.
became more uniform and presented higher absorbance on the SMS than the sunscreen film with silica silylate. Organoclay presented almost the same thickening effect as silica silylate in the oil phase; however, organoclay is considered to have a higher thickening effect than silica silylate in water-in-oil sunscreen emulsions because it is known to form a complex with nonionic surfactants and to stabilize water-in-oil emulsions. On the basis of these results, we selected organoclay as the oil-phase thickener and further examined the association between oil-phase viscosity and UV absorption or the uniformity of the film applied on the SMS using sunscreen formulated with organoclay.

The sunscreen samples showed an increase in UV absorption with increasing organoclay concentration when applied onto the SMS at 2.0 mg/cm². Furthermore, the oil-phase viscosity at low shear rates was directly proportional to the organoclay concentration, and it positively correlated with UV absorption when organoclay was used as an oil-phase thickener.

Conversely, although the mean thickness of the film formed on the surface of the SMS showed no apparent correlation with the concentration of organoclay, the differences in the standard deviations of the film thickness decreased with an increase in the concentration of organoclay. The film of the sunscreen sample with 2.0 wt% organoclay covered the hills of the SMS, unlike that of the sunscreen sample without organoclay. These results indicated that increasing the oil-phase viscosity at a low shear rate by introducing organoclay produced an evenly distributed film.

In addition, increasing the oil-phase viscosity at a low shear rate had a greater effect on UV absorbance. Despite the same UV filter concentration, the UV absorbance of the film formed by the sunscreen sample with 2.0 wt% organoclay was two times higher than that of the film formed by the sunscreen sample without organoclay (1.64 and 0.80, respectively). Additionally, sunscreen containing 1.0 wt% DHHB and 2.0 wt% organoclay exhibited UV absorption equivalent to that of sunscreen containing 2.0 wt% DHHB without organoclay when applied on the SMS at 2.0 mg/cm². Furthermore, the absorbance of the film formed by the application of sunscreen (1.0 mg/cm²) with 2.0 wt% DHHB and 2.0 wt% organoclay...
was significantly higher than that of the film formed by sunscreen (2.0 mg/cm²) prepared with 2.0 wt% DHBB alone (without organoclay). However, applying 0.5 mg/cm² sunscreen eliminated the additional effects of organoclay on UV absorption (Fig. 4). Although it is difficult to demonstrate, we speculated that the application of only 0.5 mg/cm² sunscreen might have been insufficient to cover the SMS surface.

In summary, increasing the oil-phase viscosity at a low shear rate by adding organoclay to sunscreen products may reduce the application amount of sunscreens and achieve lower concentrations of UV filters on the skin surface. Although UV filters are recognized to have no negative effects on the skin, they have been reported to result in the generation of reactive oxygen species through the photosensitization reaction and to generate radicals during photoisomerization due to the release of UV energy absorbed as thermal energy. Furthermore, previous studies have demonstrated the risk of photo-induced skin irritation and photo-induced skin sensitization caused by UV filters under sun exposure. Reducing the concentration of UV filters by increasing the oil-phase viscosity will reduce the UV filter-associated adverse events. Our study proposes an effective way to achieve adequate UV protection with sunscreen even at a low UV filter concentration and with a lower application amount of the product.

5 Conclusions

In this study, with a view to improve the effectiveness of sunscreens even at a low UV filter concentration or a low sunscreen application amount, we investigated the association between the viscosity of the oil phase containing the UV filter and UV absorption or the evenness of the film formed on the SMS upon sunscreen application. The increased oil-phase viscosity afforded by organoclay positively correlated with UV absorption and was associated with a lower deviation in film thickness on the SMS. We conclude that the use of thickeners, such as organoclay, increases the viscosity of the oil phase at a low shear rate after the high shear of application. This is an effective strategy for optimizing sunscreen efficacy, even at a low concentration of the UV filter or a low application amount of the sunscreen. This sunscreen formulation may be helpful in reducing the risks associated with UV filters.

Acknowledgment

We acknowledge the support of the Shiseido Global Research Center and Nippon Shikizai, Inc. for allowing us to use the confocal laser microscope in their facility.

Conflict of Interest

There are no conflicts of interest to declare.

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