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Impact of Titanium Dioxide Concentration on Whitecast Formation in Day Cream Formulation

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ABSTRACT

Titanium dioxide (TiO_2) is widely used in day cream formulations as a physical UV filter due to its broad-spectrum protection and stabilizing properties. However, its tendency to produce a visible whitecast on the skin presents a major aesthetic drawback, particularly for consumers with medium to dark skin tones. This study aimed to formulate three variants of day cream containing different concentrations of TiO_2 (6%, 3.3%, and 2%) and evaluate their visual characteristics, pH compatibility, and consumer-perceived whitecast intensity to determine the optimal balance between UV protection and cosmetic elegance. All formulations were prepared following a standardized emulsification protocol using identical excipient compositions, with TiO_2 concentration as the only variable. Organoleptic and pH evaluations were conducted, followed by a sensory assessment involving 20 respondents who evaluated whitecast visibility and overall preference using structured questionnaires. All formulations demonstrated desirable visual and organoleptic characteristics, including homogeneous white color, soft mango fragrance, and smooth texture with a pH within the ideal physiological range (4.5–5.5). Sensory evaluation revealed that higher TiO_2 concentrations led to more pronounced whitecast. Formulation F3 (2% TiO_2) was most preferred by 75% of respondents for its minimal whitecast and natural finish. The results indicate a direct correlation between TiO_2 concentration and whitecast intensity. While higher TiO_2 concentrations improve opacity and UV protection, they compromise cosmetic acceptability. Formulation with 2% TiO_2 offers an optimal balance for daily cosmetic use, supporting the development of aesthetically pleasing and functionally protective skincare products.

Key words: Titanium Dioxide, Whitecast, Day Cream, Cosmetic Formulation, Sensory Evaluation, UV Protection, Consumer Perception.

INTRODUCTION

The importance of daily skincare products, particularly day creams, has grown substantially in recent years as consumers increasingly recognize their role in maintaining skin health, appearance, and protection against environmental aggressors. Day creams are commonly formulated to deliver multiple benefits such as hydration, UV protection, and antioxidant defense, making them indispensable in modern skincare routines. Hydrating agents like glycerin help maintain skin moisture and barrier integrity ((De Paepe et al., 2001; Yoo et al., 2024), while SPF components and antioxidants minimize photoaging and oxidative stress (Fluhr et al., 2024; Santoro & Lachmann, 2019).

Alongside their functional attributes, modern day creams are also expected to offer aesthetic appeal and multifunctionality, reflecting evolving consumer preferences. Users now demand products that integrate various benefits into a single, sensorially pleasant formulation (Waldman et al., 2016) Visual and tactile aspects—such as smooth texture, elegant packaging, and matte finish—significantly influence product acceptance and perceived efficacy (Reppa & McDougall, 2022; Zhang, 2024). In this context, formulation success is defined not only by clinical performance but also by the emotional and sensory experience it delivers.

One of the key ingredients that enables such multifunctionality is titanium dioxide (TiO_2), widely recognized for its broad-spectrum UV protection, opacity, and formulation-stabilizing properties. TiO_2 acts as a physical sunscreen by reflecting and scattering UV radiation, significantly reducing skin damage and the risk of photoaging (Chaiyabutr et al., 2021; Ghamarpoor et al., 2023). Its high refractive index enhances the visual appearance of cosmetic emulsions, producing a brighter and more uniform finish that appeals to consumer aesthetics (Racovita, 2022; Sztorch et al., 2023).Furthermore, TiO_2 improves formulation viscosity and texture, aiding product spreadability and stability (Wang, 2024). Its potential antibacterial and anti-inflammatory effects also expand its applications in skincare products for sensitive or acne-prone skin (Aditya et al., 2021). Regulatory assessments continue to support the safety of TiO_2 in its bulk and coated forms when used appropriately in cosmetics.

Despite these benefits, the use of titanium dioxide in topical products—particularly at higher concentrations—has been associated with a notable cosmetic drawback known as whitecast. Whitecast is defined as the visible white or ashy residue that appears on the skin’s surface after applying products containing physical UV filters such as TiO_2 or zinc oxide. This occurs when such ingredients remain on the skin's surface, forming a film that contrasts with the natural skin tone (Santoro & Lachmann, 2019). The aesthetic implications of whitecast can negatively influence user perception and product marketability. Research indicates that the avoidance of whitecast is critical to consumer satisfaction and acceptance (Callejon et al., 2023; Hwang et al., 2021).

The issue of whitecast formation is closely tied to the concentration and physical characteristics of titanium dioxide used in cosmetic formulations. Higher concentrations of TiO_2 are generally associated with more pronounced whitecast though some studies have not established a direct correlation between concentration and visibility on skin across various skin tones (Bilkan et al., 2022). Their work highlights the need for more targeted studies assessing TiO_2 visibility post-application under varying formulation conditions. Particle size and surface treatment also play a vital role; smaller, surface-modified TiO_2 particles have been found to disperse better and reduce whitecast intensity (Barilyuk et al., 2024).

Nevertheless, existing literature presents limited quantitative evaluations of whitecast intensity, especially in the context of day cream formulations. Many studies have explored consumer perceptions and general acceptability, but few have directly correlated formulation variables, such as TiO_2 concentration, with measurable aesthetic outcomes. Some studies studies discuss broader aspects of consumer behavior in bio-cosmetics but do not focus on the formulation-appearance relationship of physical UV filters (Choi, 2022). Furthermore, although user acceptance is known to decline when visual performance deteriorates, evidence directly linking TiO_2 load in emulsions to consumer rejection due to whitecast remains scarce.

This study, therefore, aims to formulate day creams with varying concentrations of titanium dioxide, evaluate the impact of these concentrations on the potential for whitecast formation, and identify the optimal TiO_2 concentration that balances effective UV protection with acceptable cosmetic appearance. By addressing these objectives, the research seeks to fill the gap in current knowledge and contribute to the development of cosmetically elegant yet functionally protective skincare formulations.

The significance of this research lies in its contribution to the development of more consumer-acceptable cosmetic products, particularly those that integrate physical UV filters like TiO_2. Moreover, this study aims to provide scientific formulation guidelines for the cosmetic industry to optimize sunscreen efficacy without compromising aesthetic performance, thereby enhancing both user experience and product competitiveness in the marketplace.

MATERIAL AND METHODS

Material

Purified water, glycerin, acrylates/alkyl acrylate crosspolymer, aloe vera extract, seaweed extract, cetyl alcohol, stearic acid, Emulium, Delta, triethanolamine (TEA), almond oil, cetearyl alcohol, dimethicone, titanium dioxide, phenoxyethanol, fragrance, vitamin E, niacinamide. All ingredients are cosmetic grade and purchased online on market place.

Preparation of Day Cream Formula

In this study, three different day cream formulations were developed, designated as F1, F2, and F3, which varied in titanium dioxide (TiO_2) concentration to assess its impact on whitecast formation. Formulation F1 contained 6% TiO_2, F2 contained 3.3% TiO_2, and F3 contained 2% TiO_2. All other ingredients and formulation steps were kept consistent across samples to isolate the effect of TiO_2 concentration.The base formula was designed to resemble the composition of Wedlyn Day Cream, a commercially available cosmetic product manufactured by PT Rumah Rumput Laut. Table 1 show the ingredients of each formulation by mass. Apart from the addition of TiO_2 there is no other ingredient that affect the color of the product when it is applied to the skin of respondent. Further research must be done to know this phenomenon.

Table 1. Ingridients mass of F1, F2 and F3

Ingredients	F1	F2	F3
Aqudes	67,4 g	70,1 g	71,4 g
Glycerin	5 g	5 g	5 g
Alkyl Acrylates	1 g	1 g	1 g
Cetyl alcohol	1 g	1 g	1 g
Stearyl alcohol	1 g	1 g	1g
Emulium delta	3 g	3 g	3 g
Stearic acid	1,5 g	1,5 g	1,5 g
Almond oil	3 g	3 g	3 g
Aloe Vera Extract	3 g	3 g	
Seaweed Extract	6 g	6 g	3 g 6 g
Vitamin E	2,5 g	2,5 g	2,5 g
Niacinamides	2 g	2 g	2 g
TEA	0,3 g	0,3 g	0,3 g
Titanium dioxide	6 g	3,3 g	2 g
Phenoxyethanol	1 g	1 g	1 g
Fragrance	0,3 g	0,3 g	0,3 g

Preparation of Premix 1

Premix 1 consisted of purified water, glycerin, and acrylates/alkyl acrylate crosspolymer, which served as the aqueous base phase in the day cream formulation. The three components were placed into a 150 mL glass beaker and heated to a temperature of 70–75 °C. Temperature was monitored using a thermometer to ensure the thermal stability of the ingredients throughout the heating process. Once the desired temperature was reached, the mixture was homogenized using a standard laboratory mixer until a fully homogeneous solution was achieved. This step was essential to ensure that the polymer was completely dissolved and uniformly integrated within the aqueous phase, thereby producing a stable gel texture and facilitating subsequent emulsification with the oil phase.

Preparation of Premix 2 and Emulsification

Premix 2 was composed of oil-phase ingredients, including almond oil, cetyl alcohol, stearyl alcohol, stearic acid, Emulium® Delta, and dimethicone. All components were weighed and combined in a 150 mL glass beaker, then heated to a temperature of 70–75 °C. Temperature was continuously monitored using a thermometer to ensure thermal stability and to prevent degradation of heat-sensitive ingredients. Once all components were fully melted and uniformly blended, the mixture was homogenized using a laboratory mixer until a stable and uniform oil phase was obtained. While maintaining the temperature within the same range (70–75 °C), Premix 1 (aqueous phase) was gradually added to Premix 2 (oil phase), followed by homogenization. This emulsification step was performed to produce a consistent oil-in-water emulsion, forming the structural base of the day cream formulation.

Preparation of Premix 3

Premix 3 was prepared following the emulsification step, once the temperature of the combined mixture (Premix 1 and Premix 2) had decreased to approximately 40 °C. This premix contained heat-sensitive active ingredients, including aloe vera extract, seaweed extract, titanium dioxide, niacinamide, and vitamin E (tocopherol). These components were combined in a separate beaker and gently stirred until fully blended at 40 °C to prevent degradation of the actives. Once homogeneous, Premix 3 was gradually incorporated into the previously emulsified mixture of Premix 1 and 2 under continuous mixing. This final homogenization ensured uniform distribution of the active compounds throughout the formulation, resulting in the complete day cream product.

Preparation of Premix 4 and Final Adjustment

Premix 4 constituted the final step in the day cream formulation process and was designed to adjust the pH and ensure product stability and safety. This premix included triethanolamine (TEA) as a pH-adjusting agent, and phenoxyethanol and fragrance as preservative and fragrance components, respectively. The ingredients were added once the temperature of the emulsion had decreased to room temperature (approximately 30–35 °C). TEA was added slowly under continuous stirring to allow gradual pH adjustment, targeting a final product pH in the physiologically acceptable range of 4.5–5.5. Following pH adjustment, phenoxyethanol and fragrance were incorporated to complete the formulation.

Organoleptic Evaluation

An organoleptic evaluation was conducted to assess the sensory attributes of the formulated day cream, including color, fragrance, texture, spreadability, and skin feel. The assessment was performed under ambient laboratory conditions at room temperature (~25 °C) by a panel of trained evaluators. Each parameter was observed macroscopically and through direct application of the product to the skin. Evaluators assessed visual uniformity, olfactory impression, tactile consistency, and ease of application using standardized descriptors.

Sensory Evaluation by Respondents

A sensory evaluation was conducted involving 20 voluntary respondents to assess the formulated day cream's texture and whitecast visibility. The respondents consisted of adult individuals with varying skin tones, and none had a known history of skin sensitivity to cosmetic products. Each respondent was asked to apply a small amount of the cream on their forearm under natural lighting conditions. The assessment was performed using a structured questionnaire employing a 5-point hedonic scale, where 1 indicated "very poor" and 5 indicated "excellent" for visibility of white residue after application.

The evaluation was conducted at room temperature (~25 °C) after the product had fully cooled and was stored under controlled conditions. Respondents were instructed to wait 2–3 minutes after application before scoring, to allow for absorption and film formation. The results were tabulated and analyzed to determine consumer perception of cosmetic acceptability.

RESULT AND DISCUSSION

Visual and Organoleptic Characteristics

The day cream formulation process was successfully carried out using three variations containing different concentrations of titanium dioxide (Formulations F1, F2, and F3). Organoleptic evaluation of all three formulations demonstrated consistent physical characteristics. Each formulation exhibited a homogeneous white color without turbidity or yellowish discoloration, a soft and pleasant mango fragrance, and a smooth texture that was easy to spread and absorbed quickly into the skin without leaving a sticky residue.

Table 2. Organoleptic Evaluation of Day Cream Formulations

Attribute	Observation
Color	Homogeneous white; no turbidity or yellowish tint
Fragrance	Soft and pleasant mango scent
Texture	Smooth, gentle, easy to spread

The pH values of all three formulations were measured to ensure compatibility with the skin. The results showed that each formulation had a pH within the ideal physiological range of 4.5 to 5.5, which is considered safe and suitable for daily cosmetic application (Soleimani et al., 2023).

Table 2. pH Measurement of Day Cream Formulations

Formulation Code	pH Value	Ideal pH Range
F1	5.2	4.5 – 5.5
F2	5.0	4.5 – 5.5
F3	5.0	4.5 – 5.5

The visual and organoleptic assessments indicated that all three formulations shared similar sensory qualities in terms of color uniformity, texture, and fragrance, suggesting that the emulsification process was successfully executed. Each cream presented a smooth and homogenous texture, which is typically indicative of stable emulsion systems (Wang, 2024).

However, despite their similar visual appearance in the jar, differences in titanium dioxide (TiO_2) concentration are expected to influence the degree of whitecast upon application. Formulation F1, containing the highest TiO_2 concentration (6%), is likely to exhibit the most noticeable whitecast, due to the increased reflectance and scattering of light caused by a higher pigment load (Santoro & Lachmann, 2019). In contrast, Formulation F3, which contains only 2% TiO_2, is expected to have minimal or no whitecast, although this may come at the expense of reduced coverage or visual opacity (Bilkan et al., 2022)

The homogeneous white appearance observed across all samples indicates that the dispersion of TiO_2 particles was effectively achieved, without visible clumping or phase separation. This is supported by previous findings showing that uniform particle dispersion contributes to better visual quality and reduced surface-level residue (Barilyuk et al., 2024).

Apart from the incorporation of titanium dioxide (TiO_2), no other formulation component appeared to influence the visual color outcome upon application to the respondents' skin. This observation suggests that TiO_2 was the primary determinant of visible surface whitening in the tested emulsions. However, further investigations are warranted to elucidate the underlying mechanisms and to assess whether other formulation factors—such as ingredient interactions, particle dispersion, or refractive index effects—may also contribute to this phenomenon.

Sensory Evaluation by Respondents

To assess whitecast perception from a user-centered perspective, a structured sensory questionnaire was administered to 20 voluntary respondents with diverse skin tones. Each respondent applied the three formulations (F1, F2, and F3) to their forearm and responded to three evaluation questions:

(1) Is whitecast visible after application?

(2) How natural does the finish appear on your skin?

(3) How disturbed are you by the appearance of whitecast?

Results revealed a clear trend in whitecast visibility across formulations. Formulation F1 (6% TiO_2) was identified as producing the most noticeable whitecast, while F3 (2% TiO_2) was consistently perceived as producing the least.

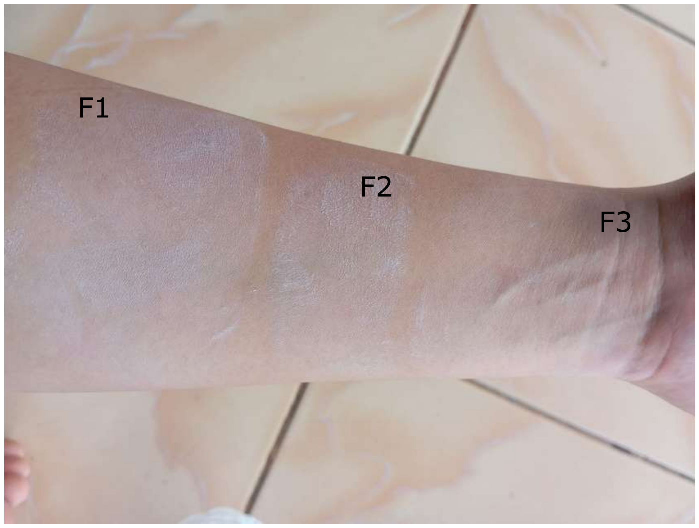

Figure 1. Visible whitecast of each formula

In the final preference-based question—*Which formulation produces the least visible whitecast?*—15 out of 20 respondents selected F3, 4 selected F2, and only 1 selected F1.

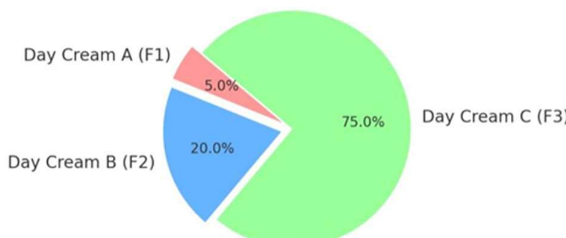

Figure 2. Respondent Preference for Least Visible Whitecast

These findings align with established literature showing that whitecast intensity correlates positively with TiO_2 concentration, as higher pigment loads tend to scatter more light on the skin's surface, particularly on medium to dark skin tones (Zhao et al., 2024). Although physical sunscreens like TiO_2 are favored for their broad-spectrum UV protection and low irritation potential, their cosmetic drawback in the form of visible residue can significantly reduce user satisfaction and product acceptance (Kera et al., 2024).

Despite Formulation F1 offering the theoretical advantage of higher UV coverage, its perceived lack of aesthetic elegance undermines its consumer appeal. On the other hand, Formulation F3 demonstrated superior sensory performance with minimal whitecast visibility, better skin conformity, and a more "natural" finish, making it the most acceptable among users.

These results reinforce the importance of balancing functional efficacy and cosmetic elegance in skincare product development. As consumer expectations for invisible, lightweight, and multifunctional formulations continue to rise, optimizing TiO_2 concentration to mitigate whitecast without compromising UV protection remains a critical challenge for formulators.

Influence of TiO_2 Concentration on Whitecast Formation

Titanium dioxide (TiO_2) is widely used in cosmetic formulations as an effective physical UV filter. However, its inclusion—particularly at higher concentrations—has been consistently associated with the formation of whitecast, a visible whitening film on the skin that can affect consumer acceptability. In the present study, three formulations (F1, F2, and F3) were evaluated, containing 6%, 3.3%, and 2% TiO_2, respectively. The findings revealed a clear relationship between TiO_2 concentration and whitecast intensity, with Formulation F1 (highest concentration) exhibiting the most pronounced whitecast, and Formulation F3 (lowest concentration) showing minimal visible residue.

These observations align with prior research by Bilkan et al. (2022), which demonstrated that higher concentrations of bulk TiO_2 result in increased light scattering and reduced skin translucency, particularly on medium to dark skin tones. The whitening effect occurs because TiO_2 particles—especially in their larger or uncoated forms—reflect and refract visible light, disrupting the optical harmony between the product and the user's natural skin tone. This light-scattering behavior is inherent to the high refractive index of TiO_2 and its particulate nature (Chaiyabutr et al., 2021; Racovita, 2022).

From a formulation standpoint, the increase in TiO_2 load enhances the opacity and UV protection of the cream, but it also exacerbates film visibility on the skin. The dispersed TiO_2 particles, particularly in bulk or micronized form, remain largely on the surface after application, contributing to the characteristic pale or chalky finish. This phenomenon is especially undesirable in daily-use products like day creams, where subtle and natural skin aesthetics are highly valued.

Moreover, the limitations of using untreated or bulk TiO_2 must be acknowledged. Traditional TiO_2 particles lack surface modification and often agglomerate, leading to uneven dispersion in emulsions and amplifying the whitecast effect. By contrast, surface-treated or nano-sized TiO_2 particles can enhance transparency, improve skin adherence, and reduce visible whitening while maintaining UV-blocking capacity (Tamrakar & Thakur, 2023). However, these advanced materials are subject to regulatory scrutiny, particularly concerning their potential dermal absorption and long-term safety. For example, the EU Scientific Committee on Consumer Safety permits certain coated nano-TiO_2 in specific product types but mandates strict particle characterization and usage limits (Karamanidou et al., 2021).

From a consumer perspective, modern sunscreen users increasingly demand products that are not only effective but also aesthetically pleasing and inclusive across various skin tones (Lim et al., 2025). Products that leave noticeable residue may be perceived as outdated or incompatible with daily wear, especially among users with deeper complexions. Therefore, balancing functional efficacy with cosmetic elegance has become a key formulation challenge. Meeting this demand requires both ingredient innovation and consumer-informed design strategies, such as selecting the appropriate particle size, coating method, and concentration of TiO_2 to ensure minimal whitecast without compromising UV protection.

In the present study, the efficacy of titanium dioxide (TiO_2) as a UV-protective agent was not evaluated. Future research is recommended to assess the photoprotective performance of TiO_2 within the formulated emulsions, particularly in relation to its concentration, particle size, and dispersion stability.

CONCLUSION

This study successfully formulated and evaluated three variations of day cream containing different concentrations of titanium dioxide (TiO_2) to investigate its influence on whitecast formation and overall cosmetic acceptability. All formulations demonstrated acceptable physical and organoleptic properties, including homogeneity, desirable fragrance, smooth texture, and physiological pH. However, sensory evaluation and respondent feedback revealed a clear correlation between TiO_2 concentration and whitecast visibility. The highest concentration (6%) in Formulation F1 produced the most noticeable whitecast, while the lowest concentration (2%) in Formulation F3 yielded a more natural skin finish and was most preferred by respondents.

These findings highlight a critical formulation trade-off: while increased TiO_2 concentration enhances UV protection, it also exacerbates the visibility of white residue, potentially reducing consumer acceptance. Formulation F3 demonstrated an optimal balance between sensory performance and aesthetic elegance, indicating its suitability for broader consumer use, particularly for individuals seeking physical sunscreens with minimal visible residue.

This research underscores the importance of formulating cosmetically elegant skincare products that meet both functional and sensory expectations. Future efforts should explore the incorporation of surface-modified or nano-sized TiO_2 to enhance transparency while maintaining safety and efficacy, in line with evolving regulatory standards and diverse consumer needs.

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