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Novel Multifunctional Sunscreen for Comprehensive Oily Skin Protection

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1. Introduction

Oily skin is characterized by increased sebum secretion due to sebaceous gland hyperactivity [1]. Skin sebum is a key component of the skin barrier and plays a critical role in maintaining hydration, reducing trans epidermal water loss (TEWL), protecting against external environmental factors (e.g., ultraviolet (UV) radiation), and supporting overall barrier function [2]. Despite its physiological relevance for skin health, excessive sebum production may lead to adverse effects, such as increased skin oiliness, which can negatively impact self-image and contribute to psychosocial distress [3]. Moreover, sebaceous hypersecretion also influences the skin microbiome, as the excessive lipidic substrate promotes the proliferation of *Cutibacterium acnes*, is recognized for its role in mediating inflammatory responses and contributing to the formation of acne lesions [4].

In addition to endogenous factors, extrinsic aggressors like UV radiation further impair skin health. UVB exposure damages the stratum corneum (SC), increases TEWL, and reduces hydration [6], while UVA radiation accelerates photoaging through oxidative stress and extracellular matrix degradation [7]. These cumulative effects underscore the importance of multifunctional skincare, especially for oily skin types.

Given the variety of skin damage caused by solar radiation and increasingly fast-paced lifestyles, multifunctional cosmetics have gained prominence by combining practicality with therapeutic and aesthetic benefits. Among these, sunscreens stand out for offering not only high sun protection factor (SPF) and broad-spectrum coverage but also additional skincare benefits [8]. This study evaluated the effects of a multifunctional sunscreen (DC-230013-11, SPF 60) developed with chemical filters and botanical actives, aiming to improve the physiological and clinical features of oily skin, while offering antioxidant, antipollution, and regenerative properties.

2. Materials and Methods

2.1. Preclinical Studies

The multifunctional efficacy of the test product was demonstrated through a set of preclinical studies approved by the Ethics Committee (CAAE 56005722.8.0000.5514, approval no.

5.503.565). For IR-A photoprotection, human fibroblasts were treated with non-cytotoxic concentrations of the product, exposed to infrared-A radiation (360 J/cm²) using Hydrosun 750 and HBM1 devices, and subsequently incubated with the formulation. The MMP-1 levels were measured using an ELISA kit (R&D Systems). The antipollution effect was assessed by exposing human keratinocytes to pollution simulated by the controlled combustion of two Marlboro cigarettes, followed by quantification of AhR activation using colorimetric assays and absorbance readings at 450 nm (Multiskan GO, Thermo Scientific). Antioxidant activity of the product was evaluated in an ex vivo human skin model exposed to UV radiation (10 J/cm²) using UVA Cube 400, SOL 500 H1 filter, and UV Meter devices. ROS generation was assessed via fluorescence microscopy (OLYMPUS BX53, CellSens software) using the DCFH-DA probe, and fluorescence intensity was quantified with ImageJ. Finally, the potential of the product to enhance skin firmness was assessed through the results of type I procollagen synthesis in human skin culture (ELISA assay, R&D Systems). Statistical analysis was performed with a significance level of 5% ($P < 0.05$) using ANOVA or T-test.

2.2. Clinical Study

This study was approved by Ethics Committee under opinions No. 6.219.240 and 6.334.190, linked to CAAE numbers 70815223.9.0000.5514 and 74012723.2.0000.5514. A total of 35 participants (aged 20–50 years; 89% female), with combination or oily facial skin were included. Of these, 22 participants were enrolled in the sauna-induced perspiration evaluation for ocular tolerability. Measurements of skin hydration, transepidermal water loss (TEWL), sebum content, and facial imaging were performed at multiple time points after a single application of the test product.

Skin hydration was assessed using the Corneometer® CM825 (Courage & Khazaka), which measures electrical capacitance of the SC. TEWL was measured using the Tewameter® TM Hex (Courage & Khazaka), based on passive diffusion of water vapor through the skin barrier. Sebum secretion was quantified with the Sebumeter® SM10 (Courage & Khazaka), using a photometric method. Facial pore intensity was evaluated using the Visia® imaging system (Canfield Scientific Inc.), which integrates high-resolution photography and image processing to quantify structural skin parameters.

Comedogenic and acnegenic potential were assessed through clinical lesion counting at baseline and after home use, focusing on inflammatory and non-inflammatory lesions. A subjective questionnaire was administered at the end of the study to assess participants' perception of the product's efficacy on a 5-point Likert scale. For ocular tolerability, participants applied the product and stayed in a sauna for 20 minutes (37.8 ± 2 °C; 35% ± 5% RH). After exposure, they were questioned regarding potential eye irritation or product dripping into the ocular area. Statistical analysis included normality testing (Shapiro–Wilk test) and used a 5% significance level ($P < 0.05$). Depending on the data distribution, comparisons were made using ANOVA, Student's t-test, or Wilcoxon test.

3. Results

3.1. Preclinical effects on cell culture

DC-230013-11 demonstrated protective effects against both infrared-A (IR-A) radiation and environmental pollution in preclinical models. IR-A exposure increased MMP-1 production in human fibroblasts by 95.67% compared to non-irradiated controls ($P < 0.001$), confirming its role in photodamage. Treatment with the product significantly reduced MMP-1 levels by 35.43% and 24.73% at 0.010 and 0.032 mg/mL, respectively ($P < 0.001$), indicating reduced collagen degradation, and effective photoprotection against IR-A damage. In keratinocytes exposed to environmental pollution, cytoplasmic AhR levels decreased by 10.01% versus non-exposed controls ($P < 0.001$), suggesting nuclear translocation linked to inflammatory pathways. DC-230013-11, SPF 60 prevented this translocation, increasing cytoplasmic AhR by 6.90% at 0.1 mg/mL ($P < 0.05$), indicating pollutant neutralization and supporting its antipollution efficacy.

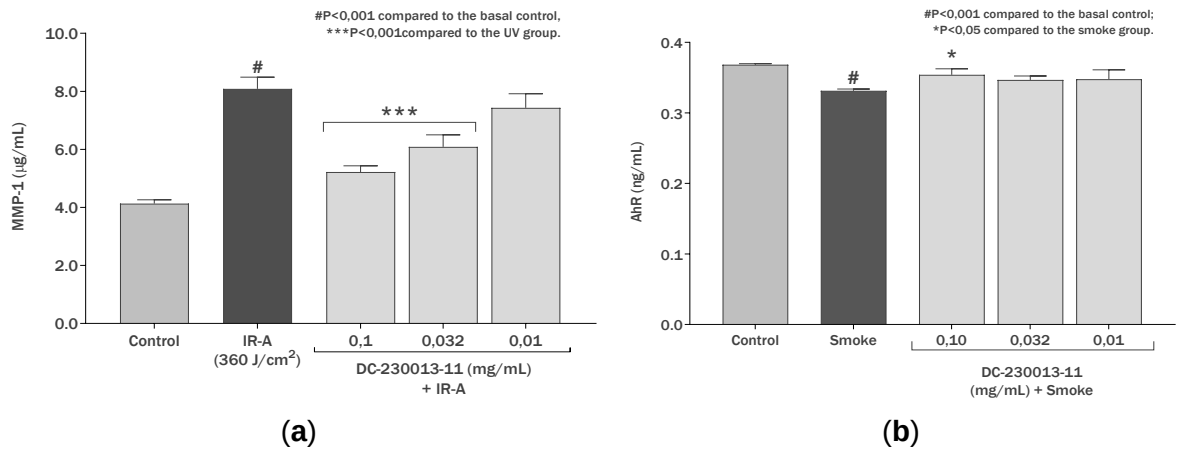


Figure 1. Effect of the product on (a) MMP-1 production in human fibroblasts exposed to infrared-A radiation (IR-A) and (b) AhR production in human keratinocytes exposed to pollution (ELISA assay). Data are presented as mean ± SD of 3 replicates (ANOVA - Bonferroni).

3.2. Preclinical effects on *ex-vivo*

Treatment with the DC-230013-11 product increased type I procollagen production by 57.12% compared to the basal control ($P < 0.05$), indicating stimulation of dermal matrix components. UV exposure, on the other hand, induced a 111.57% increase in reactive oxygen species (ROS) production compared to non-exposed samples ($P < 0.001$), confirming oxidative stress. In contrast, DC-230013-11 significantly reduced ROS generation by 53.52% when compared to the UV-exposed group ($P < 0.001$), as evidenced by semi-quantitative fluorescence analysis.

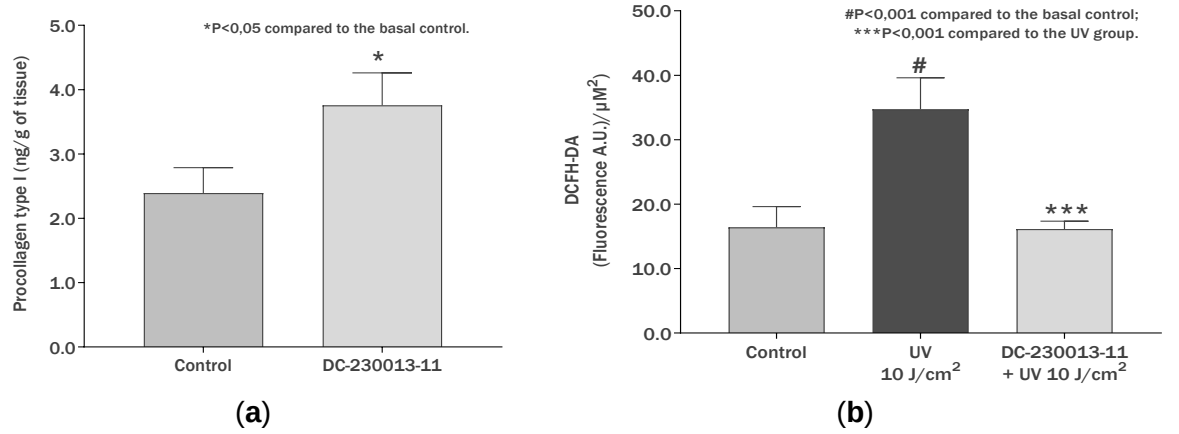


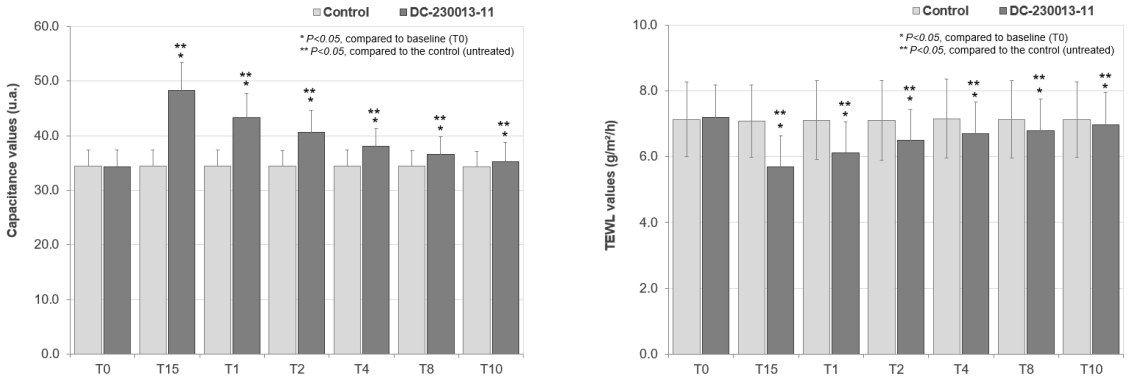
Figure 2. (a) Effect of the product on type I procollagen synthesis in human skin culture. Data are mean ± standard deviation of 3 replicates (Unpaired T-test). (b) Evaluation of free radical synthesis in human skin fragments exposed to UV radiation and incubated with the product. Data are mean ± SD of 6 replicates (ANOVA - Bonferroni).

3.3. Clinical effects on skin hydration and skin barrier function

The sunscreen DC-230013-11 significantly increased skin hydration at all evaluated time points ($P < 0.05$) compared to both baseline and untreated control (Figure 3a). The product promoted a hydration increase of 41.6% at 15 minutes, 26.4% at 1 hour, 18.6% at 2 hours, 11.0% at 4 hours, 6.6% at 8 hours, and 3.2% at 10 hours post-application. Notably, 100% of participants exhibited improved hydration up to 8 hours post-application, with 74% maintaining the effect for up to 10 hours.

Conversely, DC-230013-11 significantly reduced TEWL at all evaluated time points ($P < 0.05$), compared to both baseline and untreated control, indicating an enhancement of skin barrier

function (Figure 3b). Reductions in TEWL were 19.9% at 15 minutes, 14.5% at 1 hour, 9.0% at 2 hours, 6.7% at 4 hours, 5.3% at 8 hours, and 2.8% at 10 hours post-application. Improvement in skin barrier function was observed in 100% of participants up to 8 hours, and in 83% up to 10 hours post-application.



(a) **(b)**

Figure 3. (a) Mean capacitance values measured at baseline (T0), and at 15 minutes, 1, 2, 4, 8, and 10 hours after product application. Data are expressed as mean ± SD (n = 35 participants; paired Wilcoxon test). Mean TEWL values measured at all time points. Data are expressed as mean ± SD (n = 35 participants; paired Student-t test for comparisons with the respective T0; paired Wilcoxon test for comparisons between product and the control).

3.4. Clinical effects on skin oiliness

The clinical assessment of skin oiliness showed that DC-230013-11 significantly reduced sebum secretion at 15 minutes and 2 hours post-application ($P < 0.05$), indicating an immediate seborregulatory effect. From 4 to 8 hours, sebum levels returned to baseline ($P > 0.05$), while a significant increase at 10 hours suggested a rebound. When compared to the control site (water-based cleansing), the test product showed a less pronounced initial effect, but outperformed the control from 4 to 10 hours post-application ($P < 0.05$), indicating longer-lasting regulation of sebum production.

Relative to the control, the test product reduced oiliness by 8.4% at 4 hours, 11.3% at 6 hours, 13.7% at 8 hours, and 16.1% at 10 hours. Additionally, a progressive increase in participant response was observed: 77% showed reduced oiliness at 4 hours, 80% at 6 hours, 83% at 8 hours, and 86% at 10 hours. These findings support the product's ability to maintain oil control over an extended period.

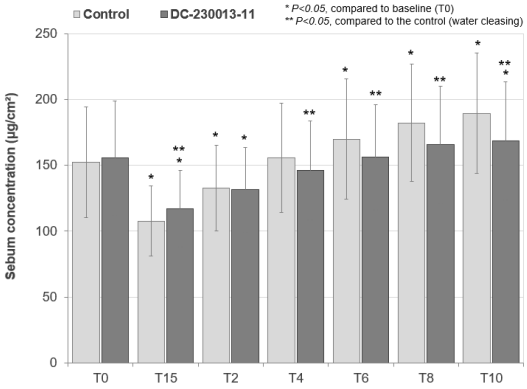


Figure 4. Mean values of sebum secretion measured at baseline (T0), and at 15 minutes, 2, 4, 6, 8, and 10 hours after product application. Data are expressed as mean ± SD (n = 35 participants; paired Student-t test).

3.5. Clinical effects on pores intensity

Treatment with the DC-230013-11 product resulted in a statistically significant reduction ($P < 0.05$) in pore intensity, with decreases of up to 31.2% at T15, 26.6% at T2, 22.5% at T4, 21.0% at T6, and 20.2% at T8 considering the upper confidence limit. Furthermore, 100% of participants showed a reduction in pore intensity at T15, 91% at T2, 89% at T6, and 83% at both T4 and T8.

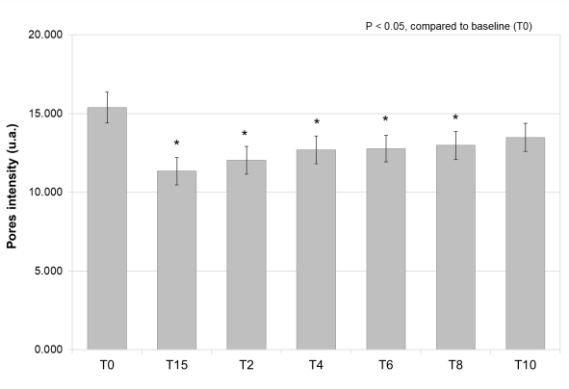


Figure 5. Mean values of pores intensity obtained at all time points. Data are expressed as mean ± standard error (SE) (n = 35 participants; ANOVA – Friedman test)

3.6. Clinical effects on acnegenicity and comedogenicity potential

At T28, the test product was clinically classified as anti-comedogenic, due to a significant reduction in non-inflammatory lesions compared to baseline ($P < 0.05$). Inflammatory lesions showed no significant change ($P > 0.05$), supporting its classification as non-acnegenic.

3.7. Self-perceived efficacy

Participant-reported outcomes at T15 and T28 showed high satisfaction with the product's sensory and functional attributes. At T28, 100% of users agreed that the product promoted hydration, had an ultra-light texture and consistency, spread easily, and left no residue or white cast. Agreement was also high for anti-shine effect (97%), oil control (94%), and pleasant fragrance (94%). Notably, perceptions improved over time for most attributes, including a rise from 71% to 86% for the refreshing sensation and from 86% to 94% for oil control. The product was also consistently rated as non-sticky, quickly absorbed, and non-irritating to the eyes. Overall, these findings reflect strong user acceptance and suitability for oily or combination skin. According to the predefined validation criteria (≥70% agreement), all assessed attributes were approved at both T15 and T28.

Thus, the test product demonstrated efficacy in delivering the following benefits: dry touch, anti-shine effect, oiliness control, refreshing sensation, hydration, rapid absorption, easy spreading, non-sticky and non-oily texture, ultra-light texture and consistency, no residue or white cast, no flaking, no eye irritation, matte finish, and a pleasant fragrance.

3.8. Ocular tolerability following induced perspiration

The results shows that none of the 22 participants (100%) reported that the product ran into their eyes during perspiration. Regarding ocular discomfort, 21 participants (95%) reported no irritation, while 1 participant (5%) experienced a mild burning sensation. No cases of itching, tearing, or other types of eye discomfort were reported. These findings suggest that the test product presents good ocular tolerability, even under conditions that favor perspiration and potential eye contact.

4. Discussion

Multifunctional sunscreens are increasingly valued not only for their ability to provide broad-spectrum photoprotection, but also for delivering dermatological benefits tailored to specific

skin needs, such as hydration, oil control, and anti-aging effects. These features are particularly relevant for individuals with oily or acne-prone skin, where excessive sebum secretion and low adherence to greasy or occlusive formulations pose a challenge to routine sun care.
In this study, the DC-230013-11 sunscreen, formulated with chemical UV filters and botanical actives, demonstrated consistent efficacy in both preclinical and clinical models. In vitro and ex vivo assays confirmed its antioxidant, regenerative, and protective effects—reducing IR-A-induced MMP-1 expression, preventing nuclear translocation of the AhR receptor in response to environmental pollution, stimulating type I procollagen synthesis, and reducing UV-induced ROS production. These outcomes reinforce the biological relevance of the formulation's active components, such as Centella asiatica, known to stimulate fibroblast activity and collagen production, thereby contributing to dermal repair and firmness [10].
Clinically, the product demonstrated sustained efficacy in improving skin hydration and barrier function, with effects lasting up to 10 hours post-application. These parameters are crucial for maintaining the integrity of the stratum corneum (SC), the skin's first line of defense. Literature suggests that dehydration of the SC can enhance UV penetration, compromising barrier function and increasing the risk of radiation-induced damage [11]. Thus, the hydrating properties of this formulation not only improve skin feel but may also indirectly contribute to photoprotection.
In terms of sebum regulation, the product outperformed the water-based control. Both groups initially showed a reduction in oiliness; however, the control group experienced a rebound effect after 4 hours, with increasing sebum levels up to 10 hours. In contrast, DC-230013-11 maintained baseline levels for up to 8 hours, significantly reducing oiliness compared to the control thereafter. These results suggest a more stable and durable seborregulatory effect, likely due to the inclusion of sebum-controlling actives in the formula.
Additionally, the significant reduction in pore intensity observed immediately after application (T15) and maintained throughout the day (T8) suggests that, beyond photoprotection, the product contributes to the visible reduction of dilated pores, a common concern for individuals with oily skin. This indicates an added benefit for daily oily skin care, potentially increasing adherence to photoprotector use among this consumer group.
Importantly, the clinical classification of the product as anti-comedogenic and non-acnegenic reinforces its safety profile for acne-prone individuals. Participants also reported high satisfaction across a range of functional and sensory attributes, including dry touch, matte finish, rapid absorption, and lack of residue. These perceptions are especially relevant for maintaining adherence to daily sunscreen use—a key factor in long-term skin health outcomes. Additionally, the product demonstrated excellent ocular tolerability under sweat-inducing conditions, with no reports of product run-off into the eyes and minimal irritation, supporting its safe use during physical activity or high-temperature exposure.
Altogether, the findings confirm that DC-230013-11 is not only effective in terms of photoprotection but also provides complementary benefits essential for oily and combination skin types. Its performance across biological, clinical, and user-perceived endpoints positions it as a reliable and well-tolerated option for daily, long-term use.

5. Conclusion

The multifunctional sunscreen DC-230013-11 demonstrated efficacy in protecting the skin against IR-A radiation and environmental pollution, promoting antioxidant activity, stimulating collagen synthesis, and improving skin hydration, barrier function, and sebum regulation, while also reducing pore intensity. Its classification as anti-comedogenic and non-acnegenic, along with high user acceptance and excellent ocular tolerability, supports its suitability for oily and combination skin types. These findings substantiate the product's potential to provide both immediate and long-term dermatological and sensory benefits, positioning it as a comprehensive solution for contemporary skincare needs.

6. References

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