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"Addressing the Challenges of In Vivo SPF Testing: A Critical Review of the ISO 23675:2024 "Double Plate" In Vitro Method"

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1. Introduction

The detrimental effects of intense sun exposure on the skin are well-documented and diverse, ranging from immediate reactions like erythema and pigmentation, appearing minutes to hours after exposure, to more profound cellular and molecular damage affecting DNA. These effects can manifest in the long term as cosmetic concerns or even life-threatening conditions: photoaging, hyperpigmentation, melasma, actinic keratosis, carcinoma, and at a less extend melanoma[1]. Therefore, sunscreens are a critical component of sun protection strategies, whether for mitigating the risks of intentional sun exposure or protecting against unavoidable exposure. Even low SPF sunscreens have demonstrable benefits[2].

Given their importance, sunscreens and the methods used to measure their performance, especially the Sun Protection Factor (SPF), are subject to close scrutiny. Sunscreens represent the only category of cosmetics with ISO standards specifically addressing performance measurement, which national regulations often reference or draw inspiration from. ISO method for SPF measurement (ISO24444[3]) was first published in 2010, marking an achievement in harmonization, following a period characterized by a patchwork of disparate local references.

Despite the continuous nature of the solar spectrum, sunscreen performance is evaluated in segments throught a toolbox of indexes or methods: protection against UVB and UVA are covered together by the SPF and the UVA-Protection Factor (UVA-PF). More recently, beyond ISO standards, protection against visible light (VL) has been proposed, and some claim up to infrared radiation (IR). UVC, which is blocked by the Earth's atmosphere, is excluded from these assessments. Water resistance is a standardized measure of UVB performance when the product is exposed to water[4], and ad hoc tests evaluating resistance to rubbing, sand, sweat, and other factors can supplement the claims.

Historically, SPF measurement has relied on an *in vivo* approach: the ratio of the Minimal Erythema Dose (MED) on protected skin (MED_p) to the MED on unprotected skin (MED_u). This ratio provides the SPF value familiar to consumers, though its precise meaning is often poorly understood[5].

Since its inception, the *in vivo* method has faced criticism regarding its ethical implications, lack of precision, regulatory inconsistencies, discrepancies with real-world usage, and its focus on erythema as the primary endpoint, overlooking other potential biological effects[6]. More recently, further criticisms have emerged, highlighting limitations in scientific and technical innovation, cost, time efficiency, and inclusivity[7]. These concerns have led to calls for alternative methods[8]. These critics challenge the conventional focus on simple correlation between alternative and reference methods. This raises the question of whether alternative methods should merely strive for equivalence to the *in vivo* method or offer genuine improvement.

Numerous alternative methods have been proposed, ranging from hybrid *in vivo*/*in vitro* approaches to fully in silico models, as well as analytical and *in vitro* techniques[9]. Among *in vitro* methods, the most common approach draws inspiration from calculations presented in the ISO standard for *in vitro* determination of UVA-PF (ISO 24443[10]), leading to various attempts using different substrates, irradiation spectra, application conditions, and calculations. The term " *in vitro* SPF" thus encompasses a multitude of methods, with each research group often having its own variation. Despite the known influence of chosen parameters on results, these diverse methods are often grouped under the same umbrella term, complicating assessment and comparison. Primarily offered for screening, these methods may also have been used for market surveillance.

Recently, two alternative methods have completed the standardization process and achieved ISO standard status: the HDRS method (ISO 23698:2024), a hybrid *in vivo*/*in vitro* approach, and the fully *in vitro* Double Plate method (ISO 23675:2024[11]). This landscape provides a timely opportunity to analyze the challenges associated with SPF measurement in light of recent publications. We chose to focus on the Double Plate method because it best addresses the requirements of European regulations[12], which prioritize *in vitro* methods when available. Furthermore, there's a lack of clarity in the current scientific literature regarding the differences between the Double Plate and other "ad hoc" *in vitro* SPF methods. This narrative review aims to provide a clear and detailed overview of the Double Plate method (DPM), enabling researchers, industry professionals, and regulatory bodies to understand its specific features, advantages, and limitations and contribute effectively to research and development in this field**.**

Due to space constraints, we won’t offer an exhaustive survey of the literature but rather focuses on key publications that highlight the challenges and advancements in SPF testing methodologies.

2. A Critical Review of Challenges Linked to *In Vivo* SPF Determination

2.1 The In Vivo SPF Method: A Summary

The *in vivo* SPF method determines the Sun Protection Factor by comparing the Minimal Erythema Dose (MED) of protected skin to unprotected skin after exposure to UV radiation. Key steps include selecting volunteers, applying sunscreen to the designated area, irradiat-ing both protected and unprotected skin with increasing UV doses, a waiting period of 16-24 hours, and visual assessment of erythema to determine MED for each area. The SPF is calculated first individually (SPF_i) as the ratio of MED for individual protected skin (MED_{ip}) to MED for individual unprotected skin (MED_{iu}), then averaged across typically 10 volunteers.

The generic procedure for *in vivo* SPF determination is presented in Fig 1, together with the associated main challenges.

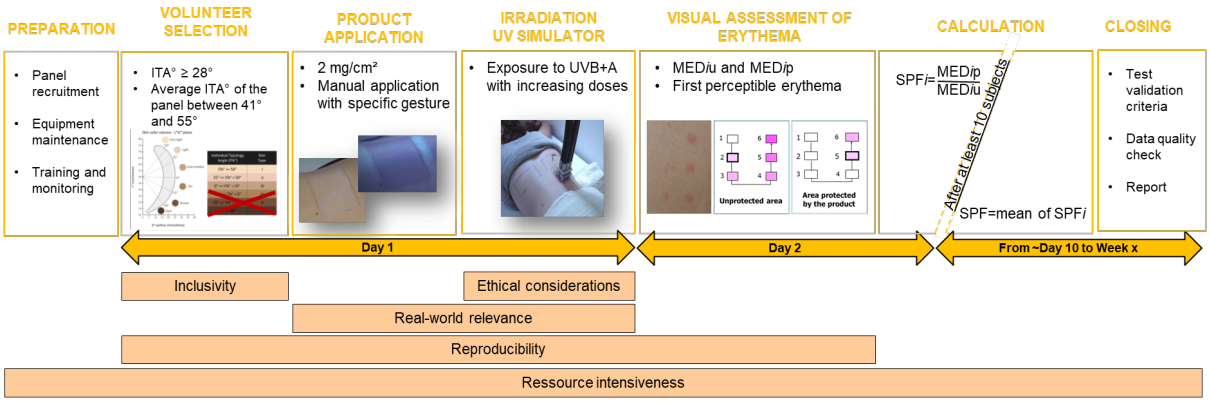

Figure 1 : Presentation of the generic steps in the *in vivo* SPF determination, together with time frame estimation and associated main challenges.

2.2 Ethical Considerations

The most significant criticism of *in vivo* SPF testing is its inherent requirement to expose human volunteers to erythemal doses of UV, known to be harmful. Mitigation measures, outlined in the method, include limiting the number of volunteers (10-20), restricting participation frequency (every 8 weeks), calculating MED_u based on the Individual Typological Angle (ITA°), gradually increasing UV doses during the test, and basing MED_p on the manufacturer's stated SPF target. While these measures aim to minimize harm, the ethical concern of intentionally exposing humans to UV radiation persists.

2.3 Reproducibility Concerns

In vivo SPF measurements exhibit substantial variability, notably between different laboratories. Studies demonstrate this inter-lab variability, with coefficients of variation often exceeding 20%[13-15]. Even with the improvements introduced in ISO 24444:2019 to standardize parameters like volunteer selection (based on ITA°), application gesture, and equipment monitoring procedures, recent studies indicate that considerable variability remains a challenge[16]. This impacts the reliability of SPF claims and affects manufacturers, testing labs, regulators, and consumer confidence.

2.4 Real-World Relevance

Critics question the *in vivo* method's real-world relevance, citing the standardized 2 mg/cm² application, which is higher than typical consumer usage (0.5-1 mg/cm²), the prescribed application technique, the limited UV spectrum used in testing (compared to full sunlight), and the acute exposure scenario, which doesn't represent chronic daily exposure[17, 18].

While these points are valid, others support –and we agree with them– that the SPF is a standardized performance metric designed to rank products by their protection efficacy against (mainly) UVB. It does not predict real-world personalized protection, which depends on individual usage habits and exposure conditions[19].

2.5 Inclusivity

The *in vivo* method faces inclusivity challenges on two fronts. First, the reliance on a "fair skin" model (ITA ≥ 28°) for optimal experimental conditions raises concerns among some about the applicability of SPF values to individuals with darker skin tones[20]. Second, the practical constraints of assembling volunteer panels with ITA° ≥ 28° and an average ITA° between 41° and 55° limit the global applicability of the method.
While the SPF, as a relative measure, remains conceptually relevant across skin tones, the feasibility of conducting the *in vivo* test is indeed geographically restricted (Fig 2).

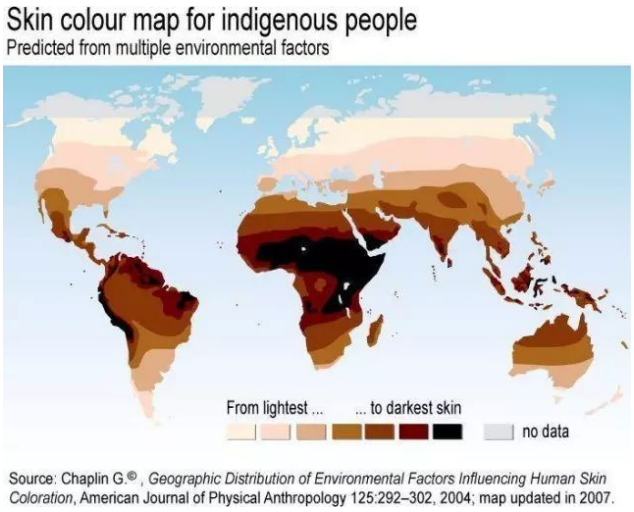

Figure 2 : Geographic distribution of human skin colors is a technical limitation to the implementation of the *in vivo* SPF testing globally.

2.6 Resource Intensiveness

In vivo testing is resource-intensive, requiring specialized equipment, trained personnel, and suitable facilities, in addition to volunteer recruitment and compensation. The time required, including preliminary testing and data quality check, often stretches to several weeks. This impacts the frequency and scope of testing, potentially limiting product innovation and thorough regulatory oversight. While optimization strategies like testing multiple formulations on the same volunteer can reduce resource needs, they may heighten ethical considerations.

3. The Double Plate Method: A Standardized *In Vitro* Solution

3.1 Existing In Vitro Methods and Their Limitations

Numerous *in vitro* SPF methods exist, all based on spectrophotometric measurements of a thin product film applied to a UV-transparent substrate. While conceptually similar to the *in vitro* UVA-PF measurement described in ISO 24443, these methods historically struggled to accurately predict *in vivo* SPF values[21]. A key issue is that the raw *in vitro* SPF, calculated using the product's absorbance spectrum, the erythemal action spectrum, and the solar irradiance spectrum, typically mis-estimates the *in vivo* SPF. Various adjustments and refinements have been explored to address this discrepancy, including different substrates[22], application conditions[23-25], and calibration procedures[26]. The search for an optimized *in vitro* SPF method has led to a proliferation of methods, each with its own set of parameters and limitations, and this until recently[27], seeming to be unaware that one of them specific has been selected to be worked on by ISO experts since 2018: the Double Plate method.

3.2 The Double Plate Method: Distinguishing Features

The Double Plate Method (DPM), now standardized as ISO 23675:2024, offers a significant advancement in *in vitro* SPF determination. Principles, mathematical and practicals aspects of DPM have been initiated in 2015 by Miksa et al[28, 29]. Key features that distinguish DPM from other *in vitro* approaches include:

- **Dual PMMA Plates**: The use of two Polymethyl methacrylate (PMMA) plates—one with a molded surface and another with a sandblasted surface—overpass the specific affinity of some products with one type of plate[22]. The standardized rough surface, characterized by six controlled roughness parameters, was shown to be critical to reproducibly measure the absorbance of the product spread on its substrate and accurately estimate the SPF[30].
- **Automated Spreading**: Automated, mechanical spreading ensures a highly standardized application of the sunscreen, minimizing variability associated with manual application[24].
- **Standardized Irradiation**: DPM employs the same standardized irradiation spectrum, as the *in vivo* method (ISO 24444:2019). Dose, and conditions are standardized, as they proved to be compulsory for reaching reproducibility and *in vitro*/*in vivo* correlation [28, 31].
- **Controlled Experimental Conditions**: Precise temperature control of the surface of the plates (27 +/- 2°C) throughout the process minimizes variability due to temperature fluctuations, ensuring consistent and reproducible measurements[32].
- **Specific Calculation Methods**: DPM uses a unique calculation method involving weighted averaging of absorbance values from both PMMA plates. The correction factors are product-type-specific (e.g. emulsion, alcoholic monophase, oil,…). A final calibration function further enhances accuracy and correlation with *in vivo* results[33].

Fig 3 synthetizes the key steps and features of the Double Plate method.

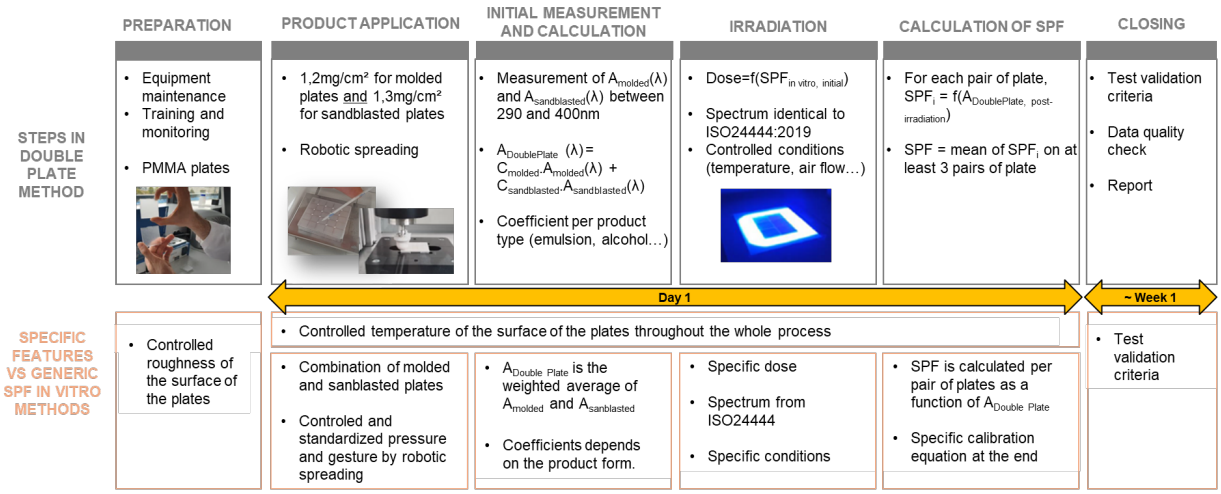

Figure 3: Key steps of the Double Plate method and key features versus generic *in vitro* SPF methods. $A_{Double\ Plate}(\lambda)$ is the absorbance calculated for each pair of plates as the weighted average of the absorbance of the product spread on the molded plate $A_{molded}(\lambda)$ and the absorbance of the product spread on the sandblasted plate $A_{sandblasted}(\lambda)$, with correction factors C_{molded} and $C_{sandblasted}$ defined by product type.

3.3 Advantages of the Double Plate Method

3.3.1 Correlation and Reproducibility

The Double Plate Method distinguishes itself through both strong correlation with the *in vivo* gold standard (ISO 24444:2019) and significantly improved reproducibility. Multiple peer-reviewed studies provide compelling evidence for this dual advantage. Initially, a Cosmetics Europe ring test, involving 24 emulsion-type formulations tested across three *in vivo* and three *in vitro* labs, showed very good correlation within a defined "funnel" of acceptance, acknowledging the inherent variability of the *in vivo* method[34]. This study expanded to encompass 76 additional formulations, including water-in-oil emulsions and mineral sunscreens (TiO2 and ZnO), solidifying the observed correlation[35]. Statistical analysis, including Bland-Altman assessments, provided quantitative support for agreement between DPM and *in vivo* results. Further validation came from two ring tests conducted by the ALT-SPF Consortium[33, 36]. A key outcome of the first ring test was the development and validation of a calibration function that, in the second ring-test, demonstrably reduces bias, enhancing the DPM's accuracy and alignment with the *in vivo* gold standard. These tests, using specifically designed statistical criteria, not only confirmed the correlation but also revealed the DPM's superior reproducibility.

This was expected since the standardized protocol—controlled roughness, automated spreading, controlled temperature, and precise irradiation conditions—minimizes variability stemming from operator technique or environmental factors. This contrasts sharply with the *in vivo* method, where inherent biological variation, manual application and subjective erythema assessments lead to higher inter-laboratory variability. Consequently, the DPM delivers more consistent and reliable SPF measurements across different laboratories, building confidence in its results and enabling more robust comparisons across studies and between sunscreen products. This data-driven approach ensures the DPM provides a robust and reliable alternative to traditional *in vivo* testing.

3.3.2 Addressing the Key Challenges of *In Vivo* Testing: A Comprehensive Solution

The Double Plate Method offers a comprehensive solution to several limitations inherent in the traditional *in vivo* SPF testing method.

- **Ethical Considerations:** By eliminating the need to expose human volunteers to potentially harmful UV radiation, the DPM effectively addresses ethical concerns associated with *in vivo* testing. This is a major advancement in sunscreen testing, aligning with growing ethical awareness and regulatory pressures.

- **Inclusivity and Global Applicability:** The *in vitro* nature of the DPM eliminates geographical constraints associated with recruiting specific volunteer panels. This enhances the method's inclusivity and enables standardized SPF testing across global markets. Labs anywhere in the world can implement this method, promoting consistent and reliable SPF measurements internationally.

- **Resource Efficiency:** The DPM significantly reduces the resources required for SPF testing. While the initial investment in equipment might be comparable to setting up an *in vivo* testing facility, the DPM offers substantial long-term cost savings due to reduced running costs, faster turnaround times, and less reliance on highly trained personnel for conducting the tests. This efficiency frees up resources for research and development, leading to faster innovation cycles and potentially reinforced monitoring of the products on the markets, which benefits consumer protection.

- **Real-World Relevance Considerations**: While the DPM, like the *in vivo* method, uses a standardized protocol that doesn't replicate real-world sunscreen application conditions, it represents a significant step towards addressing real-world relevance challenges. By controlling key parameters like film thickness and uniformity, the DPM provides a more consistent and objective basis for comparing the relative performance of different sunscreen products. This relative performance ranking, while not a perfect predictor of real-world protection, offers more valuable information for consumers and researchers than *in vivo* testing burdened with higher variability and ethical limitations. Furthermore, the DPM's *in vitro* nature allows for easier exploration of the impact of different ingredients or processes, sunscreen layering, and other factors relevant to real-world usage, paving the way for future research that can better bridge the gap between standardized testing and consumer behavior.

4. Limitations and Future Perspectives

4.1 Applicability to Different Formulations

Currently, the DPM is primarily applicable to emulsions and alcohol-based products due to the availability of coefficients specific to these formulations[11]. This limitation in the current scope of the standardized method reflects the currently available data rather than inherent technical constraints[29]. Expanding the database of coefficients to encompass a broader range of formulations, including oil and sticks, is a priority for future research. This expansion will enhance the DPM’s versatility and enable its application to a wider variety of sunscreen products.

While concerns have been raised about the DPM's accuracy for formulations containing high concentrations of ZnO[37], it is important to note that these concerns stem from observations

made with *ad hoc in vitro* methods derived from ISO 24443. These findings were then inappropriately extrapolated to the Double Plate method. As previously discussed, the Double Plate method is distinct from these earlier *ad hoc* methods, incorporating key improvements in substrate selection, application technique, and data processing. Therefore, it's inadequate to conclude that the DPM is inherently unsuitable for high-ZnO formulations.

4.2 Water Resistance Testing

While the DPM effectively measures baseline SPF, it currently lacks a standardized *in vitro* method for assessing water resistance. Multiple approaches are being explored, including methods using plates or solutions and in silico modeling[38-41]. Establishing and standardizing a robust and reliable *in vitro* water resistance test is crucial to fully replace *in vivo* testing and provide a comprehensive evaluation of sunscreen performance.

4.3 Future Research Directions

Beyond addressing current limitations, research should explore the full potential of the DPM as a tool for comprehensive sunscreen assessment. This includes investigating the impact of different ingredients and ingredient combinations, including UV filters, polymers, and other excipients, on *in vitro* SPF. Further research should examine the effects of manufacturing processes, layering of different sunscreen products, and other factors relevant to real-world usage. These investigations will provide valuable insights into the complex interplay of factors affecting sunscreen performance, facilitating the development of more effective and user-friendly sun protection products.

5. Conclusion

The ISO 23675:2024 Double Plate method represents a major advancement in SPF testing. By eliminating the need for *in vivo* testing, it addresses key ethical concerns, improves reproducibility, reduces resource requirements, and expands the possibilities for global implementation. This shift aligns with broader industry trends emphasizing ethical and sustainable practices, supporting the growing global movement towards non-animal testing and contributing to a more environmentally responsible approach to product development. While limitations remain, notably regarding the applicability to certain formulation types and the lack of a standardized *in vitro* water resistance test, ongoing research and development efforts hold promise for expanding the method's scope and solidifying its position as the gold standard for SPF determination. The Double Plate method ultimately paves the way for more efficient, ethical, and inclusive sunscreen testing, driving innovation and enhancing consumer safety by enabling more reliable and accessible evaluation of sunscreen performance.

References

1. Moyal, D. and A. Fourtanier, *Acute and chronic effects of UV on skin*, in *Photoaging*. 2004, CRC Press. p. 31-48.
2. Iannacone, M.R., M.C. Hughes, and A.C. Green, *Effects of sunscreen on skin cancer and photoaging.* Photodermatol Photoimmunol Photomed, 2014. **30**(2-3): p. 55-61.
3. International Organisation for Standardization, *ISO 24444:2019(Amd1:2022) Cosmetics — Sun protection test methods — In vivo determination of the sun protection factor (SPF)*. 2019.

4. International Organisation for Standardization, *ISO 16217:2020 - Cosmetics — Sun protection test methods — Water immersion procedure for determining water resistance*. 2020.
5. Passeron, T., et al., *Sun exposure behaviours as a compromise to paradoxical injunctions: Insight from a worldwide survey.* J Eur Acad Dermatol Venereol, 2023. **37**(12): p. 2481-2489.
6. Osterwalder, U. and B. Herzog, *Sun protection factors: world wide confusion.* Br J Dermatol, 2009. **161 Suppl 3**: p. 13-24.
7. Zou, W., et al., *Sunscreen testing: A critical perspective and future roadmap.* TrAC Trends in Analytical Chemistry, 2022. **157**.
8. Breneman, A. and D.V. Belsito, *Sun Protection Factor Testing: A Call for an In Vitro Method.* Cutis, 2022. **110**(2): p. E15-E17.
9. Osterwalder, U., R. Schütz, and J. Vollhardt, *SPF assessment revisited–status and outlook.* Sofw J, 2018. **144**: p. 38-42.
10. International Organisation for Standardization, *ISO 24443:2021 - Cosmetics — Determination of sunscreen UVA photoprotection in vitro*. 2021.
11. International Organisation for Standardization, *ISO 23675:2024 - Cosmetics — Sun protection test methods — In Vitro determination of Sun Protection Factor (SPF)*. 2024.
12. Verheugen, G., *Commission recommendation of 22 September 2006 on the efficacy of sunscreen products and the claims made relating thereto*. 2006, Official J Eur Union. p. 39-43.
13. Miksa, S., et al., *Sunscreen sun protection factor claim based on in vivo interlaboratory variability.* Int J Cosmet Sci, 2016. **38**(6): p. 541-549.
14. Bacardit, A., *Determining the ability to differentiate results between independent sun protection factor tests using the ISO24444 method.* Frontiers in Medicine, 2023. **10**.
15. Zago, D.I., et al., *Overview of proficiency testing results for the in vivo determination of sun protection factor.* International Journal of Cosmetic Science, 2024. **46**(6): p. 1097-1104.
16. Cole, C., B. Colson, and S. Uhlig, *The Variability of Sunscreen Sun Protection Factor Values* Int J Cosmet Sci, 2025. **[under review]**.
17. Young, A.R., et al., *A sunscreen's labeled sun protection factor may overestimate protection at temperate latitudes: a human in vivo study.* J Invest Dermatol, 2010. **130**(10): p. 2457-62.
18. Portilho, L., et al., *Effectiveness of sunscreens and factors influencing sun protection: a review.* Brazilian Journal of Pharmaceutical Sciences, 2022. **58**.
19. Pissavini, M., B. Diffey, and O. Doucet, *The perplexing dilemma of measuring sun protection factors.* Int J Cosmet Sci, 2017. **39**(4): p. 465-466.
20. Damian, D., G. Halliday, and S. Barnetson, *Sun protection factor measurement of sunscreens is dependent on minimal erythema dose.* The British journal of dermatology, 1999. **141**(3): p. 502-507.
21. Rohr, M., et al., *In vitro sun protection factor: still a challenge with no final answer.* Skin Pharmacol Physiol, 2010. **23**(4): p. 201-12.
22. Pissavini, M., S. Marguerie, and O. Doucet, *SPF tests reveal no ideal in vitro substrate exists.* Cosm & Toil, 2016.
23. Fageon, L., et al., *Importance of sunscreen products spreading protocol and substrate roughness for in vitro sun protection factor assessment.* Int J Cosmet Sci, 2009. **31**(6): p. 405-18.
24. Miksa, S., D. Lutz, and C. Guy, *In vitro UV testing-robot vs. human spreading for repeatable, reproducible results.* Cosmt. Toil, 2013. **128**: p. 742-752.

25. Miksa, S., D. Lutz, and C. Guy, *Influence of pressure during spreading on UV transmission results.* Cosm. Toil, 2013. **128**(9): p. 822-832.
26. Batzer, J., et al., *The 'Dispersal Rate' - a product dependent characteristic to predict the reliability of the calibrated in vitro SPF on WW5 plates.* Int J Cosmet Sci, 2016. **38**(3): p. 294-304.
27. Asakura, K., et al., *In vitro Evaluation Method of UV Protecting Ability of Sunscreens: Clarifying and Overcoming Problems to Develop New Method.* J Oleo Sci, 2024. **73**(2): p. 121-134.
28. Miksa, S., D. Lutz, and C. Guy, *New approach for a reliable in vitro sun protection factor method Part I: Principle and mathematical aspects.* Int J Cosmet Sci, 2015. **37**(6): p. 555-66.
29. Miksa, S., et al., *New approach for a reliable in vitro sun protection factor method - Part II: Practical aspects and implementations.* Int J Cosmet Sci, 2016. **38**(5): p. 504-11.
30. Pissavini, M., et al., *Characterising roughness: a new substrate to measure SPF.* Cosm & Toil, 2009. **124**: p. 56-64.
31. Miksa, S., D. Lutz, and C. Guy, *Improving the UV exposure of sunscreen during in vitro testing.* Cosmet. Toil, 2014. **129**: p. 34-40.
32. Miksa, S., D. Lutz, and C. Guy, *UV transmission assessment: influence of temperature on substrate surface.* Cosmetics & Toiletries magazine, 2013. **128**(7): p. 484-494.
33. Pouradier, F., et al., *Performance assessment of the Double Plate method (ISO23675) in ALT-SPF Consortium: a highly reproducible and accurate in vitro method to determine SPF.* Int J Cosmet Sci, 2025. **[under review]**.
34. Pissavini, M., et al., *Validation of an in vitro sun protection factor (SPF) method in blinded ring-testing.* Int J Cosmet Sci, 2018. **40**: p. 263-268.
35. Pissavini, M., et al., *Validation of a new in vitro Sun Protection Factor method to include a wide range of sunscreen product emulsion types.* Int J Cosmet Sci, 2020. **42**(5): p. 421-428.
36. Colson, B., et al., *ALT-SPF study – Validation of alternative methods for the determination of SPF and UVA-PF – Design, criteria and performance of the reference methods.* Int J Cosmet Sci, 2025. **[under review]**.
37. Osterwalder, U., et al., *Sun-protection factor of zinc-oxide sunscreens: SPFin vitro too low compared to SPFin vivo—a brief review.* Photochemical and Photobiological Sciences, 2024. **23**(10): p. 1999-2009.
38. Pissavini, M., et al., *In vitro assessment of water resistance of sun care products: a reproducible and optimized in vitro test method.* Int J Cosmet Sci, 2007. **29**(6): p. 451-60.
39. Sohn, M., et al., *In vitro water resistance testing using SPF simulation based on spectroscopic analysis of rinsed sunscreens.* Int J Cosmet Sci, 2018.
40. Bielfeldt, S., C. Rock, and K.P. Wilhelm, *Chances and limits of an improved method to assess water resistance of cosmetic sunscreen products in vitro on polymethylmethacrylate plates.* Int J Cosmet Sci, 2013. **35**(1): p. 89-93.
41. Pissavini, M., et al., *A new in vitro approach for determining the water resistance of sunscreen products, validated by a blinded ring test.* Int J Cosmet Sci, 2025. **(accepted for publication)**.