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Review Article

Formulation And Performance Evaluation of Tinted Sunscreen Containing Rosehip Oil and Lavender Oil: A Comprehensive Review

Anudeep Kaur*¹, Himanshu Sharma², Balwinder Singh³

¹Final Year M. Pharmacy (Pharmaceutics), Department of Pharmaceutics, Shaheed Bhagat Singh College of Pharmacy Patti, Tarn Taran, Punjab

²Assistant professor, Department of Pharmaceutics, Shaheed Bhagat Singh College of Pharmacy, Patti, Tarn Taran, Punjab

³Principal, Department of Pharmaceutical chemistry, Shaheed Bhagat Singh College of Pharmacy, Patti, Tarn Taran, Punjab

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ABSTRACT

Tinted sunscreen products have become a unique class of cosmetics due to the fact that the pigmentary TiO₂ and the Fe₂O₃ which are responsible for the colour of these sunscreens also act as a light attenuator and the light attenuator which is included in the waveband that is associated with melasma and post-inflammatory hyperpigmentation. In this review, the scientific evidence for the synergy of two Botanical oils roseship (*Rosa canina*) and lavender (*Lavandula angustifolia*) with fatty acids, tocopherols, carotenoids and monoterpenes that provide complementary antioxidant, barrier-repair and anti-inflammatory properties, with a tinted mineral base, is considered. Both the oils are assessed both chemically in terms of phytochemistry and formulation to stabilise unsaturated lipids and pigments in an oil emulsion, as well as by physical, spectroscopic and biological evaluation of the performance. Evidence is quite good for individual ingredients, but there is no controlled research testing the specific combination, and question remains as to pigment dispersion, stability in the presence of oxidizing agents and regulatory acceptance. These imbalances are identified and priorities are set for rational, good quality development of multifunctional tinted formulations to address the wide range of photo types

INTRODUCTION

1.1 The Solar Spectrum and Mechanisms of Photodamage

*Corresponding Author: Anudeep Kaur

Address: Final Year M. Pharmacy (Pharmaceutics), Department of Pharmaceutics, Shaheed Bhagat Singh College of Pharmacy Patti, Tarn Taran, Punjab

Email ✉: anudeepsandhu1997@gmail.com

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Skin exposure to solar radiation occurs across the ultraviolet (UV), visible and infrared (IR) wavelengths and each is uniquely associated with a skin injury. The DNA (nuclear) directly absorbs UVB radiation (280 to 320 nm), creating cyclobutane pyrimidine dimers and pyrimidine (6-4) photoproducts which, if not repaired, will initiate the classic mutations associated with keratinocyte carcinomas (Rittié and Fisher, 2002). Ultraviolet A (320-400 nm) lights penetrate deeper in the dermis and its effects are mainly mediated by the generation of ROS, which induces the expression of matrix metalloproteinases leading to the degradation of collagen and elastin underpinning the process of photoageing (Pittayapruek et al., 2016). Chronic irradiation has been a known risk factor for both the development of non-melanoma (NM) skin cancer and melanoma (Hockfield, 2015; Pitaya Pruk et al., 2016), as well as accelerated ageing and pigmentation disorders (Rittié and Fisher, 2002). In this context, topical photoprotection is the most available measure of primary prevention for daily use by the general population.

1.2 Conventional Sunscreens and their Limitations

Thirty-five years of research have now put sunscreen's clinical utility beyond doubt. A higher incidence of actinic keratoses, SCCs of the skin and of invasive melanoma and a slowed rate of visible photo-aging after prolonged follow-up are seen after regular use (Osterwalder et al., 2014). With regard to modern products, they are expected to be broadspectrum (to block UVA as well as UVB); and the increasingly rigorous regulatory regimes across most jurisdictions demand a defined balance between UVA and UVB attenuation. (Schalka and Reis, 2011; Osterwalder et al., 2014). UV filters can be divided into two types: Organic (chemical) and inorganic (mineral)

compounds. The latter are primarily zinc oxide and titanium dioxide, long assumed to work through reflectance but found to work mainly by absorption recently (Cole et al., 2016; Schneider and Lim, 2019). However, the existing conventional sun cream has an Achilles' heel; most mineral filter particle sizes are small enough to maintain cosmetic transparency, but reduce the availability of the visible light component of the sun's spectrum by essentially nothing (Lyons et al., 2021).

1.3 Visible Light and the Emergence of Tainted Sunscreens.

Because this is also a limitation, visible light (400-700 nm) and especially blue light, a high-energy form of UV, causes erythema in lightly pigmented skin and persistent pigmentation on more melanized skin, such as that of a tanned Caucasian rider. The limitation, however, is important because visible light (400-700 nm) and high energy blue light in particular, will catalyze erythema in lightly pigmented skin and enduring pigmentation in heavily pigmented skin, such as that of a tanned Caucasian rider. The finding that melanocytes express melanopsins that contain a blue-light sensor, opsin-3, linking SWSW visible-light absorptions to melanogenesis created a rationale for these clinical observations (Regazzetti et al., 2018). As noted above, the notion of 'transparent protection' is in direct conflict with 'visible-light protection' in a filter that is not pigmented, meaning those are two competing objectives for a colourless mineral base (Lyons et al., 2021). Tinted sunscreens address this balance by using coloured pigments, predominantly iron oxides alongside pigmentary titanium dioxide, to provide them a shade that blends with a person's complexion to help keep the shade in check, however minimize the visible



wave band (Dumbuya et al., 2020; Lyons et al., 2021).

Therefore, one can say that the change is from just a UV focus to a combined concert of photoprotection from tinted sunscreens. The original tinted film products were mainly sold because of their cosmetics benefit – to help disguise the car; but controlled testing subsequently proved that there was some useful function. When products containing iron oxide were compared with non-tinted mineral sunbright of the same SPF, they were more effective at preventing visible-light-induced pigmentation and clinical trials in melasma reported fewer relapses in newly discovered short visible wavelengths of sunlight that were protected by iron oxide (Castanedo-Cazares, 2014 et al., Boukari, 2015 et al., Dumbuya, 2020). These conclusions changed the view of the tint as a mere cosmetic, and they are particularly helpful when it comes to skin colors other than white, where pigmentary disorders occur more often and are a source of psychological distress (Morgado-Carrasco et al., 2022).

1.4 Botanical Oils as Adjuvant Actives

With interest in visible light comes an interest in using botanical ingredients that could help to provide antioxidant properties and skin conditioning benefits to the base photoprotective ingredient. Mineral emulsions containing plant oils, which are rich in unsaturated fatty acids and lipophilic antioxidants, can help to act as a barrier, remove existing free radicals triggered by residual UV and visible photons, and enhance the sensory acceptability of mineral emulsions that may be quite heavy (Lin et al., 2018). These are two oils reviewed. Their inclusion was designed to provide a secondary major benefit (as mentioned) of antioxidant and reparative properties in an appropriate filtered product; however, it is

appropriate to note that it is common for plant oils to have a higher inherent SPF than claimed (Kaur and Saraf, 2010).

Rosehip oil extracted from *Rosa canina* and other rose species contains the polyunsaturated fatty acids linoleic and alpha-linolenic acid, in a large proportion and low levels of oleic acid, respectively, combined with unsaponifiable fraction containing tocopherols, carotenoids and phytosterols (Grajzer et al., 2020; Ilyasoğlu, 2014). It forms a basis for its traditional applications in scars and irritated skin treatment and has recently been assessed for wound healing and photoageing (Mármol et al., 2017; Belkhelladi and Bougrine, 2024). Biological activity is provided by the same unsaturation that makes the oil easy to oxidize, a common issue in formulation (Grajzer et al., 2020).

Lavender oil obtained by steam distillation, from *Lavandula angustifolia* flowers, is a monoterpene rich, essential oil in which linalool and linalyl acetate usually predominate (Cavanagh and Wilkinson, 2002). The anti-inflammatory and antimicrobial action of these components may help the tolerance and microbiological stability of a leave-on product (Peana et al., 2002, Cardia et al., 2018). On the other hand, lavender oil can be dangerous because the terpenes it contains are prone to auto-oxidation on exposure to air, and the safety vs benefit can be tricky to manage (Hagvall et al., 2008; Prashar et al., 2004).

1.5 Knowledge Gap and Aims of the Review

There is a gap in knowledge regarding individual elements, which are and remain plausible; however. The effectiveness of mineral tints, the phytochemistry of rosehip and lavender oils, and the analysis of the formulation of botanical sunscreens have all proven to be topics of research interest, but to date there has been no controlled



study looking at a tinted sunscreen combining all three. The issue of compatibility of oxidation-prone oils with catalytically active metal-oxide pigments, the role of the oils in pigment dispersion, and their effect on pigment colours have found only marginal, uninformed and naïve answers in peer-reviewed literature, if any. Questions regarding opaque oil-colour combination with active metal-oxide pigments have not been adequately addressed in the literature either. The problem of the interaction of catalytically active metal-oxide pigments and opaque oil-colours has not been properly addressed in the literature either for opaque combination or regarding the influence of the oils on pigment dispersion and colour.

This review is therefore designed to pull together existing evidence to provide a reasoned argument for, and an evaluation of, rosehip and lavender tinted sunscreens. These include the study of cutaneous photo biology, pigment science, the phytochemistry and dermal pharmacology of the two oils and the principles of emulsion formulation and quality by design, followed by an analysis of the assessment of such products and identification of future directions for the field. Wherever possible, we differentiate between facts and speculation, and we identify places where existing evidence is limited.

2. Biology of the Skin and Photoprotections

2.1 Skin Architecture and Wavelength-Dependent Injury

Stratified skin is the main barrier to the entry of xenobiotics and water loss, with the outermost layer of this structure being the stratum corneum. The living epidermis contains the keratinocytes and melanocytes and the dermis offers the fibrous protein support system, consisting of collagen fibers and elastins that gives skin its mechanical

ability. Photoprotection has to be interpreted in the context of this architecture since various wavelengths deposit their energy at different depth and thereby cause damage to the different places (Rittie and Fisher, 2002).

UV-B can evoke the erythematous (sunburn) response which is the basis of the sun protection factor (SPF), and, when directly absorbed by the epidermis, UV-B induces formation of the DNA-activating agents called dimers (Schalka and Reis, 2011). The demand of UVA is low, although more penetrating and abundant, it indirectly oxidises lipids, protein and DNA through the formation of ROS and perifocal inflammation (Pittayapruek et al., 2016). These mechanisms include the downstream induction of matrix metalloproteinases that results in degradation of dermal collagen, a key pathway of the cumulative photoageing and a central mechanism of extrinsic ageing, which could be minimised by using a sunscreen with limited UVA coverage while an acceptable level of sunburn protection is achieved (Rittie and Fisher, 2002; Pittayapruek et al., 2016)

2.2 Visible Light, Melanogenesis and Opsin-3.

With this realization came a change in direction of the field as visible light is also a skin injury. High energy visible light produces immediate and lasting pigment darkening and exacerbates dyschromia phenomena clinically important for Fitzpatrick phototypes III – VI (Mahmoud et al., 2010). Experimental studies showed the pigmentary component of visible light was wavelength dependent and additionally synergistic (synergistic pigmentation when combined with long-wavelength UVA1) leading to darker and more long-term pigmentation than when using each waveband individually (Kohli et al., 2018). The discovery of the opsin-3 as a blue-light receptor on melanocytes enabled the elucidation of the pathway by which sub-erythemal doses of



visible light stimulate melanogenesis induces calcium-dependent-signalling and activate tyrosinase (Regazzetti et al., 2018). This is why melasma and postoperative hyperpigmentation patients frequently experience recurrence when using only UV blocking sunscreens.

2.3 Endogenous Defences and the Case for Antioxidants

This injury is offset by endogenous defences. More deeply pigmented skin has higher intrinsic photoprotection, lower skin-cancer risk because of ability to scatter and absorb radiation as well as to quench reactive species, but with a higher risk for pigmentary disorders (Mahmoud et al., 2010). There are antioxidants to fight ROS present in the body that are of two types, EAS and small molecules, which tend to get overwhelmed with repeated or high-level exposure of the ROS, thus the need for supplemental topical antioxidant photoprotection (Nichols and Katiyar, 2010). Botanical polyphenols, carotenoids and tocopherols have been suggested in this adjuvant capacity as they are capable of scavenging radicals and in several cases help in repairing DNA damage and reduce inflammatory signalling (Nichols and Katiyar, 2010; Korać and Khambholja, 2011).

2.4 Photoprotection as a Layered Strategy

The concept of protection is then layered with regard to photoprotection. There are three layers: the first is the blocking of the photons by filters and pigments; the second is the neutralization of the reaction they inevitably create in the material; and the third is the strengthening of the barrier and repair ability of the tissue itself. The first layer is because of the presence of certified UV filters, the second layer is due to the botanical antioxidants and the third layer is due to the emollient oils (Lyons et al., 2021; Lin et al., 2018). A properly formulated "tinted" sunscreen, if correctly

designed, could work at all three levels if the active ingredients don't counteract each other.

2.5 Barrier Biology and Ingredient Selection

Ingredient selection is also based on an understanding of barrier biology. The lipid matrix around corneocytes, which forms the epidermis' stratum corneum, can be potentiated and lipid-coated by topically applied fatty acids, which will lead to decrease in the transepidermal water loss and increase in barrier competence (Lin et al., 2018). A physiological barrier-loving component of the epidermal ceramides is linoleic acid, for this reason linoleate rich plant oils are attractive in barrier supportive formulations while oleic-acid-dominant oils could overpower the barrier (Lin et al., 2018). This applies directly to rosemary and rises, as both have a high content of linoleate of which the presence is favourable; the fine detail of composition is more important than the overall label 'plant oil'.

Finally, photodamage is depth dependent, so whatever the topical products can do will be limited. Many triglyceride oils (with a molecular weight > 500 Da) do not penetrate into human skin to any great depth, and most of them therefore have their effect as emollients and film formers in the outer part of the skin (Bos and Meinardi 2000). Understanding this critical factor is essential when setting expectations: the antioxidant/barrier activity of oils that remain on the surface is true and it remains true only at the surface and in the 'product film,' not necessarily in deep dermal delivery, unless it is added in a specially formulated carrier.

3. Tinted Sunscreens

3.1 Definition and Pigment Composition



Tinted Sunscreen is simply a broad spectrum sunscreen with coloured inorganic pigments added in to both conceal skin tone and block visible light. The pigment almost always consists of a mixture of iron oxides, which are responsible for red, yellow and black colours, and pigmentary grade titanium dioxide, which scatters visible wavelengths, whereas UV-filter grade does not (Lyons et al., 2021). Manufacturers can produce a range of shades by altering the ratio and overall concentration of these pigments to achieve a desired shading and provide a measurable visible-light protection factor (Lyons et al., 2021).

3.2 Mechanisms: UV Filtering vs Visible Light Attenuation

Sometimes, the mechanism of action of the different roles of metal oxides in the UV and VIS filters is not completely differentiated in the market, but it is critical for the formulators. These nano-metre sized zinc oxide and titanium dioxide particles are manufactured to be transparent and both of these mixtures are designed to protect primarily in the UV region by absorption, and to transmit almost all visible light, making them transparent at a nano-level (Cole et al., 2016; Smijs and Pavel, 2011). In opposition to this, particles of iron oxides and pigmentary titanium dioxide are opaque only in the visible region because scatter and absorpt processes of longer wavelengths (Lyons et al., 2021). The colour of a tinted product is therefore not incidental it is the physical evidence of the activity it demonstrates in terms of visible light. A protective tint cannot be 100% clear, a tint it is not (Lyons et al., 2021).

3.3 Clinical Evidence in Melasma and Skin of Colour

The benefits of the tint in terms of helping patients' conditions have grown more and more evident. When the formulation was tested on skin of colour

in a controlled comparison, it was found that an iron-oxide-based product caused a reduction in visible-light induced pigmentation, while an SPF 50+ sunscreen without iron-oxide did not; it was concluded that it was the pigment, not the UV filter, that caused the difference (Dumbuya et al., 2020). A trial with a UV-protective agent that also covered short visible wavelengths showed fewer relapses than a comparator UV sunscreen; also, a double blind study showed better reduction in the severity of melasma by a sunscreen that contained iron oxide — which covers short-range UV wavelengths — compared to a sunscreen containing no iron oxide — found to cover only medium-range UV wavelengths (Boukari et al., 2015; Castanedo-Cazares et al., 2014). The findings are in line with the mechanism of action where the visible light stimulates melanogenesis which has been the reason why tinted sunscreens are recommended as part of the melasma treatment (Morgado-Carrasco et al., 2022).

Tinted products are most clinically useful for patients whose diseases are provoked or made worse by the presence of visible light. These include other photodermatoses that have proven to be unresponsive to broad-spectrum UV cover (Lyons et al., 2021; Morgado-Carrasco et al., 2022), and post inflammatory hyperpigmentation, which is a type of hyper pigmentation. Tinted sunscreens also address a long-standing cosmetic challenge of mineral sunscreens, the creation of an ashen or whitening effect caused by transparent filters containing nanoparticles, which historically decreases uptake by people with darker skin (Morgado-Carrasco et al., 2022).

3.4 Formulation and Regulatory Challenges

However, creating a tinted sun cream poses particular challenges. Careful dispersion of pigments is important to ensure uniformity in the colour and the absence of any flocculation to



maintain the high optical coverage/ TOH (Tadros, 2004); this should be done so that there are no signs of pigment aggregation. Colour matching in diversity is challenging; and a small colour range can rule out the very patients who needs it most (Morgado-Carrasco et al., 2022). Further complicating the picture is regulatory classification: as colourants, iron oxides are not detected as UV filters but are not so easily quantifiable from a visible-light perspective and thus are not easily labelable (Osterwalder et al., 2014).

Commonly agreed-upon indicators for visible light protection have only just started to evolve. There are no known in vivo and in vitro standards for determining visible-light protection factor, unlike the use of the sun protection factor and UVA protection factor, and various in vitro approaches have been described, resulting in different indices, either based on transmittance or on darkness/pigment content, which are not necessarily comparable (Lyons et al., 2021). This methodologic lack of comparison makes it more difficult to make an honest comparison between tinted products, and is actively being developed as emphasized in the discussion of performance evaluation.

Moreover, the safety of pigment use for association with other active ingredients is a pertinent issue that needs to be taken into account within this review. While the pigmentary form of iron oxides is generally very inert, its catalytic properties and the high surface area of the finely divided particles, in principle, could catalyse the oxidation of unsaturated lipids, in the formulation. (Grajzer et al., 2020, Kockler et al., 2012). This brings material that is a combination of a tinted mineral base and oxidation prone botanical oils into consideration, and will be further explored in subsequent sections, that material prognosis must

be considered when linking a tinted mineral base with oxidation prone botanical oils.

3.5 Summary: The Niche of Tinted Sunscreens

When viewed together, tinted sunscreens have a clear place to hold: they deliver photoprotection across an important waveband that isn't offered by conventional UV filters; they're better for cosmetic acceptability for skin of colour; they stem from a small however consistent body of proof of efficacy; and they're supported by a small physique of effectiveness. The standardisation of visible-light metrics, the variety and inclusion of available shades, and the physicochemical controls and handling of the pigments in complex formulations, are their major open challenges, which highlight the need for botanical and pharmaceutical approaches brought forward below (Lyons et al., 2021; Morgado-Carrasco et al., 2022).

4. Rosehip Oil

4.1 Botanical Origin and Provenance

Rosehip oil is extracted from the fruit and seeds of different Rosa species, particularly Rosa canina (Goebel, 2017), but also Rosa rubiginosa and Rosa mosqueta, which are wild shrubs found throughout Europe, North-west Africa and Western Asia (Mármol et al., 2017). The botanical and geographical origins are significant since the oil's fatty acid and antioxidant content differ considerably depending on the plant and conditions of cultivation, and it has been suggested that the variability between species and cultivation practices is information about the oil's chemotaxonomy, but it adds complexities when standardising the oil for cosmetic use (Ilyasoğlu, 2014; Mármol et al., 2017).



4.2 Methods of Extraction and quality

The extraction method has a significant effect on composition and quality. While all methods of oil extraction result in an oil with a narrow range in tocopherols, the synovial extraction method (cold pressing) does not destroy the thermolabile antioxidants carotenoids and tocopherols, and the extraction of oil from these seeds results in an oil with favourable oxidative indices; oil extraction by solvent extraction may lead to a loss of quality and yield, while extraction of these oils by supercritical carbon dioxide is a solvent-free extraction method, which retains lipophilic antioxidants such as carotenoids and tocopherols (Grajzer et al., 2020). In addition to being a rich source of α -linolenic acid, cold-pressed rosehip oil is also an excellent source of polyphenolic acids identified also for the first time during a detailed physicochemical study (Grajzer et al., 2020), phytosterols and tocopherols. Thus, the type of extraction will dictate the phytochemical content of the ingredient and the stability of the resultant ingredient

4.3 Phytochemical Composition

The response is the predominance of triglycerides in the phytochemistry of the oil. Linoleic acid is regularly reported as the main fatty acid often around 45 to 55 per cent followed by alpha-linolenic acid and oleic acid, meaning the polyunsaturated fats make up the bulk of the oil (Ilyasoğlu, 2014). The degree of unsaturation is one of the reasons for the biological activity of the oil and also for its chemical sensitivity (Grajzer et al., 2020). While insignificant in percentage, unsaponifiable fraction is most significant: beta-sitosterol as the dominant phytosterol, tocopherols – with the gamma predominating, and carotenoids which are both colour and antioxidant (Ilyasoğlu, 2014; Grajzer et al., 2020).

One special category of interest to the skin is the essential fatty acids. Linoleic acid is part of epidermal ceramides and acts as a barrier repair agent and moisture retainer, and alpha-linolenic acid affects the pathways of eicosanoids, thereby providing anti-inflammatory activity (Lin et al., 2018). The blend of omega-6 and omega-3 fatty acids gives rosehip oil the emollient attributes and barrier supportive properties that encompass the scientific proof that linoleate containing oils support the barrier better than oleate containing oils (Lin et al., 2018).

In addition to the fatty acids, the oil contains lipophilic vitamins and provitamins. Tocopherols serve as chain-breaking antioxidants and prevent the polyunsaturated triglycerides from being peroxidized while also adding to the skin's antioxidant repository when applied to the skin (Grajzer et al., 2020; Nichols and Katiyar, 2010). Carotenoids contribute to an additional radical scavenging ability and are the source of some of the natural colour of the oil (Grajzer et al., 2020). As mentioned it is the water soluble content of the flesh (ascorbate) in the rosehip fruit that is the well-reported source of vitamin C and not the oil: this is often confused in popular literature (Ilyasoğlu, 2014).

4.4 Antioxidant, Anti-inflammatory and Reparative Activity.

Rosehip oil has been shown to possess antioxidant activity, by using standard radical-scavenging assays, and cold-pressed samples possessed measurable activity from their tocopherol, carotenoid and phenolic content (Grajzer et al., 2020). Mechanistically this activity is important for its role in photoprotection because exogenously added antioxidants could block the production of ROS by UV and visible photons before they propagate to lipid peroxidation and induction of matrix metalloproteinases (Nichols,



Katiyar, 2010; Pittayapruek, et al., 2016). But the level of benefit in a completed sunscreen relies on the oil's resistance to the oxidative products which isn't guaranteed.

The Pro phage oil to moderate inflammation and repair has been attributed to fatty-acids and minor constituents in the oil. Topical linoleic acid- and Alpha-linolenic acid-containing plant oils can modulate inflammatory signaling pathways and assist in the repair of impaired barrier function, whilst rosehip extracts have also been found active in repair, wound healing and collagen synthesis and pigmentary regulation in preclinical and clinical studies (Lin et al., 2018; Mármol et al., 2017). Pharmacological properties have been the scientific substantiation of the use of the oil in modern and traditional medicine for irritated, scarred and photoaged skin (Mármol et al., 2017).

4.5 Clinical Evidence

Encouraging clinical evidence is sparse, and is not very robust. Only a few studies were eligible for the systematic review on rosehip oil use in post-surgical scars and only half of these showed significant positive effects; these improvements were found with twice-daily application and were thought to be associated with the ability of linoleate to repair affected skin barriers, as well as the anti-inflammatory action of alpha-linolenic acid (ALA) from linoleic acid (Belkhelladi and Bougrine, 2024). In one study, a standardised *Rosa canina* powder was tested on a randomized group of volunteers to assess the effect on the elasticity, moisture and wrinkled appearance of the skin, which were perceived to be anti-aging - this suggests that other preparations of *Rosa canina* might have a similar effect (Phetcharat et al., 2015). Earlier systematic reviews of *Rosa canina* also revealed a limited number of sample sizes and a variety of preparations (Chrubasik et al., 2008).

4.6 Limitations as a Cosmetic Active

Although rosehip oil has many limitations from a cosmetic active standpoint, it is not a biological one. It has a high polyunsaturation, and because of this is very prone to autoxidation, resulting in loss of bioactive fatty acids and the formation of potentially irritating peroxidation products, thereby jeopardizing shelf life unless antioxidants and proper packaging are applied (Grajzer et al., 2020; Kockler et al., 2012). Variability in composition from different botanical sources (Mármol et al., 2017) makes it difficult to ensure batch-to-batch consistency. Lastly the size of the molecules of the triglycerides restricts dermal penetration and hence the oil's activity would be mostly in the outer layers of the skin where appropriate for barrier and antioxidant properties, but not for any depth of dermal penetration (Bos and Meinardi, 2000). The constraints, not the intrinsic bioactivity of the oil define the formulation problem discussed later in this review.

5. Lavender Oil

5.1 Botanical Origin and Chemotypes

The volatile essential oil extracted from the flowering tops of the perennial shrub, *Lavandula angustifolia*, from the Mediterranean basin, is lavender oil (Cavanagh and Wilkinson, 2002). A number of other and related taxa (*Lavandula latifolia* and lavandin) are commercially distilled, and their oil has distinct chemical differences as well, meaning that whether it is Lavandin or *Lavandula latifolia* that is used as a functional ingredient and not just a perfume, species-based or chemotypification based specifiers must be applied (Cavanagh and Wilkinson, 2002; Koulivand et al., 2013).



5.2 Chemical Composition

The main constituents of *L. angustifolia* oil are oxygenated monoterpenes. Linalool and its ester linalyl acetate are the two main constituents found from the results of gas chromatographic analyses carried out across cultivars, often comprising a large proportion of the oil, with smaller proportions of 1,8-cineole, camphor, lavandulyl acetate, terpinen-4-ol, and beta-caryophyllene (Cavanagh and Wilkinson, 2002). Reported proportions have changed for different cultivars and environments, and linalool content can range from a quarter to almost half of the oil, and linalyl acetate of similar amount, meaning that “lavender oil” is not a uniform product, but rather a variable natural product (Cavanagh and Wilkinson, 2002; Koulivand et al., 2013).

5.3 Anti-inflammatory, Antimicrobial and Antioxidant Activity

These monoterpenes are responsible for most of the biological activities that the oil possesses. The anti-inflammatory activity of linalool and linalyl acetate has been reported and in experimental studies with control assays, it has been shown that linalyl acetate in particular plays a role in the suppression of inflammatory responses (Cardia et al., 2018; Peana et al., 2002). To establish anti-inflammatory activity of lavender essential oil, an acute inflammation animal model was used, where the lavender essential oil was able to decrease the inflammatory mediators and oedema, which is in line with its proposed mechanistic action as terpene alcohols and esters (Cardia et al., 2018). The activity may have an impact on the low order irritation that may occur with mineral based emulsions and can help to improve tolerability thus making leave-on sunscreens more appropriate.

Oil's broad range of functional attributes is extended by its antimicrobial and antioxidant properties. Lavender oil is inhibitory against several Gram-positive and Gram-negative bacteria and some fungi, and it is believed that this comes from the effects of the dominant components, linalool and linalyl acetate, on the microbial membrane (Cavanagh and Wilkinson, 2002). Within a cosmetic context this antimicrobial activity may be important for the microbiological robustness of a formulation, but cannot replace an appropriate preservative system and is not intended to replace the antioxidant activity of an appropriate preservative system, which has a significantly greater radical scavenging potential than the antioxidant activity offered by this antimicrobial agent (Cavanagh and Wilkinson, 2002). Lavender oil is also popular in the control of pleasant fragrance to enhance sensory acceptability and as a consequence adherence of daily sunscreen application (Koulivand et al., 2013).

5.5 Safety Profile and Allergenicity

The safety of lavender oil needs to be critically and fairly evaluated, as it is the major constraint for its utilization. The terpenes of its oil are readily autoxidized in air and the hydroperoxides formed are well described contact allergens - a problem important since it has not been determined whether the oil itself has sufficient inherent antioxidant protection. (Hagvall et al., 2008). In vitro tests have also demonstrated that lavender oil and its chief constituents are cytotoxic to human skin at high concentrations as there exists a definite dose/response relationship that has to be taken into account when using lavender topically in a product (Prashar et al., 2004). The results indicate that lavender oil can be added to formula at low levels (ideally at well-justified levels), should be shielded against oxidative degradation, and



should, preferably, be monitored for hydroperoxides.

The basis of rational use is the concentration dependence of benefits and harmful effects. It is plausible that at low concentrations, the oil provides anti-inflammatory, antimicrobial and sensory benefits and has a reasonable margin for safety while at high concentrations the potential sensitization and cytotoxicity increases but without commensurate improvements in benefits (Prashar et al., 2004; Hagvall et al., 2008). Linalool is considered a fragrance allergen in regulatory documents and as such must be labelled to further limit use in the product to below 10% for leave-on products (Antignac et al., 2011). In the defensible formulation lavender oil is a minor functional sensorial adjunct, instead of a main active.

5.5 Photoprotective Claims in Perspective

In addition, it will be essential not to overestimate any role played by the oil in terms of protection. While oil derived from some plants has small and inconsistent intrinsic ultraviolet absorption and has been reported to increase the measured sun protection factor of simple systems, and properties that may increase their measured sun protection factor are reported, integrity claims that they can provide meaningful sun protection in the absence of the added sun protection factors provided by certified filters are not supported (Kaur and Saraf, 2010). Rather than being the main purpose of the tinted sunscreen, the protective effects of lavender oil are only partially applicable to the product's actual function since it is a composition part of a larger product called a filtered tinted sunscreen.

5.6 Summary

Overall, benefited applications of lavender oil are limited and compelling in a sunscreen for hyper

sensitive or hyper pigmentative skin, but can be limited by its known allergenic and cytotoxic properties, which can be controlled by low additions, oxidation processes and the allergen profile (Hagvall et al., 2008; Antignac et al., 2011). This oil is an example of this general rule, which is part of the science of cosmetic dermatology from plants: nothing natural is necessarily safe, and one needs to know how to dose it safely.

6. Formulation Strategies

6.1 Overview of Formulation Requirements

Turning all of the above, including color-adhering, high potency, presumed anti-inflammatory benefits, and intended stability, religious and medical science, into a stable, working product is a powerful pharmaceutical challenge given that any incipient product with these ingredients must balance multiple requirements in a single selection. It should provide a certification of UV filters and inorganic pigments at certifiable levels, prevent the chemical degradation of oxidation prone oils, distribute the coloured particles in even numbers, be physically stable as well as be physically acceptable on the skin. In what follows the principle components are introduced as well as the reasons that led to their selection, after which specific challenges are described, and finally the approach of a quality-by-design model to the management of these challenges.

6.2 Emulsion Vehicle Selection

Most contemporary sunscreens are emulsions, and the type used – oil-in-water or water-in-oil – has functional implications. Water-in-oil systems may provide more continuous coverage of filters and/or pigments while being more water resistant (Osterwalder et al., 2014); and oil-in-water methods are generally lighter, less occlusive,



which is preferred for daily facial application and provides better adherence. If the product is to be used regularly, an oil-in-water base is generally more acceptable and the oils and/oil-dispersible pigments are subdivided into the internal-phase, while an appropriate selection of the emulsifier system appropriates a relatively high internal-phase volume (Tadros, 2004).

6.3 The Photoprotective Core: Filters and Pigments

The UV filters and the pigments are the core which has a photoprotective effect. Inorganic ultraviolet filters, especially when applied in nanoparticulate form (typically zinc oxide and titanium dioxide), offer excellent UV coverage and have a very favourable safety and photostability profile for a botanical product and are not associated with many of the tolerability and environmental concerns of some organic filters (Cole et al., 2016; Schneider and Lim, 2019; Smijs and Pavel, 2011). When there is a combination of organic filters and their addition to a formula to increase the sun protection factor or to modify the ultraviolet spectrum, they must be shown to be photostable, as some are prone to absorbing sunlight and become decomposed; co-formulated actives may also be affected (Kockler et al., 2012; Gilbert et al., 2013). The tint itself comes from the iron oxides and pigmentary -form of TiO₂ which are dispersed to give the desired tint and visible light attenuation (Lyons et al., 2021).

6.4 Incorporating the Botanical Oils

Both as an emollient-active and as a natural carrier of antioxidants, rosehip oil has been added in a moderate concentration to achieve a beneficial dose of EFA without adding too much oxidative burden to the formulations (Grajzer et al., 2020; Lin et al., 2018). Lavender oil, however, should be used at a lower concentration for allergy, as an

anti-inflammatory and sensory aid, and not as a bulk phase oil (Hagvall et al, 2008; Antignac et al, 2011). The fact that they are used at varying levels for each appropriate use is their risk burden and benefit versus their risk-less and benefit-less level of use and is not an arbitrary decision.

6.5 Antioxidant and Stabilisation Strategy

However, both oils and organic filtering materials can get oxidized and as a result an antioxidant and stabilisation approach is not an option at all, but an important part of the package. The presence of chelating agents to bind with the low levels of transition metals which catalyze peroxidation is important, as these would catalyse the process if present, and the use of lipophilic antioxidants to support the inherent protection within the oils is another consideration to reinforce the benefit (Kockler et al., 2012; Grajzer et al., 2020). The best manufacturing conditions that keep the oil phase exposed to minimal heat and oxygen should be used, and the packaged product will be opaque and will be surrounded by air that will help to retard oxidation during shelf life (Kockler et al., 2012).

6.6 Emulsifiers, Rheology and Pigment Dispersion

Physical stability and sensory quality are controlled by the type of emulsifier and the type of rheology-modifier. Apart from exerting the desirable effect of suspending the dense mineral pigments, a good emulsifier system must also help stabilize the products at the interface with the products against coalescence. In addition, with the aid of thickeners, it must develop a sufficiently high yield stress so that the settlement of the pigment is prevented as a result of gravitational forces since settlement (both discolor the appearance of the product and cause the medium's optical uniformity to be compromised) is the



product of coalescence. (Tadros, 2004). This is therefore a kind of a "double duty" role for the rheological design: physical stability is ensured and spreadability, and non-greasy after-feel properties are determined, which imply that it is necessary to use a mineral-containing product or not at all (Tadros, 2004; Osterwalder et al., 2014). Typical formulation also includes a preservative system, humectants to prevent drying effect of pigments and pH adjusters, but the preservative is not presumed from the moderate antimicrobial activity of lavender oil (Cavanagh & Wilkinson 2002) but was actually proven through challenge testing.

Pigment dispersion particularly important as it is where the cosmetic and functional components of tinted products are most aligned deserves special mention. Iron oxides and pigmentary TiO₂ must also be deagglomerated and wetted (usually with the help of a dispersing agent and/or milling) such that they disperse as fine, stable particles, as poor dispersion will cause streaking, colour drift and/or the colour coverage of visible light. Poor dispersion of the iron oxides can cause serious streaking, colour drift and/or a reduced colour coverage of visible light, while poor dispersion of pigmentary TiO₂ can cause poor dispersion of the printer used to make the plates. Poor dispersion: Streaking, colour drift and/or the colour coverage of visible light will be issues that will arise with iron oxides and pigmentary TiO₂ dispersion, while poor dispersion will be an issue with the dispersion of the printer used to make the plates. Therefore, properties such as the wettability of the pigments, compatibility with the oil phase, and/or modification of any residual catalytic activity with unsaturated lipids can be modified by the surface treatment of the pigments, rendering pigment grade and coating a meaningful formulation variable rather than a fixed input parameter (Smijis and Pavel, 2011; Grajzer et al., 2020).

6.7 Advanced Delivery Systems

Advanced delivery systems provide one way to balance some of these tensions. The nano-emulsions which have a droplet size of about 10-100 nm will not only protect the sensitive oil from the surrounding water but also protect it from air and provide better oxidative and physical stability than the bulk oil, but also will provide better spreadability and skin feel (McClements, 2012; Solans et al., 2005). Essential-oil and plant-oil nanoemulsions with good kinetic stability and preserved bioactivity have been prepared using both low-energy and high-energy homogenisation methods, and have been obtained with both phase-inversion and high-pressure homogenisation (and ultrasonication) (Solans et al., 2005; McClements, 2012). This is a logical approach to prevent damage to rosehip and lavender oils in a base containing pigments, but a more complex and expensive process that is only compatible if there is a convincing advantage for the stability offered.

6.8 Principal Formulation Challenges

The key challenges in formulating go away and are now clearly identified. The first is chemical: by preventing the rosehip oil from becoming peroxidised and the lavender terpenes from autoxidation caused by potentially catalytic pigments, and possibly by photolabile organic filters (Grajzer et al, 2020; Hagvall et al, 2008; Kockler et al, 2012). The other is physical which involves maintaining the pigment densities and preventing coalescing of the emulsion that occurs during the range of temperature to be stored and utilized (Tadros, 2004). The third factor is optical and sensory, which entails establishing a uniform colour and sense with a high mineral content (Lyons et al., 2021; Morgado-Carrasco et al., 2022). The fourth one concerns regulatory and safety aspects, and is related to limiting the exposure to fragrance-allergen and the product



being safe to use as leave-on cosmetic (Antignac et al., 2011).

6.9 A Quality-by-Design Framework

These interdependent constraints are a product of a quality by design approach. Unlike optimization by trial and error approaches to formulation development, quality by design starts with the development and use of a quality target product profile, and identifies, by risk assessment along with designed experiments, the critical quality attributes (including the value levels) such as maximum sun protection factor, visible-light attenuation, uniformity of colour, physical and oxidative stability, and relates them to critical material attributes as well as critical process parameters (Yu et al., 2014). When applied to this context it would modify the factors that would be studied as part of a defined design space as opposed to them being discovered by accident – for example, the combination of pigment content with antioxidant content would be studied, but not necessarily discovered during the process – pigment grade and load, oil concentrations, emulsifier system, antioxidant level, and homogenisation conditions (Yu et al., 2014; Tadros, 2004). This is a systematic approach that helps build a product that has so intertwined attributes, like a botanical-tinted sunblock.

7. Performance Evaluation

7.1 Principles of a Multi-Parameter Evaluation

A sunscreen that uses botanical oils should be evaluated across a wide range of physical, optical, chemical, microbiological and biological properties since it offers multiple benefits, such as photoprotection, antioxidant effects, tolerability, and cosmetic acceptability. There are no single measures that represent a performance, and any individual test has to be interpreted within the

context of a knowledge of what it represents and what it does not represent. Each of the main parameters is addressed in turn, attention being paid to the underlying ideas of each, and to debates over methods related to each.

7.2 Organoleptic and Physicochemical Characterisation

This is followed by organoleptic and basic physicochemical characterisation. Appearance, colour, odour, pH, viscosity and density are recorded since they deviate before it becomes visible either as separation or discolouration (Tadros, 2004). The appearance of the pH value is especially revealing in the case of an emulsion that contains unsaturated oils, as hydrolysis or oxidation can cause drift and the emulsion should also be within a range compatible with the skin. These are inexpensive measures, they are replicated easily and when measured over time, will be sensitive to change.

7.3 Rheological Evaluation

Rheological evaluation then opens up the link with mechanical behaviour related to stability and to sensory quality. The physical stability of an emulsion against creaming and sedimentation, which determines texture, is often hard to predict and have been correlated for long time with flow curves, yield stress and viscoelastic moduli that describe whether the system can suspend dense pigments and their ability to spread in the emulsion. As long as there is too much pigment in the product, the flowability will get worse, while it is undersized, the yield will be too low, so the rheological design is not absolute but must be verified.

7.4 Globule Size and Colloidal Stability



The size of globule and their distribution play pivotal role in emulsions and particularly in the system based on nanoemulsion. The other variables measured typically using the dynamic light scattering and electrophoretic method are used to assess both the fineness of the dispersion, and its likely colloidal stability; a large surface charge is effective against the tendency for the dispersion to be in contact with other species, to coagulate (Solans et al., 2005; McClements, 2012). In addition to protecting the sensitive oils, and affecting skin feel, the effect of these parameters will also be seen during storage, with changes in these parameters being a direct indication of physical stability, in the case of an encapsulated formulation (McClements, 2012).

7.5 Sun Protection Factor and UVA Protection

The most important indicator of a sun protective product is the sun protection factor (SPF) which must be read with great care. Essentially it is an index of protection from erythema from UVB, which is in vivo determined as the ratio of the dose of UVB giving erythema on unprotected skin to that giving erythema on protected skin in a standardised protocol (Schalka and Reis, 2011). These methods are in vitro and hybrid techniques that can be used to estimate the sun protection factor and to minimize reliance on human irradiation, although these need to be validated against the in vivo reference, and are also sensitive to application and substrate details even though they use the in vitro reference technique (Osterwalder et al., 2014). One important mistake, which is relevant to botanical formulations, is the assumption that an in vitro sun protection factor (SPF) with protective value would likewise be expected to demonstrate a protective effect in vivo (clinical photoprotection). This is misleading because the lab-based systems only give small in

vitro SPFs and not necessarily protective value (Kaur and Saraf, 2010).

The coverage of the ultraviolet-A band must be evaluated on its own as these values can differ and be both high and low. The most widely used descriptors are the UVA protection factor and the critical wavelength; the UVA protection factor quantifies protection that is correlated with persistent pigment darkening, and the critical wavelength is the point below which the frequency of the absorbance curve reaches ninety per cent of the area. The UVA label standards for different regions are based on the protection standard determined in vitro on roughened substrates and adapted to the actual sun protection factor (SPF) found in vivo, and there is continued interest in harmonisation of these methods (Osterwalder et al., 2014; Schalka and Reis, 2011).

7.6 Visible-Light Protection

Tinted products do not differ from regular sunscreens, other than visible-light protection; this is the least standardised parameter. All the above ignores the fact that Iron Oxides also ablate visible wavelengths and quantitative data for the visible-light benefit must therefore be acquired and determined directly from measurements by spectrophotometric transmittance in the 400-700 nm range or by means of clinical assessments of the pigmentation caused by a visible-light source (Dumbuya et al., 2020; Lyons et al., 2021). Lack of a single harmonised visible-light protection factor causes a difficulty in comparing reported VLPF values among studies and this methodology is immature and cannot be a perfect objective tool to rank tinted products (Lyons et al., 2021). Clinical designs that subject the skin to known visible light exposure and then rate the skin pigmentation by colourimetry or expert evaluation currently offer the most compelling evidence to



show whether or not functional benefit is achieved (Mahmoud et al. 2010; Dumbuya et al. 2020).

7.7 Photostability

Photostability testing is performed to determine if protective effect alive at time 0 after addition withstands planned and realistically expected light exposure. There are some filters that don't withstand irradiation and many botanical additives that break down into coloured or reactive breakdown products (Kockler et al., 2012). When the product is then irradiated and the degree of each loss determined by measuring the product's spectral absorbance, or by measuring the breakdown of individual actives, this loss provides a measurement of the effectiveness of the stabiliser/antioxidant element as well as its ability to retain the integrity of the product under such conditions. (Kockler et al., 2012; Grajzer et al., 2020).

7.8 Antioxidant Capacity and Oxidative Stability

Testing the sun resistance of a botanical by a foreseeable chemical evaluation method is a valuable parameter for the formulation of a botanical sun cream. Such methods as the DPPH and others are simple test to see how the formulation and its oils can neutralise free radicals, and can track how much the rosehip oil contributes to the antioxidant capacity during processing and storage (Brand-Williams et al., 1995; Grajzer et al., 2020). However, because only a single method reflects one radical system, more than one should be used to obtain a more balanced picture and the results should only be used as an index of potential not a measure of in vivo protection (Brand-Williams et al., 1995).

It is generally accepted that the stability of the oils themselves is one of the most formulation-critical

chemical endpoints. The monitoring of peroxide value, anisidine value, and instrumental methods as DCS indicates the process of lipid peroxydation and its monitoring under accelerated conditions predicts shelf life and alerts the beginning of rancidity and the occurrence of potentially irritating oxidation products (Grajzer et al., 2020). These measures specifically test the success of the antioxidant and packaging strategy for such a product, and, therefore, should form part of any stability programme (Grajzer et al., 2020; Kockler et al., 2012).

7.9 Physical and Microbiological Stability

In expanded terms, the stability testing is conducted according to the drug and medical logic. The Johnson emulsion reacts to these stresses during accelerated storage at high temperatures, in real-time storage, and freeze-thaw and centrifugation to show creaming, coalescence, phase separation, colour change and pigment sedimentation before the final predicted shelf life. These stresses are applied to the Johnson emulsion during accelerated storage at elevated temperatures, real-time aging, freeze-thaw, and centrifugation stresses to demonstrate creaming, coalescence, phase separation, colour change, and pigment sedimentation before the ultimate claimed shelf life (Tadros, 2004). In the case of tinted botanical, the parameters used in monitoring colour and oxidative stability may be monitored separately, in addition to a typical set of emulsion parameters (Grajzer et al., 2020; Tadros, 2004).

Preservative-efficacy (challenge) tests should be used instead of antimicrobial activity of the essential oil to ensure its microbiological quality. Lavender oil provides some microbial protection, however, this is an ineffective approach for effectively controlling microbial contamination in a leave-on formulation containing water, and a validated preservative system must be available



which has been tested against standard microbiological challenges (Cavanagh and Wilkinson, 2002; Antignac et al., 2011). Routine microbial limits testing is used alongside the challenge test to assure the product meets the safety cosmetics expectations.

7.10 In-Vitro biology and Human Assessment

A greater number of in vitro biological and safety evaluations are supplementing physicochemical testing. Skin cell based assays may provide data on cytotoxicity, antioxidant effect, anti-inflammatory effect, and support in cell movement for barrier repair, as well as alternative methods like reconstructed skin and the HET-CAM assay can be used to screen for irritation and phototoxicity without any animal use (Prashar et al., 2004; Nichols and Katiyar, 2010). These methods are especially relevant to a product that would include lavender as an ingredient, because of the concentration-dependent cytotoxicity of the oil and because they are among the first to make predictions of the safety margin for the addition of lavender at a chosen concentration (Prashar et al., 2004).

Human skin compatibility and efficacy will be the ones to decide. There was slow irritation and sensitisation potential as determined by the patch and repeat-insult patch testing in case of fragrance allergens contained in lavender oil, and instrumental barriers and conditioning data as determined by transepidermal water loss, hydration and elasticity in case of the rosehip oil (Antignac et al., 2011; Lin et al., 2018). The trials supporting the use of iron-oxide pigmentation in protection show the highest degree of evidence for the visible-light and pigmentary benefits, i.e., for melasma and skin of colour (Castanedo-Cazares et al., 2014; Dumbuya et al., 2020). In simple terms, a coherent evaluation programme – first the benz physiochemistry, then the in vitro biology, then the

in vivo human testing, applying the results of each segment to the specific constraints of that particular test.

8. Current Challenges

8.1 Oxidative Instability

There are a number of issues that remain to be addressed between the idea of a sun-up/down product and a viable commercial product, while they are problems in and of themselves, they really are better understood as a combination of problems. Oxidative instability is the basic one. Rosehip oil is very polyunsaturated and lavender oil contains terpenes that are susceptible to autoxidation, both degrading quickly and loss of intended benefits as well as formation of irritating or sensitising species (Grajzer et al., 2020; Hagvall et al., 2008). The added worry is that transition-metal surfaces offer a predisposition for catalysing lipid peroxidation, making it possible for the colourant and the actives to be antagonistic (Grajzer et al., 2020; Kockler et al., 2012).

8.2 Physical Stability

Maintaining good physical stability of any emulsion with a high concentration of heavy minerals is always a challenge. The density of the particles used (iron-oxide and titanium-dioxide) has to be sufficient enough to make sure that the particles are not allowed to settle in the continuous phase, but it should not be so large that it encourages the particles to coalesce in the oil-water interface or to flocculate which is what is happening with high density particles. The system has to be a pleasing balance between not letting the particles settle in the continuous phase and not being so dense as to encourage co-precipitation at the oil-water interface or flocculation of the particles (Tadros, 2004). Failure occurs when it takes the form of creaming, colour drift, or gritty



texture interfering with its functionality and the consumers' confidence (Tadros, 2004; Lyons et al., 2021).

8.3 Colour Inclusivity and Pigment Dispersion

There is a problem with pigments other than suspension. This is the challenge in providing a broad and cosmetically pleasing color spectrum to accommodate all skin tones while excluding those with a darker skin tone the group most likely to benefit from visible-light protection (Morgado-Carrasco et al., 2022). Insufficient dispersion results in negative effects on both cosmetic and functional performances resulting in streaking and not even dispersion (Tadros, 2004; Lyons et al., 2021).

8.4 Regulatory Constraints

An underestimated level of complexity is the regulatory aspect. Even though they are demonstrated to absorb visible light, they are not approved for this purpose as UV filters, so these benefits do not benefit from the internationally recognised sun protection factor (SPF) and cannot be marketed on this basis, and a harmonised or standard protection factor for visible light is still not granted, which makes claims somewhat fragile (Lyons et al., 2021; Osterwalder et al., 2014). Meanwhile the allergic concerns of the fragrance components in lavender oil, specifically linalool, are still expected to be labeled and quantified, while the safety claims for all botanical ingredients are still required for leave-on cosmetic products within the framework of leave on cosmetics (Antignac et al., 2011).

8.5 Scale-Up and Manufacturing

Scale-up causes issues that cannot be seen on the bench. Issues relating to the large-scale production of processes that disperse pigments and produce

fine emulsions, such as controlled milling and high shear or high pressure homogeniser (HHH), have been identified as some of the critical processes that need to be reproduced with consistency while minimizing any heat or other inputs that would cause the sensitive oils to oxidize (Kockler et al., 2012; McClements, 2012). You need to ensure that the same pigments are in the same size droplet in all scales – which is challenging, and which could directly affect colour and stability variations (Tadros, 2004; McClements, 2012).

8.6 Shelf Life and Convergent Failure Modes

A natural endpoint where these issues come together is the shelf life. An initial product test might succeed, but this is followed by failure over time due to the multiple interactions that can lead to a product failure, such as oxidation of oils, settling of pigments, colour change, loss of preservative effectiveness, or decreases in levels of specific sweeteners and minerals or other microbial growth (Grajzer et al., 2020; Tadros, 2004). The point is that the very characteristics which make botanical tinted sun screens interesting to users, their inherent oils, functional pigments, also are responsible for their major instabilities, and there are currently few data on what is best to be considered when combining them.

9. Future Perspectives

9.1 Advanced Delivery Systems

This is the first where advanced delivery systems guarantee the integrity of the sensitive oils and enhance performance. Rosehip and lavender oils could be encapsulated in the interior by using these nanoemulsion and related nanostructured carriers, with the aim of delaying the oxidation of the encapsulated compounds, improve the spreadability and retain their bioactivity, as it has



already been successfully done with a variety of plant and essential oils (McClements, 2012; Solans et al., 2005). The development of these techniques to a pigment-containing, tinted base, and the characterization of the changes in oil/iron oxide interaction that occur when the base is tinted are logical and manageable extensions that may rectify some of the stability issues discussed above.

9.2 Green and Sustainable Chemistry

The sourcing and processing of ingredients is likely to be impacted by Green and Sustainable chemistry. In addition to antioxidants, the rosehip oil contains other nonvolatile compounds, the preservation of which is achieved through solvent free extraction processes, which also enhance its quality and create sustainability opportunities (Grajzer et al., 2020); the valorisation of rosehip seeds as a fruit by-product also demonstrates a circular approach to raw materials (Grajzer et al., 2020). Furthermore, when evaluating best practices in the use of naturally-derived or plant-based actives, the now-increasing interest in mineral filter is also a response to concerns raised by the environment created by some organic filter usage (Schneider and Lim, 2019; Gilbert et al., 2013).

9.3 Computational and Data-Driven Design

Computations and data-driven approaches provide a path to handle the daunting multivariate optimisation requirements these products have. In addition to a quality by design approach based on designed experiments, which reduces empirical guesswork, a quality by design approach combined with predictive modelling of the emulsion stability, colour and light transmission characteristics of the formulation could be used to speed up the identification of stable formulations within a defined design space (Yu et al., 2014;

Tadros, 2004). As well, there is a promise in developing maturing modelling to reduce the development time and to reveal, as opposed to emerge, how the interactions between the pigments, oils and process parameters play out.

9.4 Personalised Photoprotection

Tint personalisation is becoming a reality and is particularly relevant to tinted products. Tinted sunscreens are a natural choice for being tailored, because the shade and intensity of visible-light protection depends on an individual's pigmentary tendency and phototype, and increasing the shade range to cater for skin of colour is not only a scientific necessity, but an equity one (Morgado-Carrasco et al., 2022; Dumbuya et al., 2020). Matching the product to the patient this way may enhance efficacy and compliance with treatment among pigmentary disorders, which benefit from when the light is visible.

9.5 Clinical Research Priorities

The priorities for clinical research are directly derived from the gaps revealed in this review. In particular, the specific association of the mineral base tinted with the addition of rosehip and lavender oil has never been tested in controlled studies, so its efficacy in terms of photoprotection and its antioxidant and tolerability effects as well as its colour stability have yet to be demonstrated in reality (Lyons et al., 2021; Belkhelladi and Bougrine, 2024). To continue the concept of creating evidence beyond plausibility, the next steps for characterization would be to standardise the measure of the protective effect of the visible-light component, collect more long-term data on the antioxidant effects of the oils in a completed product and firmly secure the safety of the lavender component (Lyons et al., 2021; Prashar et al., 2004).



10. CONCLUSION

Tinted sunscreens are an evidence-based step forward from UV sunscreens and include pigmentary and iron-oxide titanium-dioxide colourants with consistent (though limited) evidence for their efficacy in cases of melasma, post-inflammatory hyperpigmentation and skin of colour (Dumbuya et al., 2020; Lyons et al., 2021). The idea of adding rosehip and lavender oils to this basic formula is sensible: once added to the base, these oils deliver barrier supportive essential fatty acids and lipophilic antioxidants that have credible reparative and anti-ageing properties in addition to lavender offering anti-inflammatory action, anti-microbial and sensory characteristics in appropriate concentrations (Ilyasoğlu, 2014; Belkhelladi and Bougrine, 2024).

But a critical appraisal is tempered with realism. The science behind the individual components is stronger than the science behind their combination, which has never been tested under controlled conditions, and the very qualities that make the oil highly prized—its flavor, coloring, and aroma properties—make it extremely vulnerable to chemical breakup, especially in the company of catalysts such as colored pigments. The risk properties of lavender oil, the lack of an inclusive stable colour and the infancy of visible-light protection standards are not just incidental but actual limitations.

The gaps in knowledge the principal identified are thus very specific and solvable. These are related to the physicochemical interaction between the oxidation prone oil and the Fe-oxide pigments, the effect of the oil on measured protection and measured colour, stability of the product over time, and clinical performance and safety of the combination. Quality by design Formulation, using advanced formulation technologies along

with clinical evaluation properly controlled would ensure it would stand on a solid evidence basis.

For the large number of individuals who have visible light aggravated pigmentary disorders, a well-developed, aesthetically pleasing antioxidant containing tinted sunscreen may have a relevant clinical impact with better outcome and compliance. But it's also obvious that this is relevant to industry, as consumer demand is keen for natural, multifunctional and sustainable photoprotection. With sound stability taking place in the field, if the field is ready, then certainly, the evaluation of safety and evidence, otherwise, the marketing of tinted eg lavender and rosehip oils is a possible and viable direction to go if they hope to stay in the field.

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