Bemotrizinol: Key driver of modern broad-spectrum sun protection

Myriam Sohn and **Victor Low** of **BASF** outline the science and pivotal role of bemotrizinol in modern sunscreens*

Decades of photobiology, photochemistry and formulation science converge to a simple conclusion: effective sun protection must shield the skin from both UVB (290–320 nm) and UVA (320–400 nm) wavebands. UVB photons carry higher energy per photon than UVA and are the principal driver of immediate sunburn (erythema) occurrence. However, UVA also meaningfully contributes to total erythema, accounting for roughly 20% of the biological effect under sunlight.

This article reviews why dual-band coverage matters and why bemotrizinol (INCI: Bis-Ethylhexyloxyphenol Methoxyphenyl Triazine, or BEMT) has become the backbone of modern sunscreen design. After a short history of its development, we will discuss its performance benefits and translate recent research on recrystallisation and vehicle effects into practical formulation guidance.

In practice, a UVB-only sunscreen will plateau around sun protection factor (SPF) 10-15 because unattenuated UVA passes through the film. Compared to UVB, UVA rays penetrate deeper and damage dermal collagen, thereby accelerating photoageing. Both UVB and UVA have been shown to contribute to carcinogenesis.[1,2] Modern sunscreens must, therefore, ensure true broad-spectrum coverage to

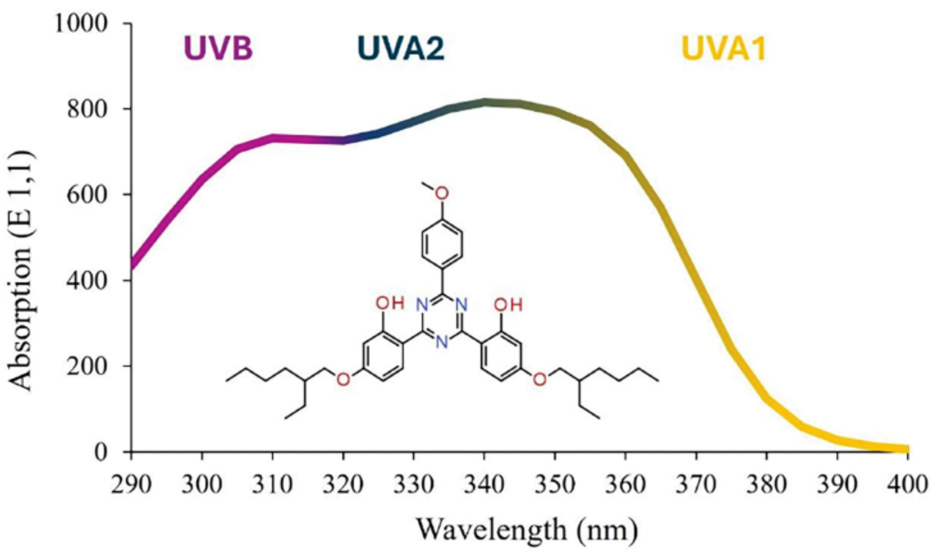

Figure 1 - Molecular structure & absorption features of bemotrizinol

provide high SPF alongside effective UVA protection.

The shift from sunburn prevention during the 20th century to today's focus on skin integrity maintenance has driven the industry to seek photostable, broad-spectrum molecules and synergistic systems that maintain protection under real sun exposure and realistic use conditions.

Science of bemotrizinol

Bemotrizinol, or Tinosorb** S, the original product launched by Ciba Specialty Chemicals and later acquired by BASF, was industrialised after a multi-year R&D programme exploring hydroxyphenyl 1,3,5-triazine (HPT) chromophores for cosmetic application. Researchers screened more than 500 HPT derivatives to optimise three axes simultaneously: spectral efficacy across UVB and UVA, inherent photostability and oil solubility via tailored alkoxy substituents.

Through this extensive R&D effort, Tinosorb S emerged. The synthetic route via Grignard functionalisation and Friedel–Crafts acylation was scaled to high purity, enabling consistent cosmetic-grade manufacture and establishing the product as a flagship of the hydroxyphenyltriazine class.[3-5]

Spectral fingerprint

The UVB absorption profile of HPT-based molecules can be tuned and shifted toward greater UVA coverage by adding one or more ortho-hydroxyl groups at the phenyl moieties. Researchers at Ciba and BASF designed Tinosorb S to obtain an optimised broad-spectrum absorption curve.

Tinosorb S set the benchmark for broad-spectrum UV filters in the marketplace: its UV absorption profile shows two maxima at 310 nm (UVB) and 343 nm (UVA) with very high E1,1 values (absorption of 1% (w/v) solution at an optical thickness of 1 cm) of approximately 735 & 820, respectively (Figure 1).

Photostability & photocompatibility

The structure of bemotrizinol contains two intramolecular hydrogen bridges (between ortho OH groups and triazine nitrogens) that create an excited-state intramolecular hydrogen transfer upon photoabsorption. This process is known as phototautomerism. This internal conversion pathway enables a redistribution of the absorbed energy from electronic to vibrational excited states, which is then dissipated to surrounding molecules by collisions as harmless heat.

The entire proton transfer cycle occurs in less than one picosecond and this ultrafast photophysical funnel outcompetes bond-breaking or other reactive pathways. With this process, the molecule returns to its original ground state without undergoing chemical degradation.

In laboratory studies, in whatever tested medium (solutions, emulsions, realistic film optical densities), Tinosorb S consistently appears in the photostable cohort, serving both as a primary UV attenuator and as part of photostabilising pairs.[6-8] Indeed, it has been shown to help stabilise photolabile UV filters via two possible independent mechanisms.

In **spectral shielding**, the simple presence of bemotrizinol reduces the number of photons reaching a labile molecule that absorbs in the same range. In **energy-excited state quenching**, it deactivates the photoexcited state of the sensitive UV-filter, thereby limiting its photodegradation.

Detailed kinetic laboratory trials supported by density functional theory-informed Jablonski analysis were conducted on binary mixtures of bemotrizinol with either avobenzone (INCI: Butyl Methoxydibenzoylmethane) or octinoxate (INCI: Ethylhexyl Methoxycinnamate).[8]

The study showed that both spectral shielding and excited state energy transfer contribute to the photostabilisation of avobenzone by bemotrizinol, with the energy transfer mechanism accounting for roughly 60% of the overall effect. For the bemotrizinol–octinoxate combination, excited-state energy transfer also predominates, with quenching accounting for about 70% of the photostabilisation.

These results align with photophysical feasibility (energy gaps) and molecular proximity in the oil phase. None of the processes, however, can achieve complete stabilisation of photolabile UV filters. The best strategy for designing modern sunscreens remains using fully photostable UV filters whenever the available approved UV-filter palette permits.

Figure 2 shows the recovery of avobenzone after UV irradiation (10 MED for skin type II) alone and in combination with bemotrizinol or octocrylene, alongside the recovery of the photostable UVA filter diethylamino hydroxybenzoyl hexyl benzoate (DHHB).

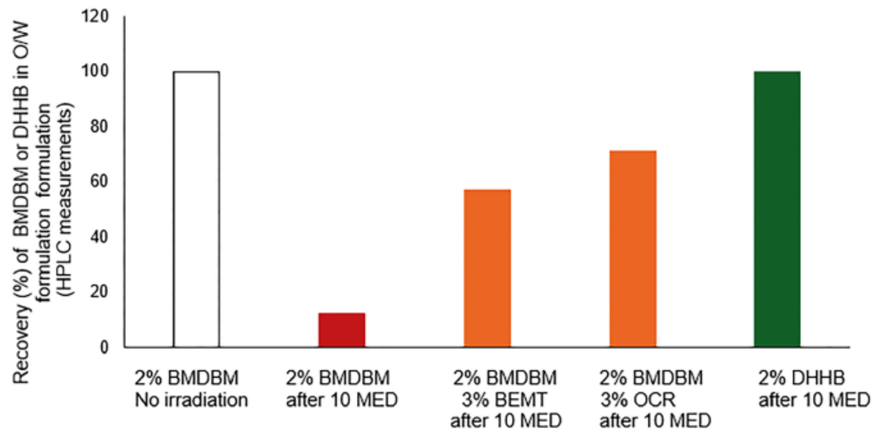

Figure 2 - Recovery of avobenzone (BMDBM) alone & in combination with bemotrizinol (BEMT)/ octocrylene (OCR) & diethylamino hydroxybenzoyl hexyl enzoate (DHHB) after UV irradiation

SPF & UVA protection

Tinosorb S offers a powerful, photostable, broad-spectrum backbone for any UV-filter system. With its wide UV coverage and high absorption, it substantially plays a role in both SPF and UVA protection. It not only pairs well with other UV filters, but also acts synergistically, especially with water-soluble and particulate filters.

Water-soluble UV filters complement bemotrizinol by closing gaps in the applied sunscreen film that would otherwise persist in the hydrophilic parts. Particulate UV filters do this by scattering, redirecting photons, which increases the optical path length of the photons through the applied film and thus raises the probability that photons will be absorbed by the surrounding bemotrizinol or other soluble UV filters.

Safety & regulatory

A common concern about UV filters is their potential to penetrate the skin. Molecular weight (MW) is a key factor in this. A value of above 500 Dalton is commonly used as a practical threshold: molecules below this value are more likely to permeate the skin, while those above it are generally unlikely to penetrate and reach viable skin layers.[9]

The MW of bemotrizinol is 628 g/mol, a value that strongly predicts low or negligible skin permeation. This therefore supports its suitability for use in a wide range of sunscreen applications.

Developed and first approved in Europe in 2000, bemotrizinol will become available for global use after pending FDA approval in the US, which is currently underway. In Europe in 2025, it was included in over 80% of newly launched organic UV filter-based sunscreens.[10] Once regulatory approval is granted in the US, it will broaden consumer access to sunscreens with improved broad-spectrum performance.

Regulatory approval does not automatically grant unrestricted use of a UV filter. Patents and patent applications may limit how a substance can be used. BASF owns multiple patents and patent applications related to the preparation and use of bemotrizinol.

A one-size-fits-all sunscreen is a myth; individuals have different needs and expectations regarding skin sensitivity, preferred application formats and sensorial preferences, or the purpose and area of intended use. Being oil-soluble, Tinosorb S can be used flexibly across all formulation types, from emulsions and sticks to non-aerosol sprays, to meet a wide range of individual needs. Figure 3 gives an example of a sunscreen composition with SPF 50.

Solubilisation considerations

A study showed that recrystallisation of a UVA UV filter reduced UVA protection by about 20% in a representative emulsion, which is sufficient to jeopardise broad-spectrum claims, depending on the SPF.[11] Recrystallisation of a UVB UV-filter would similarly lower SPF.

Bemotrizinol, like other existing lipophilic organic UV filters, is a crystalline solid and must be solubilised in the formulation's oil phase. It was designed with ethylhexyloxy substituents (Figure 1) to enable its solubilisation in common cosmetic oils, such as benzoates, adipates, and triglycerides. Its solubility is low (<1%) in apolar oils like silicones, vegetable oils and hydrocarbons, highlighting the importance of appropriate emollient selection.

If the oil-phase composition (or storage/temperature cycles) drives a crystalline solid UV-filter above its equilibrium solubility, recrystallisation can occur over time. Once crystals form and multiply in the formulation, the effective UV absorbing area in the applied sunscreen film decreases, lowering the UV protection delivered

$C_{12\text{-}15}$ alkyl benzoate (Cetiol** ABV) and dibutyl adipate (Cetiol B) repeatedly emerge as strong (and widely used) solubilisers for many crystalline UV filters, while dicaprylyl carbonate (Cetiol CC) is often used in sunscreen products to add sensorial elegance. Binary (or even more complex) oil mixtures are commonly used in sunscreens; each crystalline UV filter may preferentially dissolve in a different emollient.

To help select appropriate emollients, BASF developed the Sunscreen Simulator, which has been on the market since 2000. This digital tool predicts the performance of a chosen filter combination and provides solubility estimates for crystalline filters in a selected emollient or emollient blend.[12]

Solubility measurements

The available solubility data are typically measured for each individual UV-filter in single emollients, which is the most favourable condition for the risk of recrystallisation. The values provided by BASF tend, therefore, to be very conservative, especially for the standard emulsion sunscreens.

In practice, achieving roughly 80% of theoretical solubility value is generally sufficient to keep bemotrizinol (but also the other crystalline solid UV filters like ethylhexyl triazine (EHT, Uvinul** T150) and DHHB (Uvinul A Plus) dissolved in oil-in-water (O/W) emulsions. Attention must be paid to the continuous lipophilic phases, such as water-in-oil (W/O) and lipophilic systems.

Figure 3 - SPF 50 broad-spectrum sunscreen with bemotrizinol
Note: SPF *in vivo* 53, UVA1/UV >= 0.70

Phase	Ingredient	INCI	% by weight
A	Eumulgin BA 25	Beheneth 25	2.00
A	Cutina Shine	Dioctyl Pentaerythrityl Distearyl Citrate	3.00
A	Cetiol B	Dibutyl Adipate	10.00
A	Cetiol ABV	C12-15 Alkyl Benzoate	10.00
A	Cetiol CC	Dicaprylyl Carbonate	2.00
A	Lanette 22	Behenyl Alcohol	2.00
A	Preservative	Preservative	qs
A	Uvinul N 539 T	Octocrylene	10.00
A	Neo Heliopan OS	Ethylhexyl Salicylate	5.00
A	Tinosorb S	Bis-Ethylhexyloxyphenol Methoxyphenyl Triazine	6.00
A	Eusolex 9020	Butyl Methoxydibenzoylmethane	3.00
B	Water, demin.	Aqua	37.80
B	Verdessence Xanthan	Xanthan Gum	0.20
B	Hydrasensyl Glucan Green	Water, Pentylene Glycol, Beta-Glucan, Caprylyl Glycol	3.00
B	Cosmedia HP Starch	Hydroxypropyl Starch Phosphate	1.00
B	Tinomax CC	Calcium Carbonate, Hydroxyapatite	3.00
C	Verdessence RiceTouch	Oryza Sativa Rice Starch	2.00

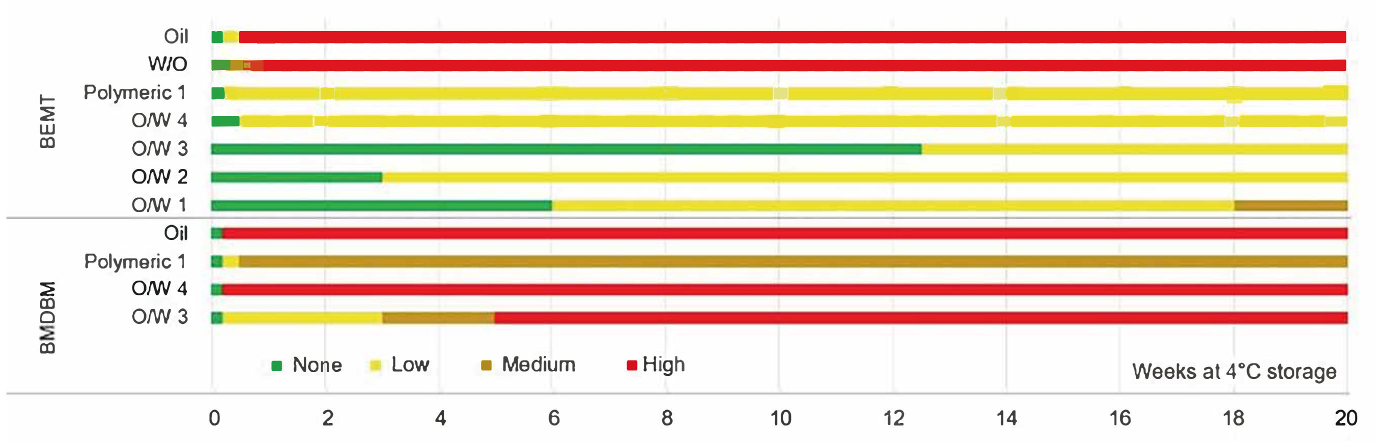

Figure 4 - Recrystallisation speed of bemotrizinol (BEMT) & avobenzone (BMDBM) in different formulation chassis at 4°C storage

Vehicle & emulsifier influence

A study including 24 formulations covering different emulsifier systems (O/W, polymeric, W/O and neat oil systems) monitored the recrystallisation of four crystalline UV filters—bemotrizinol, avobenzone, EHT and DHHB—under high relative oversaturation for 20 weeks at two storage temperatures (4°C and 23 °C).

The results can be summarised in three key findings. First, vehicle continuity matters, Recrystallisation was much faster in neat oils and W/O emulsions with a continuous lipophilic phase, where nucleation propagates rapidly through a single, connected oil network.

Second, emulsifiers play a role. Certain polymeric systems (e.g., Acrylates/Beheneth 25 Methacrylate Copolymer (Tinovis** GTC)) and anionic systems (e.g., Sodium Stearoyl Glutamate (Eumulgin** SG)) delayed recrystallisation relative to other O/W systems. This is consistent with literature explaining that surface-active species can promote or inhibit nucleation depending on interfacial ordering and interfacial tension effects.

Third, the UV filter used matters. Under matched oversaturation, smaller/more rigid molecules (e.g., avobenzone) recrystallised faster than larger, highly flexible molecules such as bemotrizinol. Figure 4 presents the results for the two filters: bemotrizinol and avobenzone.[11]

The key takeaways for the formulation playbook from this are:

1. Start with the right selection of UV filters - make Tinosorb S the core of your UV-filter system: broad-spectrum protection, photostable foundation for lasting performance, photostabiliser of labile UV filters, compatible with all formulation types of spectrum protection
2. Continue with the right selection of the emollient blend for preventing recrystallisation and loss of protection
3. Leverage on formulations: continuous aqueous phase formulations tend to limit recrystallisation over time

Conclusion

The development of Tinosorb S exemplifies how research structure-enabled photostability, high and broad-spectrum absorption, and how a single molecule can play the dual roles of primary UV-filter and stabiliser.

The industry's focus is unchanged: reliable, elegant broad-spectrum protection sunscreens that consumers like to use every day. User compliance drives final effectiveness of the sunscreen product. The most efficient sunscreen pairs good chemistry with good physics: photostable chromophores like bemotrizinol, placed into a vehicle engineered to keep the contained UV filters dissolved, and with memorable sensorial experience. ●

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