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Photodegradation of (−)-epigallocatechin-3-gallate in topical cream formulations and its photostabilization

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ABSTRACT

The aim of the study was to examine the photostability of the major catechin of green tea, (−)-epigallocatechin-3-gallate (EGCG), which possesses important antioxidant and skin photoprotective properties. In order to simulate realistic conditions of use of topical preparations, the photolysis studies were performed in model creams (oil-in-water emulsions) containing 1% (w/w) EGCG and exposed to a solar simulator at an irradiance corresponding to natural sunlight. The extent of photodegradation was measured by HPLC–UV and HPLC–ESI-MS. EGCG was found to decompose by 68.9 ± 2.3%, after 1 h irradiation. Addition of the coantioxidants, vitamin E or butylated hydroxytoluene to the emulsion formulation, significantly enhanced the photolability of the catechin, the EGCG loss reached 85.7 ± 1.3% and 80.5 ± 1.4%, respectively. On the other hand, inclusion of the UVB (290–320 nm) filter, ethylhexyl methoxycinnamate in the cream produced a small but significant reduction of EGCG photodegradation to 61.0 ± 2.9%, while the UVA (320–400 nm) filter, butyl methoxydibenzoylmethane was ineffective (EGCG degradation, 67.8 ± 1.5%). A more marked decrease in the light-induced decomposition of EGCG to 51.6 ± 2.7% was achieved, under the same conditions, using the water-soluble UVB filter, benzophenone-4 (BP-4). This effect was concentration dependent, maximal EGCG photostabilization (catechin loss, 29.4 ± 2.2%) was attained in the presence of 2.1% (w/w) BP-4. Therefore, BP-4 represents a useful additive to improve the light stability of EGCG in topical formulations for skin photoprotection.

1. Introduction

In recent years, green tea has received considerable attention because of epidemiological studies showing that its consumption is associated with a reduced risk of cardiovascular and neurodegenerative diseases and certain cancers [1–4]. Moreover, the extract of green tea has gained great interest for the prevention of the harmful effects (photodermatoses, cutaneous photoageing, immunosuppression and various forms of skin cancers) induced in human skin by exposure to the solar UV radiation [5–7].

This protective activity has been ascribed mainly to the polyphenolic flavonoid constituents, known as catechins, present in high amount in green tea [5,7,8]. These compounds are powerful antioxidants exhibiting several pharmacological properties exerted through different mechanisms [6–9].

In particular, (−)-epigallocatechin-3-gallate (EGCG; Fig. 1), the major and the most physiological active catechin of green tea [6,9–11] has been shown, in animal and human skin, to prevent, in vitro and in vivo, oxidative injuries (proteins and lipid oxidation, DNA single strand breaks) and depletion of antioxidant enzymes caused by exposure to the UVB (290–320 nm) and UVA (320–400 nm) components of the solar UV radiation [6,12–14]. Moreover, topical application of EGCG inhibits the carcinogenic activity of UV light in mice [12,15,16]. Treatment of human and mice skin with EGCG has also been found to protect against UV-induced suppression of the cutaneous immune system [7,12], to decrease the inflammatory response produced by sun exposure [7,17] and to prevent photoageing of the skin [7,18].

However, EGCG, as others catechins from green tea, is highly unstable due to hydrolytic, oxidative, epimerization and polymerization processes [19–22]. Published studies have reported on the EGCG degradation in solvents appropriate for topical application [11,20–22] and in dermatological formulations [10,23]. Consequently, several strategies have been developed to enhance the catechin stability, including the use of acidic pH vehicles,

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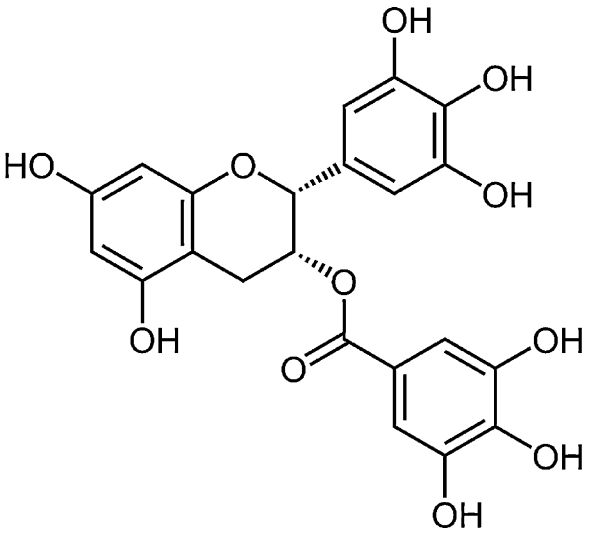

Fig. 1. Chemical structure of EGCG.

encapsulation in nanoparticles and, especially, addition of antioxidants [10,11,22,23].

Although the chemical stability of this catechin has been extensively investigated [10,11,19–23], surprisingly, there are no data available concerning its stability under light exposure. This is a major limitation for the effectiveness of EGCG as cutaneous photoprotective agent, since the degradation of the catechin following solar irradiation will lead to a reduction in its activity against skin damage caused by UV light. Hence, to optimize the potential therapeutic application of EGCG, its photochemical behaviour need to be examined and improved.

Accordingly, in the present investigation a systematic evaluation of the stability of EGCG under simulated sunlight exposure was carried out in model formulations (oil-in-water emulsions) suitable for topical application. In addition, the use of antioxidants and sunscreen agents as photostabilizers for EGCG is also presented.

2. Materials and methods

2.1. Materials

EGCG (purity > 94%) was from DSM (Basel, Switzerland). The sunscreen agents, butyl methoxydibenzoylmethane (BMDBM), and ethylhexyl methoxycinnamate (EMC) were supplied by Merck (Darmstadt, Germany), methylene bis-benzotriazolyl tetramethylbutylphenol (Tinosorb M) was from BASF (Ludwigshafen, Germany) and benzophenone-4 (BP-4) from 3 V SIGMA (Bergamo, Italy). Butylated hydroxytoluene (BHT), vitamin E as well as the excipients for the cream preparations were from Seppic (Paris, France) and ACEF (Piacenza, Italy). Methanol, acetonitrile and water were high-performance liquid chromatography (HPLC)-grade from Merck. All other reagents and solvents were of analytical grade (Sigma Aldrich, Steinheim, Germany).

2.2. High-performance liquid chromatography

The HPLC apparatus consisted of a modular chromatographic system (Model 1580-PU pump and Model 975-UV variable wavelength UV–Vis detector; Jasco, Tokyo, Japan) linked to an injection valve with a 20 μl sample loop (Model 7725i Rheodyne, Cotati, CA, USA). The detector was set at 280 nm. Data acquisition and processing were accomplished with a personal computer using Borwin software (JBMS Developpements, Le Fontanil, France). Sample injections were effected with a Model 701 syringe (10 μl; Hamilton, Bonaduz, Switzerland). Separations were performed at ambient temperature, on a 5-μm Luna C18 column (150 mm × 4.6 mm i.d.; Phenomenex, Torrance, CA, USA) fitted with a guard column (5 μm particles, 4 mm × 3 mm i.d.) and eluted isocratically at a flow-rate of 1.0 ml/min. Sodium phosphate buffer (pH 2.8; 0.03 M)–acetonitrile (82:18, v/v) was used as the mobile phase. The identity of the EGCG peak was assigned by co-chromatography with the authentic standard. Quantification was carried out by integration of the peak areas using the external standardization method.

2.3. HPLC–mass spectrometry

The HPLC/mass spectrometric (HPLC/MS) system employed was a modular Surveyor liquid chromatograph (Thermo Scientific, Waltham, MA, USA) equipped with an autosampler, a quaternary micro pump and a 2.5 μm Luna C18 HST column (100 mm × 2.1 mm; Phenomenex) eluted, at a flow rate of 0.1 ml/min, with a linear gradient from 10 to 90% of methanol in formate buffer. The column was coupled with a LTQ XL (Thermo Scientific) linear ion trap mass spectrometer. An electrospray ionization (ESI) interface was used as ion source (capillary temperature, 270 °C; capillary voltage, 5 V; spray, 4.8 kV; tube lens, 75 V).

2.4. Emulsion formulations

For the photolysis experiments, cream preparations (oil-in-water emulsions) containing 1% (w/w) EGCG, were prepared. The emulsion excipients were: cetearyl alcohol (1.5%), glyceryl monostearate (1.5%), sweet almond oil (5.0%), cetearyl isononanoate (5.0%), dimethicone (0.5%), Phenonip (0.8%; phenoxyethanol and parabens), Montanov 82 (5.0%; emulsifying agent based on cetearyl alcohol and cocoglucoside) for the internal phase and propylene glycol (5.0%), EDTA (0.1%), sodium dehydroacetate (0.1%), citric acid (qs pH 5) and deionized water (qs 100%) for the external phase. The creams were prepared according to the common procedure used in compounding practice. Briefly, the oil- and aqueous-soluble components were separately heated to about 60 °C and the aqueous phase was added to the oil phase while stirring with a mixer. EGCG (solubilized in propylene glycol) was added in the cooling phase of the emulsion preparation at about 35 °C. Creams containing the catechin in conjunction with equimolar concentrations of vitamin E, BHT, BMDBM, EMC, BP-4 (after neutralization with NaOH) or Tinosorb M were also prepared and examined.

2.5. Photodegradation studies

Irradiation experiments were performed in the solid-state, in propylene glycol solutions, or in cream (oil-in-water emulsion) formulations. Solid samples were weighed and spread onto the bottom of beakers (surface area, 4.5 cm^2) to give a layer thickness not exceeding 3 mm [24]. The propylene glycol solutions (0.5 ml) were transferred into quartz cells (2 mm path length) closed with screw caps and inserted horizontally in the test chamber. Portions (ca. 40 mg) of the cream preparations were transferred by means of a polypropylene syringe (capacity, 1 ml) onto the bottom of beakers (surface area, 16 cm^2) at a level of 2.5 mg/cm^2, according to COLIPA standard [25]. The formulations were spread by circular movements of the syringe tip to produce as uniform as possible layer. The samples were secured by gumming them to a support and then irradiated for 1 h with a solar simulator (Suntest CPS+, Atlas, Linsengericht, Germany) equipped with a Xenon lamp, an optical filter to cut off wavelengths shorter than 290 nm, an IR-block filter to avoid thermal effects and an air cooling system. The solar simulator emission was maintained at 500 W/m^2, corresponding to an UV irradiance of 54.9 W/m^2 (irradiation dose, 198 kJ/m^2), compa-

Table 1
Comparative photodegradation values for EGCG in the solid state, in solution (1%, w/w) and in cream formulations (1%, w/w), after 1 h irradiation with the solar simulator.

Sample	% EGCG loss[a]	P[b]
Solid product	1.1 ± 0.3	
Propylene glycol solution	10.8 ± 0.5	
Control cream	68.9 ± 2.3	
Cream containing Amphysol K instead of Montanov 82	60.2 ± 1.1	<0.001
Cream without sodium dehydroacetate	55.8 ± 1.5	<0.001

[a] Each value is the mean ± SD of at least 6 determinations.
[b] *P*-values (unpaired *t*-test) versus control cream.

rable with natural sunlight whose irradiance ranges between ca. 10 W/m^2 (cloudy) and ca. 60 W/m^2 (sunny day) [26]. The temperature inside the solar simulator during irradiation never exceeded 38 °C. After the exposure interval, the samples were quantitatively transferred into a 20-ml calibrated flask with methanol (2 × 8 ml), subjected to sonication (10 min) and analysed by HPLC after dilution to volume (20 ml) and filtration (0.45 μm membrane filters). The degree of photodegradation was evaluated by measuring the percentage of recovered EGCG with respect to non-irradiated samples. The results were the average of at least six experiments.

2.6. Assay validation

Cream test samples were prepared by adding EGCG at levels of 0.1% and 1.0% (w/w) to the formulation components listed in Section 2.4. The percentage recoveries were calculated by comparing the peak areas of EGCG extracted from the test samples with those obtained by direct injections of equivalent concentrations of the analyte dissolved in methanol.

The chromatographic precision was evaluated by repeated analyses ($n = 6$) of the same sample solution from a cream containing 1.0% (w/w) EGCG. The method precision was calculated by extraction and HPLC assay of independent samples ($n = 6$) from the same cream formulation.

Calibration curves of peak area versus concentration were generated with blank formulation extracts spiked with known amounts of EGCG in the concentration range 0.002–0.02 mg/ml.

2.7. Statistical analysis

Statistical analysis of data was performed using Student's *t*-test, analysis of variance (ANOVA) and Tukey's post test. *P*-values < 0.05 were considered significant. All computations were carried using the statistical software GraphPad Instat (Graphpad Software, San Diego, CA).

3. Results

3.1. EGCG photodegradation assessment

To investigate the photochemical behaviour of EGCG, the photolysis studies were carried out initially in the solid-state. The EGCG sample was exposed to the solar simulator, at an irradiance corresponding to natural sunlight, and the extent of degradation was measured by HPLC. As illustrated in Table 1, the degree of photodecomposition was about 1%. Moreover, following irradiation of propylene glycol solutions containing 1.0% (w/w) EGCG, a 10.8% loss of the catechin was measured (Table 1). Hence, these preliminary experiments showed only minor catechin photoinstability in the solid state and in solution.

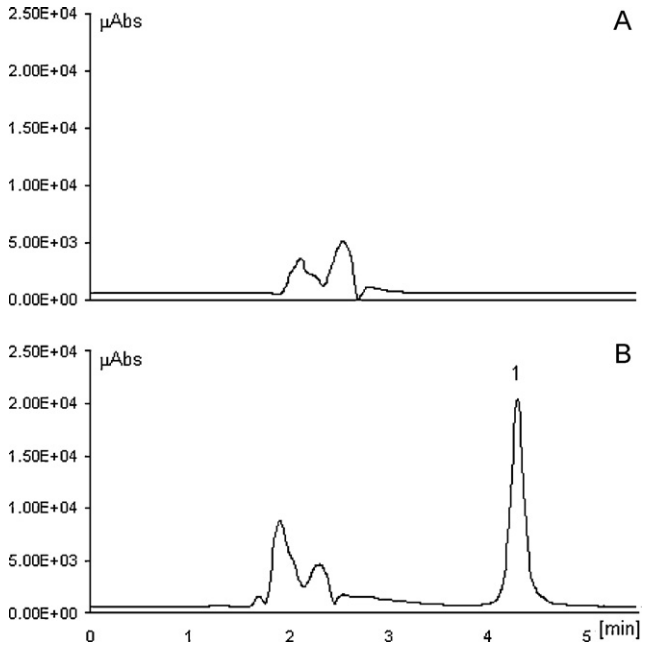

Fig. 2. Representative HPLC–UV chromatograms of: (A) a blank cream preparation and (B) the same product spiked with EGCG. Peak 1 = EGCG.

In order to simulate the real conditions encountered in the topical administration of EGCG, subsequent photolysis studies were performed on hydrophilic cream (oil-in-water emulsion) preparations. This system was selected as model formulation since it comprises the majority of dermatological products [27] and has been employed as a suitable vehicle for the in vivo evaluation of EGCG photoprotective effects in hairless mouse skin [6,16]. The pH of the formulations was adjusted to 5 to ensure sufficient chemical stability for the catechin [11,28] and compatibility with the skin physiological pH [27]. Moreover, in order to minimize possible interactions between the excipients and the EGCG active agent, a simplified emulsion formulation was selected (see Section 2.4). Following HPLC–UV analysis, no interference was observed from the cream excipients in the EGCG retention window (representative chromatograms are shown in Fig. 2). The accuracy of the HPLC assay was examined by recovery experiments. The average recoveries of EGCG from the cream matrices were satisfactory, with values higher than 96.4%. The precision of the method was shown by relative standard deviation (R.S.D.) values of 1.7% and 3.5% for the chromatographic and the method precision, respectively. Calibration curves ($n = 6$) were linear over the range 0.002–0.02 mg/ml, with correlation coefficients greater than 0.995. The intercept with the *y*-axis was not significantly different from zero ($P > 0.05$). The minimum quantifiable amount (i.e., 0.002 mg/ml) corresponded to a EGCG concentration in the final formulation of 0.1% (w/w).

Under the same conditions reported above, exposure to the solar simulator of the cream containing EGCG (1.0%), lead to a 68.9% decrease of the initial catechin concentration (control cream, Table 1). The marked EGCG degradation under simulated sunlight measured by HPLC–UV was verified by HPLC–ESI-MS analysis (Fig. 3) which also confirmed the identity of the EGCG peak from the irradiated samples [29]. Under the HPLC–MS conditions used, no peaks traceable to decomposition products were observed (Fig. 3B), as found also for the EGCG degradation at alkaline pH, using HPLC combined with atmospheric pressure chemical ionization MS [11].

To examine the influence of the formulation components on EGCG photolysis, a systematic study of the effect of the cream excipients was performed. Accordingly, the nonionic emulsifier Montanov 82 (cocoglucoside) was replaced by an ethoxylated non-

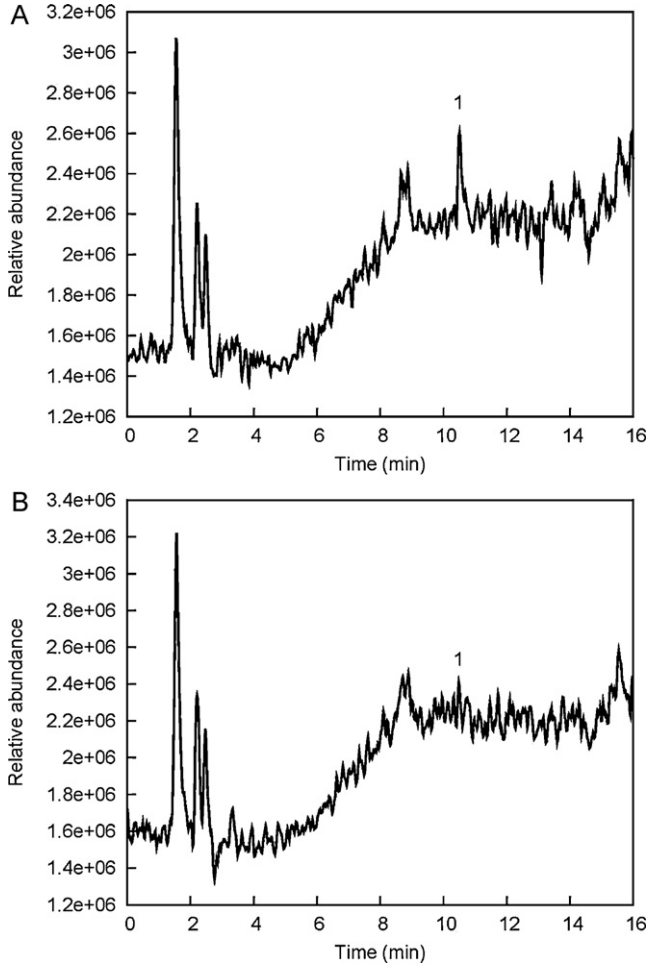

Fig. 3. Total ion current traces obtained by HPLC–ESI-MS analysis of a cream preparation containing EGCG before (A) and after (B) 1 h irradiation with the solar simulator. Peak 1 = EGCG.

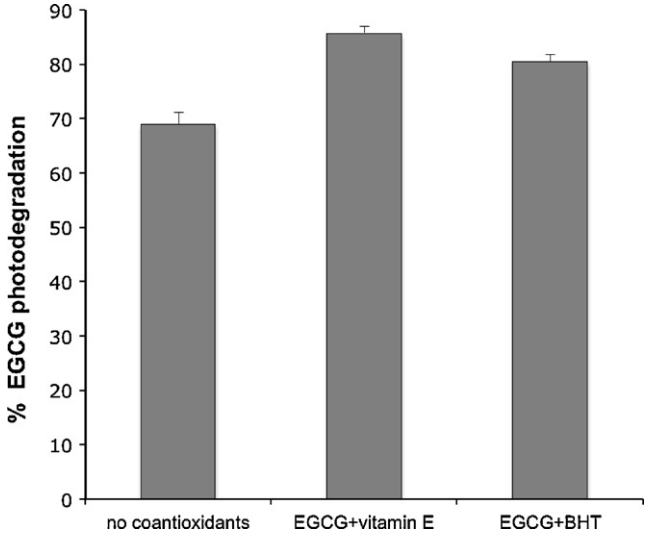

Fig. 4. EGCG photodegradation (%) in its formulations, without or with coantioxidants (vitamin E, BHT), after 1 h irradiation with the solar simulator. Values are means ± SD of at least 6 experiments.

ionic surfactant (Polawax) and an anionic surfactant (Amphysol K), respectively. When Polawax was included in the cream, phase separation occurred. On the other hand, the use of the anionic surfactant instead of Montanov 82 diminished the light-induced degradation of the catechin from 68.9% to 60.2% (Table 1), the difference being significant ($P < 0.001$, unpaired t-test). Moreover, the removal of sodium dehydroacetate, a commonly used anti-fungal agent, from the formulation also lead to a statistically significant ($P < 0.001$, unpaired t-test) decrease of the extent of photodecomposition, the EGCG percentage loss being 55.8 (Table 1). The other ingredients of the cream (Phenonip, sweet almond oil, glyceryl monostearate, cetearyl isononanoate, dimethicone, EDTA) did not affect significantly the photoreactivity of the catechin. However, the original formulation containing Montanov 82 as emulsifier and sodium dehydroacetate as anti-fungal preservative was utilized for further experimentation, due to its superior chemical stability, exhibiting the highest percentage (87.8 ± 2.2) of EGCG remaining, after 3 months storage of the formulations at room temperature and in the dark.

3.2. Photostabilization of EGCG formulations

The addition of antioxidants to EGCG-containing vehicles is the most commonly employed strategy to enhance the catechin chemical stability, although variable effects have been reported [10,11,22,23]. In order to assess the influence of antioxidants on the light-sensitivity of EGCG, the frequently used [30] vitamin E (0.9%, w/w) or BHT (0.5%, w/w) were incorporated into the cream, at a EGCG/antioxidant molar ratio of 1. Following illumination with simulated sunlight of the obtained formulations, no improvement in the catechin photostability was observed; on the contrary, a significant ($P < 0.01$, ANOVA and Tukey's post test) increase (16.8–24.4%) in the light-induced degradation of the catechin was measured, compared to the cream without coantioxidants (Fig. 4). The loss of EGCG reached 85.7 ± 1.3% and 80.5 ± 1.4%, in the presence of vitamin E and BHT, respectively (Fig. 4).

An alternative and commonly used approach for protection of photolabile drugs against light-induced degradation, is based on competitive absorption of photons by suitable excipients that absorb in the same wavelength region as the target compound [30,31]. Sunscreen agents are among the most common photostabilizers [31]. Accordingly, for the present study, the UV filters, EMC and BMDBM were selected, as they are widely used and very efficient UVB (280–320 nm) and UVA (320–400 nm) absorbers, respectively [32]. Under the same irradiation conditions reported above, EGCG was found to degrade by 61.0 ± 2.9% in the cream containing EMC (0.6%, w/w; EGCG/EMC molar ratio, 1) and by 67.8 ± 1.5% when BMDBM (0.6%, w/w; EGCG/BMDBM molar ratio, 1) was included in the formulation (Fig. 5). Therefore, compared to the cream without sunscreen agents (EGCG degradation, 68.9%), a small (11.5%) but significant ($P < 0.01$, ANOVA and Tukey's post test) reduction of EGCG photodecomposition was achieved by the UVB filter EMC, while the UVA sunscreen, BMDBM was ineffective ($P > 0.05$, ANOVA and Tukey's post test).

Additional photolysis experiments were performed in order to evaluate the effect of water-soluble sunscreen agents, as photostabilizers, instead of the lipophilic EMC. Accordingly, the water-soluble UVB filter, BP-4 (0.7%, w/w; EGCG/BP-4 molar ratio, 1) was incorporated in the cream containing EGCG and the obtained formulation was exposed to the solar simulator, under the same experimental conditions outlined above. As illustrated in Fig. 5, in the presence of BP-4, a more marked decrease ($P < 0.001$, ANOVA and Tukey's post test) in the light-induced decomposition of EGCG to 51.6 ± 2.7% was attained, compare to EMC. The use of Tinosorb M, a broad-spectrum UV filter (covering both the UVB and UVA ranges) which is added and dispersed in the aqueous phase of the emulsion [33] was also examined. Tinosorb M produced a stabilizing effect (EGCG degradation, 50.1 ± 2.5%) comparable to that of BP-4, thus confirming the results reported above, indicating that

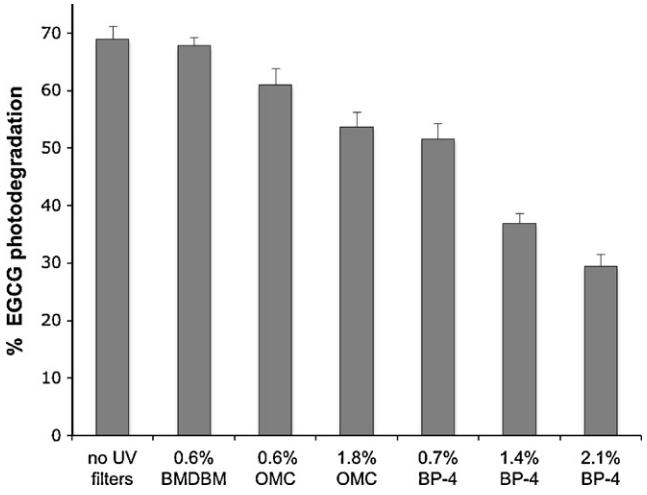

Fig. 5. EGCG photodegradation (%) in its formulations without or with varying amounts of different UV filters, after 1 h irradiation with the solar simulator. Values are means ± SD of at least 6 experiments.

the EGCG photosensitivity is caused mainly by the UVB wavelengths with no significant contribution by the UVA rays. Moreover, the photoprotective effect of the water-soluble UVB filter, BP-4 was concentration dependent; the EGCG percentage degradation further decreased ($P < 0.001$, ANOVA and Tukey's post test) to 36.9 ± 1.8 and 29.4 ± 2.2 in the presence of 1.4% (w/w; EGCG/BP-4 molar ratio, 0.5) and 2.1% (w/w; EGCG/BP-4 molar ratio, 0.33) BP-4, respectively (Fig. 5). At higher BP-4 concentrations, no significant improvement in EGCG photostability was observed. On the other hand, the lipophilic UVB filter, EMC at the highest level used for BP-4 (1.8%, w/w; EGCG/EMC molar ratio, 0.33), exhibited a much lower photostabilization activity, the extent of EGCG degradation being 53.7 ± 2.6% (Fig. 5).

4. Discussion

While the protective activity of topical EGCG against several types of sunlight-induced skin damages has been well documented [5–7,12–18], at present there is no information in the literature on the photoreactivity of EGCG in dermatological preparations. On the other hand, the inherent chemical instability of this catechin has been thoroughly investigated in different vehicles, by examining the influence of several parameters including pH, temperature, ionic strength, solvent type and addition of antioxidants [10,11,20–23,28]. The lack of data on the stability of EGCG under sunlight represents a major limitation for the potential applicability of this catechin in the protection of the skin against the harmful effects of solar UV radiation. In order to overcome this drawback, in the present investigation the photochemical behaviour of EGCG was systematically examined under conditions simulating the actual application of cutaneous products. The obtained results demonstrated, using a simple emulsion based formulation, that EGCG undergoes a pronounced degradation under simulated sunlight, 68.9% of the catechin was lost after just 1 h irradiation. In the HPLC–MS chromatogram of the cream exposed to the solar simulator, no distinct peaks originated from the light-induced decomposition of EGCG were detected (Fig. 3B). This could be due to total degradation of the catechin or formation of photoproducts (e.g., polymeric compounds) strongly retained by the stationary phase. Conversely, under the same chromatographic conditions used in the present study for the HPLC–MS analysis (Section 2.3), the chemical degradation of EGCG generated well resolved new peaks which were identified as oxidation products, dimers and epimers by combined HPLC–MS [20,34]. These data suggest that the mechanism of EGCG photodegradation is different from the decomposition pathways involved in the catechin chemical instability. The expected consequence of the observed EGCG photodecomposition is a loss of potency of the product during sun exposure. However, the biological activity of the photodegradants should be evaluated in order to obtain more conclusive information.

In the only report found in literature dealing with green tea polyphenol photoreactivity, electron paramagnetic resonance (EPR) spectroscopy was used to monitor the antioxidant power of the tea leaves [35]. The EPR signals were found to be affected by illumination of the leaves samples with a xenon lamp, thus indicating that photodegradation occurred, in accordance with the results reported here for EGCG in topical cream preparations.

As photochemical processes in formulations can be affected by the medium, due to possible light induced reactions involving the excipients [30], the influence of the ingredients used for the cream vehicle was examined. Although some photo-destabilizing effect due to the emulsifier and anti-fungal components was observed, variations in the formulation excipients did not achieve a sufficient inhibition of the light-induced decomposition of EGCG, the catechin loss remaining quite high (>55%).

Antioxidants have been shown to enhance the chemical stability of EGCG, both in solution and emulsion vehicles [10,11,22,23], although contradictory results, such as no improvement or destabilizing effects have also been reported [11,23]. On the other hand, the data obtained in this study clearly pointed out that the addition of the examined antioxidants (vitamin E, BHT) to the EGCG-containing hydrophilic cream, significantly enhanced the degradation of the catechin under UV light (Fig. 4). In particular, although BHT has been shown, in several studies, to improve the chemical stability of EGCG [10,11], it produced a 16.8% increase in the catechin photodegradation (Fig. 4). Hence, the presence of molecules that can inhibit oxidation processes, quench light-activated species and act as radical scavengers, such as the examined antioxidants, unexpectedly led to an increase EGCG photolability. This phenomenon could be probably ascribed to interactions between EGCG and the coantioxidants [11] that resulted in an energetically preferred form of the catechin for the irradiation-induced decomposition process. For instance, the light-sensitivity of vitamin E, which degrades by photo-oxidation [36], could favour the photolysis of EGCG.

In order to protect the photosensitive EGCG, the addition of light-absorbing species was also investigated, by examining the influence of the incorporation of different sunscreen agents in the cream formulation. As illustrated in Fig. 5, the data obtained indicated that the UVB filter, EMC achieved a greater protecting effect on EGCG photodegradation than the UVA filter, BMDBM used at the same catechin/sunscreen molar ratio. Since EGCG shows an absorption maximum around 280 nm, the observed difference in the UV filter stabilization activity can be traced to a more efficient spectral overlapping (absorption in the same wavelength region) by EMC (λ_{max}, 306–308 nm) compared to BMDBM (λ_{max}, 357–360 nm). Moreover, a further decrease in the extent of the light-induced decomposition of EGCG (Fig. 5) was attained when the lipophilic UVB filter, EMC was replaced by the hydrophilic UVB absorber, BP-4, despite the former has a stronger molar extinction coefficient in the UVB range (23,300) compared to BP-4 (13,400). Hence, the photostabilization activity exerted by the examined UVB filters on EGCG was more dependent on their hydrophilicity rather than their absorptive capacities. It is reasonable to assume that, due to its hydrophilic characteristics, EGCG will preferentially partition in the water phase of the emulsion and hence the presence of the photoprotective sunscreen agent in this phase should lead to more favourable interactions with the catechin. The stabilization exerted by BP-4 was concentration dependent, the highest effect, measured at 2.1% (w/w) BP-4, produced a 56.9% reduction in the light-induced degradation of EGCG (Fig. 5).

In conclusion, the present study represents the first report on the photodegradation of EGCG in formulations suitable for topical application. The observed marked EGCG instability under simulated sunlight is a major disadvantage for the development of products for skin photoprotection, since the therapeutic activity will be rapidly lost under UV radiation. The photolability of EGCG may represent one of the factor that has prevented the wide spread use of the catechin for the treatment of light-induced skin disorders. Because EGCG is a very useful ingredient for protection of the skin against the damaging effects of solar UV radiation, its stabilization is of paramount importance for the preparation of effective dermatological products containing EGCG. Antioxidants additives failed to protect the catechin against light-induced degradation, whereas efficient EGCG photostabilization was achieved by the water-soluble UVB filter BP-4. Therefore, the incorporation of this sunscreen agent in EGCG-containing formulations represents a useful strategy for the development of efficacious topical products for the treatment of cutaneous photodamage.

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