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Research Article

Incorporation in Lipid Microparticles of the UVA Filter, Butyl Methoxydibenzoylmethane Combined with the UVB Filter, Octocrylene: Effect on Photostability

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Abstract. The aim of this study was to reduce the photoinstability of butyl methoxydibenzoylmethane (BMDBM), the most widely used UVA filter, by incorporating it in lipid microparticles (LMs) alone or together with the UVB filter octocrylene (OCR), acting also as photostabilizer. Microparticles loaded with BMDBM or with combined BMDBM and OCR were produced by the hot emulsion technique, using glyceryl behenate as lipid material and poloxamer 188 as surfactant. The LMs were characterized by release studies, scanning electron microscopy, and powder X-ray diffractometry. The BMDBM and OCR loading was 15.2% and 10.6%, respectively. In order to reproduce the conditions prevalent in commercial sunscreen products, the photoprotective efficacy of the LMs was evaluated after their introduction in a model cream (oil-in-water emulsion) containing a mixture of UVA and UVB filters. A small but statistically significant decrease in BMDBM photodegradation was obtained when the UVA filter was encapsulated alone into the LMs (the extent of degradation was 28.6% ±2.4 for non-encapsulated BMDBM and 26.0% ±2.5 for BMDBM-loaded microparticles). On the other hand, the co-loading of OCR in the LMs produced a more marked reduction in the light-induced decomposition of microencapsulated BMDBM (the UVA filter loss was 21.5% ±2.2). Therefore, incorporation in lipid microparticles of BMDBM together with the sunscreen OCR is more effective in enhancing the UVA filter photostability than LMs loaded with BMDBM alone.

KEY WORDS: butyl methoxydibenzoylmethane; lipid microparticles; octocrylene; photodegradation; sunscreen formulation.

INTRODUCTION

The use of topical products for sun protection is constantly increasing (1) due to the rising level of public awareness of the numerous harmful effects (erythema, cutaneous photoaging, immune suppression, and various forms of skin cancers) of solar UV radiation (2,3). The sunscreening ingredients incorporated in these preparations, referred to as sunscreen agents or UV filters, decrease the dose of UV rays impacting on the skin by absorbing, reflecting, or scattering the radiation (4).

Although the sunlight-induced skin damage has been attributed mainly to the UVB rays (290–320 nm), more recently the important contribution of UVA wavelengths (320–400 nm) has been well documented (5,6). Therefore, sunscreen products should provide an effective protection throughout the whole UV range (290–400 nm) of sun radiation reaching the Earth's surface (3,6). In order to achieve these characteristics, combinations of several UVB and UVA filters are introduced in the formulation of sunscreening preparations (4,7,8).

Within the class of UVA absorbing substances, butyl methoxydibenzoylmethane (BMDBM; Fig. 1) is the most widely used sunscreen compound (7,9,10). It is included in the list of authorized sunscreen agents in Europe, USA, Australia, and Japan (11). BMDBM exhibits high absorptive capacity in the UVA region, but it suffers from marked decomposition under sunlight irradiation which leads to a reduction in the protective efficacy of the sunscreen preparation during solar exposure (9,12,13). In addition, its photofragmentation results in the formation of free radicals which may directly or indirectly initiate skin damage (14,15). The photochemical inactivation of BMDBM is thus a limiting factor for the formulation of sun-care products (9).

The instability of BMDBM under sunlight can be reduced by the addition of UVB filters, such as octocrylene or methylbenzylidene camphor, with triplet energy similar to BMDBM and acting as quenchers of its triplet state (8,9). Because of the lower effectiveness of methylbenzylidene camphor and concern with its safety (8), octocrylene (OCR; Fig. 1), a UVB filter with moderate extinction coefficient, is generally employed as photostabilizer for BMDBM (9,16). However, this effect is reduced when in combination with octyl methoxycinnamate (OMC) (13,15,17). This aspect is extremely relevant, since OMC is the most widely used UVB

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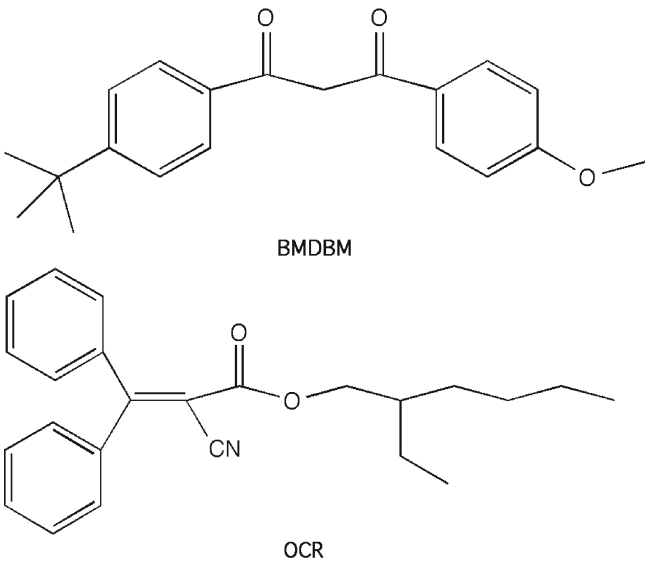

Fig. 1. Chemical structures of BMDBM and OCR

absorber worldwide (9,15,16) and its association with BMDBM dominates the ranking of sunscreen market shares in most countries (7,9,10). Hence, there is a need for new systems exhibiting enhanced photostability for BMDBM, especially when it is combined with the UVB absorber OMC, as in most commercial formulations (9).

Inclusion complexation with cyclodextrins, encapsulation in micro- and nano-particles have been investigated in order to improve the efficacy and stability of BMDBM under solar radiation (9,14,18–20).

Recently, attention has been focused on lipid microparticles (LMs) as a promising carrier system for sunscreen agents (19,21,22). They consist of a solid lipid core based on naturally occurring lipids and stabilized by a layer of surfactant molecules on the surface (23). Consequently, their components are physiologically compatible and biodegradable, providing excellent *in vivo* tolerability (24). Additional advantages of LMs include high loading capacity for lipophilic substances, such as most of the UV filters, and decreased skin penetration of encapsulated sunscreens (21). Moreover, their solid matrix protects incorporated actives against decomposition (24,25).

Previous investigations, demonstrating the photostabilizing effect of LMs on the encapsulated sunscreen agents, have been performed on individual UV filters (19,21,22,26). However, these systems do not simulate the actual conditions of use, since commercial sunscreen products always contain a mixture of UVA and UVB absorbers (7–10). In order to overcome this drawback and enhance the lipid microparticle protective effect, the present study reports on the incorporation of BMDBM in LMs together with the UVB filter OCR, acting also as photostabilizer. The LMs loaded with the BMDBM/OCR combination were then introduced in a model sunscreen formulation (emulsion) containing OMC as additional UVB filter, and their influence on the light-induced degradation of BMDBM was evaluated. For comparison purposes, LMs containing BMDBM only were also prepared and examined.

MATERIALS AND METHODS

Materials

Butyl methoxydibenzoylmethane and octyl methoxycinnamate were supplied by Merck (Darmstadt, Germany). Octocrylene and poloxamer 188 were from BASF (Ludwigshafen, Germany). Glyceryl behenate (a mixture of mono-, di-, and tri-esters of glycerol and behenic acid) was obtained from Gattefossé (Cedex, France). Tristearin was purchased from Fluka Chemie (Bucks, Switzerland). Hydrogenated soybean phosphatidylcholine was a gift by Cargill (Hamburg, Germany). The excipients for the cream preparations were from Sigma Aldrich (Steinheim, Germany) and Henkel (Fino Mornasco, Italy). Methanol, acetonitrile and water were high-performance liquid chromatography (HPLC)-grade from Merck. All other reagents and solvents were of analytical grade (Sigma).

Methods

High-Performance Liquid Chromatography

The HPLC apparatus comprised a Model LabFlow 3000 pump (LabService Analytica, Bologna, Italy), a Model 7125 injection valve with a 20-µl sample loop (Rheodyne, Cotati, CA, USA) and a Model 975-UV variable wavelength UV-Vis detector (Jasco, Tokyo, Japan) set at 330 nm, which is the optimum wavelength to obtain satisfactory UV responses for the examined sunscreen agents exhibiting different absorption maxima. Data acquisition and processing were accomplished with a personal computer using Borwin software (JBMS Developpements, Le Fontanil, France). Sample injections were performed with a Model 701 syringe (10 µl; Hamilton, Bonaduz, Switzerland). Separations were performed according to the method of Simeoni *et al.* (27), using a 5-µm Zorbax SB-CN column (150×3.0 mm i.d.) fitted with a guard column (5-µm particles, 4×2 mm i.d.) and eluted isocratically, at a flow-rate of 0.5 ml/min, with methanol–acetonitrile–water (35:20:45, *v*/*v*/*v*), containing 0.5% (*v*/*v*) acetic acid. The identities of the UV filter peaks were assigned by co-chromatography with the authentic standards. Quantification was carried out by integration of the peak areas using the external standardization method.

Lipid Microparticle Preparation

Lipid microparticles were prepared by adding preheated (75–85°C) water (50 ml) containing 1% (*w*/*w*) of previously dispersed (magnetic stirring) surfactant, to the melted lipid phase (3.6 g) in which BMDBM (1.0 g) or the BMDBM/OCR mixture (1.7 g) has been dissolved. The hot aqueous phase was poured into the melted lipid, rather than the contrary, to avoid loss of lipid excipients and sunscreen agents during the manufacturing process. The sample was then mixed (13,500 rpm for 2 min) with an Ultra-Turrax T25 (IKA-Werk, Staufen, Germany) at 75–85°C. The resulting oil-in-water emulsion was rapidly cooled at room temperature under magnetic stirring and the formed LMs were recovered by centrifugation (6,000 rpm for 15 min) and freeze-dried.

In Vitro Release

The sunscreen dissolution and release from the LMs were studied by adding BMDBM (5 mg) and OCR (3.5 mg) or LMs containing an equivalent amount of the sunscreens, to propylene glycol (50 ml) under mechanical stirring at 50 rpm and 37°C. At appropriate time intervals, 1-ml aliquots of the release medium were withdrawn and replaced with an equal volume of fresh medium. The samples were filtered (0.45 μm) and assayed for BMDBM and OCR by HPLC, after dilution (1:1) with methanol. Each series of experiments was repeated six times.

Microparticle Characterization

Microparticle morphological structure was examined by scanning electron microscopy (SEM; Cambridge Stereoscan 360, Cambridge Instruments, Bar Hill, UK). The particle size was determined by computerized image analysis (Micrometrics™ camera 122CU and software Vision 1.0) of at least 100 particles on photomicrographs obtained with an optical microscope (Nikon Diaphot inverted microscope, Tokyo, Japan).

The powder X-ray diffraction patterns were recorded on a D 5000 powder diffractometer (Siemens, Munich, Germany) using a voltage of 45 kV and a current of 25 mA for the generator, with Cu anode material. The wavelength of the graphite-monocromated radiation was 1.5406 Å. The diffractograms were recorded from 3° (2θ) to 50° (2θ) at an angular speed of 1° (2θ) per minute using 1–1–1–0.15° slits.

The amount of BMDBM and OCR entrapped in the LMs was determined by dissolving the microparticles (35–40 mg) in ethanol under sonication (2×5 min). The obtained sample was diluted to volume (20 ml), filtered and assayed by HPLC. The encapsulation efficiency was calculated as the percentage ratio between the quantity of sunscreen agents entrapped in the microparticles and added to the melted lipid phase, during preparation. Data were determined from the average of at least six determinations.

Emulsion Formulations

The photolysis experiments were performed in cream preparations (oil-in-water emulsions) containing BMDBM (1%, *w*/*w*) and OCR (0.7%, *w*/*w*) incorporated in lipid microparticles. Creams containing equivalent amounts of plain BMDBM and OCR in conjunction with blank LMs or BMDBM-loaded microparticles with non-encapsulated OCR were also examined. The UVB filter OMC (1%, *w*/*w*) was added to each formulation. The emulsion excipients were: sorbitan monostearate (2%), polyoxyethylene sorbitan monostearate (4.5%), butylated hydroxyanisole (0.05%), octyl palmitate (6.0%), liquid petrolatum (5.5%), cetearyl alcohol (5.0%), sodium benzoate (0.1%), glycerin (2.0%), dehydroacetic acid (0.1%), EDTA (0.1%), and water (67.0%). The creams were prepared according to the common procedure used in compounding practice. Blank or loaded lipid microparticles (6.0–6.5 g per 100 g of cream) were dispersed in water and added in the cooling phase of the emulsion preparation at about 40°C.

Photodegradation Studies

Portions (35–45 mg) of the test creams were homogeneously spread onto a Transpore™ tape (3M Health Care, Neuss, Germany) at a level of 2 mg/cm^2. The obtained samples were 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 and an IR-block filter to avoid thermal effects. The solar simulator emission was maintained at 750 W/m^2. The applied UV energy was equivalent to ten minimal erythemal dose (MED), which is considered representative of half-day solar emission close to the equator (12). After the exposure interval, the Transpore™ tape was cut into small pieces and extracted with ethanol (5 ml) under sonication (5 min). The sonication was repeated twice with methanol (5 ml) followed by overnight extraction, under stirring, with fresh methanol (15 ml). The combined fractions were adjusted to volume (50 ml) and the obtained sample was filtered (0.45 μm membrane filters) and analyzed by HPLC. The degree of photodegradation was evaluated by measuring the percentage of recovered sunscreen agents with respect to non-irradiated samples. The results were the average of at least ten experiments.

In Vitro Sun Protection Factor Measurement

The *in vitro* determination of the cream sun protection factor (SPF) was carried out according to the Diffey and Robson (28) technique, with minor modifications. The method is based on the measurement of the transmission spectrum of the UV radiation (290–400 nm) through a Transpore™ tape, before and after application (2 mg/cm^2) of the sunscreen preparation. The tape was placed into the spectrophotometer (Model V-530PC UV-VIS; Jasco, Tokyo, Japan) sample compartment, over the quartz input optics of the detector. The spectral data were processed with a personal computer and the SPF calculated according to Diffey and Robson (28).

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, USA).

RESULTS AND DISCUSSION

In Vitro Release of UV Filters from Lipid Microparticles

For the preparation of lipid microparticles loaded with combined BMDBM and OCR, a hot emulsion technique (23) was employed, utilizing different lipid materials (tristearin, glyceryl behenate) and surfactants (hydrogenated phosphatidylcholine and poloxamer 188). To evaluate the influence of these excipients on the retention efficacy of the LMs for the loaded sunscreens, *in vitro* release studies were performed using a medium (propylene glycol) in which BMDBM and OCR were sufficiently soluble to ensure sink conditions,

whereas the LMs remained intact. Distinct differences were observed among microparticles based on tristearin or glyceryl behenate as lipid matrix and poloxamer 188 or phosphatidylcholine as stabilizer (Fig. 2). The slowest release rates for both BMDBM and OCR were achieved by the LMs prepared with glyceryl behenate and poloxamer 188 (Fig. 2a and b), which indicated a more efficient incorporation of the UV filters in this system. The reduction in release was statistically significant (ANOVA and Tukey's post test) at 60 and 120 min ($P<0.01$). Moreover, the lack of burst effect phenomena (Fig. 2) suggested that there was no adsorption of the sunscreens at the microparticle surface. The obtained data pointed out that the nature of the lipid and surfactant excipients is an important factor for the LMs release modulation capacity (23). This effect can be ascribed to lipid polymorphic transformations (23), different affinity between the UV filters and the lipid materials (29), and to differences in the extent of lipid surface coverage by the surfactant (30). In addition, the different melting points of the examined lipids (glyceryl behenate, ca 83°C; tristearin, ca 65°C) determining the production temperature of the LMs can affect their release behavior (24). On the basis of the above results, LMs prepared with glyceryl behenate and poloxamer 188 were used for further experimentation since they exhibited the greatest retention capacity for the examined UV filters (Fig. 2).

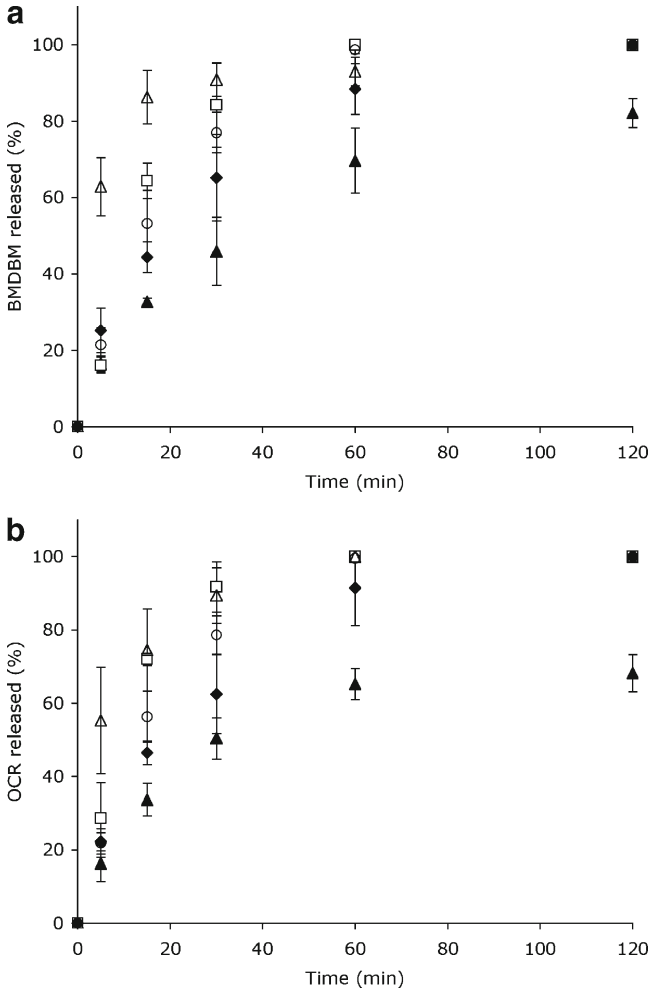

Fig. 2. BMDBM (**a**) and OCR (**b**) dissolution (*empty triangles*) and release from LMs prepared with tristearin and phosphatidylcholine (*filled diamonds*), tristearin and poloxamer 188 (*empty circles*), glyceryl behenate and phosphatidylcholine (*empty squares*), or glyceryl behenate and poloxamer 188 (*filled triangles*). Values are means±SD ($n=6$)

The highest microparticle yield (percentage ratio between the weight of microparticles and the weight of lipid, surfactant, and active fed initially) was obtained at a lipid/emulsifier ratio of 7:1. Additional production parameters including the stirring rate (9,500–17,500 rpm) and time (1–5 min) were evaluated in order to obtain particles with satisfactory morphological structure and size homogeneity. The best results in terms of particle size, polydispersity and surface smoothness were attained using a stirring rate of 13,500 rpm for 2 min.

Lipid Microparticle Characterization

SEM analysis on the optimized LMs, based on glyceryl behenate and poloxamer 188, showed a spherical shape although some irregular fragments were present (Fig. 3). The particle size was between 7 and 25 μm (mean diameter, 12.7 μm; polydispersity index, 0.69), the majority (73%) of the population being in the range 7–15 μm, which is appropriate when skin penetration should be minimized, as for the sunscreen agents (31). In fact, microparticles do not permeate the skin (31), whereas percutaneous penetration of nanometer-sized particles has been demonstrated (29,32), though other studies have reported that nanoparticles do not permeate the stratum corneum, but they diffuse into the hair follicles (33).

Additional information on the solid state of the LMs was obtained by powder X-ray diffractometry (Fig. 4). The diffraction pattern of the corresponding physical mixture of the sunscreen agents with the lipid microparticle excipients (Fig. 4d) displayed the crystalline peaks of glyceryl behenate (4.1°, 21.1°, 23.3°; Fig. 4a), poloxamer 188 (18.9°, 23.3°; Fig. 4b), and BMDBM (10.7°, 13.2°, 16.2, 17.3°, 19.5°, 20.3°, 24.9°; Fig. 4c); the OCR being an oil did not exhibit any signal. The characteristic peaks of BMDBM were not detected in the diffractogram of the lipid particles (Fig. 4e), suggesting its amorphization in the LMs. On the other hand, the typical signals of glyceryl behenate were observed in the LMs pattern (Fig. 4e), indicating that it is, at least partially, crystalline in the LMs.

The quantity of BMDBM and OCR incorporated into the LMs was 15.2%±0.4 (*w*/*w*) and 10.6%±2.1 (*w*/*w*), respectively. The encapsulation efficiency ranged from 76.9% to 80.9%.

Glyceryl behenate- and poloxamer 188-based LMs containing BMDBM without OCR were also prepared and characterized. No significant differences in particle morphology, dimensional distribution (mean diameter, 10.6 μm; polydispersity index, 0.67), encapsulation efficiency (76.6%), and BMDBM release profile (curve not shown) were observed compared with the systems containing BMDBM in combination with OCR. Therefore, the physical characteristics of BMDBM-loaded LMs were not affected by the co-loading of OCR.

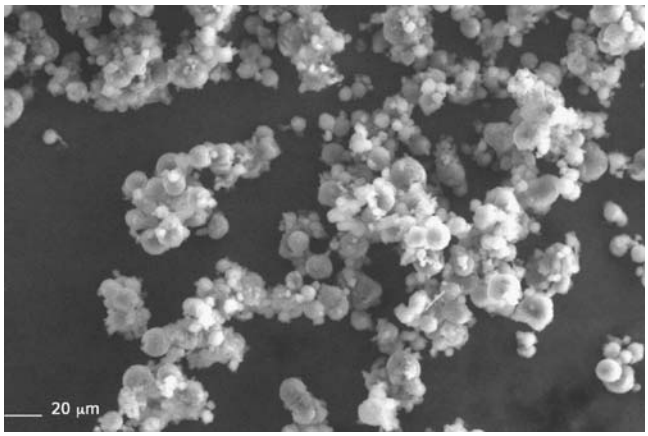

Fig. 3. Scanning electron microscopy (SEM) micrographs of LMs loaded with BMDBM and OCR

Photodegradation Studies

Previous investigations on the improvement of BMDBM photostability by its encapsulation in lipid microparticles have been performed in cream formulations containing BMDBM as the only UV filter (19,26). Although this option provides valuable information on the photochemistry aspects (9), the relevance of these studies to the real conditions of use of sunprotective products is limited, since in a typical sunscreening preparation not just one but a mixture of UVB and UVA filters is always employed in order to provide broad spectrum protection (3,7,9,10). Moreover, as the light-induced decomposition of a sunscreen agent is affected by the presence of other UV absorbers, the resulting photoinstability in UV filter combinations may be different from that observed for the individual sunscreen agent (8–10,13).

Accordingly, in the present work, the photochemical behavior of encapsulated BMDBM (UVA filter) was examined in the presence of the UVB absorbers OCR and OMC, using a cream (oil-in-water emulsion) as a vehicle. This system reproduces the conditions prevailing under the actual application of sunscreen products, since BMDBM is associated with OMC in most commercial suncare preparations (7,9,10) and stabilizing molecules, such as OCR, are often included in order to reduce the photoinstability of this combination (8,9,16). Moreover, the oil-in-water emulsion selected as a model formulation, represents the most common type of sunscreen product (16).

In order to verify the stabilizing effect of OCR, preliminary photolysis experiments were performed on creams containing the non-encapsulated UV filter combination BMDBM/OMC or BMDBM/OMC/OCR. The emulsions were applied onto Transpore™ tapes (a surgical tape simulating the texture of human skin), irradiated with the solar simulator and the extent of degradation measured by HPLC. The percentage losses of BMDBM were 32.6±2.3 in the formulation containing the UVA filter in conjunction with OMC and 28.6±2.4 in the cream which also included OCR, the differences between the foregoing values being statistically significant ($P<0.02$, unpaired t test). These results indicated, in accordance with earlier studies (10,13,17) that the presence of OCR preserved the UVA filter BMDBM from degradation, though only partially. This stabilizing effect was also exerted on the UVB absorber OMC (the extent of OMC decomposition decreased from 62.1% ±1.7 to 53.8% ±3.1, $P<0.01$). On the other hand, OCR appeared to be rather stable under simulated sunlight (the amount lost was <4.1%), in good agreement with previous reports (8–10).

The following photodegradation studies were carried out, under the same experimental conditions, on creams containing BMDBM-loaded LMs in conjunction with plain

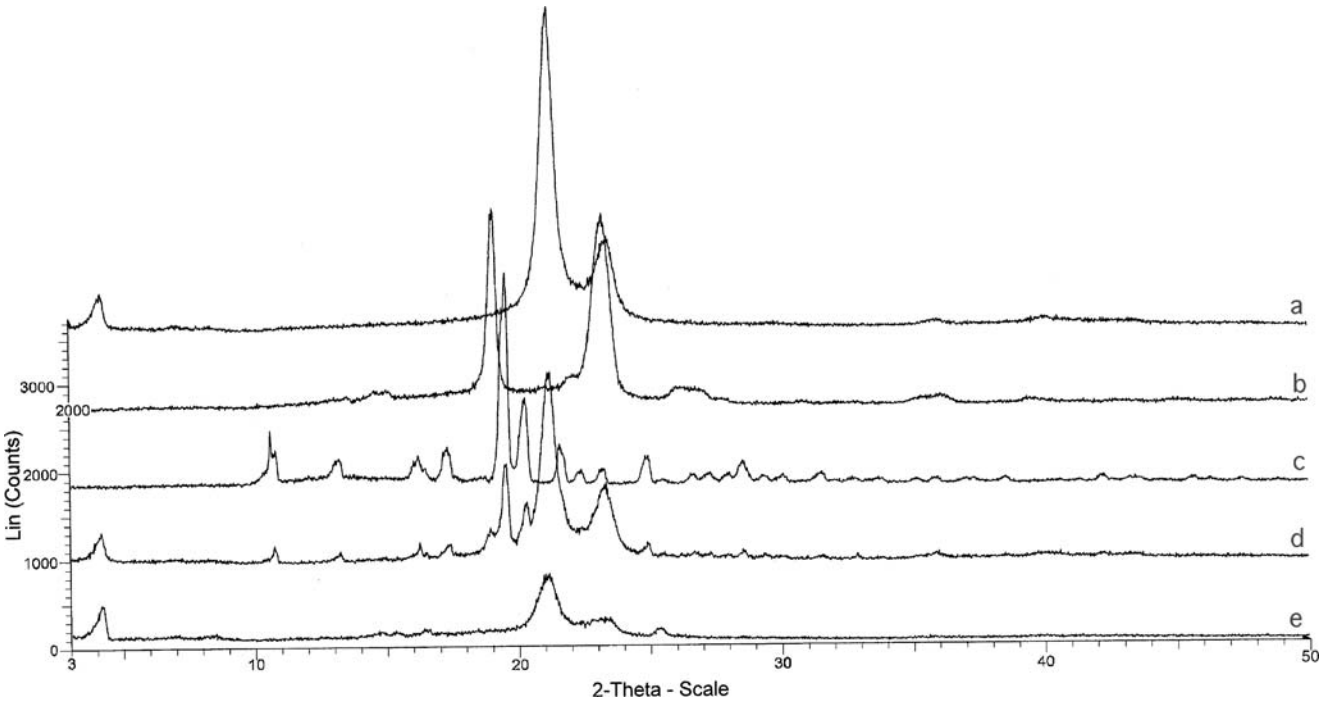

Fig. 4. Powder X-ray diffraction patterns of glyceryl behenate (*a*), poloxamer 188 (*b*), BMDBM (*c*), BMDBM-OCR-lipoparticle excipient physical mixture (*d*), and LMs loaded with BMDBM and OCR (*e*)

OCR and OMC (Fig. 5). The amount of BMDBM recovered after irradiation was 74.0%, corresponding to a decomposition of 26.0% ±2.5 (Fig. 5). These results indicated a lower UVA filter degradation compared with the formulation containing free BMDBM, OMC, and OCR (BMDBM loss, 28.6%; Fig. 5), the difference being statistically significant (unpaired t test, $P<0.05$). However, the observed protective efficacy of the lipid microparticles was not as marked as that reported in previous studies based on formulations containing BMDBM as the only sunscreen agent (19). This discrepancy may be ascribable to the fact that the photochemical behavior of BMDBM changes when in mixture with other UV absorbers (8–10,13). In addition, the photostabilization effect of OCR, based on triplet state quenching by an energy transfer mechanism (9), may be hindered when BMDBM is entrapped in the particle matrix.

Consequently, it seemed interesting to investigate whether the co-loading of BMDBM with OCR in LMs could produce a more distinct improvement in the UVA filter stability under sunlight. LMs loaded with combined BMDBM and OCR were incorporated into the cream and compared in terms of photodegradation with the formulations containing non-encapsulated BMDBM and OCR or lipid microparticles loaded with BMDBM only in conjunction with free OCR. A more marked reduction in the light-induced decomposition of the UVA filter to 21.5% ±2.1 was achieved by the microencapsulation of BMDBM together with OCR (Fig. 5). Statistical analysis of the data (ANOVA and Tukey's post test) demonstrated that the differences among the examined formulations (Fig. 5) were significant ($P<0.01$). Moreover, additional photostability experiments performed on a cream containing BMDBM/OCR-loaded microparticles prepared with tristearin, instead of glyceryl behenate, and poloxamer 188 indicated that the extent of BMDBM degradation (29.4% ±2.2) was not significantly different compared with the free UV filter. Therefore, the photostabilization effect of the examined microparticle systems correlated with their release modulation capacity (Fig. 2), LMs with higher release rate exhibiting reduced protective effect. In fact, the release of the sunscreens from the LMs decreases the UV filter fraction protected by the lipid particle matrix. These results indicated that the co-loading of OCR significantly enhanced the photostability of BMDBM encapsulated in LMs, compared with the systems based on the classical combination of free BMDBM and OCR or containing the microparticle-entrapped BMDBM with the non-encapsulated OCR. This phenomenon could be traced to a more efficient interaction (triplet state energy transfer) of the OCR photostabilizer with the BMDBM molecules in the lipid particle core, without interferences from emulsion excipients.

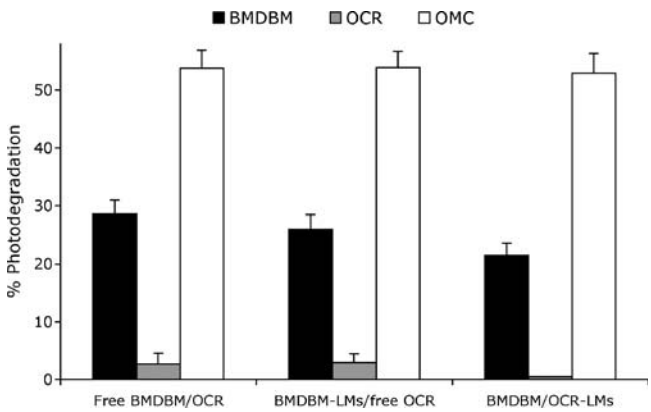

Fig. 5. BMDBM-, OCR- and OMC-photodegradation (%) in their formulations after 1 h irradiation with the solar simulator. Values are means±SD of at least ten experiments

The photolysis experiments also pointed out that the OCR stability under irradiation (Fig. 5) was improved after its incorporation in the lipid particles (OCR degradation, <0.6%). In addition, the UVB filter OMC was found to degrade by 52.9–53.8%, the extent of the light-induced decomposition being similar for all studied creams (Fig. 5). This was expected, since this UVB filter was introduced in the tested emulsions in the non-encapsulated form. However, the observed loss in OMC concentration (Fig. 5), which is consistent with published data (8,13), cannot be considered as real instability, since it is due to *trans–cis* isomerization, the obtained *cis* isomer absorbing at the same wavelength, though with a lower extinction (9,13).

In Vitro Sun Protection Factor

Since one of the most important criteria for the assessment of a sunscreen product performance is the sun protection factor (SPF) (11), this parameter was determined *in vitro* in the examined formulations, according to the Diffey and Robson technique (28). No significant differences ($P>0.05$, ANOVA) were observed among the *in vitro* SPF values (6.2–6.7) of the creams containing the various sunscreen systems described above (i.e., free BMDBM/OCR/OMC; BMDBM-loaded LMs with free OCR/OMC; microencapsulated BMDBM/OCR with free OMC). This indicated that LM-incorporation of the sunscreen agents has not modified their overall UV attenuation characteristics. Another parameter obtained from the *in vitro* SPF measurements is the UVA/UVB ratio (17), an indicator of the UVA absorbing performance in relation to that in the UVB. For all tested formulations, the UVA/UVB ratio was nearly the same (1.0–1.1), suggesting that also the UVA protection was not altered by the microencapsulation process. Moreover, the measured *in vitro* SPF and UVA/UVB ratio fulfilled the general requirements on sunscreen products (3,17).

CONCLUSIONS

The task of photostabilizing BMDBM is a primary aim of sunscreen formulators (9) because of its role as the UVA absorber of choice and therefore its potential impact on the overall sunscreen preparation performance. The results described in the present study indicate that the co-loading of BMDBM with OCR in lipid microparticles is more effective in enhancing the UVA filter photostability compared to LMs loaded with BMDBM alone. In addition, the microencapsulation process, while limiting the loss of photoprotective capacity due to UV filter decomposition under sunlight, did not alter the performance of the sunscreen preparation, as measured by the *in vitro* SPF and UVA/UVB ratio. Moreover, at variance with previous studies, the photostabilizing properties of lipid microparticles have been

assessed in a sunscreen mixture typical of commercial sun protective products and hence simulating realistic conditions of use. The developed formulations based on BMDBM-loaded LMs could provide a useful alternative to conventional sun-care products containing this UVA filter.

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