Hindawi
Advances in Materials Science and Engineering
Volume 2021, Article ID 8580992, 9 pages
https://doi.org/10.1155/2021/8580992

Research Article

Preparation and Characterization of Organic/Inorganic Composite UV Filter Microcapsules by Sol-Gel Method

Pey-Shiuan Wu, Chia-Hui Lin, Yi-Ching Kuo, and Chih-Chien Lin

Department of Cosmetic Science, Providence University, Taichung, Taiwan

Correspondence should be addressed to Chih-Chien Lin; chchlin@pu.edu.tw

Received 16 October 2021; Revised 24 November 2021; Accepted 30 November 2021; Published 14 December 2021

Academic Editor: Michelina Catauro

Octyl methoxycinnamate and butyl methoxydibenzoylmethane are organic UV filters with poor photostability and will become photoallergy or phototoxic substance when exposed to ultraviolet radiation. The organic UV filters coated by microcapsules can reduce the photodegradation and avoid direct contact with the skin. Through microencapsulation, the application of UV filters in cosmetics becomes more effective and safer. This study first used the sol-gel method to create organic/inorganic composite UV filter microcapsules. We used sodium alginate as a shell material of the microcapsule to encapsulate UV filters. $CaCO_3$ and tetraethyl orthosilicate (TEOS) were used as cross-linking agents, and sorbitan monooleate (Span 80) and polyoxyethylenesorbitan monooleate (Tween 80) were used as emulsifiers in the interfacial polymerization method for preparation. The results indicated that the microcapsules with 3 g of $CaCO_3$ cross-linking agents had a similar particle size and better entrapment efficiency. The average sizes were $61.0 \pm 4.9\,\mu$m and $48.6 \pm 4.7\,\mu$m, and entrapment efficiencies were $75.3 \pm 1.9\%$ and $74.8 \pm 1.7\%$ for octyl methoxycinnamate and butyl methoxydibenzoylmethane, respectively. Utilizing sodium alginate as a cross-linking agent is better than TEOS due to the higher calcium content. *In vitro* transdermal delivery analysis showed that the release rate became steady.

1. Introduction

Ultraviolet radiation is an important environmental risk factor that can lead to cell death, sunburn, tanning, and skin ageing [1]. There are three main types of ultraviolet radiation, namely UVA (320–400 nm), UVB (290–320 nm), and UVC (200–280 nm), and both UVA and UVB play an important role in skin cancer. Avoiding overexposure to ultraviolet radiation during the daytime is very important in skin protection. UV filters [2–4], currently used for skin protection against UV, are used to absorb specific wavelengths of ultraviolet radiation. There are two general types of UV filters, namely, inorganic UV filters and organic ones. These compounds can either be physical blockers or chemical absorbers, based on their mechanism of action. Inorganic UV filters, such as titanium dioxide and zinc oxide, protect human skin from UV radiation by deflecting or blocking [3]. However, the ability of inorganic UV filters to reflect UV lights may be affected by the used concentration of cosmetic products, which also influence the formulation's properties, such as uniformity, stability, and impressibility. Organic UV filters absorb UV radiation, and the molecules transfer from the ground state to the higher energy excited state [3, 5]. However, the excited molecules return to the ground state by different mechanisms. Under ultraviolet irradiation, organic UV filters may generate thermal instability, causing photoallergy and phototoxicity reactions [2, 6, 7]. Therefore, if we combine the organic UV filter into a solid inorganic one, the outside inorganic UV filter can reflect UV radiations directly, and the inner or released organic UV filter can also absorb UV lights and then convert them into harmless energy. Besides, the inorganic UV filter may protect organic ones when they are integrated. Moreover, the control release of the organic UV filter from the particles may provide a longer and safer protection for skin. As a result, the application of UV filters in cosmetics is

becoming more effective and safer via microencapsulation into organic/inorganic composite UV filters.

Octyl methoxycinnamate is currently the most widely used UVB absorber in UV filters with good absorbing properties [8, 9]. It is an organic compound formed from methoxycinnamic acid and 2-ethylhexanol. When mixing together, they form a clear liquid that does not dissolve in water. Octyl methoxycinnamate is 290 g·mol^{-1}; however, it is susceptible to light and becomes photoallergy or phototoxic when exposed to ultraviolet radiation. Several studies have shown that octyl methoxycinnamate possesses estrogenic activity, which might cause a hormone effect (such as reproductive impairments and female and male cancers) [10–13]. In the studies, 500, 750, and 1000 mg/kg of octyl methoxycinnamate were applied on pregnant Wistar rats; it was discovered that there is a weight reduction of testicles with a higher dose [13]. Therefore, this chemical should be used with caution in pregnant women and children (maximum use limits of 10%).

Butyl methoxydibenzoylmethane [14–16] is a commonly used UVA-1 filter (340–400 nm) among UV filters. It is a slightly yellowish oil-soluble chemical agent. Butyl methoxydibenzoylmethane is 310 g·mol^{-1}; however, several studies have confirmed that butyl methoxydibenzoylmethane has low photostability and easily degrades with ultraviolet radiation [10–12]. It interacts with other UV filters, decreasing the effectiveness of sunscreen [2, 17, 18]. Crystallization of complexes has often been associated with butyl methoxydibenzoylmethane due to heavy metal, iron, zinc, aluminium, magnesium salts, stearic acid, and formaldehyde derivatives [19]. Therefore, the stability of butyl methoxydibenzoylmethane depends on the formulation and the presence of other UV filters. A maximum use limit of 5% is recommended.

Microencapsulation technology has been widely used in chemical, cosmetic, pharmaceutical, and other related industries [20–22]. Microcapsules are mainly used as a natural or synthetic polymer; the shell material and drugs are encapsulated as a core material. Microcapsule size ranged from 1 to 1000 μm. The oxidation, temperature, UV radiation, and environmental conditions will strongly affect the stability of drugs. Therefore, the encapsulation technique can protect the drug and also control its release rate. Among the microencapsulation methods, the sol-gel emulsion method is the convenient technique that utilizes the emulsion droplets as templates to prepare the nanoparticles through polymerization, hydrolyzation, or cross-linking reactions [23]. The sol-gel method can control the materials and form the shell at the interface of the emulsion. Therefore, this method is suitable for the development of functional compound encapsulation in pharmaceutical and cosmetic industries [24, 25]. Sodium alginate is a polysaccharide carbohydrate extract from natural seaweed. It is a linear hydrophilic polymer compound consisting of β-D-mannuronic acid and α-L-guluronic acid [26]. Sodium alginate has been one of the most popular biomaterials because of its convenient accessibility, nontoxicity, excellent biocompatibility, and biodegradability [27, 28]. Tetraethyl orthosilicate is the chemical compound with the formula $Si(OC_2H_5)_4$; it is mainly used as a cross-linking agent in silicone polymers and is more stable in the air [29, 30]. In the experiment, the addition of acid makes it hydrolyze quickly.

This research aims at preparing organic/inorganic composite ultraviolet filter microcapsules; the sodium alginate was used as a shell material to encapsulate octyl methoxycinnamate and butyl methoxydibenzoylmethane by using the sol-gel method. The organic UV filters were encapsulated in microcapsules not only to avoid photodegradation and phototoxicity phenomenon, but also to avoid direct contact with the skin and reduce the chance of allergies. This study focused on the effects of preparation parameters on the properties of microcapsules containing UV filters; the properties of interest were the size distribution, entrapment efficiency, and *in vitro* release profile.

2. Materials and Methods

2.1. Materials. Sodium alginate was purchased from HAYASHI PURE CHEMICAL (Japan). Octyl methoxycinnamate (Parsol MCX) and butyl methoxydibenzoylmethane (Parsol 1789) were supplied by DSM (Holland). Acetic acid was obtained from UNION CHEMICAL (Japan). Sorbitan oleate (Span 80) and polysorbate 80 (Tween 80) were purchased from Croda (England). Mineral oil was provided by PROPAGATE (Taiwan). Calcium carbonate ($CaCO_3$) was obtained from Merck (Germany). Tetraethyl orthosilicate (TEOS) was purchased from SHOWA (Japan). Caprylic capric triglyceride and propylene glycol (PG) were supplied by Evonik (Germany). Methanol was purchased from Aencore (USA). Ethanol was provided by Echo Chemical (Taiwan). The Tegaderm™ artificial skin membrane (90022TCP) was purchased from 3M Company.

2.2. Preparation of Microcapsules by the Sol-Gel Method. For the preparation of microcapsules, 3 g of Span 80, 2 g of Tween 80, and 17.6 g of mineral oil were all warmed to 50°C in a water bath, and then 10 g of each UV filter was added to the mixtures, as oil phase. The cross-linking agents with 3 g were dissolved in 64.4 g of 1.5% sodium alginate as the aqueous phase, then the oil phase was gently added to the aqueous phase, and after that the mixture was shaken and stirred at 7000 rpm for 30 min for emulsification. Subsequently, the prepared o/w emulsion was mixed with caprylic capric triglyceride at 1 : 1 (v/v) and stirred at 1000 rpm at 4°C for 10 min. Finally, 6 g of 10% acetic acid was added dropwise and stirred for 5 min to complete the cross-linking reaction, and then washed and filtered to obtain microcapsules with ethanol. The compositions of microcapsules are presented in Table 1.

2.3. Characterization of Microcapsules. Optical microscope images of the microcapsules were obtained with an optical microscope (OLYMPUS, Taiwan). First, the microcapsules were dispersed in propylene glycol of 50 ml. Each sample was measured 10 times. The proportion of the cross-linking agent was observed using an optical microscope (magnification 4×) in order to investigate the effect on the particle size of the obtained microcapsules.

Table 1: Compositions of octyl methoxycinnamate microcapsules and butyl methoxydibenzoylmethane microcapsules.

Sample no.	Cross-linking agent		UV filters	
	$CaCO_3$ (g)	TEOS (g)	Parsol MCX (g)	Parsol 1789 (g)
1	3		10	
2	2	1	10	
3	1	2	10	
4	3			10
5	2	1		10
6	1	2		10

2.4. Field Emission Scanning Electron Microscopy Analysis. The surface morphology of prepared microcapsules was analyzed using ultra-high-resolution field emission scanning electron microscopy (FE-SEM, JEOL, Japan) at a voltage of 2.5 kV and at a working distance of 8 or 15 mm. Prior to the experiment, the resulting powder samples were coated with carbon adhesive. The samples were analyzed after gold sputtering for 30 sec.

2.5. Encapsulation Efficiency, Drug Loading Content, and Yield of Production. The filtered liquid was diluted with ethanol; the supernatant was analyzed using HPLC (Agilent Technologies 1200 series, AGILENT, America). The mobile phase was composed of methanol: water = 80: 20 (v/v), a reverse phase C18 column (Kinetex 5u EVO C18 100A 250 × 4.6 mm, Phenomenex, USA), and the flow rate was 1 mL/min; injection volume was 20 μl. Octyl methoxycinnamate was detected at a wavelength of 310 nm, whereas butyl methoxydibenzoylmethane was detected at a wavelength of 358 nm. Calibration curves of octyl methoxycinnamate and butyl methoxydibenzoylmethane were 5–200 ppm ($y = 136.2x + 256.74$, $R^2 = 0.9981$) and 5–100 ppm ($y = 118.42x - 34.054.74$, $R^2 = 0.996$), respectively. The drug entrapment efficiency (EE %), drug loading content (DLC %), and yield of production (YP %) are presented in the following equations, respectively [31]:

$$EE\% = \frac{\text{actual amount drugs encapsulated in microcapsules}}{\text{initial amount of drugs used}} \times 100\%,$$

$$DL\ C\% = \frac{\text{weight of drugs in microcapsules}}{\text{weight of microcapsules}} \times 100\%, \quad (1)$$

$$YP\% = \frac{\text{weight of microcapsules recovered}}{\text{weight of polymer and drugs fed initially}} \times 100\%.$$

\

2.6. In Vitro Transdermal Delivery Analysis. Transdermal drug delivery has been widely used in the human body to absorb *in vitro* release. This research used FDC-6 Transdermal Diffusion Cell Drive System (USA) to observe *in vitro* transdermal delivery analysis. The 3 M Tegaderm artificial skin membranes were used to simulate the stratum corneum side of human skin in this study. To prepare the sample emulsion, 2.5 g of microcapsules was dissolved in 46.5 g of water with 1 g of Lecigel™. First, in the upper donor cell, 1.0 ml of sample was placed. Second, 30% ethanol in phosphate buffer solution (a proper condition for the penetration of most hydrophilic and hydrophobic compounds) was placed in the lower receptor cell (5 ml with 0.785 cm^2 diffusion area) and bubbles were removed in the lower receptor cell. The receptor cell was stirred with a magnetic stirrer to maintain the temperature at 36.7 ± 0.3°C. Finally, the concentration distribution was balanced in the receptor cell. Each experiment used five Franz-type diffusion cells simultaneously measured at 0.5, 1, 2, 4, and 6 h. The samples were withdrawn in the receptor cell and were filtered. The amounts of drugs released from the microcapsules were evaluated using high-performance liquid chromatography (HPLC). The 20 μl sample was injected into the HPLC with a C18 reversed-phase column. The mobile phase was composed of methanol and water (80 : 20, v/v), and the flow rate was 1 ml/min.

2.7. Statistical Study. The data from experiments were analyzed using Student's *t*-tests. All results are displayed as means ± S.E. from three independent experiments.

3. Results and Discussion

3.1. Size and Morphology. As shown in Table 2, Samples 1, 2, and 3 are the size of microcapsules encapsulated octyl methoxycinnamate, whereas Samples 4, 5, and 6 are the size of microcapsules encapsulated butyl methoxydibenzoylmethane. According to the results, the effects on the particle size of microcapsules at different cross-linking agents were observed. Samples 1 and 4 were characterized by the lowest diameters, 61.0 ± 4.9 μm and 48.6 ± 4.7 μm. They used a higher calcium carbonate content without tetraethyl

Table 2: Mean diameter (μm) of prepared microcapsules with different cross-linking agents.

Sample	Size (μm)
1	61.0 ± 4.9
2	65.3 ± 9.2
3	65.7 ± 5.1
4	48.6 ± 4.7
5	67.0 ± 4.4
6	—

orthosilicate. The average size of the microcapsules decreased slightly as the Ca^{2+} concentration increased. This may be due to the higher Ca^{2+} concentration that caused a lower swelling of the microcapsules during the post-cross-linking process [32]. Varying the tetraethyl orthosilicate concentration appears to have little effect on particle size in Samples 2, 3, and 5; the average sizes were $65.3 \pm 9.2\,\mu$m, $65.7 \pm 4.4\,\mu$m, and $67.0 \pm 4.7\,\mu$m, respectively. Sample 6 was unable to measure the correct particle size due to its shape, which was not close to spherical.

Figure 1 presents optical micrograph observations of prepared microcapsules with different cross-linking agents. The microcapsule-encapsulated UV filters [Figures 1(a)–1(e)) were nearly spherical in shape. The amount of microcapsules with 3 g of $CaCO_3$ cross-linking agents was more than the microcapsules with TEOS. From the microscopic analysis after adding TEOS, there is a good dispersion due to the TEOS hydrophobic structure.

3.2. Surface Morphology. The morphology of the microcapsules with 3 g of $CaCO_3$ cross-linking agents was observed from the SEM images, as shown in Figure 2. The control did not encapsulate the UV filters (Figure 2(a)). The control (Figure 2(a)) was nearly spherical in shape and similar to the drug microcapsules (Figures 2(b) and 2(c)). This indicates that the encapsulated UV filters did not affect the shape and the matrix morphology of microcapsules with 3 g of $CaCO_3$ cross-linking agents. Moreover, the drug microcapsule surfaces (Figures 2(b) and 2(c)) were slightly denser than the control (Figure 2(a)). For the UV filter microcapsules, the microcapsules encapsulated butyl methoxydibenzoylmethane have a slightly rough surface, and the microcapsules encapsulated octyl methoxycinnamate have a smooth one.

3.3. Encapsulation Efficiency, Drug Loading Content, and Yield of Production. As shown in Table 3, the result showed that the best encapsulation efficiency is found using 3 g $CaCO_3$ as cross-linking agents, which were $75.3 \pm 1.9\%$ and $74.8 \pm 1.7\%$ (Table 3 (Samples 1 and 4)), respectively. Sodium alginate has better cross-linking due to the high calcium content [32]. The microcapsules of the structure were denser, making it easy to encapsulate more UV filters. This suggests that the preparation of organic microcapsules had a high efficiency for the encapsulation of UV filters. As observed in previous study, due to the increase in the Ca^{2+} concentration, the encapsulation efficiency could be improved [32]. The drug loading content and production yield illustrated 3 g of $CaCO_3$ as cross-linking agents with a better result than others. The drug loading content ranged from 92 to 94%, and the yield of production ranged from 73 to 74%. This may enable UV filters to adsorb on the surface and create a different particle size. Therefore, adding TEOS had lower entrapment efficiency.

3.4. In Vitro Transdermal Delivery Analysis. The effect of different cross-linking agents on microcapsules for controlled release was analyzed by an *in vitro* transdermal delivery analysis. The release behaviour of UV filters from microcapsules under the simulated human skin conditions was studied in different time intervals. The *in vitro* drug release profiles are presented in Figures 3 and 4.

As shown in Figure 3, it can be seen that the control showed the highest release amount, with $5.03\,\mu g/cm^2$ of octyl methoxycinnamate released within 6 h. After, the release rate became steady. On the other hand, the extent of octyl methoxycinnamate released at 0.5 h or the drug microcapsules (Figure 3 (Samples 1, 2, and 3)) was lower than $1\,\mu g/cm^2$. Subsequently, the release rate gradually decreased as time passed. The cumulative amount released was $2.13\,\mu g/cm^2$ within 6 h for Sample 1. Regarding Samples 2 and 3, a nearly approximated release profile was obtained within 6 h. The accumulative amount of Samples 2 and 3 were $3.25\,\mu g/cm^2$ and $3.48\,\mu g/cm^2$, respectively. Significantly, Sample 1 had the lowest cumulative release for octyl methoxycinnamate microcapsules. Therefore, the microcapsules used 3 g of $CaCO_3$ as cross-linking agents to load; octyl methoxycinnamate reduced the percutaneous absorption of UV filters.

Figure 4 presents the release profile of butyl methoxydibenzoylmethane microcapsules. The result showed that the release amount of the control was $5.13\,\mu g/cm^2$ at 0.5 h. After 6 h, the release amount for the control increases to $13.70\,\mu g/cm^2$. Conversely, the butyl methoxydibenzoylmethane in the microcapsules leads to a significant decrease in the release amount of UV filters. At 0.5 h, the release amount of microcapsules (Figure 4 (Samples 4, 5, and 6)) with UV filters was about $1.50\,\mu g/cm^2$. After 6 h, Sample 4 slowed down the diffusion rate, with only $5.60\,\mu g/cm^2$. Sample 5 and Sample 6 showed the cumulative amount released as $7.80\,\mu g/cm^2$ and $8.23\,\mu g/cm^2$ within 6 h, respectively. Thus, in Figure 4, the microcapsules with 3 g of $CaCO_3$ cross-linking agents decreased the release amount.

Several studies have demonstrated that the encapsulation of functional compounds or sunscreens can minimize the instability and skin contact, which may reduce the adverse effects of unencapsulated compounds on biological systems [33–35]. Especially for organic UV filters, the compounds are usually decomposed by the UV radiation when they are applied on human skin. The generated molecules may have opportunity to induce other side effects, such as cytotoxicity or some harmful immune response [36]. Therefore, the use of microcapsules to protect the UV filters may not only improve their stability and also decrease the negative effects.

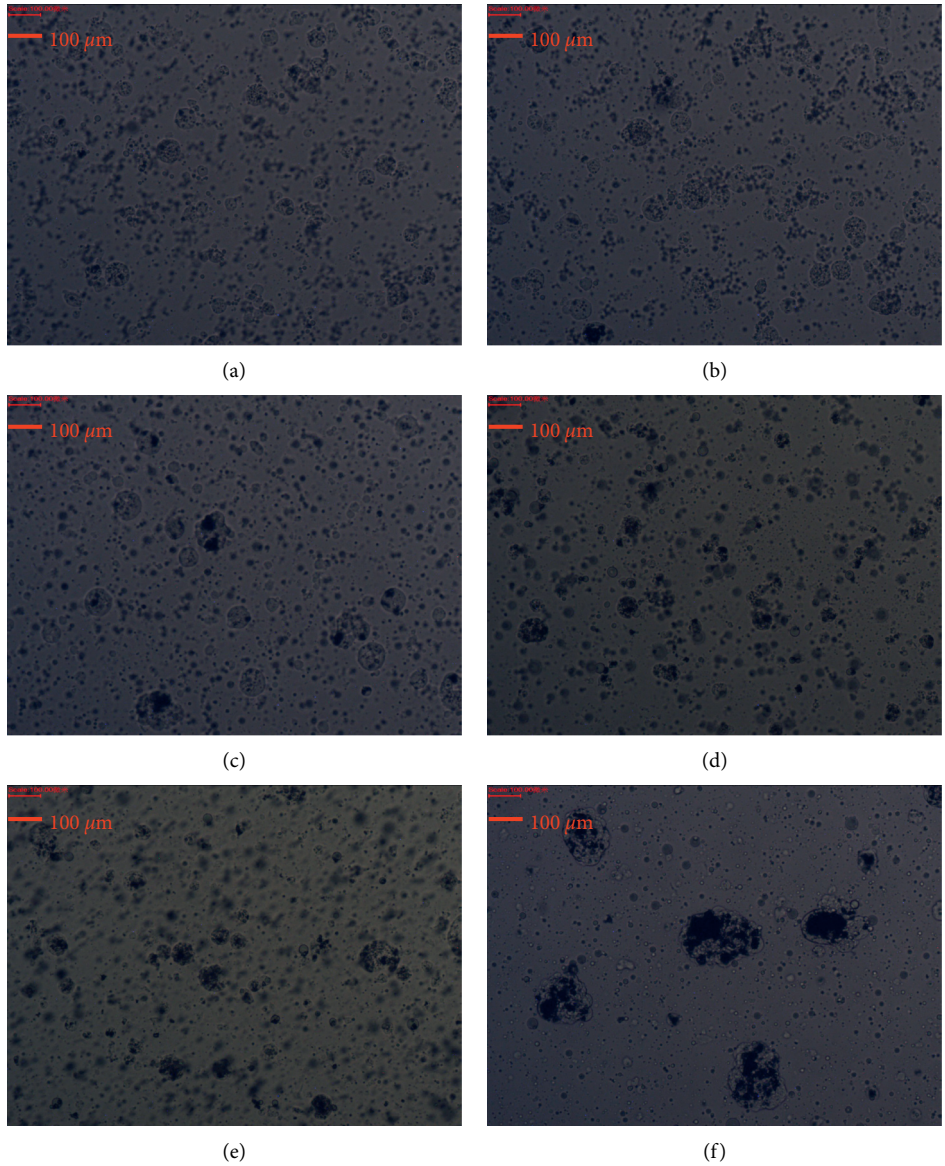
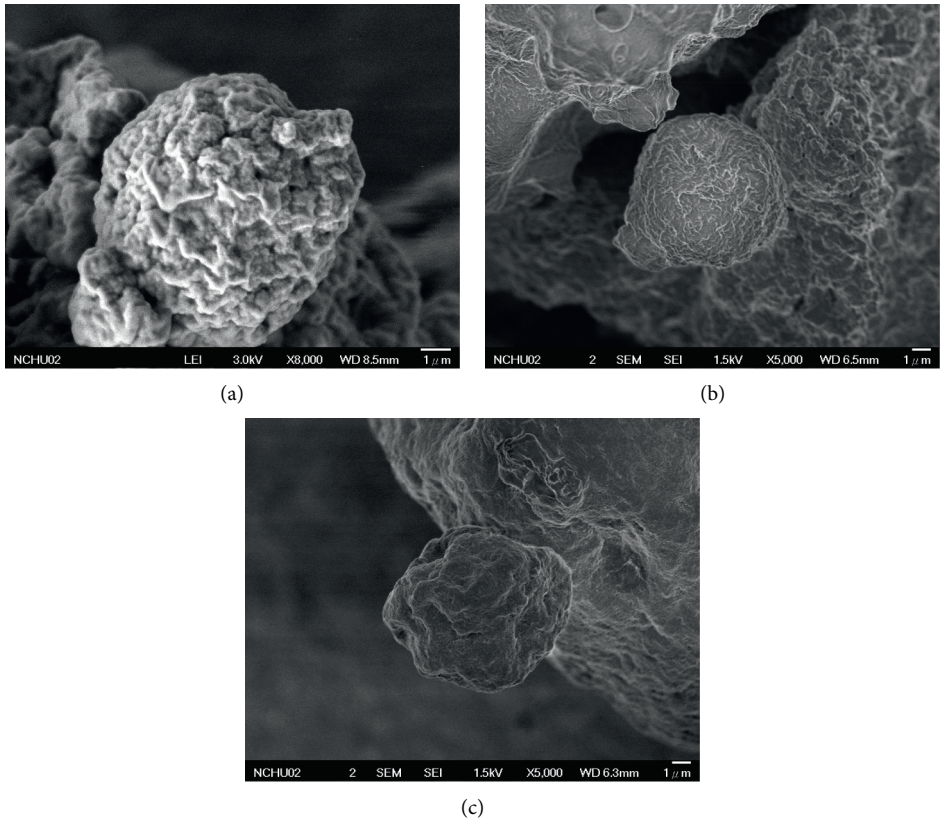


Figure 1: Optical micrograph of (a) Sample 1, (b) Sample 2, (c) Sample 3, (d) Sample 4, (e) Sample 5, and (f) Sample 6. The scale bar: 100 μm.

In the experiments, UV filters were adsorbed on the surface because of the TEOS hydrophobic structure. The percutaneous absorption led to an increase in the release amount. However, the drug release for octyl methoxycinnamate and butyl methoxydibenzoylmethane decreases significantly. This implies that butyl methoxydibenzoylmethane is more permeable to the skin than octyl methoxycinnamate due to its physicochemical characteristics. This is attributed to the improved solubility of butyl methoxydibenzoylmethane, which improves the amount of UV filters released [37]. The results described in the present study indicated that 3 g $CaCO_3$ cross-linking agents demonstrated the best result, which can control release and decrease the percutaneous absorption of UV filters.

In summary, octyl methoxycinnamate and butyl methoxydibenzoylmethane were successfully encapsulated using sol-gel technique into microcapsules, and the illustration of the composite UV filters microcapsules is shown in Figure 5. The optimum cross-linking agents were 3 g of $CaCO_3$, which produce the lowest diameter and the best encapsulation efficiency. The octyl methoxycinnamate microcapsules with 3 g $CaCO_3$ cross-linking agents produced 61.0 ± 4.9 μm of particle size and 75.3 ± 1.9% of encapsulation efficiency. The butyl methoxydibenzoylmethane microcapsules with 3 g $CaCO_3$ cross-linking agents produced 48.6 ± 4.7 μm of particle size and 74.8 ± 1.7% of encapsulation efficiency. Furthermore, drug release profiles could be controlled since the UV filters are encapsulated in the microcapsules. *In vitro* transdermal delivery analysis showed that the microcapsules with 3 g of $CaCO_3$ cross-linking agents significantly reduced the percutaneous absorption of UV filters. We found that the microcapsules of octyl methoxycinnamate were decreased to 57.7% and the microcapsules of butyl methoxydibenzoylmethane were



(a) (b)

(c)

Figure 2: SEM images of (a) control, (b) Sample 1, and (c) Sample 4.

Table 3: Encapsulation efficiencies (EEs), drug loading content (DLC), and yields of production (YPs) of prepared microcapsules.

Sample	EE %	DLC %	YP %
1	75.3 ± 1.9	94.6 ± 13.8	73.6 ± 9.4
2	71.8 ± 1.5	89.2 ± 9.9	74.1 ± 9.5
3	70.7 ± 1.3	95.6 ± 20.6	69.4 ± 14.0
4	74.8 ± 1.7	92.3 ± 12.1	74.8 ± 10.8
5	64.6 ± 1.6	81.8 ± 7.1	72.5 ± 8.3
6	71.6 ± 2.1	80.7 ± 3.7	80.9 ± 2.7

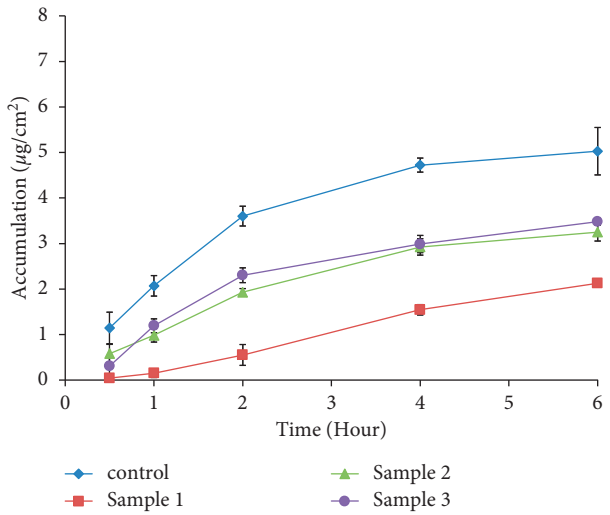


Figure 3: *In vitro* release profiles of octyl methoxycinnamate microcapsules.

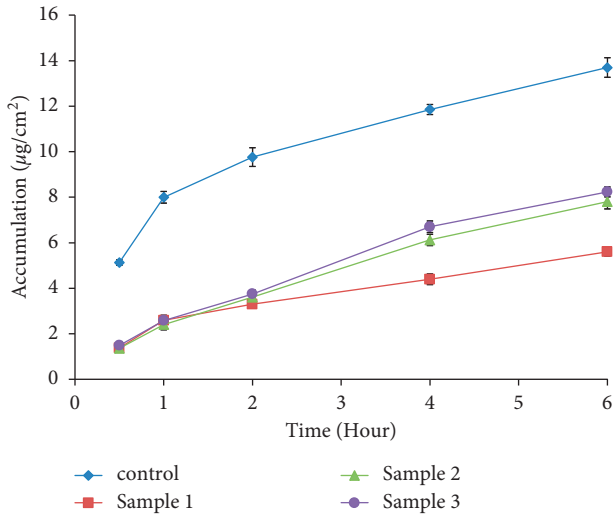


Figure 4: *In vitro* release profiles of butyl methoxydibenzoylmethane microcapsules.

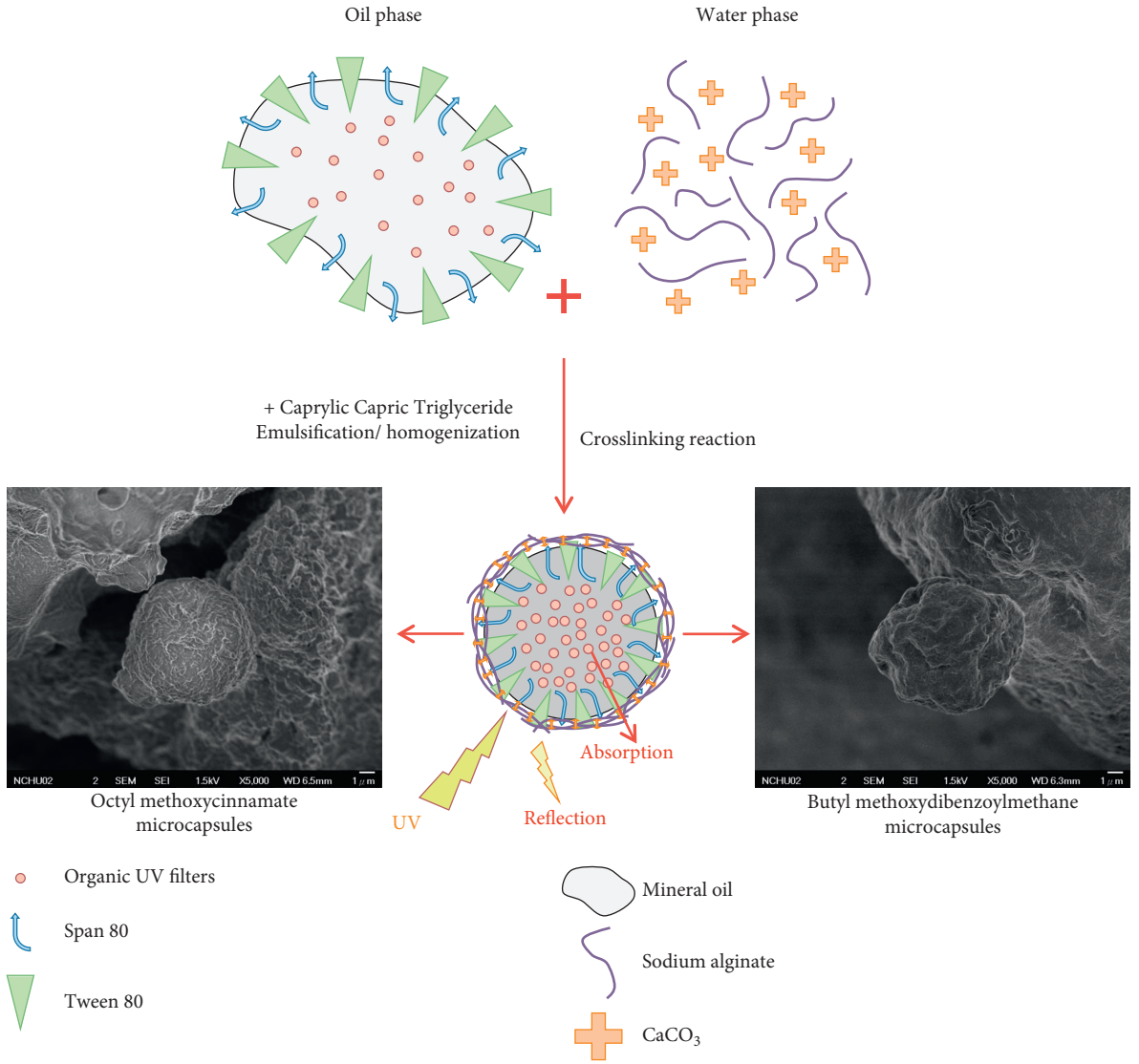


Figure 5: Illustration of the composite UV filter microcapsules in this study.

decreased to 59.1% within 6 h. In the study, 3 g of $CaCO_3$ used as a cross-linking agent emerged as other formulations for further development due to the better encapsulation capacity and the effective controlled release of UV filters for microcapsules. The benefit not only enhances the protective power of ultraviolet radiation by keeping it at the skin surface but also limits potential toxic reactions. In addition, it can reduce the chance of allergies.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This work was carried out under grants of Taiwan (ROC) (MOST 105-2622-E-126-001-CC2, MOST 105-2628-B-126-002-MY3, and MOST 109-2313-B-126-002).

References

[1] O. P. Egambaram, S. Kesavan Pillai, and S. S. Ray, "Materials science challenges in skin UV protection: a review," *Photochemistry and Photobiology*, vol. 96, no. 4, pp. 779–797, 2020.

[2] S. Afonso, K. Horita, J. P. Sousa e Silva et al., "Photodegradation of avobenzone: stabilization effect of antioxidants," *Journal of Photochemistry and Photobiology B: Biology*, vol. 140, pp. 36–40, 2014.

[3] N. Serpone, D. Dondi, and A. Albini, "Inorganic and organic UV filters: their role and efficacy in sunscreens and suncare products," *Inorganica Chimica Acta*, vol. 360, no. 3, pp. 794–802, 2007.

[4] L. R. Gaspar and P. M. B. G. M. Gaspar, "Evaluation of the photostability of different UV filter combinations in a sunscreen," *International Journal of Pharmaceutics*, vol. 307, no. 2, pp. 123–128, 2006.

[5] V. H. Sara Ramos, A. Alves, and L Santos, "Advances in analytical methods and occurrence of organic UV-filters in the environment–a review," *The Science of the Total Environment*, vol. 526, pp. 278–311, 2015.

[6] M. J. K. E. J. Kim, N. R. Im, and S. N. Park, "Photolysis of the organic UV filter, avobenzone, combined with octyl methoxycinnamate by nano-TiO2 composites," *Journal of Photochemistry and Photobiology B: Biology*, vol. 149, pp. 196–203, 2015.

[7] J. V. Freitas, N. P. Lopes, and L. R. Gaspar, "Photostability evaluation of five UV-filters, trans-resveratrol and beta-carotene in sunscreens," *European Journal of Pharmaceutical Sciences*, vol. 78, pp. 79–89, 2015.

[8] Y. W. Chen-Yang, Y. T. Chen, C. C. Li et al., "Preparation of UV-filter encapsulated mesoporous silica with high sunscreen ability," *Materials Letters*, vol. 65, no. 6, pp. 1060–1062, 2011.

[9] F. B. Carmelo Puglia, L. Rizza, P. Blasi et al., "Lipid nanoparticles as carrier for octyl-methoxycinnamate: in vitro percutaneous absorption and photostability studies," *Journal of Pharmaceutical Sciences*, vol. 101, no. 1, pp. 301–311, 2012.

[10] C. S. Holger Klammer, W. Wuttke, and H. Jarry, "Multi-organic risk assessment of estrogenic properties of octyl-methoxycinnamatein vivo: a 5-day sub-acute pharmacodynamic study with ovariectomized rats," *Toxicology*, vol. 215, no. 1–2, pp. 90–96, 2005.

[11] H. J. Margret Schlumpf, W. Wuttke, R. Ma, and L. Walter, "Estrogenic activity and estrogen receptor β binding of the UV filter 3-benzylidene camphor: comparison with 4-methyl-benzylidene camphor," *Toxicology*, vol. 199, no. 2–3, pp. 109–120, 2004.

[12] P. S. Margret Schlumpf, S. Durrer, M. Conscience et al., "Endocrine activity and developmental toxicity of cosmetic UV filters—an update," *Toxicology*, vol. 205, no. 1–2, pp. 113–122, 2004.

[13] S. Wissing and R. Müller, "The development of an improved carrier system for sunscreen formulations based on crystalline lipid nanoparticles," *International Journal of Pharmaceutics*, vol. 242, no. 1–2, pp. 373–375, 2002.

[14] S. S. S. Simeoni and H. A. E. Benson, "Influence of cyclodextrins on in vitro human skin absorption of the sunscreen, butyl-methoxydibenzoylmethane," *International Journal of Pharmaceutics*, vol. 280, no. 1–2, pp. 163–171, 2004.

[15] N. S. Valentina Iannuccelli, R. Tursilli, G. Coppi, and S. Scalia, "Influence of liposphere preparation on butyl-methoxydibenzoylmethane photostability," *European Journal of Pharmaceutics and Biopharmaceutics*, vol. 63, no. 2, pp. 140–145, 2020.

[16] M. Abou-Dahech, A. Schaefer, L. Lam-Phaure, A. N. Huynh, M. Chandler, and G. Baki, "Effect of solvents on the in vitro sun protection factor and broad-spectrum protection of three organic UV filters," *Journal of Cosmetic Science*, vol. 71, no. 3, pp. 149–165, 2020.

[17] G. C. Santo Scalia and V. Iannuccelli, "Microencapsulation of a cyclodextrin complex of the UV filter, butyl methoxydibenzoylmethane: in vivo skin penetration studies," *Journal of Pharmaceutical and Biomedical Analysis*, vol. 54, no. 2, pp. 345–350, 2011.

[18] C. Areias de Oliveira, C. M. Rugno, M. Kojima et al., "Functional photostability and cutaneous compatibility of bioactive UVA sun care products," *Journal of Photochemistry and Photobiology B: Biology*, vol. 148, pp. 154–159, 2015.

[19] B. G. Eric Chatelain, "Photostabilization of butyl methoxydibenzoylmethane (avobenzone) and ethylhexyl methoxycinnamate by bis-ethylhexyloxyphenol methox yphenyl triazine (tinosorb S), a new UV broadband filter," *Photochemistry and Photobiology*, vol. 74, pp. 401–406, 2001.

[20] G. B. Sukhorukov and Q. Yi, "UV light stimulated encapsulation and release by polyelectrolyte microcapsules," *Advances in Colloid and Interface Science*, vol. 207, pp. 280–289, 2014.

[21] M. D. Araújo Etchepare, E. M. D. Flores, L. Q. Zepka et al., "Effect of resistant starch and chitosan on survival of Lactobacillus acidophilus microencapsulated with sodium alginate," *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology*, vol. 65, pp. 511–517, 2016.

[22] E. M. Velez-Erazo, I. L. Silva, T. Comunian, L. E. Kurozawa, and M. D. Hubinger, "Effect of chia oil and pea protein content on stability of emulsions obtained by ultrasound and powder production by spray drying," *Journal of Food Science & Technology*, vol. 58, no. 10, pp. 3765–3779, 2020.

[23] E. Sgreccia, R. Narducci, P. Knauth, and M. L. Di Vona, "Silica containing composite anion exchange membranes by sol-gel synthesis: a short review," *Polymers*, vol. 1311 pages, 2021.

[24] M. Chen, G. Bolognesi, and G. T. Vladisavljevic, "Cross-linking strategies for the microfluidic production of micro-gels," *Molecules*, vol. 2612 pages, 2021.

[25] P. S. Wu, Y. C. Lee, Y. C. Kuo, and C. C. Lin, "Development of octyl methoxy cinnamates (OMC)/Silicon dioxide (SiO(2)) nanoparticles by sol-gel emulsion method," *Nanomaterials*, vol. 712 pages, 2017.

[26] F. W. Li Liu, X.-J. Ju, R. Xie, W. Wang, C. H. Niu, and L.-Y. Chu, "Preparation of monodisperse calcium alginate microcapsules via internal gelation in microfluidic-generated double emulsions," *Journal of Colloid and Interface Science*, vol. 404, pp. 85–90, 2013.

[27] M. F. Zou, X. Y. Chen, X. J. Lin et al., "Fabrication of magnetic carboxyl-functionalized attapulgite/calcium alginate beads for lead ion removal from aqueous solutions," *International Journal of Biological Macromolecules*, vol. 120, pp. 789–800, 2018, Pt A.

[28] A. Karabasz, D. Lachowicz, A. Karewicz et al., "Analysis of toxicity and anticancer activity of micelles of sodium alginate-curcumin," *International Journal of Nanomedicine*, vol. 14, pp. 7249–7262, 2019.

[29] M. C. Thongthai Witoon, "Interaction of chitosan with tetraethyl orthosilicate on the formation of silica nanoparticles: effect of pH and chitosan concentration," *Ceramics International*, vol. 38, no. 7, pp. 5999–6007, 2012.

[30] N. P. Tran and M. C. Yang, "The ophthalmic performance of hydrogel contact lenses loaded with silicone nanoparticles," *Polymers*, vol. 125 pages, 2020.

[31] A. M. R. Vanna Sanna, N. Pala, S. Marceddu, G. Lubinu, A. Mariani, and M. Sechi, "Effect of chitosan concentration on PLGA microcapsules for controlled release and stability of resveratrol," *International Journal of Biological Macromolecules*, vol. 72, pp. 531–536, 2015.

[32] Y. S. Yodthong Baimark, "Preparation of alginate microspheres by water-in-oil emulsion method for drug delivery: effect of Ca2+ post-cross-linking," *Advanced Powder Technology*, vol. 25, no. 5, pp. 1541–1546, 2014.

[33] S. R. Castro, L. N. M. Ribeiro, M. C. Breitkreitz et al., "A pre-formulation study of tetracaine loaded in optimized nanostructured lipid carriers," *Scientific Reports*, vol. 11, no. 1, Article ID 21463, 2021.

[34] R. Pavelkova, P. Matouskova, J. Hoova, J. Porizka, and I. Marova, "Preparation and characterisation of organic UV filters based on combined PHB/liposomes with natural phenolic compounds," *Journal of Biotechnology*, vol. 324S, Article ID 100021, 2020.

[35] M. N. Chretien, L. Migahed, and J. C. Scaiano, "Protecting the protectors: reducing the biological toxicity of UV sunscreens by zeolite encapsulation," *Photochemistry and Photobiology*, vol. 82, no. 6, pp. 1606–1611, 2006.

[36] L. Xiong, J. Tang, Y. Li, and L. Li, "Phototoxic risk assessment on benzophenone UV filters: in vitro assessment and a theoretical model," *Toxicology in Vitro*, vol. 60, pp. 180–186, 2019.

[37] E. D. Carmelo Puglia, A. Offerta, L. Rizza et al., "Evaluation of nanostructured lipid carriers (NLC) and nanoemulsions as carriers for UV-filters: characterization, in vitro penetration and photostability studies," *European Journal of Pharmaceutical Sciences*, vol. 51, pp. 211–217, 2014.