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1. Introduction

Titanium dioxide (TiO_2) materials are common ingredients used in cosmetic sunscreens to provide protection to the skin from the damage of ultraviolet radiation that can cause photoaging or wrinkles. It has been reported that TiO_2 nanomaterials have eliminated the problem of the natural whiteness of traditional sunscreens, and enhanced the characteristics of greater transparency, less viscosity, and easy-spreading on the skin.^{1,2} Moreover, both anatase and rutile phases of TiO_2 nanomaterials display different photocatalytic abilities under specific conditions and have been used as photocatalysts for the destruction of environmental pollutants.³⁻¹¹ When nanoscale TiO_2 is exposed to UV-irradiation in the presence of living cells, the

Carboxyfullerene decorated titanium dioxide nanomaterials for reactive oxygen species scavenging activities[†]

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Titanium dioxide nanomaterials offer superior protection for human skin against ultraviolet light. However, some reports have indicated that they might be associated with adverse effects such as cytotoxicity or reactive oxygen species (ROS) under UV-irradiation due to their nanoscale size. The surfaces of fullerenes are covered with π electrons, constituting aromatic structures, which can effectively scavenge large amounts of radicals. Unfortunately, their poor solubility in water, severe aggregation, and toxicity in biological applications when dispersed in solvent have imposed limitations on the use of fullerenes. Herein, we used carboxyfullerene as a radical scavenger to improve poor solubility. The modified materials were prepared through the esterification of C₇₀-COOH with TNR (TNR/C₇₀-COOH) and P25 (P25/C₇₀-COOH). The structures and the properties were analyzed by using X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and high-resolution transmission electron microscopy (HRTEM). In order to investigate the scavenging radical abilities of TiO₂ composites, pyridoxine (Vit. B6), nitroblue tetrazolium (NBT) and terephthalic acid (TA) were chosen to react with singlet oxygen, superoxide ions and hydroxyl radicals, respectively. The results show that both types of TiO₂ composites could reduce the ROS in the environment and exhibit great potential in anti-oxidative and anti-inflammation applications.

significant photocatalytic activity of TiO₂ generates extremely high reactive oxygen species (ROS) to damage the normal cells and induce apoptosis. It has been found that reactive oxygen species, such as superoxide ions (O_2 .⁻⁻), hydroxyl radicals (OH.) and singlet oxygen (¹O₂), have created serious disorders, including DNA damage due to oxidized nucleotide and strand breakage, lipid peroxidation in membranes and oxidation of amino acids.¹²⁻¹⁴

Fullerene and its derivatives, such as fullerenol and carboxyfullerene, have been studied to gain information about their chemical and physical characteristics, including their avid reactivity with free radicals.^{15,16} In recent years, some reports have indicated that carboxyfullerenes have been found to protect cells from oxidative stress or free radical damage by scavenging free radicals, due to the π electrons constituting their aromatic structures. Furthermore, the carboxyl groups can also improve the solubility of general fullerenes, which undergo severe aggregation when dissolved in water.17,18 Shinya Kato et al. previously reported the defensive effects of carboxyfullerene-C70 against UV-irradiation in vitro, and its evaluation for human keratinocytes.19 However, current knowledge is still restricted on specific aspects of the capability of the carboxyfullerenes to scavenge ROS generated from TiO₂ nanomaterials under UV-irradiation.

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In the present study, the surfaces of titanium dioxide nanorods (TNR) and nanoparticles (P25) are decorated with fullerene-C₇₀-carboxylic acid (C₇₀-COOH), for the purpose of scavenging ROS during UV irradiation. The modified materials were prepared through the esterification of C70-COOH with TNR (TNR/C70-COOH) and P25 (P25/C70-COOH). In order to investigate the scavenging radical abilities of TiO₂ composite powders, pyridoxine (Vit. B6), terephthalic acid (TA) and nitro blue tetrazolium (NBT) were chosen to react with singlet oxygen, hydroxyl radicals and superoxide ions, respectively. The results show that both kinds of composite powders exhibit apparent ROS scavenging abilities, but there are few effects of TNR/C70-COOH for scavenging hydroxyl radicals. TiO₂/C₇₀-COOH is expected to be a functional UV-attenuating agent for cosmetic application in sunscreens, and has great potential for antioxidative and anti-inflammation applications.

2. Experimental section

2.1 Materials

All of the materials were analytical reagents, and were used without further purification. Degussa P25 (purity > 99%), titanium(IV) chloride ((TiCl₄), purity > 98%), citric acid (purity > 99%), hydrogen chloride (purity > 99.5%), sulfuric acid (purity > 99.5%), 2-propanol (purity > 99.5%), dimethyl sulfoxide (DMSO) (purity > 99.5%), terephthalic acid (purity > 98%), pyridoxine hydrochloride (purity > 98%) and nitroblue tetrazolium (purity > 98%), were all purchased from Sigma Chemical Co. 3'H-Cyclopropa^{8,25}[5,6]fullerene-C₇₀-3'-carboxylic acid (carboxy-fullerene) was purchased from Luminescence Technology Corp. (Taiwan, ROC).

2.2 Synthesis of TiO₂ nanorods via hydrothermal process

TiO₂ nanorods (TNR) were synthesized according to the literature procedure,²⁰ described as follows: 2 mL of titanium trichloride were dissolved in a beaker containing 20 mL of hydrogen chloride, 20 mL of DI water and 1 mg of citric acid under vigorous stirring at 450 rpm at room temperature. The reaction was continued for 8 h and then the transparent solution was transferred into a 50 mL Teflon-lined stainless steel autoclave and maintained at 180 °C in an oven for 24 h. After the solution was filtered through a 0.22 μ m PVDF membrane and washed three times with deionized water. The opaque powders were obtained by lyophilization of the sample.

2.3 Fabrication of TiO₂/C₇₀-COOH composites

The weight addition ratios of C_{70} -COOH were selected as 1%, 5% and 10 wt% in the TiO₂/C₇₀-COOH composites. The required amounts of C_{70} -COOH were sonicated in 10 mL of DI water for complete dispersion. 10 µl of sulfuric acid and TNR were then added to the solutions containing the three different weights of C_{70} -COOH, which were labeled as TC71 (C_{70} -COOH 1 wt%), TC75 (C_{70} -COOH 5 wt%) and TC710 (C_{70} -COOH 10 wt%). The mixtures were then sonicated for a few minutes and slowly stirred at 340 rpm for 2 h at 70 °C. The obtained samples were

then cooled down to room temperature and filtered through 0.22 μ m PVDF membranes to remove the free ions. Ultimately, the powders were redispersed in several milliliters of DI water and then freeze-dried for 48 h to obtain TNR/C₇₀-COOH composites. The synthesis process for P25/C₇₀-COOH was similar to TNR/C₇₀-COOH, with the addition of different TiO₂ nanomaterials. Also, the P25/C₇₀-COOH composites were labeled as P25C71 (1 wt%), P25C75 (5 wt%) and P25C710 (10 wt%) by adding different amounts of C₇₀-COOH to P25. The ratios of TiO₂ and C₇₀-COOH for the samples are shown in Table 1.

2.4 Characterization

The crystal structures of the TiO2 were studied by X-ray diffraction with Cu K α radiation at a scan rate (2 θ) of 0.05° S⁻¹ (XRD, Philips X'Pert/MPD). Chemical composition was determined by Fourier transform infrared spectroscopy (FTIR, SYSTEM-2000) using conventional KBr pellets. The morphologies, microstructures and properties of the TiO2 and TiO2/C70-COOH composite powders were investigated by using scanning electron microscopy (SEM, JEOL-6330 Field-Emission) in conjunction with energy dispersive spectroscopy analysis (EDS) and high resolution transmission electron microscopy (TEM, JEOL 3010 AEM) operating at 200 kV. The selected area electron diffraction (SAED) examination was conducted on the composite samples. UV absorption characteristics were determined by a UV-VIS spectrometer (Beckman coulter®, DU®730). Fluorescence emissions were measured with a fluorescence spectrophotometer (Hitachi, F-4500).

2.5 ROS scavenging assay

2.5.1 Detection of singlet oxygen by using pyridoxine as indicator. Pyridoxine is one kind of Vit. B6 compound involved in considerable biological functions and plays an important role in reacting with singlet oxygen to reduce the oxidative pressure.²¹ An aqueous solution containing 0.1 mM pyridoxine was prepared and 1 mg of TiO₂ or TiO₂/C₇₀-COOH composite powder was dispersed into the solution. The suspension was stirred by magnetic stirrer over three different time intervals (1, 2 and 3 h) in a dark box under irradiation with a 4 W UV lamp of $\lambda = 365$ nm. The solution was then centrifuged for 10 minutes at 12 000 rpm and the supernatant was used for evaluating the UV

Table 1 Ratios of TiO_2 and C_{70}-COOH used for the synthesis of TiO_2/ C_{70}-COOH composites

Samples	C ₇₀ -COOH/TiO ₂ (mg mg ⁻¹)	Content		
			TiO_2	
		C ₇₀ -COOH (mg)	P25 (mg)	TNR (mg)
P25C71	0.01	0.5	49.5	0
P25C75	0.05	2.5	47.5	0
P25C710	0.10	5.0	45.0	0
TC71	0.01	0.5	0	49.5
TC75	0.05	2.5	0	47.5
TC710	0.10	5.0	0	45.0

intensity of the remaining pyridoxine. The intensity of the absorbance peak at 318 nm was measured with a UV/Vis spectrophotometer.

2.5.2 Detection of superoxide ions by using nitroblue tetrazolium as indicator. Nitroblue tetrazolium (NBT) is a widely used superoxide ion indicator for the formation of purple formazan, with the absorbance at $\lambda = 560$ nm.²² Samples were prepared by mixing 1 mg of TiO₂ or TiO₂/C₇₀-COOH composite powders with 0.13 mM NBT, 4% of 2-propanol as the electron donor and DMSO as the solvent. The suspension was stirred for 30 or 60 minutes in a dark box under the aforementioned UV source. After stirring, the solution was centrifuged for 10 minutes at 12 000 rpm and then the supernatant was obtained to observe the UV absorbance of the purple formazan as the superoxide ions indicator.

2.5.3 Detection of hydroxyl radicals by using terephthalic acid. Terephthalic acid is a well-known chemical used to detect hydroxyl radicals in weak base aqueous systems.²³ An aqueous solution containing 10 mM NaOH and 3 mM terephthalic acid was prepared, and 1 mg of TiO_2 or TiO_2/C_{70} -COOH composite powder was dispersed into the solution. The suspension was stirred by magnetic stirrer over five different time intervals (1, 5, 10, 30 and 60 min) in a dark box under the aforementioned UV source. Subsequently, the solution was centrifuged for 10 minutes at 12 000 rpm and the supernatant was used to evaluate the fluorescence intensity, which was attributed to 2-hydroxyterephthalic acid (TAOH), an oxidized product of terephthalic acid. The intensity of the fluorescence peak of TAOH at 426 nm with 312 nm excitation was measured with a fluorescence spectrophotometer.

2.6 MTT assay

Non-cancerous CCD-966SK skin cells and IMR90 lung cells were seeded in 96 well plates incubated with TiO_2 materials for 48 hours. Cell viability was then measured by MTT assay, according to the manufacturer's instructions (https://Goldbio.com).

2.7 Luciferase reporter assay

293T cells, stably expressing constructs containing promoter regions of control (pcDNA), or antioxidant response element (ARE), or nuclear factor kB (NFkB) response element with luciferase, were established and applied in this assay. Stable cells were treated with hydrogen peroxide (H_2O_2) with or without TiO₂ materials for 2 hours, and then the luciferase activity was measured (Promega).

3. Results and discussion

Fig. 1a shows the XRD patterns of the P25 and P25/C₇₀-COOH composites. The diffraction patterns indicate that the majority of P25 is in the anatase TiO_2 phase, matched to JCPDS card no. 21-1272 and no. 21-1276.²⁴ The ratio of anatase and rutile phases determined from XRD was calculated by Depero *et al.* using the following equation:²⁵



Fig. 1 XRD patterns of (a) P25 and P25/C $_{70}$ -COOH composites, (b) TNR and TNR/C $_{70}$ -COOH composites.

$$R(T) = 0.679 \frac{I_{\rm R}}{I_{\rm A} + I_{\rm R}} + 0.312 \left(\frac{I_{\rm R}}{I_{\rm A} + I_{\rm R}}\right)^2$$

where R(T) is the temperature dependent percentage content of rutile, and I_A and I_R are the intensities of the main anatase and rutile reflections, respectively. According to the XRD patterns and the formula, the P25 anatase and rutile phase structure



Fig. 2 SEM images of (a) P25, (b) TNR, (c) P25C710 and (d) TC710. The patterns show that C_{70} -COOH does not change the morphologies of P25 and as-prepared TNR.



Fig. 3 EDS spectra for (a) P25, (b) P25C710, (c) TNR and (d) TC710.

Table 2Ratios of elements in P25, TNR, P25C710 and TC710

Element	Atomic%				
	P25	P25C710	TNR	TC710	
С	0	29.91	14.86	22.82	
0	74.84	55.06	58.67	57.50	
Ti	25.16	15.03	26.46	19.67	

ratio is about 74 : 26. Moreover, there was no change in the P25 structure before and after modification with C_{70} -COOH. The results indicate that C_{70} -COOH did not influence the lattice structure of P25. Fig. 1b reveals the XRD patterns of the TNR and TNR/C₇₀-COOH composites. According to JCPDS card no. 21-1276, TNR and TNR/C₇₀-COOH are in the rutile phase; the structure did not change after decoration of the surface with C₇₀-COOH.

In order to observe the morphologies of P25, the as-prepared TNR and the TiO₂ modified with C₇₀-COOH, scanning electron microscopy (SEM) images were obtained as shown in Fig. 2. It can be seen that P25 has a particle-like morphology with a diameter of 20–50 nm, and TNR has a rod-like morphology with a diameter of 30–60 nm and a length of about 150–300 nm. After the modification of TiO₂ with C₇₀-COOH on the surface,



Fig. 4 TEM images and SAED patterns for (a) P25C710, (b) TC710.

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both P25 and TNR retained their morphologies without any apparent changes. Fig. 3 presents the energy dispersive X-ray spectra (EDS) of P25, as-prepared TNR and the composites, to provide evidence that the C_{70} -COOH is coated on the TiO₂. Carbon element was present in the as-prepared TNR, probably due to impurities during the synthesis procedure. It was also found that the carbon signal intensity increased when comparing P25 and as-prepared TNR with P25C710 and TC710, respectively. This was attributed to the C_{70} -COOH modification on the surface of the TiO₂. The elemental ratios of TiO₂ and TiO₂/C₇₀-COOH composites in the samples are shown in Table 2.

To confirm that C_{70} -COOH was coated on the surface of TiO₂, TEM images and selected area electron diffraction (SAED) patterns for the TiO₂ composites were obtained, as shown in Fig. 4a and b. The lattice spacing of 0.438 nm



Fig. 5 FTIR spectra for C₇₀-COOH, P25, P25C710, TNR and TC710. According to the spectra, C₇₀-COOH has been successfully anchored to the surface of TiO₂.



Fig. 6 UV-VIS intensities of pyridoxine reacted with singlet oxygen under UV-irradiation at 318 nm. (a) P25, P25C71, P25C75 and P25C710 reacted with 0.1 mM pyridoxine. (b) TNR, TC71, TC75 and TC710 reacted with 0.1 mM pyridoxine.



Fig. 7 UV-VIS intensities of formazan generated from nitroblue tetrazolium (NBT) under UV-irradiation at 530 nm. (a) P25, P25C71, P25C75 and P25C710 reacted with 0.13 mM NBT. (b) TNR, TC71, TC75 and TC710 reacted with 0.13 mM (NBT).

corresponds to the (101) plane of P25, and the lattice spacing of 0.408 is in good agreement with the (110) plane of TNR, and it is clear that a thin and inconspicuous amorphous structure covers the surface of TiO₂. According to previous reports, the diameter of a C_{70} particle is about 1.12 nm;²⁶ therefore, it was estimated that the outer layer was composed of about 4–7 layers of C₇₀-COOH. It is hard to confirm the existence of C₇₀-COOH by HRTEM and so chemical analysis was used to provide more evidence that C₇₀-COOH was indeed conjugated on the surface of TiO₂. FTIR was used to confirm the chemical structure of TiO₂ and TiO₂ composites. The IR spectra of C₇₀-COOH, P25, P25C710, TNR and TC710 are shown in Fig. 5. There are no infrared spectral peaks of TiO₂ overlapped with C₇₀-COOH in the range of 1400–1800 cm⁻¹, and only one peak can be found at 1633 cm⁻¹ for TiO₂, corresponding to a previous report.²⁷ C₇₀-COOH has strong absorptions at 1421 and 1720 cm⁻¹, attributed to the C=C aromatic ring and C=O stretching, respectively. Both P25C710 and TC710 revealed tiny peaks at these two wavelengths, which can be explained by the C₇₀-COOH modification



Fig. 8 Fluorescence intensity of 2-hydroxyterephthalic acid (TAOH) generated from terephthalic acid (TA) reacting with hydroxyl radicals under UV-irradiation at 426 nm. (a) P25, P25C71, P25C75 and P25C710 reacted with 3 mM TA. (b) TNR, TC71, TC75 and TC710 reacted with 3 mM TA.



Fig. 9 TiO₂ materials exhibit good biocompatibility in human cells. (a) The TiO₂ series of materials measured by MTT assays are shown. (b) CCD966SK skin cells were incubated with these materials at three concentrations for 48 hours, and then cell viability was measured by MTT assays to monitor the cell growth, relative to untreated control cells. (c) The morphologies of the CCD966SK cells were also monitored under the microscope, and the representative pictures of the cells incubated with 1.25 μ g mL⁻¹ are shown. (d) IMR90 lung cells were incubated with these materials at three concentrations for 48 hours, and then cell viability was measured by MTT assays to monitor the cell growth, relative to untreated control cells.

of the surface of TiO_2 , *via* the esterification of –OH and –COOH groups on TiO_2 and C_{70} -COOH. The FTIR results indicate that C_{70} -COOH was successfully anchored to the surface of TiO_2 .

 TiO_2 nanomaterials produce large amounts of ROS under UV-irradiation, which is harmful to human skin cells, bringing about apoptosis.²⁸ C₇₀-COOH was therefore chosen for anchoring to the surface of TiO₂ nanomaterials, to absorb ROS generated from electron and hole separation of TiO₂. In order to provide the evidence for the scavenging radical abilities of TiO₂/ C₇₀-COOH composites, pyridoxine (a kind of vitamin B6), nitroblue tetrazolium (NBT), and terephthalic acid (TA) were selected to react with singlet oxygen, hydroxyl radicals and superoxide ions, respectively. It has been reported that these chemicals have been utilized to observe the radical scavenging conditions,²¹⁻²³ *via* detecting the intensity of ultraviolet adsorption or fluorescence emission.

As shown in Fig. 6, the UV spectra were obtained, measuring pyridoxine absorption intensity at 318 nm, by using different samples to react with 0.1 mM pyridoxine under UV irradiation for various times. The results reveal that the concentration of



Fig. 10 TiO₂ materials exhibit potential for anti-oxidative and anti-inflammation applications. Stable non-cancerous 293T human cells expressing promoter regions of pcDNA or ARE or NFkB response elements with luciferase were applied in the luciferase reporter assay. (a) Cells were incubated with 50 μ M H₂O₂ with or without the P25 series of materials as indicated in the figure, for 2 hours, and then luciferase activity was measured. (b) Cells were incubated with 50 μ M H₂O₂ with or without TNR series materials as indicated, and then luciferase activity was measured.

pyridoxine was increased in three hours for TiO₂ modified with C_{70} -COOH, as compared with P25 or as-prepared TNR. However, the elevating trends of the concentration of pyridoxine disappeared for P25C710, and decreased for TC710. The explanation of this phenomenon could be the saturation of C_{70} -COOH on adsorbing singlet oxygen, or the overproduction of singlet oxygen because of C_{70} -COOH. Ernest M. *et al.* have reported that C_{60} could produce singlet oxygen under UV-irradiation with a mechanism similar to TiO₂.²⁹

Nitroblue tetrazolium has been used as an established chemical for detecting superoxide ions for several years. To further observe the superoxide ion scavenging conditions of TiO_2 and TiO_2/C_{70} -COOH, the UV spectra of formazan at 530 nm was obtained, as shown in Fig. 7; formazan was obtained when 0.13 mM nitroblue tetrazolium reacted with superoxide ions under UV irradiation for various durations. Regardless of P25/ C_{70} -COOH or TNR/ C_{70} -COOH, only 1 wt% C_{70} -COOH coated on TiO₂ demonstrated scavenging abilities for superoxide ions. TiO₂ and C_{70} -COOH generate superoxide ion and singlet oxygen through the similar mechanism, and the added amounts of C_{70} -COOH for scavenging ROS under UV-irradiation is very crucial and inseparable.

The fluorescence spectra were observed by measuring TiO_2/C_{70} -COOH with 3 mM terephthalic acid under UV irradiation for

various durations, as shown in Fig. 8. Tsutomu *et al.* reported that terephthalic acid reacting with hydroxyl radicals would produce the TAOH product, emitting fluorescence at 424 nm.²³ The results show that P25/C₇₀-COOH composites effectively decreased the concentration of hydroxyl radicals in one hour, but TNR/C₇₀-COOH composites did not show scavenging effects. It was considered that the amounts of hydroxyl radicals generated from TNR/C₇₀-COOH were less than P25/C₇₀-COOH. In the meantime, C₇₀-COOH could also generate hydroxyl radicals under UV-irradiation against the scavenging effects.²⁹ Hence, the scavenging effects of TNR/C₇₀-COOH composites were not apparent and the scavenging rate was slower than the rate of generation.

In order to broaden the future applications of these TiO_2 materials, we closely evaluated whether these materials caused cell death in non-cancerous CCD966SK skin and IMR90 lung cells. Materials applied in this study are shown in Fig. 9a. Both cell types were incubated with three concentrations of these materials for 48 hours, and then the proliferation rates of these cells were measured (Fig. 9b and d). The data indicated that only a couple of samples resulted in slightly lower growth rates and none of these TiO_2 materials caused severe cell death in both cell types (Fig. 9b and d). Photos of cells were also taken to monitor cell morphology, and data for skin cells

incubated at middle concentration were shown as representative pictures (Fig. 9c, data for other concentrations, and pictures of IMR90 cells are not shown). Fig. 9 demonstrates that TiO_2 materials did not induce obvious cell death or morphology changes.

In order to investigate the protection capacity of these TiO₂ materials in human cells, the luciferase reporter assays were performed. Stable non-cancerous 293T cells expressing constructs containing promoter regions of pcDNA or ARE, which can be activated under oxidative stress, or NFkB response element, which can be activated during the inflammatory signaling pathway, with luciferase were applied in the luciferase reporter assay. A positive control experiment was carried out by using a low concentration of H_2O_2 (50 μ M) to induce oxidative stress or inflammation signaling and activate luciferase activity. We examined whether TiO₂ materials provide protection against oxidative stress in the ARE cells, while testing whether TiO₂ materials provide protection against inflammation signals in the NFkB cells. The results showed that H2O2-induced luciferase activity was suppressed by most P25 series materials, suggesting that the P25 series materials were capable of eliminating H2O2-induced oxidative stress or inflammation (Fig. 10a). The TNR series materials were also investigated in the assays, and the results showed that H2O2-induced luciferase activity was suppressed by some of them at specific concentrations, indicating that these materials were capable of reducing inflammation signals (Fig. 10b). Therefore the data suggest that these TiO₂ materials exhibit great potential for anti-oxidative and anti-inflammation applications.

4. Conclusion

Major rutile phase TiO2 nanorods were successfully synthesized by a hydrothermal method, which successfully anchored carboxyfullerenes onto the surface of two types of crystal phase TiO₂ nanoparticles. The structure and properties were determined using X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and high-resolution transmission electron microscopy (HRTEM). Carboxyfullerenes decorated on TiO2 decreased the amounts of singlet oxygen produced under UV-irradiation in three hours, but was invalid for 10 wt% C70-COOH. At a low concentration of 1 wt%, C₇₀-COOH capped onto TiO₂ showed the most effective scavenging activities for superoxide ions, compared to high concentration under UV-irradiation in one hour. P25/C70-COOH composites generated more hydroxyl radicals than TNR/C70-COOH composites under UV-irradiation in general, and showed apparent scavenging effects on hydroxyl radicals for P25/C70-COOH composites in one hour, while no scavenging effects for TNR/C₇₀-COOH composites were observed. In summary, carboxyfullerene decorated TiO₂ nanomaterials are expected to be functional UV-attenuating agents for cosmetic application in sunscreens, and could have great potential in anti-oxidative and anti-inflammation applications.

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