

Exploration of the Origin of the UV Absorption Performance of Windmill Palm Fiber

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This study aims to investigate the ultraviolet (UV) absorption property of palm fiber and to reveal the mechanism underlying its UV-shielding behavior. The UV spectra of various solvent extracts of palm fiber were investigated. Fourier transform infrared spectroscopy (FTIR) and UV spectra were used to analyze the treated palm fiber, 100% α -cellulose, and raw palm fiber. The UV absorbances of palm, bamboo, and ramie fibers and their lignin extracts were comparatively investigated. The results showed that lignin is the main contributor to the UV absorption property of palm fiber. UV spectroscopy of the solvent extracts showed that a dioxane solution exhibited an excellent extraction capacity. The analysis of the FTIR and UV spectra of treated palm fiber, 100% α -cellulose, and raw palm fiber confirmed that there was a strong correlation between the UV absorption property and the chemical components. The results showed that the palm fiber exhibited superior UV absorption properties and that the lignin content noticeably affected the UV absorption degree.

Keywords: Palm fiber; UV absorption property; Lignin

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INTRODUCTION

Environmental pollution is gradually damaging the ozone layer. As a result, harmful ultraviolet (UV) rays can easily penetrate the atmosphere and threaten human health. Clothing and accessories made of protective materials are typically used to reduce the amount of UV ray exposure, thereby avoiding or limiting the health risks caused by UV rays. Scholars have developed fiber and fabrics using different methods. Given that fibers with high cellulose content are vulnerable to UV light, Mao *et al.* (2009) assembled cotton fibers with nano-ZnO to improve the UV-blocking capacity. Cotton and flax fabrics are also dyed with multifunctional plant extracts to achieve better UV-protective properties (Grifoni *et al.* 2014). The finished fibers or textiles are excellent for use as an ultraviolet shield. However, the use of chemicals in these fibers is inevitable.

In general, the ultraviolet radiation (UVR)-shielding properties of textiles depend on the fiber type, fabric construction, and the nature of the finishing chemicals (Grifoni *et al.* 2014). Thus, understanding the UVR-shielding properties of the fiber itself is important. Polyester has a benzene ring structure at a high concentration; causing this fiber to have strong absorbance properties below the 300-nm UV region (Zhu 2006). Cotton shows poor performance against UV ray exposure because it lacks active groups that help to absorb the UV rays (Zhu 2006). Hemp fibers possess strong UVR-blocking properties because of their oblique hole structure, a characteristic of pectin, which can eliminate light waves reaching the fiber (Yu *et al.* 2011). Afrin *et al.* (2012) investigated the UV absorption properties of bamboo, whose chemical components were extracted by

utilizing several polar and non-polar solvents, concluding that the UV absorption properties of bamboo are due to lignin components. The UV-shielding property of natural fiber has been the focus of considerable attention because of its eco-friendliness.

Palm fiber, as a natural fiber, shows excellent weatherability during the natural growth process. Therefore, palm fiber is deemed to have inherent UV-blocking properties and is applied as reinforcement for dam construction. Palm fiber, which has various active groups, has higher lignin content than that of flax and bamboo (Zhang *et al.* 2010). Lignin is an aromatic polymer with an abundant amount of benzene structures, like polyester, and these structures can absorb the UV rays well (Zhu 2006). Palm fiber also has a unique structure similar to that of hemp fiber. Palm fiber is a multicellular fiber with a “lacuna” from the transverse section, and all individual fibers are elongated cells aligned in the longitudinal direction (Cheng *et al.* 2014). Palm fiber also has the potential to reflect and absorb UV rays. Many studies have investigated palm fibers from the perspectives of biology, anatomy, and wood science (Munawar *et al.* 2007; Sahari *et al.* 2012; Zhai *et al.* 2012). However, independent scientific investigations on the unique characteristics of palm fiber, such as aging resistance, corrosion resistance, and excellent UV-blocking properties, are still lacking. Given its inherent excellent reflection and absorption capacities in the UV region, palm fiber can be a promising material for developing effective UV protection materials, such as UV protection additives, blockers, and screening agents. Therefore, the UV-blocking properties of palm fiber should be investigated.

This study explores the origin of the UV absorption property of palm fiber. Palm fiber extracts were obtained by using polar and non-polar solvents to reveal the origin of the UV absorption property. Palm fiber was treated to remove its hemicellulose and lignin. Correlations between the components and UV absorbance were determined by a UV absorption test. The UV absorbance of palm, bamboo, ramie fibers, and their lignin extracts were also compared to analyze their UV absorption performances, respectively.

EXPERIMENTAL

Materials

Palm fiber samples were sourced from a local plantation in Honghe County, Yunnan Province, China. No other treatment was applied to the fiber before the specimen was ground into powder form, approximately 200 μm in size. The bamboo and ramie fiber powders, approximately 200 μm in size, and α -cellulose samples were purchased from High-tech and composites Co., Ltd., in Hangzhou City, Zhejiang Province, China. The detailed information of palm, bamboo, and ramie fibers are shown in Table 1.

Table 1. Detailed information of Palm, Bamboo, and Ramie Fibers

Fiber name	Sources	Scientific name	Genus	Species
Palm	Yunnan, China	Windmill palm leaf sheath fiber	<i>Trachycarpus</i>	<i>fortunei</i>
Bamboo	Zhejiang, China	<i>Phyllostachys pubescens</i>	<i>Phyllostachys</i>	<i>pubescens</i> var. <i>heterocycla</i>
Ramie	Guangxi, China	<i>Boehmeria nivea</i>	<i>Boehmeria</i>	<i>nivea</i>

Methods

Polar solvents (ethanol), non-polar solvents (hexane and acetone), and a dioxane solution (dioxane/water, 9:1 (v/v)), were used to obtain extracts from the palm fiber powder. The powder samples were placed in solvents, containing material and liquor at a ratio of 1:30 (w/w) and were maintained at room temperature under continuous stirring for 72 h. All the powder-liquid mixtures were centrifuged separately, and the supernatants were collected. The extracts in the 90% aqueous dioxane, ethanol, hexane, and acetone extracts were diluted 50 times by their respective extracting solvent. The UV absorbance of the extracts was investigated by using a UV-Vis absorption spectrometer (TU 1901, Pgeneral, China) in transmission mode.

The palm fiber powder was treated to remove the wax, water-soluble compounds, pectin, and hemicellulose using the chemical reagents sodium hydroxide, ammonium oxalate, ethanol, and benzene, respectively, in accordance with the Chinese standard method GB 5889 (1986), otherwise known as the ramie chemical composition quantitative analysis method. The scheme for the treatment of palm fiber powder is illustrated in Fig. 1. A 90% aqueous dioxane solution was used to remove the lignin content from the treated palm fiber powder, and the residue was washed in distilled water and dried. All the treated and raw fiber samples were characterized using Fourier transform infrared spectroscopy (FTIR) and an UV/Vis/NIR spectrophotometer. The FTIR test was conducted using the TENSOR 27 instrument (Bruker Corporation, USA) to analyze the functional groups and chemical structure of the samples. The UV-Vis spectroscopy measurement of the palm fiber powder was conducted in diffuse reflectance mode, using a UV/Vis/NIR spectrophotometer (UV-3600, Shimadzu, Japan) equipped with an integrating sphere.

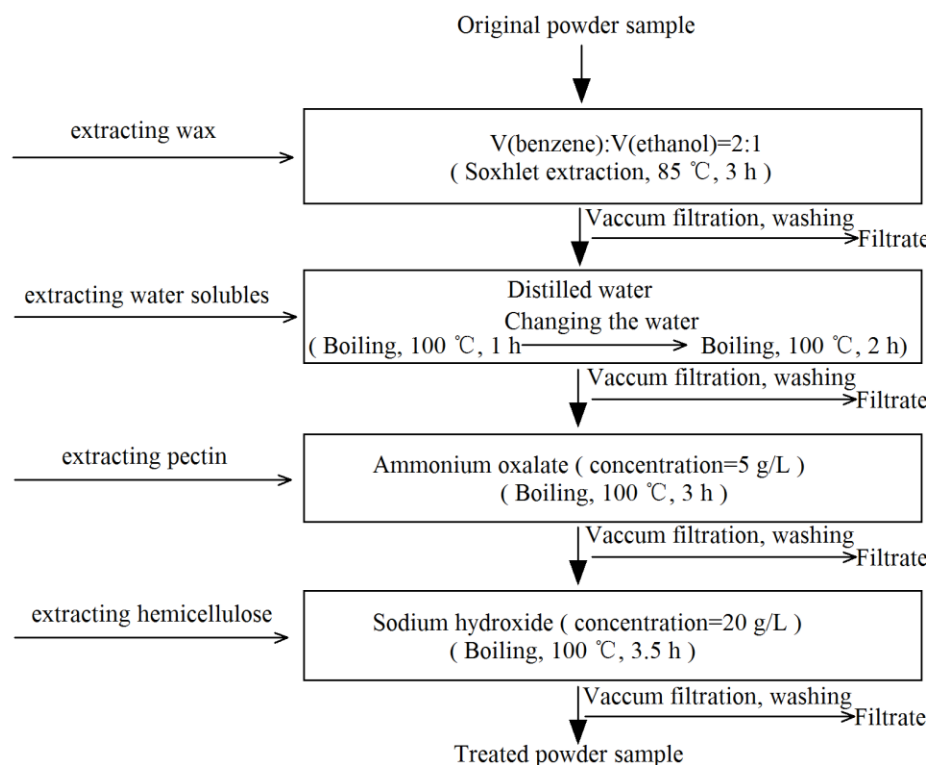


Fig. 1. Schematic illustration of the palm fiber composition extracting process

The determination of the UV absorbance of the palm, bamboo, and ramie fiber powders was conducted by dispersing the powders in ethanol (w/v = 0.093%) and measured using a UV spectrophotometer. The lignin content of palm, bamboo, and ramie fibers was extracted in a dioxane/water mixture solution (9:1 v/v). The UV absorbance of the fibers and their lignin extracts was also investigated using a UV-Vis absorption spectrometer (TU 1901, Pgeneral, China) in transmission mode. All of the extracts in the 90% aqueous dioxane extracts were diluted 40 times by their respective extracting solvent.

RESULTS AND DISCUSSION

UV Absorption Property of Palm Fiber Extracts

Figure 2 shows the UV absorbance spectra of the extracts in the dioxane solution, containing dioxane/water at a ratio of 9:1, ethanol, hexane, and acetone. The extracts in the different solvents exhibited distinguishable UV absorption properties. In Fig. 2, the absorption of the palm fiber extract in the dioxane solution was strong in all the UV wavelengths, including the UVA, from 320 to 400 nm, the UVB, from 280 to 320 nm, and the UVC from 100 to 280 nm regions. The dioxane solution, containing dioxane/water at a ratio of 9:1, is extensively regarded as a lignin solvent. The extracts were deemed to be consisting of palm fiber lignin. The strongest peak appeared at 288 nm, which corresponds to the characteristic absorption peak of lignin. However, the extracts in the ethanol and hexane showed strong UV absorbance only in the 200 to 250 nm UVC wavelength regions, as shown in Fig. 2. This phenomenon indicates that other chemical components besides lignin are responsible for UV absorption. The curve of the acetone extract was different from that of the other extracts, with a an absorption peak appearing near the 320 nm wavelength, exhibiting a particularly low absorption intensity. Generally, the acetone did not extract as much UV-absorbing lignin as the dioxane/water mixture, hexane, and ethanol solvents. The results confirmed that the dioxane solution was effective in extracting the lignin from palm fiber. The UV-shielding nature of the palm fiber powder may have a strong relationship with lignin.

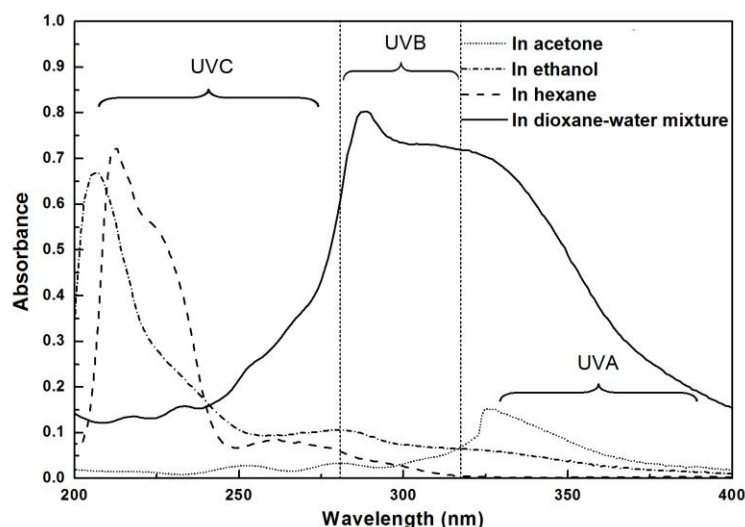


Fig. 2. UV absorbance spectra of palm fiber powder extracts in the acetone, ethanol, hexane, and the dioxane-water mixture (diluted 50 times)

UV Absorption Property of Palm Fiber Powders

Figure 3(a) shows the FTIR spectra of the raw palm fiber. The strong absorption peaks of cellulose at 1,055.3, 2,859, and 2,919.7 cm^{-1} can be ascribed to the C-O stretching vibration, the symmetrical stretching vibration of $-\text{CH}_2$, and the unsymmetrical stretching vibration of $-\text{CH}_3$, respectively (Wan *et al.* 2004). The characteristic absorption peak of hemicellulose is centered at 1,730 cm^{-1} , which is attributed to the stretching vibration of the C=O bonds (Liu *et al.* 2004). The peaks at 1,460.4 and 1,634 cm^{-1} can be attributed to the C-H bending vibrations in methylene and methyl, which are the characteristic peaks of cellulose and lignin, respectively (Li *et al.* 2010).

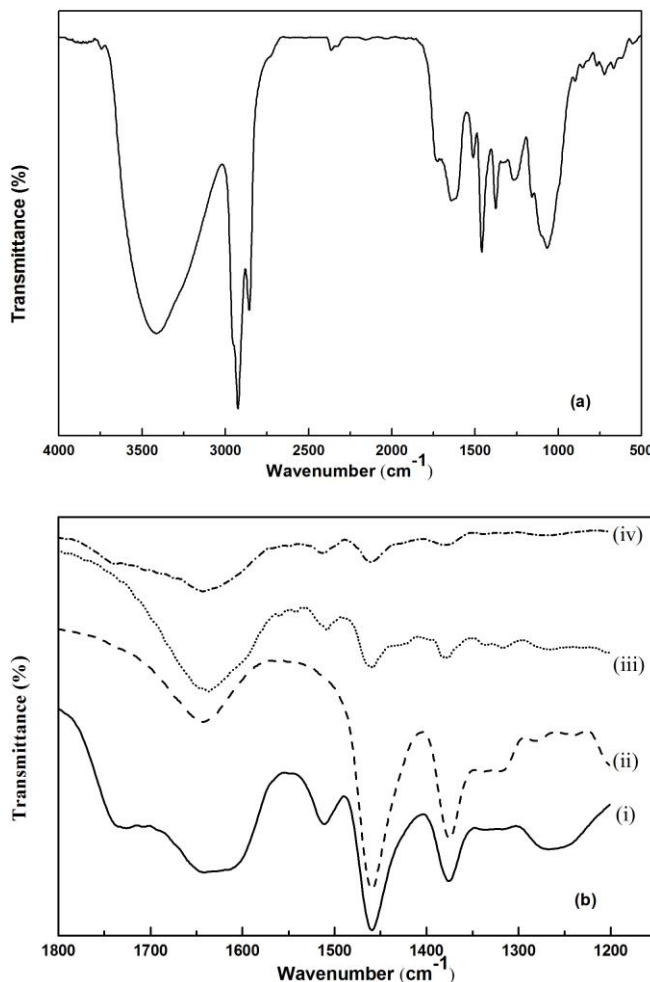


Fig. 3. (a) FTIR spectrum of raw palm fiber, and (b) FTIR spectra of (i) raw palm fiber powder; (ii) 100% α -cellulose; (iii) sample removed from wax, water solubles, pectin, and hemicellulose; and (iv) sample extracted lignin with dioxane-water mixture

The FTIR spectra comparison of the four samples is presented in detail in Fig. 3(b). The samples are as follows: (i) untreated palm fiber powder; (ii) 100% α -cellulose; (iii) sample removed from wax, water-soluble compounds, pectin, and hemicellulose; and (iv) lignin sample removed by the dioxane/water mixture. Compared with those of samples (i) and (ii), the peaks at 1,375.5 and 1,460.4 cm^{-1} of samples (iii) and (iv) were evidently weakened because of the CH and CH_3 bending vibrations of cellulose I, which reflected a decrease in the cellulose content. The peaks at 1,266.3 and 1,512.4 cm^{-1} can be

ascribed to the C-O stretching vibration and the benzene ring C=C stretching vibration of lignin, respectively (Garside and Wyeth 2003; Tserki *et al.* 2006). The two peaks, together with the characteristic peak of hemicellulose at $1,730\text{ cm}^{-1}$ of the untreated palm fiber, evidently disappeared in the three other samples. This result indicated that the palm fiber treatment successfully removed the lignin content and the hemicellulose.

Figure 4 shows the absorbance spectra of the four samples. The untreated palm fiber sample showed the strongest UV absorption property, compared with the other samples. By contrast, the 100% α -cellulose showed the weakest UV absorption property. Based on the lower absorption of samples (iii) and (iv), and on the results of the FTIR analysis, the UV absorption capacity evidently became weakened with the disappearance of the lignin and a part of the hemicellulose. To some extent, the UV absorption properties could be attributed to the lignin content, and could be correlated with hemicellulose.

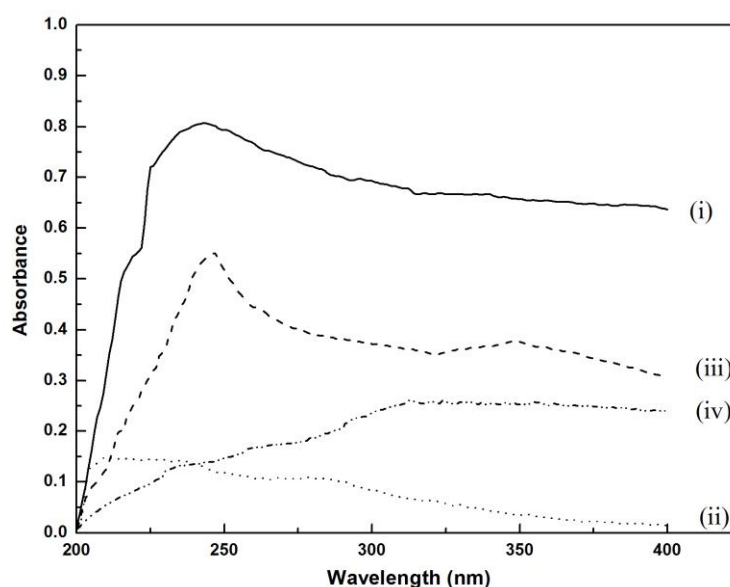


Fig. 4. UV absorbance spectra of (i) raw palm fiber powder; (ii) 100% α -cellulose; (iii) sample removed wax, water solubles, pectin, and hemicellulose; and (iv) sample extracted lignin with dioxane-water mixture

Comparison of the UV Absorption Properties of Palm, Bamboo, and Ramie Fibers

Figure 5 shows the UV absorption spectra of the palm, bamboo, and ramie fibers. Notably, in the wavelength range of 216 to 400 nm, the palm fiber exhibited the strongest UV absorbance. Meanwhile, the UV absorbances of the bamboo and ramie fibers were lower. As shown in Table 2, the lignin content of palm fiber was the highest, followed by the bamboo and ramie fibers, which is consistent, to some extent, with their UV absorbance sequence. Lignin is an aromatic compound that possesses a strong UV light absorption capacity. As such, the lignin content plays a crucial role in the UV light absorption, *i.e.*, the more lignin in the fiber, the better the UV absorbance. By contrast, hemicellulose and cellulose are classified as carbohydrates, and they do not have UV light absorption ability. As such, hemicellulose and cellulose do not have a substantial influence on the capability of UV absorbance. The absorption peaks of the bamboo, palm, and ramie fibers appeared in the wavelength range of 200 nm to 216 nm, and their UV

absorbance has the following decreasing order: bamboo, palm, and ramie. This finding is attributable to the existence of a conjugated double bonds in the fibers, which give rise to the UV absorption peak. The different lignin chemical compositions of the three fibers may lead to different UV absorbances.

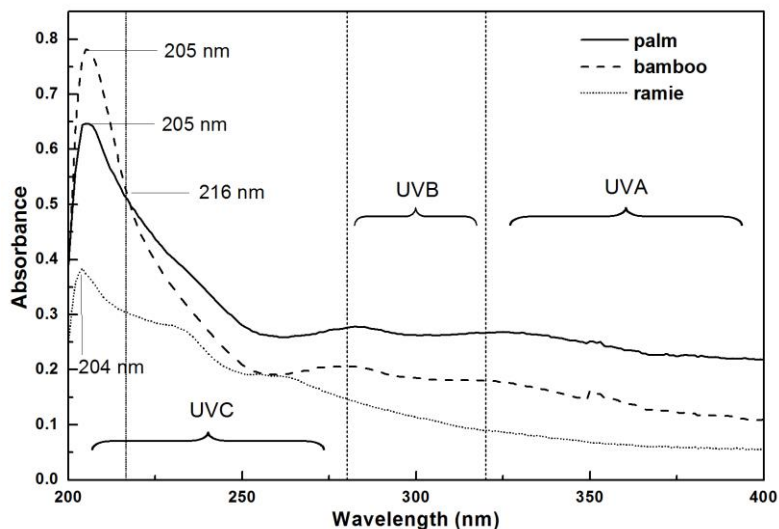


Fig. 5. UV absorbance spectra of palm, bamboo, and ramie fiber powder

Table 2. Chemical Composition of Palm Fiber and Other Natural Fibers (Wang *et al.* 2010; Cordeiro *et al.* 2011; Zhang *et al.* 2015)

Fibers	Palm	Bamboo	Ramie
Lignin (%)	44.07	10.15	0.6 to 0.7
Hemicellulose (%)	20.60	12.49	13-16

The UV absorption property of the lignin extracts of the palm, bamboo, and ramie fibers in the dioxane/water mixture was also investigated. Figure 6 shows the UV absorbance spectra of the three fibers.

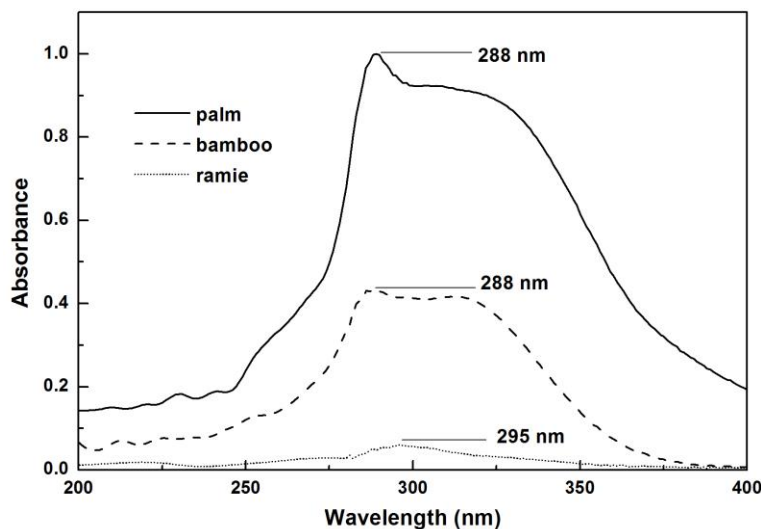


Fig. 6. UV absorbance spectra of palm, bamboo, and ramie fiber extracts in dioxane:water (9:1) (diluted 40 times)

Notably, the palm fiber extracts exhibited the highest UV absorbance, followed by the bamboo and ramie fiber extracts, which is consistent with the order of their lignin content, listed in Table 2. The results reveal that the higher the lignin content is, the more excellent the fiber's UV absorption properties are. The maximum absorbance of the palm and bamboo fiber extracts was located at 288 nm, whereas that of the ramie fiber extract was located at 295 nm. Their UV absorption properties may be due to their different types of lignin, which is the collective of phenylpropanoid macromolecules (Hatfield and Fukushima 2005).

CONCLUSIONS

1. Polar solvents (ethanol), non-polar solvents (hexane and acetone), and a dioxane solution (dioxane/water, 9:1 (v/v)), were able to extract the chemical components responsible for the UV absorption property. The extracts of palm fiber in various solvents demonstrated that lignin was the component responsible for the UV absorption property of palm fiber.
2. Compared with the treated palm fiber powders, the raw palm fiber powder showed a stronger UV absorption capacity. The results indicated that the UV absorption property was significantly correlated with the amount of lignin content and partly correlated with hemicellulose.
3. The UV absorbance of palm, bamboo, and ramie fibers and their lignin extracts were measured by using a UV spectrophotometer. The results showed that the palm fiber exhibited the strongest UV absorption property. The higher the lignin content in the fiber is, the more excellent the fiber's UV absorption properties are. Thus, it can be concluded that the UV absorption property of fibers is mainly attributable to the presence of lignin in the fibers.

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