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This article describes ultra violet (UV) light shielding behaviour of Australian grown bamboo (*Phyllostachys pubescens*). Optical reflectance showed that untreated bamboo plant has UV absorption properties. To reveal the origin of the UV absorption property, its chemical components were extracted using several polar and non-polar solvents. The extracts in most of the polar and non-polar solvents showed UV absorption property. Prootic polar solvents showed better ability to extract UV absorbing chemicals than aprotic and non-polar solvents, except hexane. The chemical components of bamboo were analysed by FT-IR spectroscopy and the findings were correlated with the UV absorbance characteristics. The results confirmed that the UV absorption ability of bamboo originates from nothing but lignin. It is thus indicated that the conventional methods to manufacture bamboo fibres, such as complete degumming or viscose methods, that involve the removal of lignin, cannot retain the unique UV absorption property of bamboo plant in bamboo fibres.

Keywords: bamboo; UV absorption; fibre; lignin

Introduction

In the past decade, the atmospheric ozone layer has much deteriorated due to industrial development and modern life styles. As a result, nowadays harmful ultra violet (UV) rays easily penetrate atmosphere to reach our body, causing health problems such as melanin generation, cerebral cortex ageing, cataracts and skin cancer. In particular, skin-related disorder caused by UV rays is a serious issue in Australia. According to Cancer Council Australia (2010), Australia has the highest incidence rate of skin cancer, melanoma. More than 1200 people embrace death from melanoma each year and over 10,000 cases are diagnosed yearly. Although clothing is regarded as an effective means to protect skin from UV rays, only one-third of present commercial summer clothing items (such as cotton T-shirt) provide a sun protection factor of 7 (Xin, Daoud, & Kong, 2004). The UV-blocking effects of clothing are induced by two mechanisms, namely, UV absorption and UV scattering (Belzile, Vincent, & Kumagai, 2002). Since cellulose does not have UV absorption properties, summer clothing made of cotton normally relies only on light scattering effects for its UV protection, which gives a relatively poor sun protection factor (Kerr, Capjack, & Fedosejevs, 2000). Hence, it is highly desirable to develop a new type of textile fibre that has wicking properties similar to cotton but has improved UV absorption properties.

Recently, textile manufacturers have started to claim that bamboo fabrics have inherent UV-blocking properties (Bamboosa, 2009; Bambrotex, 2008). If the claim is true, bamboo fibres can be a promising material for making effective UV protecting clothing. Bamboo consists of lignocellulosic fibres and is a natural nanocomposite (Afrin, Tsuzuki, & Wang, 2010) where cellulose is imbedded in the matrix of lignin and hemicelluloses (Rao & Rao, 2005). It has nearly 30% of lignin, the gummy material. Bamboo is regarded as an eco-friendly, i.e. “green” raw material for its renewable nature and growing conditions. It is well reputed for its multi-functionality serving the daily need of over 1.5 billion of people for centuries (Liese, 2009). For example, its use in engineering composite materials is well described (Das & Chakraborty, 2008; Jain, Kumar, & Jindal, 1992). However, as a relatively new material in the textile sector, not many characteristics of bamboo are rigorously examined scientifically. Most of the available information about bamboo fibre and clothing, such as UV blocking, antimicrobial and moisture evaporation properties, has been from commercial industry bodies, without any scientific evidence presented to support the claims. The research

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reports on these unique characteristics of bamboo are rarely available to the public and, mostly, only in non-English languages. Therefore, there is a strong need for unbiased and independent scientific investigation on bamboo’s unique characteristics (Afrin, Tsuzuki, & Wang, 2009).

Depending on the fibre manufacturing methods, the unique properties of bamboo may be realised differently in the final form of textiles and fabrics. It appears that, currently, the viscose methods are commonly used for manufacturing bamboo fibres in which bamboo pulp is treated with sodium hydroxide (NaOH) and highly hazardous carbon disulphide (CS₂) to produce an alkali soluble cellulose xanthate derivative, then fibres are spun by wet spinning (Vehviläinen et al., 2008). The use of harmful chemicals goes against the commercial claim of bamboo fabrics as “green” products. Therefore, in some countries (such as USA, Canada), legislation is made to label bamboo as bamboo viscose or rayon if they are coming from the regenerated source (Just Style, 2011; Treehugger, 2010). The generic name bamboo may only be used if bamboo from plant stems is mechanically processed and enzyme is retted into natural bamboo fibre, similar to the process of making hemp fibres (Candilo et al., 2010).

This paper investigates the origin of UV absorption property of bamboo and gives a guideline towards developing the methods to retain this unique property during the fibre manufacturing process.

**Experimental**

**Materials**

Bamboo (Phyllostachys pubescens) samples were sourced from Earthcare Farm at Crystal Waters Permaculture Village in Queensland, Australia. About 3 kg of already dried, matured culms (stems) were used for the present study. The very outer and inner layers were removed and the specimen was crushed into a powder form (~500 µm in diameter) in a milling machine (Hafco, Super Power BM-52VF, Hare and Forbes, Australia). Non-polar solvents (hexane and toluene), polar aprotic solvents (acetone and dimethyl sulfoxide [DMSO]) and polar protic solvents (ethanol and water) were used as extracting solvents. Commercial bamboo viscose fibres were obtained from a manufacturing company in China. One hundred percent cellulose microcrystalline powder was sourced from Aldrich (Sigma-Aldrich, Australia) (~20 µm, Cat No. 310697, Batch No. MKAA3342). Cotton balls were bought from a local supermarket in Geelong, Australia and were scoured and bleached. Hundred percent cellulose powder and cotton balls were used as benchmarks for the studies of UV absorption characteristics against bamboo. For the solid state UV–Vis spectroscopy and FT-IR measurement, a thin slice of untreated bamboo was cut into the dimension of 50 × 30 × 2 mm and the surface was polished.

**Extractions**

Bamboo lignin was extracted in a diaoxane–water mixture solution (9:1 v/v) that is widely regarded as a lignin solvent (BJörkman, 1954). In addition, several polar and non-polar solvents such as water, ethanol, hexane, DMSO, acetone and toluene were used for extracting bamboo plants in order to elucidate the origin of the UV shielding ability of bamboo. The extractions, except in water, were carried out by immersing washed and dried bamboo powder in the solvents (material:liquor = 1:30 w/w) for 72 hours with continuous stirring at room temperature. For water extraction, bamboo powder was boiled for 1 hour and then kept in the water for another 71 hours at room temperature with continuous stirring. The powder–liquid mixtures were then centrifuged and the supernatant was collected.

**Characterisation**

A Fourier transform infrared spectroscopy (FT-IR) was carried out using the Attenuated Total Reflectance mode with a Bruker Vertex 70 spectrometer (Ettlingen, Germany) and OPUS 5.5 software. UV–Vis spectroscopy of bamboo extracts in liquid was performed using a Varian Cary 3 spectrometer using the transmission mode. The extracts in 90% aqueous dioxane was diluted 100 times and water, ethanol and hexane extracts were diluted 50 times. The extracts in DMSO, acetone and toluene were measured without dilution. The UV absorbance measurement of solid bamboo slices, commercial bamboo viscose fibre, 100% cellulose powder and cotton balls were carried out in the diffuse reflectance mode, using a Varian Cary 300 spectrometer equipped with an integrating sphere, Labsphere DRA-CA-30L. The bamboo slices were directly placed on the integrating sphere. The cotton, cellulose and commercial bamboo viscose samples were packed into 2 mm thick films in a custom-made polystyrene sample holder. The morphology of bamboo powders after lignin extraction was studied by a scanning electron microscopy (SEM) using a Neoscope JCM-5000 instrument (Jeol Neo-scope JCM-5000, Nikon, USA).

**Results and discussion**

**Chemical structure**

A FT-IR spectrum of untreated bamboo is shown in Figure 1(a). It represents the typical cellulose finger print where 1050 cm⁻¹ band is assigned to the complex vibration associated with C–O, C–C stretching...
and C–OH bending in polysaccharides (Rodríguez-Lucena, Lucena, & Hernández-Apaolaza, 2009; Yueping et al., 2010), O–H stretching is evident at 3400 cm\(^{-1}\) and C–H stretching in methyl and methylene group is seen around 2900 cm\(^{-1}\). Lignin is visible in the range from 1500 to 1750 where 1740 cm\(^{-1}\) and 1675 cm\(^{-1}\) band are nonconjugated carbonyl stretching, and conjugated carbonyl stretching, respectively. 1600, 1505 and 1425 cm\(^{-1}\) bands are aromatic skeletal vibrations (Buta, Zadrazil, & Galletti, 1989; Sakakibara & Sano, 2001; Yueping et al., 2010).

Figure 1(b) shows the FT-IR spectra of untreated bamboo, commercial bamboo viscose fibres, 100% cellulose powder and cotton in the lignin region (1500–1750 cm\(^{-1}\)). It is evident that the absorption bands at 1505, 1600 and 1740 cm\(^{-1}\) are not evident in the spectra of cotton, 100% cellulose powder and commercial bamboo viscose fibre. Therefore, it indicates that the conventional degummed (lignin removed) bamboo may lack certain properties that are derived from the lignin in the untreated bamboo (Afrin et al., 2010).

### UV shielding property of bamboo extract

Figure 2(a) shows a UV–Vis absorbance spectrum of lignin extract in the diaoxane–water mixture. It is evident that lignin extracts absorb UV light. The absorption was the strongest below 250 nm (UVC region: 100–280 nm). The absorption in the UVA (315–400 nm) and UVB (280–315 nm) regions, which is of most importance for the UV-protecting textile applications, was also clearly evident but low. However, it should be mentioned that, it was 100 times the diluted sample. The results confirm that the UV-shielding nature of bamboo is due to the lignin contents of bamboo.

As in Figure 2(b), bamboo extracts in water, ethanol and hexane also showed strong UV absorbance even after 50 times of dilution. Since water and hexane are representative of extremely polar and non-polar liquids, respectively, the results indicate that more than one chemical components in lignin are responsible for the UV absorption of the lignin extract. Among the three spectra in Figure 2(b), the UV absorbance curve of ethanol extract resembled most to that of...
Figure 3. SEM images of bamboo powders (a) before and (b) after lignin extraction.

Figure 4. UV absorbance spectra of bamboo extracts in acetone, DMSO and toluene.

Figure 5. UV absorbance spectra of untreated bamboo, commercial bamboo viscose fibre, 100% cellulose powder and cotton.

of dioxane (non-polar-water (polar) mixture solutions), possibly because the polarity of ethanol was such that a broad range of ionic and anionic components were extracted simultaneously.

Figure 3 shows SEM images of bamboo powders before and after lignin extraction in the dioxane–water mixture. It can be seen that, after extraction, the bamboo particles swelled and the micropores in bamboo became wider. This swelling behaviour appeared similar to the cases where swelling occurs after mercerization (treating with NaOH) in lignocellulosic materials (Cheek & Roussel, 1989).

Figure 4 shows UV–Vis absorbance spectra of lignin extracts in acetone, DMSO and toluene. It is to be noted that acetone, DMSO and toluene themselves absorb UV light below 330, 260 and 290 nm, respectively, and hence the measurements of the UV absorption of the extracts in these solvents were not possible below the respective wavelengths. It is interesting to note that the UV absorbance intensity of the undiluted extracts in acetone, DMSO and toluene extraction samples was more or less the same as the 50-times diluted extracts in water, ethanol and hexane, indicating that acetone, DMSO and toluene did not extract as much UV absorbing components as water, ethanol and hexane. The reason for this low extraction ability of acetone, DMSO and toluene is a subject of further study.

**UV absorption properties of solid bamboo**

In Figure 5, the absorbance spectra of a solid untreated bamboo are compared with those of the commercial bamboo viscose fibre, 100% cellulose and cotton in the UV region. The untreated bamboo
sample showed significantly higher UV absorption intensity than other samples. Cotton was the least UV absorbing among all and the 100% cellulose powder showed a spectrum similar to cotton. The commercial bamboo viscose fibre had weaker UV absorption than the untreated bamboo, but much stronger than cotton and 100% cellulose. As discussed earlier, the amount of lignin decreases in the order of untreated bamboo, commercial bamboo viscose fibre, cotton and 100% cellulose powder (Figure 1b). Hence, the strength of UV absorption showed direct correlation with the amount of lignin, i.e. the strength of UV absorption increases as the amount of residual lignin increases. The results support the findings through the UV absorption properties of bamboo lignin extracts that the UV absorption nature of bamboo is due to its lignin content.

**Conclusions**

In this paper, the origin of the UV absorption property of bamboo (*P. pubescens*) was investigated. FT-IR and UV diffuse reflectance measurements of untreated bamboo, cotton, 100% cellulose and commercial bamboo viscose fibres were compared. It was revealed that the untreated bamboo possesses UV absorption properties and that the strength of UV absorption increased as the amount of residual lignin increased. It was also found that the lignin extracts in various solvents showed UV absorption properties. These results indicate that the UV absorption properties of untreated bamboo stem from the components of the lignin.

The chemical components which are responsible for the UV absorption property can be extracted by aqueous dioxane or protic polar solvents such as water and ethanol. However, non-polar solvent hexane can also extract the UV absorbing chemical components. Acetone, DMSO and toluene should not be used as extraction solvents because of their poor extraction ability and UV responsiveness.

FT-IR study indicated that the degumming process during fibre production may remove most of the lignin, which may contribute to the loss of the UV-screening properties in the textile fibre. The results suggest that the viscose method is not suitable to produce UV-blocking bamboo fibres.

**References**


