A UV dosimeter label made from films of polyvinyl alcohol and *Swietenia mahagoni* bark extract

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Abstract. In daily life, we are all exposed to ultraviolet (UV) radiation, which, in excessive doses, is very harmful to skin health. To measure UV intensity in everyday life, UV labels must be developed to determine the UV dose received in a simple and practical way. This paper reports on the development of a UV dosimeter label that is fabricated from polyvinyl alcohol (PVA) film and natural dye extract. The film labels were prepared by mixing extracts of *Swietenia mahagoni* and PVA with dye to 30% concentration. The film was characterized by using Fourier transform infrared spectrometry, UV-visible spectrometry, and colorimetry. The response of film labels to UV exposure was studied by exposing them to UV radiation at intensities of 0, 2, 3, 4, and 5 kJ/m². The effects of time and storage conditions on the color stability of the film labels were evaluated for seven days. After exposure to UV radiation, the film labels change color from brown before exposure to increasingly dark brown with increasing UV intensity. The results of this experiment show that film labels made of PVA and *Swietenia mahagoni* extract provide a sensitive measure of the intensity of UV radiation.

Keywords: ultraviolet, label, *Swietenia mahagoni*, polyvinyl alcohol

1. Introduction

Ultraviolet (UV) radiation is nonionizing electromagnetic radiation in the wavelength range from 200 to 400 nm [1]. Depending on the dose, UV radiation may have negative or positive effects on health. Exposure to UV at specific doses is very beneficial for the synthesis of vitamin D and for healing rickets, eczema [2], and psoriasis [3]. However, excessive exposure is extremely dangerous, especially for the eyes and skin, and can result in sunburn, tanning, photokeratitis, photoconjunctivitus, photoaging, clouding of the lens, cataracts, and/or skin cancer [2,4]. Thus, it is important to know the UV dose received by the body, which is the motivation for developing a personal UV dosimeter.

Personal dosimeters play an important role in determining UV dose and typically take the form of small film labels. Several material dosimeters have been reported for detecting UV dose; these are divided into two groups; namely, dosimeters with and without coloring agents. Dosimeters without coloring agents include phenothiazine film [5], biological dosimeters (uracil molecules, bacteria, DNA) [6], and polyphenylene oxide [7]. Several other researchers have reported the use of coloring agents to indicate UV radiation [3,4,8]. Coloring agents can be obtained from synthetic and natural dyes, and natural coloring agents are environmentally friendly because they are much more biodegradable than synthetic coloring agents [9]. However, few studies have focused on the use of coloring agents from natural dyes. In one such work, Bhatti *et al.* [10] reported the use of Eucalyptus bark as a UV-sensitive dye in a dosimetry label. In their study, one of the coloring agents was immobilized on the polymer polyvinyl alcohol (PVA).
PVA is often used as a dosimeter label matrix [11] and is an environmentally friendly synthetic polymer. To prepare film labels, the properties of PVA must be considered: its solubility in water, mechanical strength, biodegradability, and thermal stability [12].

This paper reports the development of a UV dosimeter label made from PVA and Swietenia mahagoni (SM) bark extract. SM is an Indonesian tree species whose extract is used to color batik [13]. The sensitivity of the proposed UV dosimeter label to UV radiation is tested by using colorimetry.

2. Experimental

2.1. Materials
The SM bark used as coloring agent in this research was obtained from a local market. The absolute ethanol solution used to extract the SM bark was purchased from J. T. Baker. The PVA used as matrix was supplied by Merck.

2.2. Extraction of Swietenia mahagoni bark
The extraction of SM bark was done in several steps: First, to reduce the water content, the SM bark was heated to 40 °C for three days in an oven. After drying, the bark was cut into small pieces and weighed at 40 g, mixed with 150 mL of ethanol, and left for one day at room temperature. The extract solution produced had pH of 5.9. To remove residue, the solution was filtered twice by using Whatman no. 1 paper. Finally, the solution was stored at 5 °C in the dark.

2.3. Preparation of labels
The film labels were made from a coloring agent extract and the PVA matrix. The PVA matrix was prepared by diluting 20 g of PVA powder into 1000 mL of Aquades 2% (v/v) that was then stirred at 300 rpm at 55 °C until a homogeneous solution was reached. The PVA solution was then mixed with 50% extract of SM bark, stirred for 10 minutes, and then 50 mL of the solution was poured into a mold on a 15 cm × 15 cm acrylic board to create the film. The PVA-SM films were then dried at 20 °C for 48 hours. After drying, the labels were stored in the dark at ambient temperature.

2.4. Test of stability of label colour
The stability of the label color was tested under dark and bright conditions. The label stored in dark conditions was enveloped in UV-resistant material, and the label stored in bright conditions was illuminated by a lamp with very low UV emission. Both samples were placed in a transparent room temperature chamber with a relative humidity of 53%.

2.5. UV irradiation
All samples were irradiated by using an ATLAS UV2000 (Chicago, USA). The UV chamber contained four UV-A lamps, each emitting 40 W at 340 nm. The UV-A intensity on the label was 0.77 W/m². The sample was then cut into 2 cm × 3 cm labels, placed in a special holder, and then put into the UV chamber. The labels were exposed to UV radiation at doses of 2, 3, 4, and 5 kJ/m² at 30 °C.

2.6. Characterization of labels
The pH of the PVA, SM extract, and PVA-SM was recorded by using a pH meter (Horiba Scientific, Japan). The label color before and after UV exposure was measured by using a Nix Pro colorimeter (Nix sensor Ltd, Ontario, Canada). The label absorbance was measured by using a Spectral UV-vis (Thermo Genesys 10S) over the wavelength range 200–800 nm with 1 nm resolution. The functional groups of the labels were obtained by using Fourier transform infrared spectroscopy (FTIR) with a Nicolet iS5 spectra (Thermo Scientific) at wavenumbers 500–4000 cm⁻¹.

3. Results and discussion

3.1. Effects of UV radiation on label colour
Extraction of SM bark yields a brownish-red solution, which is consistent with the experience of Fauziyah et al. [14]. The bark extract mixed with the PVA was light brown in color and produced brown film labels with a total RGB of 165.44, as shown in figure 1a.
Upon UV exposure, the PVA-SM label changed color as shown in figure 1b and figure 1c. The label changed from brown to darker brown upon exposure to 5 kJ/m² of UV radiation. The optical properties of the label were measured by using the NIX pro UV-Vis colorimeter. The decreased total RGB reveals a color change to a darker shade of brown. The decrease in RGB occurs in the blue (B) and green (G), which decrease significantly with increasing UV radiation. The largest decrease in RGB occurs in B (19.2 points), with G decreasing by 12.4 points, and red (R) decreasing by 8 points, as observed from RGB control.

3.2. UV-Vis spectra of label
The absorbance of the labels before and after UV exposure was measured by using the UV-vis spectrometer over the wavelength range 200–800 nm. Figure 2 shows the increase in the label’s absorbance after UV exposure. The maximum absorbance before and after radiation exposure has four peaks: 399, 455, 480, and 579 nm. Although the magnitude of the first peak is the largest, it is in the UV, so it may be neglected. The second and third peaks are close in wavelength; it is these peaks that provide the dominant contributions to the color of the label. At 455 and 480 nm, the label reflects the complimentary colors of yellow and orange, and the mix of these colors give the complimentary color seen on the label, which is brown. The biggest change in absorbance (0.005) occurs between the
second and third peaks. Finally, the fourth peak has the lowest absorbance. The wavelength $\lambda_{\text{max}}$ of maximum absorbance at each peak stays constant despite the increase in UV dose. The absorbance at 480 nm is greater than that at 455 and 579 nm. Thus, the 480 nm absorbance peak is suitable for calibrating the label.

3.3. FTIR spectra of labels
Figure 3 shows the FTIR spectra of the PVA film, SM-bark extract, and PVA-SM film labels before UV exposure and of PVA-SM film labels after UV exposure to 4 kJ/m². The optical properties of PVA labels were acquired at 1096, 2908, and 3226 cm⁻¹. C–O, C–H, and O–H stretching vibrations appear at 1096, 2908, and 3226 cm⁻¹, respectively [15]. The SM extract has absorption bands at 665–730, 1087–1124, and 2840–3000 cm⁻¹, which correspond to C=C, C–O, and C–H stretching vibrations, respectively. The PVA-SM labels have absorption bands at 665–730, 1085, 2915, and 3285 cm⁻¹, which correspond to C=C, C–O, C–H, and O–H stretching vibrations, respectively. The FTIR absorbance spectrum of PVA-SM film is similar to that of PVA film. The absorbance bands of the SM extract are not very apparent because the extract was not sufficiently concentrated. However, the label is brown in color, which differentiates it from the PVA film. The absorbances of the PVA-SM label before and after UV exposure has similar FTIR spectra, which indicates that UV exposure does not change the chemical structure of the labels.

3.4. Effects of UV exposure on stability of colour of film label
The stability of the color of the film label before UV exposure was tested in both dark and bright conditions (see figure 4). The color intensity of the labels was calculated at seven-day intervals by
Figure 4. Stability of film labels during storage in dark and bright conditions at room temperature with 53% relative humidity.

Figure 5. Absorbance at $\lambda_{\text{max}} = 480$ nm of PVA-SM film label as a function of UV dose using the colorimeter. The color of the labels remains relatively stable when stored in both dark and bright conditions. Although differences in intensities appeared because the labels had different homogeneities, storage in dark or bright clearly did not change the color of labels. In bright conditions, the labels were stable because the lights in the laboratory emit very little UV.

3.5. Calibration curve
Figure 5 shows the absorbance at $\lambda_{\text{max}} = 480$ nm as a function of UV dose for the PVA-SM film labels before and after UV exposure. This curve identifies the absorbance increase of the labels corresponding to UV exposures of 2, 3, 4, and 5 kJ/m$^2$. The minimum (maximum) absorbance is 0.49 (0.57) at 5 kJ/m$^2$. This increase can be seen by eye on the labels, which change from brown to dark brown in color. This curve is essentially linear, so it can be used to calibrate these UV dosimeter labels.

4. Conclusions
We fabricated UV dosimeter labels from a PVA matrix with *Swietenia mahagoni* bark as coloring agent. The dosimeter is sensitive to exposure to UV radiation up to 5 kJ/m. The color of the dosimeter label changes continuously from brown to dark brown with increasing UV radiation dose. Color gradation is demonstrated by using UV-Vis spectroscopy and a NIX Pro colorimeter to monitor the increase in absorbance and decrease in color intensity. The maximum absorbance is 480 nm and increases linearly with UV exposure up to 5 kJ/m. These UV dosimeter labels are also stable in both dark and bright conditions when not exposed to UV irradiation.

Acknowledgements
The authors would like to thank Einago (www.einago.com) for the English language review.

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