Short Communication

Optical properties of textile materials added with UV protective biomaterials

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Abstract
Scientific reports around the world indicate that solar radiation has increased its intensity and consequently its UV radiation, making it necessary to improve protective materials against this radiation. Textiles can be used as a protective material against the UV radiation, and one way to increase their UV protection capacity could be by adding biomaterials with optical absorption in the UV region. In the present study, flavonoids, natural pigments absorbing UV radiation, were extracted from corn seeds by using two methods (maceration and microwave oven assisted). The extracted flavonoids as well as a commercial protector of UV-B radiation were added to a cotton textile and then exposed to different UV-B radiation times (0 min, 30 min and 60 min). The optical absorption spectra of flavonoids and textile materials were obtained by photoacoustic spectroscopy. These spectra showed differences, observing that the textile added with commercial protector was degraded with the exposition of UV radiation; meanwhile in the case of the textile added with flavonoids increased its UV protection.

Keywords Photoacoustic spectroscopy · UV-B radiation · UV protection · Textiles

1 Introduction

Currently, technological developments seek to improve the properties of materials [1–4], with incorporation of other materials or biomaterials through different methods to increase their properties and make them more absorbent, resistant, flexible, etc., to be able to respond to the new environmental conditions of temperature, radiation and humidity, among others [5–7]. One of the problems with more repercussions is the increase in UV radiation. There are reports that the UV light radiation on several regions of the planet has varied 7% and 35% in summer and winter, respectively [8]. In the UV-B radiation, ranging from 280 to 315 nm wavelength, it has been found an aggressive impact in biological materials exposed to this radiation. In the case of humans, it has manifested as damage to DNA and RNA. Also, several investigations have been observed that visual problems are related to UV-B radiation [9, 10], as well as epidermal tissue, when exposed to this type of radiation with its high energy content, modify the DNA with serious damages, causing skin cancer [11]. In some countries, the skin damage cases have increased, which has led to preventive measures being taken to reduce damage in the population [12]. Developing materials for the protection of human body from harmful agents has led to the generation of several functional textiles for UV protection, antimicrobial, humidity, temperature, etc. [13–16]. Textiles are materials that allow the addition of substances and biomaterials to improve the protection against UV radiation. By other hand, it is desirable to have techniques to characterize the improved textiles, where the samples to be analyzed are not be altered

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or destroyed. In this sense, photothermal (PT) techniques allow the optical and thermal characterization of several materials, substances or compounds [17–21] to obtain some physical parameters, such as the optical absorption coefficient, thermal effusivity, diffusivity, thermal images, heat capacity, etc. Among the PT techniques, stand out, the photoacoustic spectroscopy (PAS), which has been used to characterize optically solid materials, homogeneous liquids and biological materials to obtain their optical absorption spectra. The considerations of the mathematical model proposed by Rosencwaig and Gersho [22] have allowed the obtaining of optical absorption coefficients and thermal properties in diverse types of materials. In this study, natural pigments, extracted from corn seeds, were added to textiles to improve their protection capacity against UV radiation. PAS was used to obtain the optical absorption spectra of natural pigments, extracted from corn seeds and textiles added with these pigments.

2 Materials and methods

2.1 Materials

The natural pigments used in this study were extracted from the cooking of commercial white corn kernels, BD-57 variety, produced in Morelos State, Mexico. It is worth mentioning when cooking different agricultural grains, several substances contained in superficial layers or skin are released; most of them are phenols and flavonoids [23–25]. For the cooking of corn kernels, 2% of $Ca\ (OH)_2$ was incorporated into boiling water with the kernels during 30 min. The extraction of the natural pigments, from the obtained samples, was done by two methods, maceration and microwave oven assisted. Finally, the obtained powder was placed in a solution methanol/water (60/40) to measure the weight transfer in components in both extraction methods of these liquid solutions. The photoacoustic spectra of the powder samples were obtained by PAS.

2.2 Addition of UV protectors and exposure to UV radiation

The obtained natural pigments from maize seeds by maceration method and commercial chemical anti-UV agent were added to samples of cotton textiles by the preparation and fixation method. The natural pigments obtained by maceration method were chosen due to their high content of phenols and flavonoids, when compared with the pigment contents extracted from the microwave-assisted method. Subsequently, the samples were placed inside a UV-B radiation camera with an emission range between 290 and 315 nm, with power of 2.5 W, and a distance of 15 cm between the lamp and the samples. After samples were exposed to 10, 30 and 60 h, and their photoacoustic spectra were obtained.

2.3 PAS experimental setup

Figure 1a shows the PAS experimental setup consisting of a xenon lamp, as a source of excitation light, a monochromator to obtain a monochromatic light beam at different wavelengths, a mechanical chopper, to obtain a modulated light beam at constant frequency of 17 Hz, and an optical fiber for guiding the light beam into the photoacoustic (PA) cell, which is hermetically sealed, where the sample is contained. The generated PA signal, within the PA cell, is detected by an electret microphone connected to a lock-in amplifier, which processes the PA signal being sent to a computer to record the photoacoustic signals, amplitude and phase, as a function of the incident wavelength. The sample PA spectra were obtained as a function of the incident wavelength, ranging from 250 to 500 nm. These spectra were analyzed to study these natural pigments, in their liquid form, and also, the textile materials without and after addition of the bio-protective material against UV radiation.

3 Results

Figure 1b shows the PA spectra obtained from the solution of the corn grain residues when performing the extraction by both methods. It is possible to observe differences in the PA signal, which could be due to the fact that the maceration extraction is performed without energy that excites the solution, while in the microwave-assisted method the solution is excited by a radiant energy. In both extraction methods, the PA signal has a similar behavior, but the microwave-assisted method has a lower intensity level, indicating that the absorption of the sample decreases when compared with the maceration method. The extracted solutions by the two methods have an optical absorption band ranging from 260 to 400 nm, being this absorption band characteristic of solutions with extracts of phenolic acids and flavonoids, reported in the literature by different characterization techniques [26–28].

Figure 2 shows the PA spectra of the cotton textiles, (a) added with the anti-UV commercial protector and (b) added with the extracted solution (phenols and flavonoids) of the corn grains; also, the first derivative can be observed in the inset of both figures to observe better the wavelength of the maximum absorption peaks of the samples. In Fig. 2a, is observed that commercial protector anti-UV-B, when it is exposed to 30 and 60 h, due

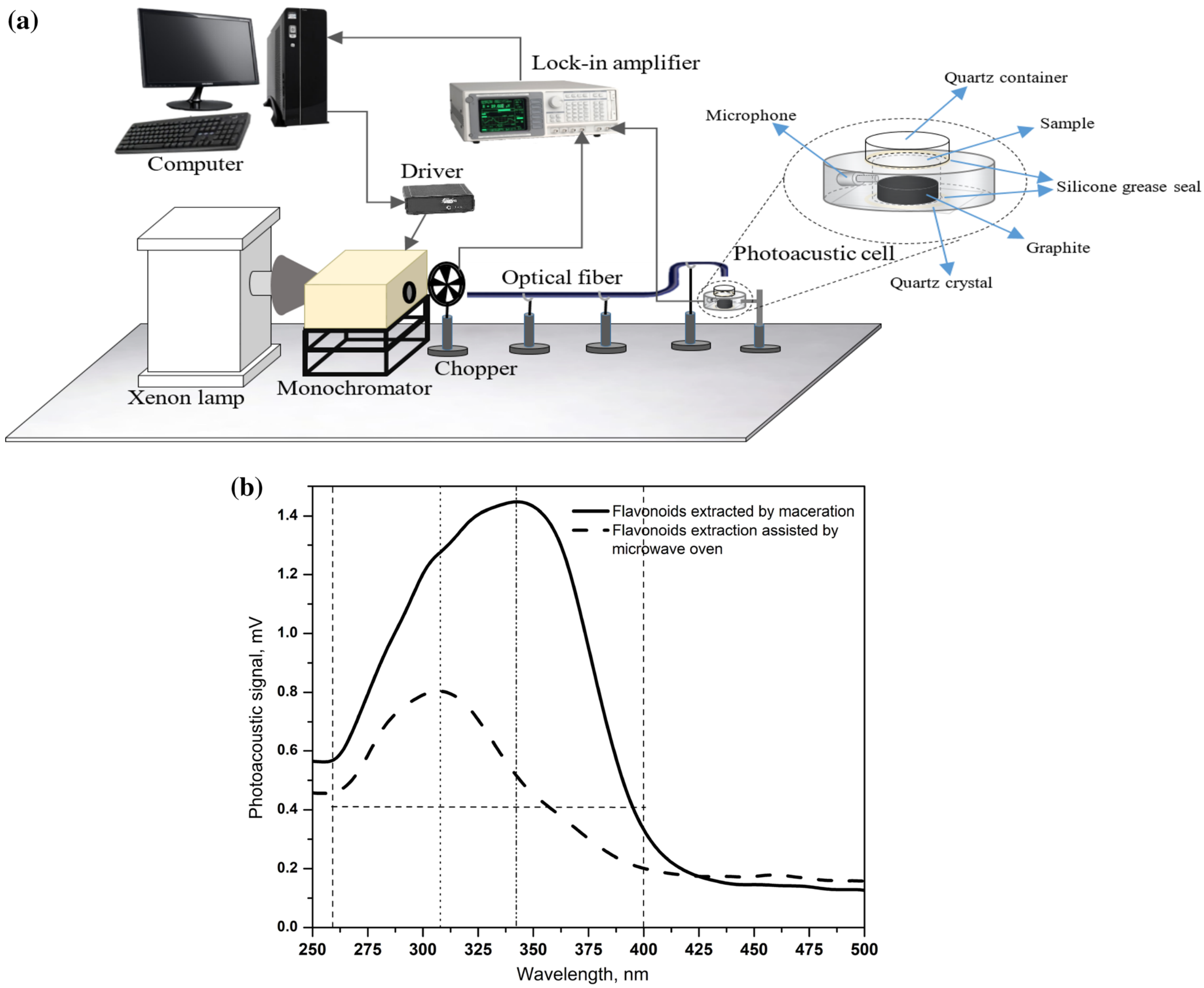

Fig. 1 **a** PAS experimental setup and **b** photoacoustic spectra. Flavonoid extracts by different methods

to the UV-B radiation it begins to degrade minimally at 30 h with respect to the sample without exposure, but degradation increases at 60 h. This degradation being more noticeable in the range of 350 to 500 nm. On the other hand, in Fig. 2b we can observe the photoacoustic spectra of the cotton textiles added with the solution extracted from the corn grains, showing that it increases the absorption throughout the range measured from 250 to 400 nm. After 400 nm, the absorption remains similar, even when the sample was exposed to 30 and 60 h of UV-B radiation, having a greater increase in the maximum absorbent peak at 300 nm. Observing the differences shown between the photoacoustic spectra in Fig. 2a, b in both cases, the optical absorption coefficients and the penetration length of the samples were calculated to compare textiles without radiation and those exposed to radiation of 30 and 60 h.

3.1 Calculation of optical absorption coefficient and optical penetration length

The optical absorption coefficient (β) and the optical penetration length (l_β) of the textiles were determined from the equation of Poulet et al. [29]. It is possible to observe in Eq. (1) that β is a function of the normalized PA signal amplitude (q) obtained by PAS.

$$\beta = \frac{q}{\mu_s}\frac{q + \sqrt{2 - q^2}}{1 - q^2}, \tag{1}$$

In Eq. (1), the normalized PA signal amplitude (q) was obtained by the ratio of the sample PA signal amplitude to the charcoal powder PA signal amplitude, in order to take into account the Xe lamp emission spectrum. After verification of the textile thermal thickness condition: $l_s/\mu_s \gg 1$,

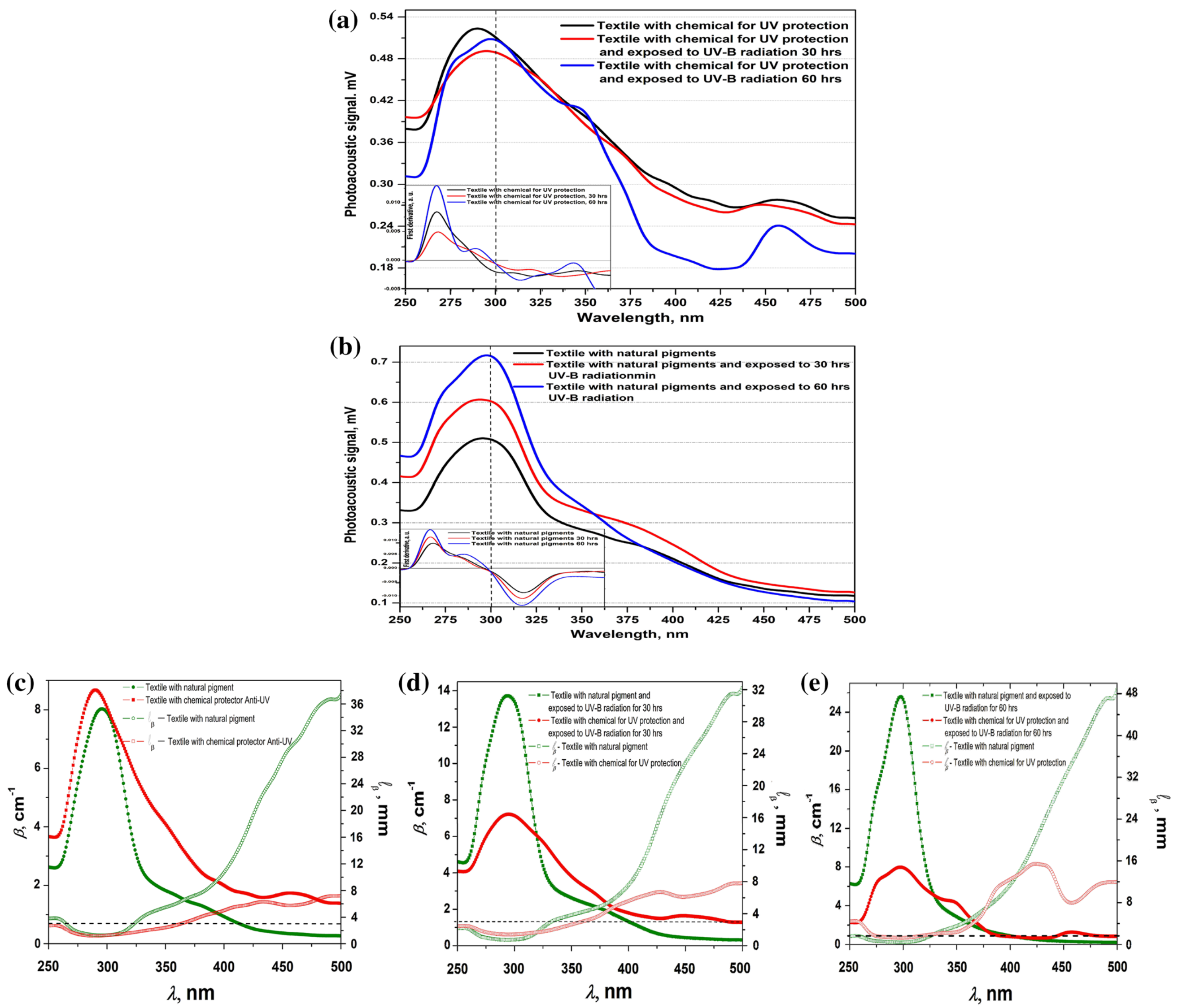

Fig. 2 Photoacoustic spectra of textiles added with **a** commercial UV protector and **b** waste solution of corn kernels, differences between optical absorption coefficients and penetration length in textiles with commercial UV protector and natural pigments **c** without radiation exposure, **d** radiation exposed 30 h and **e** 60 h

where $\mu_s = \sqrt{\alpha/\pi f}$ is the thermal diffusion length and f is the light modulation frequency, fixed at 17 Hz; finally, α and l_s are the sample thermal diffusivity and thickness, respectively.

In order to calculate β from Eq. (1), it was found for cotton textile that the reported thermal diffusivity is $\alpha = 8 \times 10^{-2}$ cm^2/s, D. Romelli et al. [30]. Finally, the optical penetration length l_β was calculated from the inverse of β, being $l_\beta = 1/\beta$.

Figure 2 shows the optical absorption spectra and the optical penetration length of textiles without radiation (c), and those exposed to UV-B radiation during 30 h and 60 h in (d) and (e), respectively. Figure 2c shows that the textile added with the commercial (chemical) anti-UV has the higher optical absorption coefficient, when compared with the textile added with natural pigments (extracted from the corn kernels), and a wider band in the optical penetration length, in a range between 250 nm and 375 nm, which indicates that this sample, in the mentioned range, shows greater opacity and less penetration of UV light. In the case of the textiles added with chemical UV protection and natural pigments exposed to UV-B radiation during 30 h and 60 h, their optical absorption spectra are shown in Fig. 2d, e, respectively. It is possible to observe from Fig. 2d that the textile with chemical UV protection preserves its optical absorption and penetration length as before of radiation, as shown in Fig. 2c for this textile, while the textile with natural pigments increases its absorption and optical penetration properties. The penetration length is similar to the UV chemical protector, ranging from 250 to 360 nm. On the one hand, from Fig. 2c, it can be observed that the textile with UV chemical protector begins to degrade its optical absorption, but optical penetration remains in the same range. On the other hand, the textile with natural pigments increases its optical absorption and penetration properties, showing an optical penetration length, in the range from 250 to 370 nm, close to the UV protector, being opaque both materials added to the textiles, not allowing the penetration of UV light in this region.

4 Conclusion

By means of PAS, it is possible to determine the differences that exist in extracted solutions of natural pigments obtained by means of different methods, as well as the effects of degradation produced by UV-B radiation in textile materials added with commercial protector or natural pigments, extracted from corn kernels. These pigments could be used as a protector for UV-B radiation by adding in natural textiles.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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