

Abstract

Dye dosimetry is based on the fact that ionizing radiations interact with matter and cause the color change of the dye. This property of color change of dye can be used for dosimetry as the decomposition of dye is linear with respect to the amount of dose absorbed. Synthetic and natural dyes are used for developing radiochromic dosimeters. The natural dyes are the source of strong, beautiful, stable and long-lasting colors. The natural dyes are economical and cost-effective. They are eco-friendly, less toxic and less allergic. They are unsophisticated and coherent with nature and cause lower level of pollutant emission than synthetic dyes. The turmeric dye curcumin solution in chloroform was investigated spectrophotometrically and spectrofluorometrically for its dosimetric characteristics for low dose dosimetry. The results of our studies show curcumin dye solution in chloroform shows a promising response for low dose dosimetry in the range between 0 to 30 Gy.

Objective

To study turmeric (curcumin) dyes for their potential applications as cheap low dose x-ray and gamma-ray dosimeters.

Materials & Methods

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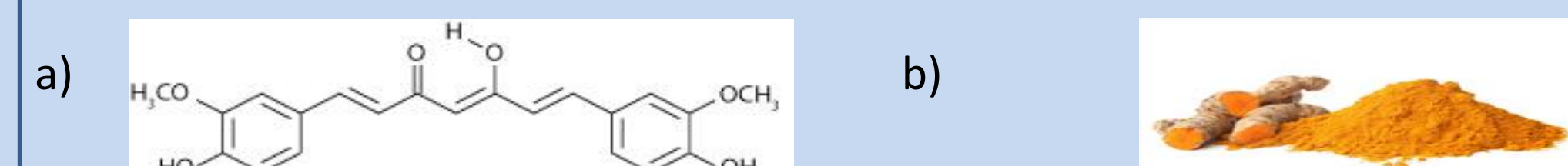


Fig. 1. a) Chemical structure of Turmeric dye (curcumin) 1,7-bis(4-hydroxy-3-methoxyphenyl)-1, 6-heptadiene-3, 5-dione b) Turmeric plant and curcumin powder.

The irradiation was conducted at a dose rate 300 & 600 cGy/minute with a field size of 10 cm x 10 cm, source to surface distance (SSD) of 100 cm, 1.5 cm acrylic build-up and additional acrylic layers at the bottom for secondary electron equilibrium. About 4 mL of the dosimetric solution was irradiated in each glass vial fitted with a solvent resistant plastic cap (Fig.2)



Fig.2. Irradiation Conditions: a) dosimetric solutions in 4 mL vial b) 6 MV medical linear accelerator c) Irradiation dimensions

Our work on heptamethine dyes show dosimetric response of radiochromic color changes as illustrated in Fig.3 [2].



Fig.3. Visual color changes of Cy7-PF6 solution in chloroform irradiated at (a) 30 Gy and (b) color

Materials & Methods

Irradiation was performed by 6 MV Medical Linear Accelerator at Centro de Radioterapia da Regiao de Bauru, Bauru, Sao Paulo, Brazil and Co-60 source of Department of Psychology at University of Sao Paulo (USP) in Ribeirao Preto, Sao Paulo, Brazil. The samples have been analyzed by UV-Vis and fluorescence spectroscopy.

Measurements of UV-Vis spectroscopy have been performed on a Shimadzu (UV mini 1240). The fluorescence measurements have been performed using a Varian fluorimeter (Cary Eclipse). The samples have been excited with a wavelength of 254 nm and 292 nm. Figs.3 & 4 show the spectrophotometric and spectrofluorometric curves for turmeric dye solutions, respectively.



UV-Vis Spectrophotometer



Fluorescence spectrophotometer

Results & Discussion

The parameters evaluated using these methods include, effects of solvents, effects of dose rate, useful dose range and effects of light and temperature on pre-irradiation stability of dosimetric solutions. The sensitivity of our dosimeter solution can fulfill the requirements for the applications in radiotherapy where low dose radiation (~ 50 Gy) is used [3]. The dosimetric characteristics in halogenated solvent chloroform and non-halogenated solvents ethanol and toluene were tested in the dose range from 0 to 30 Gy. While chloroform solution showed linear dosimetric response (Fig.5), no dosimetric responses were observed in the non-halogenated solvents. The effects of dose rate were also evaluated following the work of Basfar [4].

Our results show dose rate to have little or no significant effect on the dosimetric characteristics of the dyes. The dosimetric solutions were found to be stable before and after irradiation when kept in the dark at room temperature and at 20°C. The dose range was found to be between 0- 30 Gy. It also shows linear response below one gray (Fig.6). The ethanol- trichloroacetic acid solution of turmeric (curcumin) dye showed linear response in the range between 0 to 30 Gy. (Fig.7)

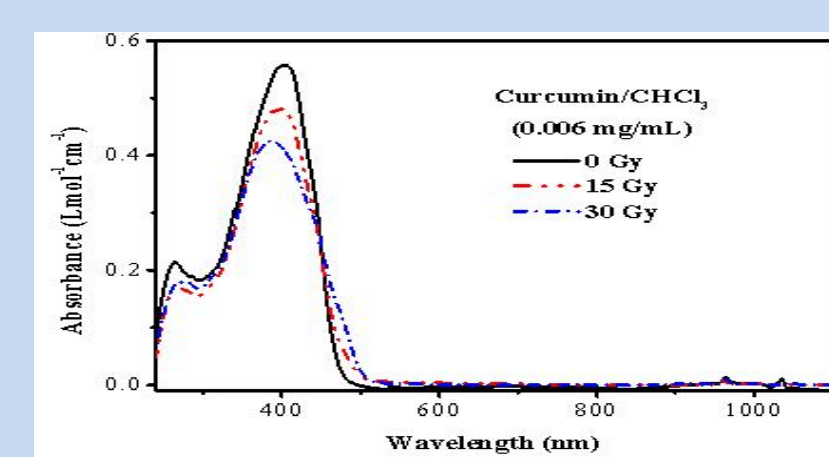


Figure 3. Absorbance spectra of un-irradiated and irradiated 0.006 mg/mL solution; top to bottom: un-irradiated, 15 and 30 Gy of the dosimetric solutions of curcumin.

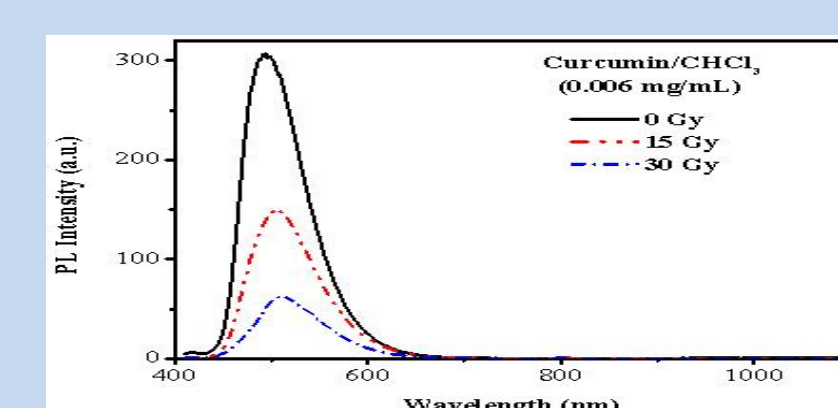


Figure 4. Photoluminescence spectra of un-irradiated and irradiated 0.006 mg/mL solution; top to bottom: un-irradiated, 15 and 30 Gy of the dosimetric solutions curcumin at 400 nm excitation

The emission spectral response curve (Figure 5) plotted as intensity (emission amplitude) ratio of irradiated per un-irradiated sample (E/E_0) at 400 nm excitation as a function of radiation dose shows linear relation. The linear response can be written for $E/E_0 = (0.96 \pm 0.08) - (0.02 \pm 0.00) D$ with $R^2 = 0.98$. D stands for applied dose and R^2 the square of linear correlation parameter. Using the angular equation of the proposed equation, a sensitivity of $(0.02 \pm 0.00) \text{ Gy}^{-1}$ for curcumin was obtained which makes it a very promising material for low dose dosimetry. This shows the possibility of using curcumin solution in chloroform for low dose dosimetry.

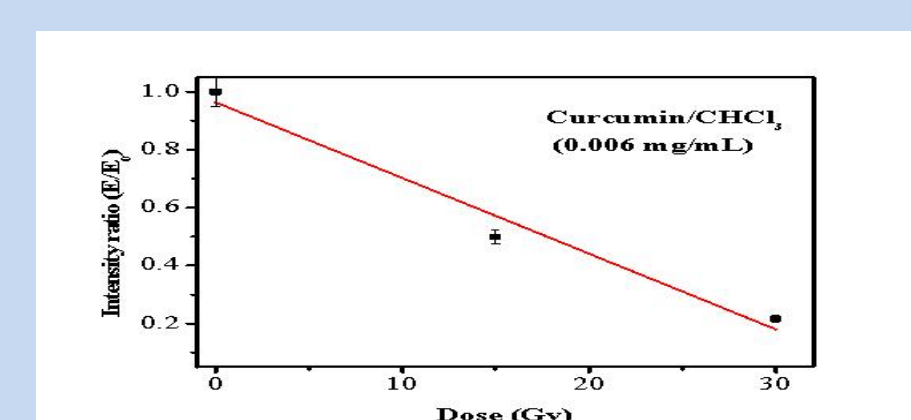


Figure 5. Response plot for curcumin (0.006 mg/mL) solution in CHCl_3 showing emission amplitude ratio (E/E_0) (at 400 nm excitation) versus absorbed radiation dose

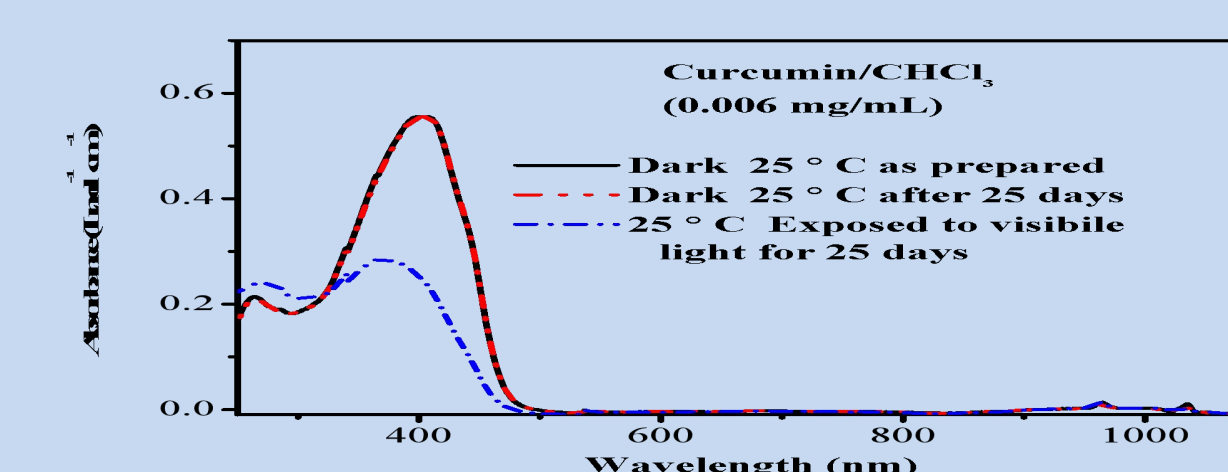


Figure 6. Absorption spectra of curcumin (0.006 mg/mL) in CHCl_3 solution pre-irradiation stability study (in dark and visible light).

Results & Discussion

The pre-irradiation stability study of curcumin solution in chloroform in dark and light at room temperature was evaluated. Our results show that the solutions kept in the dark showed remarkable stability (with < 0.5 % decrease in absorbance change after 25 days) (Fig. 6).

Curcumin was evaluated if it shows dosimetric characteristics in a non-hazardous solvent ethanol with 80% chloral hydrate. Chloral hydrate was used following the work of Abdel-Fattah et al in [5]. As can be seen from the UV-Vis spectra in Figure 7, a slight decrease in intensity of the main peak was observed after irradiation (at 20 Gy) similar to the curcumin/chloroform solution dosimeter.

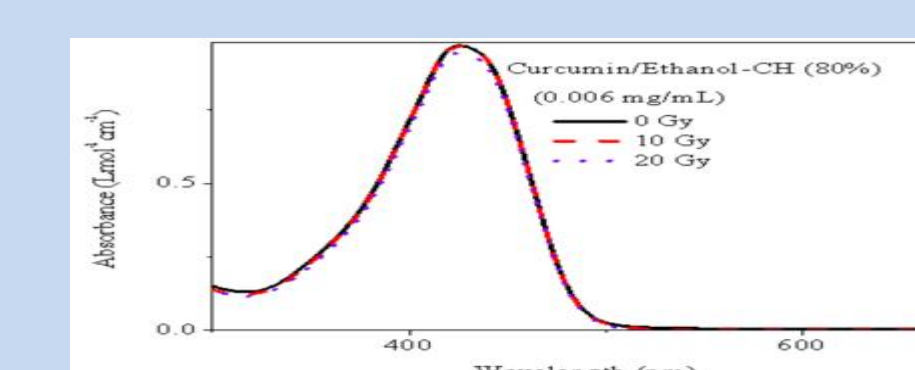
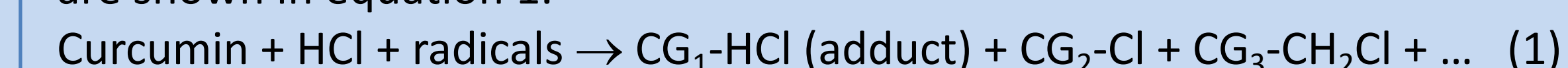


Figure 7. UV-Vis spectra of 0.006 mg/mL curcumin in ethanol with 80% chloral hydrate. Top to bottom: unirradiated, irradiated at 10 Gy and 20 Gy.

We propose that the dosimetric characteristics observed in turmeric (curcumin) dyes would be due to attack of HCl, .Cl and other radicals on the conjugated bonds of these dyes. This resulting in breakdown of the conjugation with formation of new chromophoric groups with smaller conjugation [6] as is evidenced by the enhancement of peaks at shorter wavelengths and disappearance of peaks at longer wavelengths seen in the absorption spectra (Fig.3).

The proposed mechanisms for HCl & radicals attack on the conjugated vinyl bonds are shown in equation 1.



$\text{CG}_1, \text{CG}_2, \text{CG}_3 \dots$ stand for chromophoric groups (CGI) which are expected to be formed by radical initiated fragmentation reactions.

Conclusions

The turmeric (curcumin) solutions in chloroform appear to be suitable low dose smart dosimeters in the range from 0 to 30 Gy. Moreover, these dosimetric solutions also show linear behavior below one gray. The response curves of emission amplitude or absorbance max ratios (A_1/A_2) versus absorbed doses are linear up to 30 Gy and also even below one Gy.

The dosimetric dye solutions are very useful for precise monitoring of doses delivered to patients in radiotherapy applications. The ethanol-chloral hydrate dosimetric solution of curcumin has a great potential for making a dosimeter which is based on non-toxic solvents. The shelf life of the pre-irradiated dye solutions also show good stability up to 20 days.

References

1. A. B. Neto, E. S. B. Uhle, M. V. G. Vismara, A. P. Assis, F. A. Castro, T. Geiger, F. C. Lavarda, C. F. O. Graeff, **2013**, *Curr. Phys. Chem.*, 3, 000-000.
2. Hagos Tesfay, E. S. Bronze-Uhle, A. Batagin-Neto, Anna Véron, Thomas Geiger, Teketel Yohannes, Negussie Megerssa and C.F.O. Graeff, *Current Physical Chemistry*, 2015, Vol. 5, No. 3
3. Y. S. Zhao, H. Zhong, Q. Pei, **2008**, *Phys. Chem. Chem. Phys.*, 10, 1848
4. A. A. Basfar, K. A. Rabaeh, A. A. Moussa, R. I. Msalam, **2011**, *Radiat. Phys. Chem.*, 80, 763.
5. A. A. Abdel-Fattah, M. El-Kelany, F. Abdel-Rehim, *Rad. Phys. Chem.*, 1996, 48, 497.
6. E. S. Bronze-Uhle, A. Batagin-Neto, F. C. Lavarda, C. F. O. Graeff, **2011**, *J. Appl. Phys.*, 110, 073510.

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