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## Radiation effects on the integrity of paper

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## ABSTRACT

Books and documents attacked by fungi and insects have already been treated by radiation for disinfection purposes. However, there is still need to investigate the influence of radiation on the cellulose paper structure. The aim of this research was to study the effects of radiation on paper properties, especially those related to strength and appearance.

Paper sheets for this study were prepared in the laboratory, using bleached eucalyptus pulp as raw material. No additives were used to concentrate the attention only on the effects of irradiation on the pure cellulose matrix.

The samples were irradiated at IPEN's <sup>60</sup>Co Gammacell irradiator with six radiation doses, from 3 to 15 kGy at the dose rate 0.817 Gy/s. The properties of paper sheets were tested after irradiation and compared with unirradiated samples according to ISO methods. No significant changes were detected in paper samples irradiated up to 15 kGy.

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## 1. Introduction

Fungi can cause spots or stains on paper and degrade its cellulose fibers affecting paper's integrity. These stains may be due to chemicals produced by fungi in metabolic processes, using cellulose as a nutrient source, and also to the pigmented mycelium and/or spores (Szczepanowska and Lovett, 1992; Nieto-Fernandez et al., 2004).

The deterioration of cellulose by fungi consists of enzymatic hydrolysis catalyzed by cellulase enzymes produced by fungi (Nevell and Haigzeronian, 1985). *Cladosporium* is one of the fungus's genera most prevalent in paper, in Brazil as well as in other countries (Gambale et al., 1993; Proniewicz et al., 2002; Valentin, 1986; Florian, 1997).

The presence of fungi in paper frequently represents a risk to health (Gambale et al., 1993) and disinfection is necessary. There are many ways of doing disinfection, for example the application of ethylene oxide gas or water vapor and radiation processes.

Radiation processing for medical devices sterilization and for biological control in food is quite well known and is already a commercial technology. Nonetheless, there are different opinions about what should be the radiation dose applied to paper, for disinfection and insect control, once the integrity of paper must be kept. Gonzalez and Kairiyama (2002) compared paper damage

for accelerated ageing and gamma irradiation and concluded that the former introduced larger mechanical properties differences than the latter. The authors used in their study nine different papers samples (library uses) and 14.40 kGy total radiation dose (0.15 kGy/min). Carneiro Tomazello and Wiendl (1996) pointed out some possible paper damage related to irradiation even for doses from 5 kGy up to 10 kGy. According to Pavon Flores (1975), 18 kGy was able to completely eliminate fungi from varieties of paper, inducing damages into structure of paper and it was pointed out that for the papers that contained great quantity of non-cellulosic products (newspaper paper, for instance) the results were very satisfactory.

Today radiation process for books and documents preservation is a continuous controversy, but many countries are trying to fix doses and conditions to be suggested and used as a suitable option.

The main objective of this study was to verify the influence of ionizing radiation on cellulose fibers network.

## 2. Materials and methods

*Preparation of laboratory sheets:* laboratory sheets of 75 g/m<sup>2</sup>, dimension 1500 × 1500 mm<sup>2</sup>, were made with industrial-bleached sulphate Eucalyptus pulp, following methods applied by the pulp and paper sector: the pulp was refined according to ISO 5264-2 (2002), until a refining degree of 31 Shopper Riegler Degree,

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determined according to ISO 5267-1 (1999), and the sheets were formed according to the ISO 5269-1 (2005) method.

*Sheets irradiation:* irradiation of the laboratory sheets was carried out at IPEN/SP (Instituto de Pesquisas Energéticas

e Nucleares), using a  $^{60}\text{Co}$  Gammacell 220 source, serie no. 142. The radiation doses applied to laboratory paper sheets were: 3, 6, 9, 12, and 15 kGy (dose rate 0.817 Gy/s). The radiation source and its doses were checked by an international system adopted by the International Atomic Energy Agency for Fricke Dosimetry (the variation on radiation doses at this material was <12%). During irradiation ten cellulose sheets were used for each dose and samples were packed in a plastic bag.

*Analyzed properties:* the irradiated and non-irradiated laboratory sheets were conditioned and tested at  $(23 \pm 1)^\circ\text{C}$  and  $(50 \pm 2)\%$  relative humidity. Table 1 presents the properties tested on those sheets.

The mechanical properties of paper are important and determine the durability and resistance to applied forces exhibited by paper during end-use performance. Appearance properties of paper are related to the sense of vision so they are measured by optical instrumentation.

The mechanical properties depend on the paper grammage, which is the amount of mass per area. As the paper grammage increases, the mechanical property values also increase. Therefore, the effect of grammage must be eliminated to compare results. This was done by dividing the resistance property value by the paper sheet grammage, resulting in an index value. The grammage of the laboratory sheets were determined using the method described in the ISO 536 (1995) standard.

**Table 1**  
Test methods for mechanical and appearance properties.

Property	Method
Mechanical	
Tensile strength	ISO 1924-2 (1994)
Zero span tensile strength (Pulmac equipment)	TAPPI T231 cm (1996)
Tearing resistance	ISO 1974 (1990)
Appearance	
Diffuse blue reflectance factor—ISO brightness (Elerepho 3300—Datacolor equipment)	ISO 2470 (2001) ERRATA/2002
Colour by CIE $L^*$ , $a^*$ , $b^*$ system (Elerepho 3300—Datacolor equipment)	TAPPI T527 om (2002)

TAPPI—technical Association of Pulp and Paper Industry.

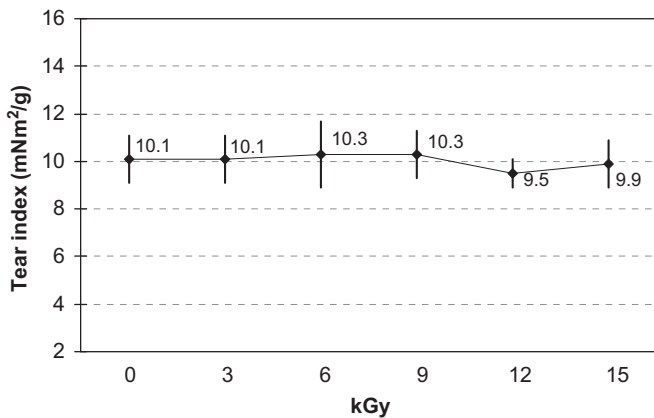


Fig. 1. Tear index vs. radiation dose.

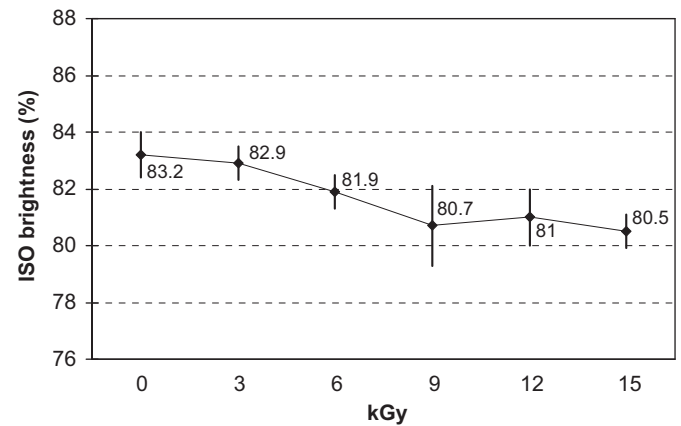


Fig. 3. ISO brightness vs. radiation dose.

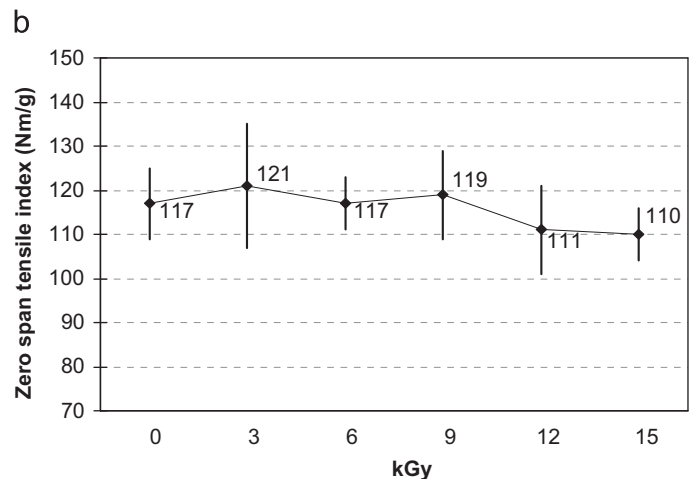
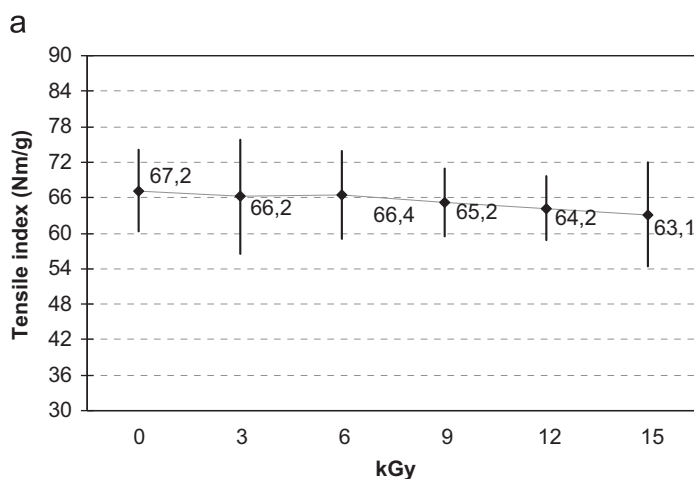


Fig. 2. (a) Tensile index vs. radiation dose and (b) zero span tensile index vs. radiation dose.

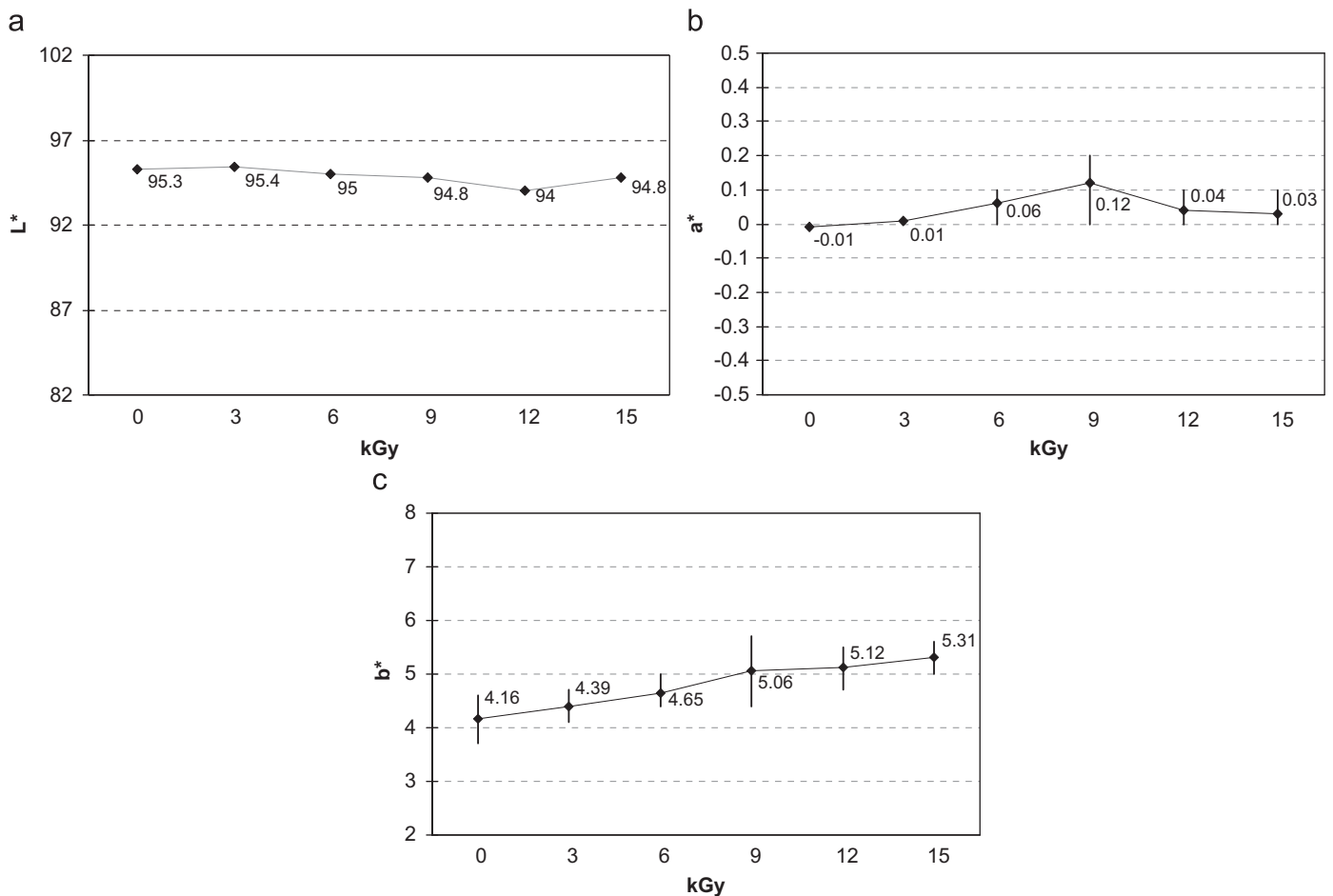


Fig. 4. Color (CIE  $L^*$ ,  $a^*$  e  $b^*$ ) vs. radiation dose. (a) Behaviour of the color coordinate  $L^*$ ; (b) behaviour of the color coordinate  $a^*$ ; (c) behaviour of the color coordinate  $b^*$ .

### 3. Results

The results are shown in Figs. 1–4. There was a decrease in the tensile, tear and zero span indexes at 12 kGy radiation dose. This was greater for the zero span tensile index, which means that the resistance of the fiber was more affected than the resistance of the paper sheet. The tensile strength is related to the paper ability to endure tension conditions. The tensile strength depends on the resistance of the fibers and on the network formed by them, while the zero span tensile strength depends only on the fibers resistance. Both tests are important once the tensile strength is useful to measure the effect of the irradiation over the fibers and network and the zero span tensile strength see the effect only over the fibers. Probably there was some cleavage on cellulose molecule, affecting the fiber, but the extension was not enough to cause significant modification at fibers network of the laboratory cellulose sheet.

For radiation process be successfully applied to books decontamination, under safety conditions, it is recommended to think about lowest radiation dose as possible and also to verify the dose rate for the process. The differences on resistance of Whatman paper (cellulose) obtained by Magaudda (2004) was related to de-polymerization of cellulose at 5 kGy. On the contrary, Gonzales et al. (2002) applied 14.4 kGy at nine different commercial papers and did not observe problems on the papers resistance.

Although decreasing continuously, the brightness showed a significant decrease from 9 kGy radiation dose and the color

parameter  $b^*$  was the one that showed more variation from 9 kGy and higher radiation dose (Fig. 4c). Brightness, measured at 457 nm, was designed primarily as a test to determine the effectiveness of bleaching cellulose pulps, but it is also well suited for measuring the aging of paper, since the change in the paper color on aging or degradation is greatest in the blue and violet regions of the spectrum. Color, as brightness, is affected by aging and degradation. The method used to measure the color, CIE  $L^*$ ,  $a^*$ ,  $b^*$  system, consists of a grey axis  $L^*$ , a yellow–blue axis  $a^*$  and a green–red axis  $b^*$  in a three-dimensional color system. The variation observed in brightness and  $b^*$  shows a yellowing of the sheet, but not significant enough to be observed by eyes.

### 4. Conclusion

The variations observed for the studied properties were small enough to be considered significant on the paper resistance or appearance. The examined properties in this study were those usually employed for paper characterization. Complementary studies must be done to better understand the effect of irradiation on paper.

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