

EVALUATION OF THE EFFECTS OF ELECTRON-BEAM IRRADIATION ON THE PUNCTURE RESISTANCE BY *LASIODERMA SERRICORNE* IN FLEXIBLE PACKAGING OF GRANOLA

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ABSTRACT

Lasioderma serricorne is a beetle that infests stored and industrialized dry foods such as cereal bars, granola, flour and pasta, amongst others, depreciating the products and causing economic losses. It is therefore critical for these products a packaging that presents, in addition to good mechanical, barrier and machinability properties, a good resistance to puncture by insects, in order to prevent the contact and spread of pests in the packaged food. This study evaluates the changes on mechanical properties and puncture resistance by *L. serricorne* in BOPP/PP structure, used commercially as granola packaging after electron-beam irradiation. The irradiations were performed using a 1.5 MeV electron beam accelerator, dose rate of 11.22 kGy/s, at room temperature in presence of air, doses up to 120 kGy. After irradiation the BOPP/PP samples were subjected to tests of puncture resistance by *L. serricorne*, tensile strength, friction coefficient, penetration and seal strength. Results showed decreases in the original mechanical properties of the structure according to the radiation doses applied and effective resistance against punctures by *L. serricorne* ($p < 0.05$). The results indicate that the irradiated and non-irradiated BOPP/PP structure, in the conditions studied in this work, is resistant against *L. serricorne*, however the decreases observed in the mechanical properties of the irradiated structure may turn it inappropriate for packaging granola.

1. INTRODUCTION

Actually many plagues like beetles, mites, moths and fungi can infest stored products as cereal bars, grains, tobacco and dry fruits causing deterioration, depreciation and economical losses. One of these plagues is the tobacco beetle, *Lasioderma serricorne* (Fabricius, 1792), widely known as a common plague of tobacco, can also infest many stored dry foods like flour, cereal bars and granola. The nymph measures around 2 to 4 mm in length and almost do not eat, being the larvae the major responsible for the damage to the stored products. After copulation the females can puncture dry food packaging, laying its eggs on the substrate, or in case it couldn't efficiently penetrate, laying the eggs on the packaging surface. After

hatching the larvae goes within the packaging and substrate, feeding itself as it digs galleries away from the light [1, 2].

Thus, the packaging has an important role on the protection and maintenance of the stored food until it reaches its final consumer, reducing the microbiological and oxidative deterioration, and offering enough resistance against invasions from plagues. It's also fundamental for the packaging to have good technical properties to run well in the equipments of the food industry, like good mechanical resistance, good machinability and sealability properties. The packaging must also not transfer any odors and flavors to the packaged food [3].

Within this context, it's known that the ionizing radiation may cause structural changes at the polymeric materials of the packaging, as well as in the additives incorporated into these polymers, changing its mechanical, chemical, thermal and barrier properties. Two simultaneous reactions are the major responsible for the physic-chemical changes due to the incidence of ionizing radiation on the polymeric structures: scission and cross-linking of the molecular chains. The prevalence of one reaction over the other dictates the changes in the polymers properties. In general the prevalence of cross-linking reduces crystallinity, increases density, tensile and flexural strength, chemical and thermal resistance. It also reduces the elongation at break, impact resistance and transparency. The prevalence of scission does the opposite to the polymer properties, and in addition, promotes a more efficient molecular orientation and hence a significant reduction in the permeation rate, since the increase in the molecular organization complicates the diffusivity of liquids or gases [4-6]. The purpose of the present study was to evaluate the effects of electron beam radiation in some mechanical properties and puncture resistance against *Lasioderma serricorne* of a flexible plastic packaging used to store granola.

2. MATERIALS AND METHODS

2.1. Materials

The commercial multilayer flexible packaging material studied in this work is composed of bi-oriented polypropylene and polypropylene (BOPP/PP), with average thickness of 50 μm , which is commonly used in packaging of granola. The granola used is composed of a mixture of oat flakes, crystallized fruits, sugar cane molasses, cornflakes, raisins, cashew nuts, dried banana, malt, cereal, organic brown sugar, corn oil and grated desiccated coconut. The BOPP/PP structures as well as the granola used in this work were obtained in the retail trade of São Paulo, made by various manufacturers.

The nymphs of *L. serricorne* were obtained from the creations of the Arthropods Laboratory of the Instituto Biológico de São Paulo, where they grow in dried bread and heated room with $27 \pm 2^\circ\text{C}$ and relative humidity of $70 \pm 5\%$.

2.2. Irradiations

The structure was irradiated in a electron beam accelerator with energy of 1,5 MeV, 25 mA current and 37,5 kW power, in room temperature and air presence. The dose range went up to 120 kGy, with the rate of 11,22 kGy/s. The doses were confirmed using cellulose triacetate dosimeters. After irradiation the samples were packaged inside plastic bags and stored in a dry and dark place until the realization of the tests.

2.3. Mechanical Evaluation

In this study were performed the mechanical tests of tensile strength at break, based on the methodology described at ASTM D 882-91 [7]; penetration resistance, based on ASTM F 1306-90 [8], using a tip drill with one millimeter of diameter; seal strength based on ASTM F 88-00 [9] in the PP surfaces, and friction coefficient (C.O.F) in the BOPP surfaces, based on ASTM D 1894-06 [10].

In order to consider and evaluate the post irradiation effects, the mechanical properties tests were carried out on the BOPP/PP structure eight days after irradiation, and repeated after sixty and again after one hundred eighty days, except for the C.O.F, done only after eight days.

2.4. Puncture by *L. serricorne*

Based on the data obtained from the mechanical tests, the doses of 10, 20 and 60 kGy were selected to run under these tests. For each radiation dose selected, including the non-irradiated, nine samples of the same size were sealed with 40 g of granola inside, and equally split in three plastic boxes of 26,5L with 20 nymphs of the beetle in each box during sixty days, starting eight days after irradiation, in a heated room like the one they were created. After the infestation period the packaging samples were evaluated for punctures with the aid of a magnifying glass.

2.5. Statistical Analysis

All the changes observed were confirmed by one-way ANOVA, using the software BioEstat (version 5.0, 2007, Windows 95, Manaus, AM, Brazil), with the significance level of $p < 0.05$.

3. RESULTS AND DISCUSSION

• **Tensile strength and elongation at break:** As shown in Fig. 1, it was observed a decrease in the original tensile strength of the BOPP/PP structure by 8- 47 % eight days after irradiation, as well as decreases by 9-52 % for the tests performed sixty and one hundred eighty days after the radiation treatment ($p < 0.05$).

The elongation at break results (Fig. 2) showed, eight days after irradiation, gains ca. 4% for the structure irradiated with 10 kGy, and decreases by 4-53 % above this dose when

compared with the original BOPP/PP structure. In the results obtained sixty and one hundred eighty days after irradiation it is observed for the doses above 10 kGy bigger decreases, by 10-55 %, when compared with the results obtained eight days after the treatment (10-55 %), although its observed an increase of ca. 7% for the dose of 5 kGy, one hundred eighty days after irradiation ($p < 0.05$).

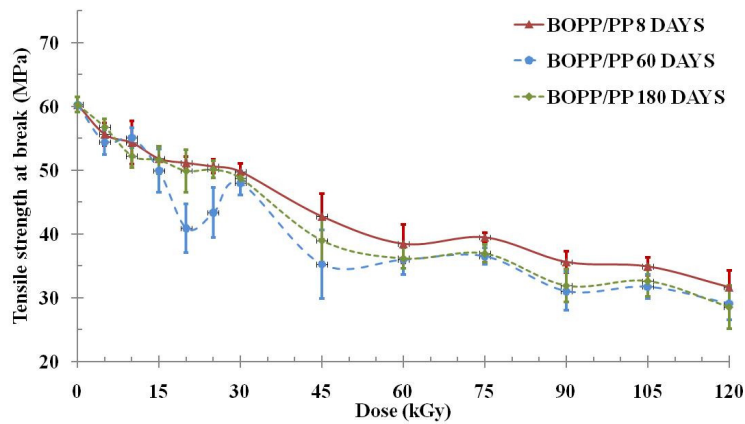


Figure 1. Tensile strength at break as a function of the radiation dose applied on the BOPP/PP structure.

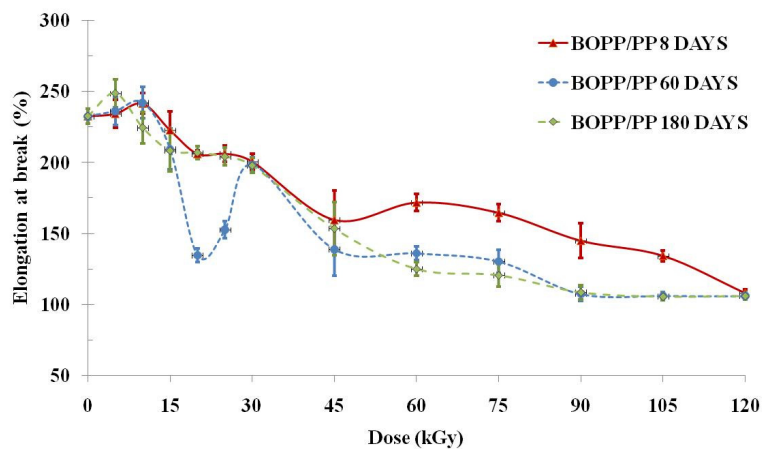


Figure 2. Percent elongation at break as a function of the radiation dose applied on the BOPP/PP structure.

• **Seal strength:** Figure 3 shows the effects of the electron-beam radiation dose applied in the sealability of the BOPP/PP structure. The results obtained showed decreases above the 10 kGy dose, by 28-96 % eight days and by 18-96 % sixty days after irradiation. The tests performed one hundred eighty days after irradiation showed bigger decreases than in the other periods evaluated, in all doses studied, by 24-100% ($p < 0.05$). It is important to consider that all the samples in this test were sealed with 210°C for 2 seconds. However, if this

temperature is used for samples irradiated with more than 30 kGy the structure is degraded, thus for the samples irradiated above this dose the sealing temperature used was of 170°C for 2 seconds.

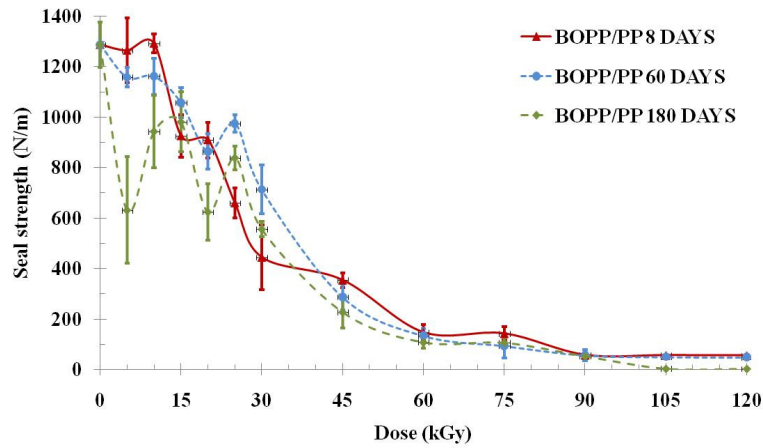


Figure 3. Seal strength as a function of the radiation dose applied on the BOPP/PP structure.

• **Penetration resistance:** The Figure 4 shows decreases in the original penetration resistance of the BOPP/PP structure as a function of the radiation doses applied, for all dose range and period studied. These decreases goes by 25-75 % eight days after irradiation, by 18-82 % sixty days after irradiation and by 26-88 % one hundred eighty days after irradiation ($p < 0.05$).

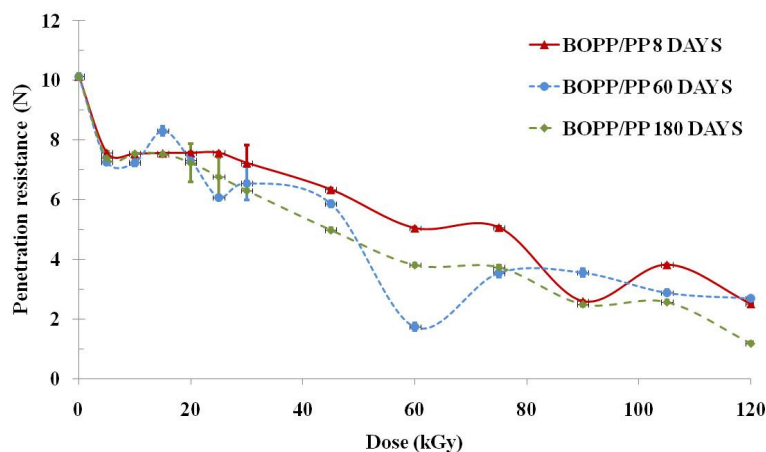


Figure 4. Penetration resistance as a function of the radiation dose applied on the BOPP/PP structure.

The decreases observed in the mechanical properties of the BOPP/PP structure shown in this work suggests that the electron beam radiation applied, in the conditions studied, favored the scission process over the cross-linking one on the polypropylene molecular chains. As it can be seen too, after sixty and one hundred eighty days the BOPP/PP structure keeps showing changes in its mechanical properties, indicating that the free radicals formed due to the radiation effects continues acting on the molecular chains of polypropylene structure and its incorporated additives even after so long. Amongst the mechanical properties evaluated the sealability is the most depreciated one.

- **Coefficient of friction:** As showed in Fig. 5, its observed an increase in the coefficient of friction in both static (22-61 %) and kinetic (46-99 %), with the increase of radiation dose applied ($p < 0.05$). These increases probably occurred due to the degradation of the resin and its incorporated slip additives.

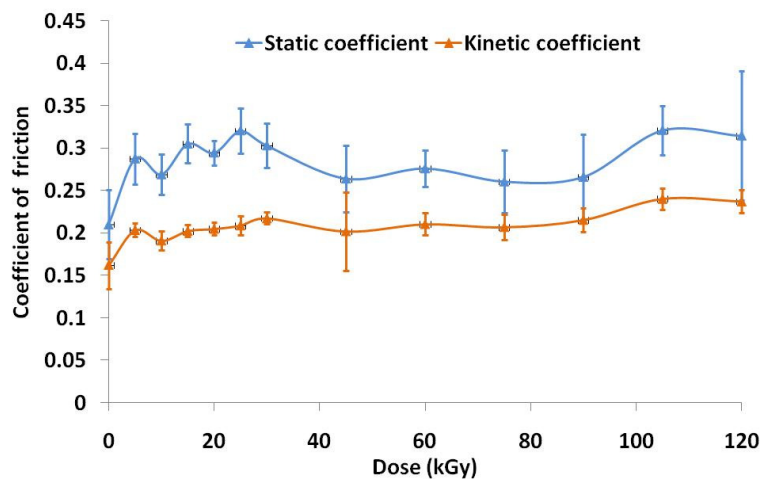


Figure 5. Coefficient of friction as a function of the radiation dose applied on the BOPP/PP structure.

- **Puncture resistance by *L. serricornis*:** In these tests the beetle was capable to do a single puncture in one of the packaged samples, on the non-irradiated and the 60 kGy packaging, with no successful punctures in the samples irradiated with the doses of 10 and 20 kGy. Thus, the low successful puncture rates observed, even after the high infestation pressure over sixty days, shows that the non-irradiated structure is already enough resistant to the beetle, keeping that resistance even after all the decreases in its mechanical properties due to the electron-beam radiation applied.

4. CONCLUSION

The use of electron-beam radiation to modify mechanical properties of the BOPP/PP structure used for granola packaging is not recommended once this study shows that the non-irradiated material is already quite resistant to the puncture by *L. serricorne* and for most of the doses applied, a decrease of the mechanical properties was observed for all periods of time that the material was evaluated.

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