# Dynamic laser speckle applied to the analysis of maturation process of irradiated fresh fruits.

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## ABSTRACT

The treatment of fresh fruits with different doses of ionizing radiation has been found effective for delaying ripening and, in this way, to extend shelf life. This preservation method is likely to produce some functional or constitutive changes in the cellular structure of the fruit. In this work, a test of the effectiveness of fruit irradiation with relatively low doses was performed by using dynamic speckle imaging. Bananas from a same lot were chosen, being a first series of them irradiated with different doses of 0.2, 0.4 and 0.6 kGy (Gy = J/kg) and a second series with doses of 0.2, 0.4, 0.6 and 1 kGy. Non irradiated bananas (0 kGy) were considered as the lot reference for contrast. Irradiation was carried out at the Semi-Industrial Cobalt 60 facility of the Ezeiza Atomic Center, with an activity of $6 \times 10^5$ Curie and a dose rate of 28.5 Gy/min. The objective of this work is to analyze differences in the maturation process between irradiated and non-irradiated fruits by means of dynamic speckle pattern evaluation.

**Keywords:** Dynamic speckle, irradiated bananas, food preservation, mobility index

## 1. INTRODUCTION

Over the years the dynamic speckle pattern techniques have been applied to the study of many processes in which there is a possibility to observe mobility on the piece under study. This mobility, either shallow (superficial) or inner (interior), generates a change on the intensity distributions that come from the speckle pattern.

Speckle dynamic pattern originates on the phase differences located on the wave front that comes from the reflection of a highly coherent light beam on a rough surface.

The observation of the speckle pattern variations on living cells such as fruit cells is a particular case of study (Rabal, Braga, 2009).

Fruit peel is composed by different cell types, each one with particular sizes and functions.

Pattern analysis must be done through digital processing of the images taken with a CCD camera. There are many different analysis methods on statistical variables that facilitate time correlation in the study.

This work presents the results obtained from an analysis of dynamic speckle patterns of irradiated fruit by applying a new algorithm based on a statistical study of a resultant image matrix.

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## 2. METHODOLOGY

### 2.1 Irradiation process

Bananas were irradiated inside cardboard boxes, at room temperature, at the Semi Industrial Cobalt-60 facility of the Ezeiza Atomic Center, activity about 600.000 Curies. Radiation doses were measured by Fricke dosimetry, with average dose uniformity =1.05, and dose rate = 40 Gy/min (Gy= Joule/kg).

### 2.2 Optical methodology

A 50 mW Helium – Neon Laser was used as a coherent light source. The wave front was amplified and filtered by a 15μm spatial filter. The fruit was illuminated directly by the filter without diffusers. A 1 MPix C-MOS camera was used to record sequences of images.
Progressive tests were performed in order to distinguish the cellular behavior of fruits that have been exposed to an irradiation process as a food preservation method. These tests are divided into two series. The first one was performed on a small number of bananas divided into two groups. Group 1 consisted of non-irradiated samples to be used as reference and group 2 consisted of samples irradiated at different doses. Tests performed on series 2 were analogous to those performed series 1, but de number of samples and irradiation doses were increased. Bananas were chosen as the study object because it is possible to extract a large amount of them proceeding from a single plant and, therefore, have the same harvesting date.

Table 1. Classification of specimens and radiation doses.

| Series | Samples | Irradiation doses kGy | Radiation source | Analysis |
|---|---|---|---|---|
| First | 8 | 0 - 0.2 - 0.4 - 0.6 | Cobalt 60 | D. Speckle |
| Second | 20 | 0 - 0.2 - 0.4 - 0.6 - 1 | Cobalt 60 | D. Speckle |

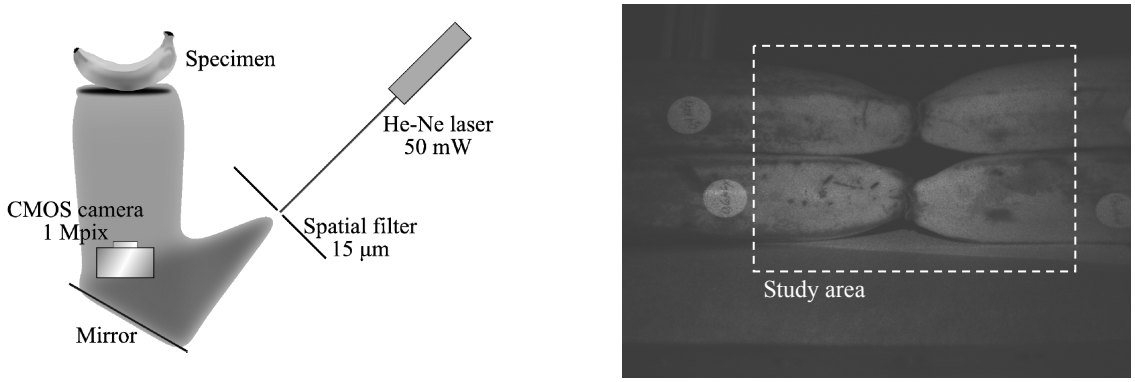


Figure -1. (Left) Experimental setup for image capture. (Right) Photograph of the bananas from series 1 and region of interest for analysis.

Four samples from series 1 were studied simultaneously, arranging them in the same capture frame, in order to ensure the same relative position in front of the camera (see figure 1). However, by using this arrangement it turns impossible two

achieve homogenous light intensity distribution. Therefore, the mobility index of different samples could not be compared.
The same method was used for the analysis of series 2. However, in this case, samples ware studied separately in order two avoid the intensity variation.
As the peel darkened made it impossible to observe cell mobility, transversal cuts were performed, dividing the fruit in half. The pieces were studied applying the same method as before. It was noticed that as the irradiation dose decreased the pulp texture showed important changes.
On the second series the same method was applied. To eliminate the intensity variations a new optical topology was designed. The samples were studied separately. On this series the experiment was divided into two groups as well. The first one consisted of five bananas with irradiation doses between 0 and 1 kGy. At first, the observation focused on peel ripening. As it darkened, the dynamic pattern became more difficult to be observed. Therefore a transversal cut was performed on samples and the pulp was analyzed. The second group consisted of fifteen bananas, three for each irradiation dose. Again, transversal cut was performed and the study focused on the pulp. In this series time intervals between photo sessions were of 12 hours, opposed to 24 hours in series one. In addition, a data logger was used to record relative humidity and temperature conditions.
More than 4,000 photos were taken in order to be processed and obtain results with the CECILIA algorithm (Conservation Evaluation by Coherent ILlumintion and Intensity Acquisition). All RMI (Relative Mobility Index) values were recorded in tables and plotted on linear graphs.

### 2.3 Processing algorithm

For the analysis of the dynamic speckle patterns, the CECILIA algorithm was developed. This algorithm was recently developed using the Matlab® interface. It consists of a digital image capture and a processing tool based on statistical analysis performed on the mobility pattern of the dynamic speckle images. As a prerequisite, it is necessary to take the photographs in a sequence having a well-defined time interval between them. Examples of the image reconstruction from the algorithm implementation can be observed in figure 2. Since it is possible to define a numeric quantity to indicate the degree of variation of speckle pattern with the ripening, the mobility can be quantified. This test studied the ripening process of a fresh strawberry during 24 hours.

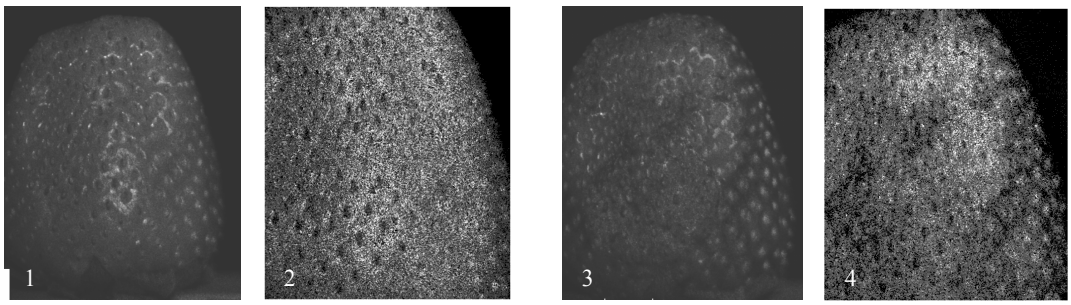


Figure-2. Photograph sequence of a strawberry reconstructed by a CECILIA algorithm. (1) First day image. (2) First day reconstructed image. (3) Second day image. (4) Second day reconstructed image.

Stability of light intensity values is very important for a proper performance of the algorithm, since a linear correlation between the mobility index and the reflected light intensity is observed. Values of the mobility index, obtained from the experiences, lay in the range between 5 and 0.01 in relative mobility units. Each index value is a repeatable average value obtained running the Matlab® routine.
The algorithm was designed considering evaluation and narrowing of measurement errors, so that the mobility index obtained can be repeated, as long as the sample´s mobility does not change.

# 3. RESULTS

## 3.1 First series

On the first experiment four bananas with different radiation doses were studied and the mobility indexes obtained indicated a significant decay. The data adjusts to a decreasing linear function. The linear graphs for the data obtained are shown on figure 3.

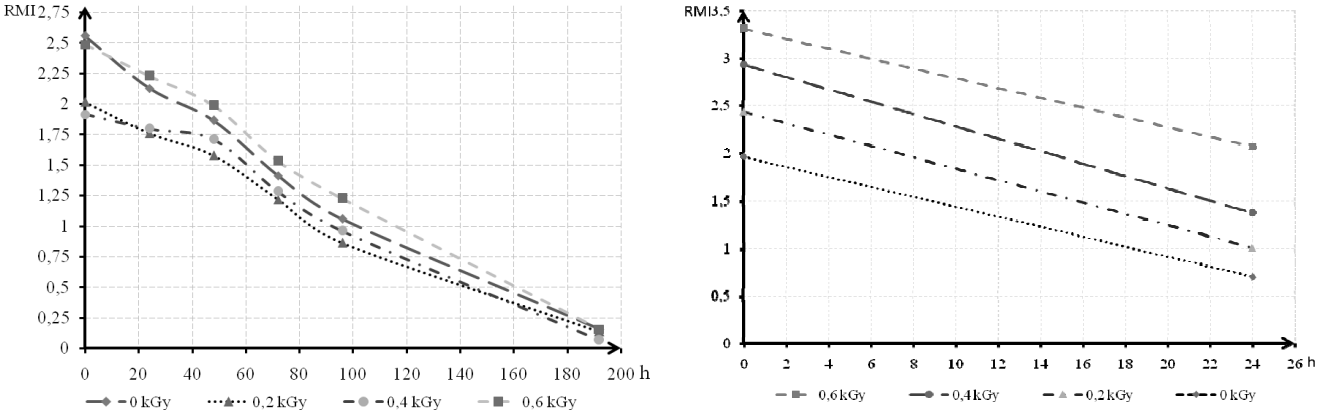


Figure - 3. (a) Mobility relative index decay for different doses in a 200 h time period. (b) Decay of pulp's mobility index during a 24 h period. The major mobility index corresponds to the maximum irradiation dose, while the minimum value was coincident with the non-irradiated fruit.

The second experiment is shown on figure 4, decreasing radiation doses from 1 to 4. In (a), first day, the non irradiated banana (4) looked more deteriorated that any of the irradiated ones. On the second day (b), all samples showed important changes in texture and mobility index.

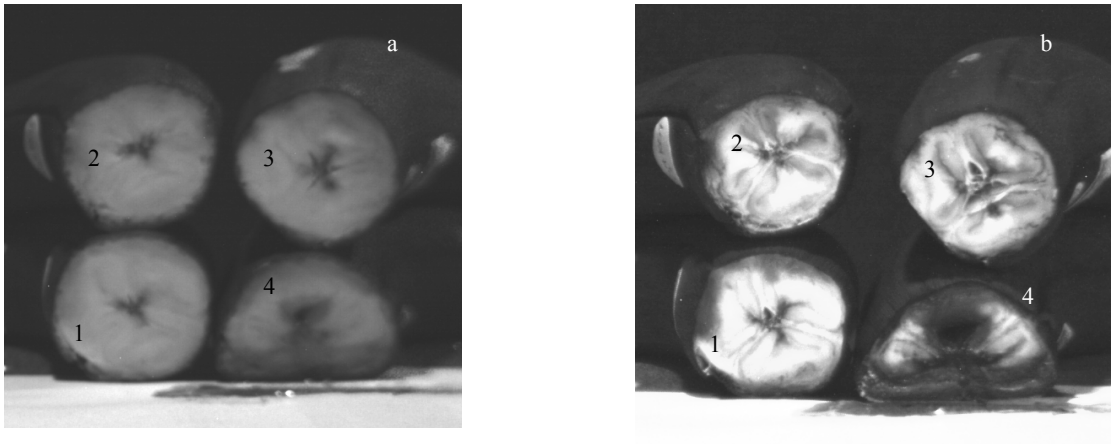


Figure - 4. Photographs of cut bananas from series in the second experiment position. (a) Immediately after being cut and, (b) after 24 h at room temperature. Labels 1 to 4 correspond (clockwise) to decreasing irradiation doses from 0.6 to 0 kGy .

### 3.2 Second series

On the second series five bananas with different radiation doses were studied and the mobility indexes obtained indicated a significant decay, as observed in series 1. In this case, the data adjusts to a decreasing exponential function. Value deviations noticed in this experiment could be caused by relative humidity variations. The linear graphs for the data obtained are shown on figure 5 and 6.

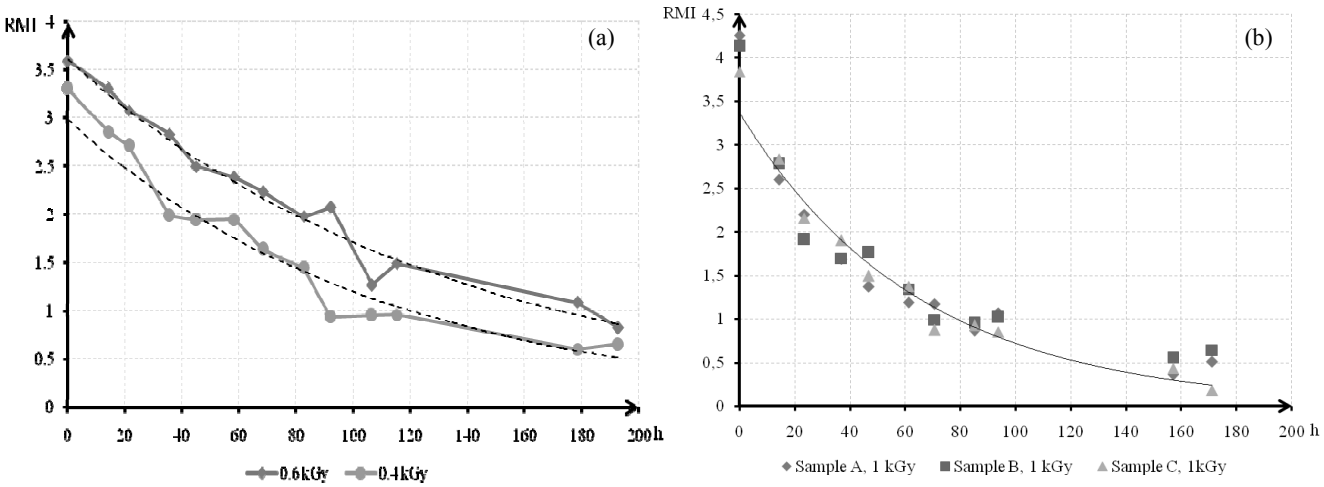


Figure -5. (a) Mobility index evolution on the peel of two samples with different irradiation doses. An exponentially decaying trend can be observed for all specimens. (b) Mobility index evolution on the pulp of three different specimens irradiated with the same dose (1 kGy), in a 7-day time period.

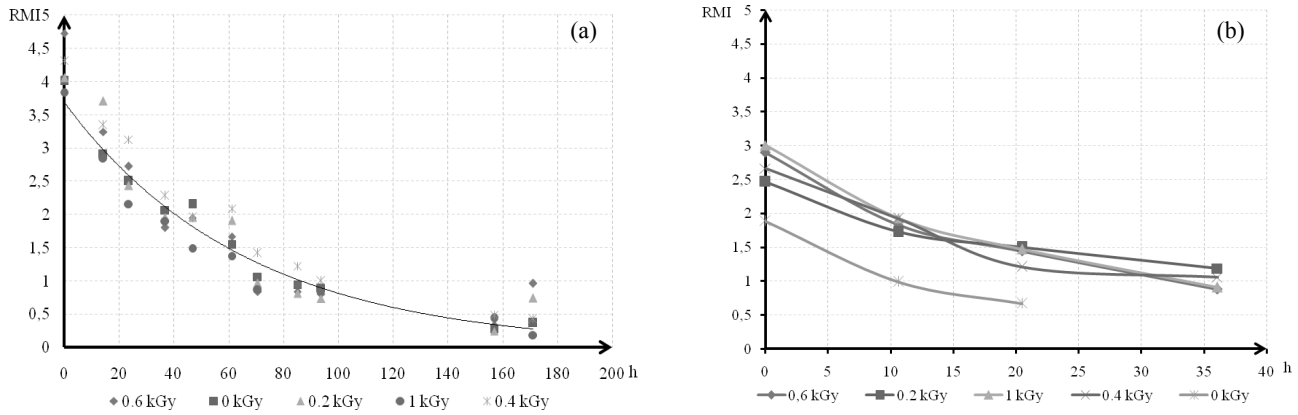


Figure - 6. Mobility index evolution (a) on the pulp of five samples with different irradiation doses between 0 and 1.0 kGy and (b) mobility index evolution on the pulp of samples previously studied with their peel.

## 4. DISCUSSION

The study documented in this article is the first of a series of experiments planned to find a possible correlation between speckle dynamic patterns and irradiation doses. This work was performed considering a sequence of experiments on two different sets of bananas (series 1 and 2).
From the analysis of the graphs it was possible to observe behavioural differences among samples with different irradiation doses, as previously shown on figures 5 and 6. All samples presented an exponential mobility decay with time. However, the mobility index values do not seem to be strongly correlated with the irradiation doses.
A further important aspect is that, by looking at the values registered on the pulp immediately after cutting the samples of series 1 and 2, about 11 days after irradiation time, a possible correlation is observed. Thus, in the pulp seems to exist a correlation linking mobility index and irradiation dose. However, further experiments with different fruits are needed in order to find a predictable connection between mobility index and irradiation dose.
The data in every graph were adjusted to a decreasing exponential function, as observed on reference sources. Outcomes for different samples with equal irradiation doses are the same, as shown on figure 5 (b).
On the eleventh day since irradiation, the samples with lower doses showed an increase in the mobility index without any apparent reason. Under the same conditions, on the twelfth day a formation of fungal colonies on the pulp was registered. These results point to an increase in the mobility of speckle pattern owing to fungal activity.

## 5. CONCLUSION

In this work, a new processing algorithm was introduced, based on the statistical analysis of a sequence of photographs taken at regular time intervals. The results of the proposed method have been verified by comparison with results obtained in experiments performed on non-irradiated fruits (0 kGy) from existing literature sources.
As a first result, there appears to be a correlation between the irradiation dose and the mobility index in the pulp when exposed to the environment, after the peel reached its maximum maturity point.


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