# Influence of colour changes and moisture content during banana drying on laser backscattering

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**Abstract:** Pre-drying treatments are frequently employed to preserve fruit quality. The objective of this research was to monitor colour changes of banana during drying by laser backscattering and to determine the influence of the fruit discolouration on the light distribution into banana tissue. Moreover, to examine the influence of drying on the laser backscatter, the relationship between moisture content and relative laser area of banana slices was analyzed with different degrees of colour degradation. The experiments were conducted at drying air temperature of 63℃ with various pre-treatments like chilling, soaking in ascorbic/citric acid and dipping in distilled water. An untreated sample was used as a control. A laser diode emitting at 670 nm with 3 mW power was used as light source. The backscattering relative laser area was used as an indicator for the light absorption into the tissue. The high result achieved on coefficient of determination $R^2$ (>0.93) confirmed linear relationship between relative laser area and moisture content. Treatment with ascorbic acid gave the best prediction of the moisture content with the standard error of 5.7 and 8.8 for the estimated intercept and slope. The results showed a significant difference of lightness ($L^*$ values) during drying according to the different treatments. As a result, colour degradation did not have a significant influence on the absorption of light at 670 nm wavelength.

**Keywords:** musa x paradisiaca, colour change, banana drying, pre-treatment, relative laser area, backscattering
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## 1 Introduction

Drying is the most common method of food preservation to enhance storability and add value to the product. During hot air drying, enzymatic and non enzymatic browning reactions can affect the quality of fruit and vegetables in terms of colour and flavour. Previous researches have reported the effect of drying on the colour of various products like mushrooms[1], bananas[2-4], and grapes[5]. Ascorbic acid[6] is the most

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common anti-browning agent, selected for use in fresh-cut fruits. Moreover, physical pre-treatments such as chilling, blanching and freezing are also used prior to drying to investigate on drying rate and quality of banana in terms of colour[7]. However, the pre-treatments affect the drying rate of various foodstuffs in a different way, according to the differences in tissue properties[8]. Recently, non-invasive techniques are employed for monitoring and controlling quality changes of agricultural products during storage and post-harvest processing. Till now, computer-assisted image processing systems for capturing scattering images on fruit by means of laser diodes as light source have been applied. Laser diode at 670 nm could be used as colour indicator of the surface because of the strong correlation between parameters obtained by image processing and red/green values from $L^*$, $a^*$, $b^*$ colour measurements[9,10]. Furthermore, laser diodes are fast and low cost devices operating without a spectrograph needed for the acquisition of the hyperspectral images[11]. In addition, laser diodes do not require calibration of colour as it is performed for the computer vision system[12]. Light scattering is a physical phenomenon dependent on the density and cell structure of fruit tissue and hence it could also be useful for the indirect measurement of fruit firmness[13]. The degree of scattering in a laser image depends on the texture of materials[14]. As a result, soft fruit tends to have a broader scattering profile than firmer fruit[15]. However, the interaction of light with the fruit tissue is complicated due to the fact that photons are also being absorbed during the multiple scattering. Qing et al.[16,17] found a correlation between laser light scattering and quality parameters of apples. Five wavelengths between 600 and 1,100 nm were used to predict firmness and total soluble solids content at different harvest conditions [18]. Baranyai and Zude[19] conducted a study to detect mechanical defect on apple tissue combining Monte Carlo simulation and laser light backscattering. Non-destructive technologies by means of changes in light penetration inside the tissue could provide a low cost way for rapid evaluation of quality of perishable products during drying. In the previous studies it has been shown that moisture content and light migration at 670 nm wavelength inside the tissue of banana were highly correlated. This also revealed the sensitivity of laser light distribution to the changing tissue absorption caused by enhanced browning at higher drying temperatures[20]. Therefore, in this research the influence of colour change on laser backscattering during banana drying was investigated. Additionally, to examine the influence of drying on the laser backscatter, the relationship between moisture content and relative laser area of banana slices was analyzed with different degrees of colour degradation. Therefore, different pre-treatments like chilling, soaking in solution of ascorbic/citric acid and dipping in distilled water were applied to banana slices.

## 2 Materials and methods

### 2.1 Sample preparation

Firm and ripe Cavendish bananas (*Musa x paradisiaca*) from a local supermarket were used for the experiments. The fruits were peeled and manually cut into slices of 5-8 mm thickness. The slices were taken from the middle section of the banana with a diameter ranging between 25 to 30 mm. The banana samples were divided into three groups of pre-treatment prior to drying. The first group was kept as whole peeled fruits in a cold room at 4℃ for 18 hours and subjected to chilling before slicing. The second group slices were immersed in a solution of 0.2% ascorbic acid/citric acid (1:1 mixture) for one minute and the third group of slices were soaked only in distilled water for 30 s. Untreated batch of slices were used as a control. The samples were wiped with tissue paper and placed in the dryer. In total 270 slices were pre-treated and 90 slices were used as a control. Before the drying trials, the fresh samples were weighted using an electronic scale and laser images were acquired.

### 2.2 Drying procedure

Drying experiments were conducted at a temperature of (63±1)℃ because it has been reported that for higher temperature, gelatinization accompanied by swelling is expected for banana[13]. A uniformly distributed hot air flow was applied parallel to the slices placed on perforated steel trays with holes of 1 cm diameter. The velocity of the air was 0.75 m/s, measured by an anemometer at the centre of each tray. All drying experiments were continued for five hours. In an hour interval, 15 samples were removed from the dryer, weighted, and brought to the optical laboratory for the acquisition of the laser images.

### 2.3 Moisture content determination and colour measurement

The moisture content was determined by drying banana slices in an atmospheric oven at 130℃ until a constant mass was reached. The moisture content was calculated in percent wet basis. The colour of fresh and dried banana slices was evaluated with a colorimeter (CR-300, Minolta, Japan) based on the CIE *L**a**b** colour space. Values of *L** represent brightness, *a** corresponds to the red-green colour gradient while *b** corresponds to the yellow-blue colour gradient.

### 2.4 Laser light backscattering

Laser backscattering images of 15 banana slices were acquired for each group of pre-treated bananas and the untreated samples at regular intervals during drying. Readings were carried out at the centre of the slice. The optical system comprised a laser diode emitting at 670 nm with 3 mW power (RS194-026, Global Laser Ltd, UK) and collimating lens. A digital camera (JVC KY-F50E, 3CCD, Victor Company, Japan) captured images of 768×576 pixel size. The distance between the camera lens and the samples were set at 24 cm. The laser diode produced a circular beam of 4.5 mm diameter. A high percentage of the photons were directly reflected, while a portion of the fruit surrounding the incident point was illuminated as a result of photon migration in the fruit tissue (Figure 1). The average value for this illuminated area was 322.5 mm$^2$.

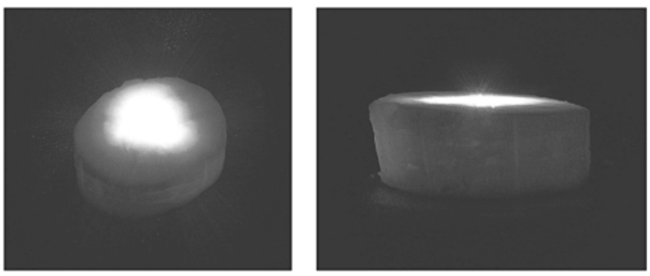

Figure 1 Top view (left) and side view (right) of a fresh banana slice illuminated by a laser beam at a wavelength of 670 nm

The backscattered light visible to the CCD sensor array of the camera was recorded, while exposure parameters such as shutter and gain were properly adjusted. The size of the relative laser area on the fruit surface (normalized to the mean value of the fresh slice) was used as an indicator for the photon migration into the sample tissue.

## 3 Results and discussion

### 3.1 Drying experiments

Figure 2 shows the course of moisture content for the four treatments during drying. Error bars represent standard deviation.

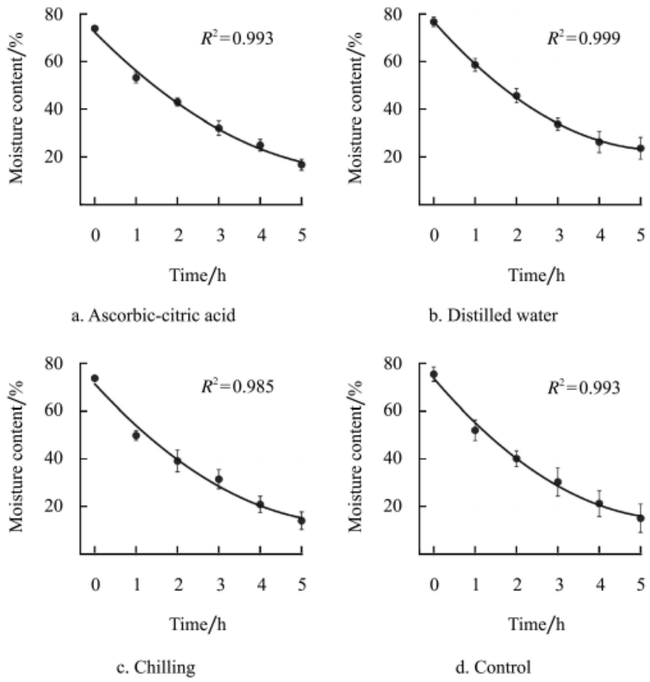


Figure 2 Moisture content vs. drying time for hot air drying of banana slices at (63±1)℃ for different treatments

The drying characteristics showed a similar trend of moisture content changes as a function of drying time for the pre-treatments of banana. Banana slices treated with distilled water and ascorbic-citric acid showed a slight difference of moisture content at the end of the drying process. This could be explained by the evaporation of the additional water added to the surface and by the different base-acid interactions.

### 3.2 Colour change

The colour of banana slices changed during the drying process. Table 1 presents the result of colour measurements of the bananas subjected to different pre-treatments. Brightness expressed as $L^*$ value seems to be the most sensitive parameter to describe the degree of colour change among the treatments. The $L^*$ value of the chilled bananas was significantly higher compared with the samples of other treatments. Samples soaked in distilled water exhibited the lowest $L^*$ value while the slices treated with ascorbic/citric acid maintained the lightness of the untreated samples.

**Table 1 Colour parameters for banana slices after different treatments (mean ± SD)**

| Colour parameters | chilling | ascorbic-citric acid | distilled water | control |
|---|---|---|---|---|
| $L^*$ | 60.30±5.69$^a$ | 58.27±7.09$^b$ | 53.65±7.89$^c$ | 57.65±7.6$^b$ |
| $a^*$ | 2.80±2.42$^a$ | 3.47±2.09$^b$ | 3.37±1.92$^b$ | 2.74±2.08$^a$ |
| $b^*$ | 15.03±2.98$^a$ | 15.37±3.15$^a$ | 14.06±3.24$^b$ | 15.16±3.8$^a$ |
| $C^*$ | 15.53±2.70$^a$ | 15.97±2.76$^a$ | 14.69±2.77$^b$ | 15.63±3.42$^a$ |
| $h^*$ | 78.50±10.87$^a$ | 76.02±9.81$^a$ | 74.87±10.87$^b$ | 77.98±11.59$^a$ |

Note: Values with different letters in the same row are significantly different at Tukey's test, $p<0.05$.

### 3.3 Backscattering images

Figure 3 shows changes of the relative laser area over time for the different pre-treatments. Lower variability was observed with slices subjected to chilling. This can be explained by the fact that storage at low temperatures may provide protection from membrane breakdown[21], minimizing lesion formation in the fruit tissue with handling and drying. Consequently, the highly organized cellular compartment of the cells decreases the intercellular air spaces[22] and less amount of light will be transmitted, maintaining a constant level of scattered photons of the banana tissue. Moreover, chilling can result in a homogeneous distribution of moisture content inside the sample, which will maintain a constant degree of scattering, thus limiting wider fluctuations of the photon dispersion in different slices.

Figure 4 shows the correlation between relative laser area and moisture content by averaging the values at each interval during drying for the different treatments of banana. The plots confirm linear relationship at $R^2$ values between 0.933 for ascorbic/citric acid treatment and 0.997 for control. The equation parameters with the estimated intercept and slope and the respective standard error are reported in Table 2. The lowest standard error was found for those fruits treated with ascorbic-citric acids.

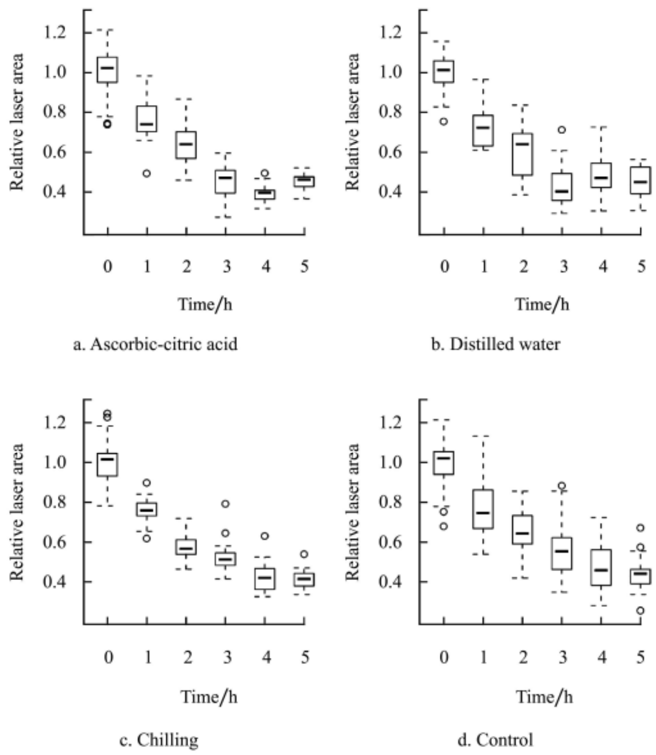


Figure 3 Relative laser area vs. time for hot air drying of banana slices at (63±1)℃ for different treatments (box plots representing the interquartile range with maximum and minimum values, the black symbols show the median and the white symbols the outliers)

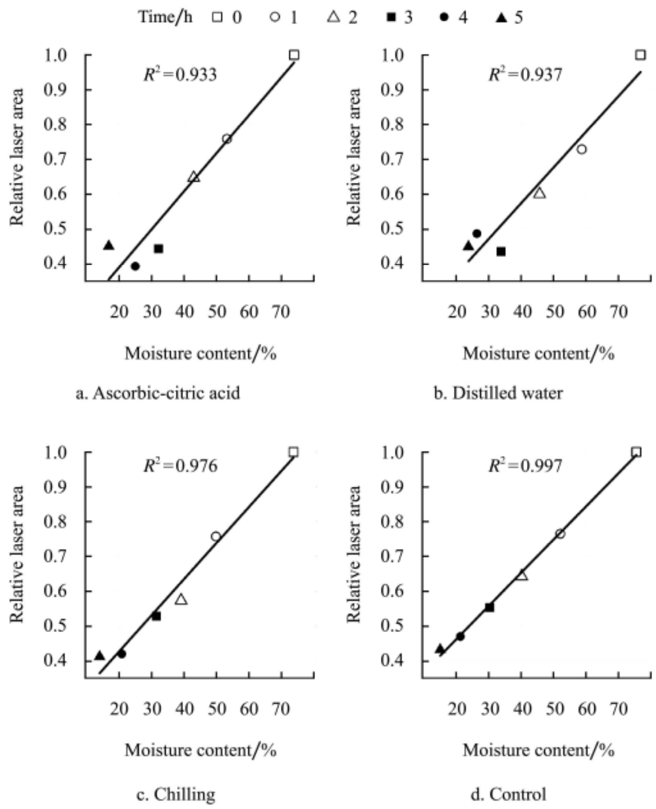


Figure 4 Relative laser area vs. moisture content during hot air drying of banana slices at (63±1)℃ for different treatments

**Table 2 Linear relationship between relative laser area and moisture content**

| | Coefficients | Estimate | Std. error | t-value | Pr(>\|t\|) |
|---|---|---|---|---|---|
| Acid | intercept | -12.106 | 5.748 | -2.106 | 0.05134 |
| | slope | 85.647 | 8.815 | 9.716 | 4.1e-08 |
| Distilled water | intercept | -12.466 | 6.158 | -2.024 | 0.0600 |
| | slope | 91.650 | 9.497 | 9.650 | 4.5e-08 |
| Chilling | intercept | -19.958 | 5.923 | -3.366 | 0.0039 |
| | slope | 94.342 | 9.129 | 10.334 | 1.7e-08 |
| Control | intercept | -28.528 | 6.563 | -4.347 | 0.0005 |
| | slope | 104.814 | 9.758 | 10.742 | 1.0e-08 |

Residual standard error: 4.619293 on 16 degrees of freedom.

The lower coefficients of determination observed for samples treated with acids and distilled water was due to a broad fluctuation of relative laser area values for those slices, which showed higher values of moisture content during the acquisition of the backscattering images at the end of drying. High moisture content results in deeper propagation of the light inside the tissue causing dispersion of photon and as a consequence less reflection. The analysis of variance of the mean values demonstrated that relative laser area was significantly affected only by the moisture content, whereas pre-treatments did not have a significant influence (Table 3).

**Table 3 Analysis of variance of the mean values of moisture content vs. relative laser area and pre-treatment[(a)]**

| Source | Df | Sum Sq | Mean Sq | F value | Pr(>F) | |
|---|---|---|---|---|---|---|
| Relative laser area | 1 | 8624.7 | 8624.7 | 404.1985 | 8.829e-13 | *** |
| Pre-treatment | 3 | 196.9 | 65.6 | 3.0752 | 0.05762 | ns |
| Interaction | 3 | 46.6 | 15.5 | 0.7278 | 0.55023 | ns |
| Residuals | 16 | 341.4 | 21.3 | | | |

Note: (a): ***: significant for $p$=0.001; ns: not significant.

This confirms that light scattering was not influenced by tissue browning during drying. Since the discolouration is accompanied by textural change[23], which can influence the laser readings, more studies are required to investigate the impact of firmness during drying on the backscattering images.

## 4 Conclusions

Backscattering images acquired by applying a laser diode emitting at 670 nm wavelength shows a progressive decrease in the relative laser area as the moisture content decreased during drying. It is possible to monitor changes in moisture content during the entire drying process with different treatments of banana slices. The best prediction was obtained with acids treatment due to the lowest standard error. Significant colour differences were observed among the treatments at 63℃. However, colour degradation did not have influence on the photon migration at 670 nm wavelength. In conclusion, this study provides the basis for future development of a very promising technique and further research is required before the laser technique can be applied at industrial level.

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