An Approach of Laser-induced Backscattering Imaging for Detecting Chilling Injury in Bananas

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Abstract

The application of laser-induced light backscattering imaging for detecting chilling injury (CI) in bananas (Musa cavendishii) was approached on a laboratory scale. Bananas at ripening stages 2 to 5 were stored at a chilling temperature of 6 °C to induce chilling injury and at 13 °C control conditions to maintain fruit quality. Light backscattering of intact fruit was measured using laser diodes emitting at wavelengths: 660, 785 nm. The backscattered light was captured with a camera and the radial profiles between the distance of incident point and total attenuation were further processed. Profiles of backscattered light from chill-injured and control bananas before, during, and after storage were analyzed. Results show that the samples were classified clearly into CI and control ones after storing at ambient temperature. The wavelength of 785 nm resulted in lower measuring uncertainty compared to 660 nm. It was pointed out that backscattering imaging is potentially useful in the detection of CI in bananas.

Keywords: banana, backscattering, chilling injury, fruit quality, imaging

1. Introduction

The presence of various health beneficial compounds, especially the potassium-power delivered by the high energy banana fruit, reflects the importance of bananas in human diet. However, maintaining fruit quality in the supply chain has been a major constraint in the marketing of fresh fruits including bananas. The banana is one of the chill-sensitive produce. Thus, it is necessary to adopt good horticultural practices and efficient postharvest handling to ensure that the bananas are of high quality when they reach the retail outlet.

Optimum temperatures for storing bananas are between 13 and 14 °C. Storing banana at below 10 °C will induce the development of chilling injury (CI) during or after storage at low temperature (Murata 1969; Abd El-Wahab and Nawwar 1977; Broughton and Wu 1979; Nguyen et al., 2003; Zhang et al., 2010; Hashim et al., 2011). The chilling injury temperature causes
damage to the plant cell membranes which then set off a cascade of secondary reactions such as autocatalytic ethylene production, increased respiration rate, interference in energy supply, accumulation of toxin, and altered cellular structure (Skog, 1998). Parallel to the development of CI, the colour of banana peel changes from green or yellow to brown and then turn completely black as the CI becomes severe. The change in peel colour has been used as a method of indicating CI. However, this method is exposed to operational error and cannot ensure that individual fruit meet the enhanced quality standard required in the currently highly competitive global market place. Thus, an advanced, accurate, rapid and non-destructive technology is needed to replace the subjective conventional method.

In recent years, there has been an increased interest in the application of non-destructive computer–aided image processing method to evaluate fruit properties and qualities. Laser-induced light backscattering imaging is one of the promising techniques that show a great potential in the detection of fruit properties such as firmness and soluble solids content (SSC). The technique has been applied successfully on several fruit and vegetables such as apple (Peng and Lu, 2006; Qing et al., 2007; Qin and Lu, 2008; Huang and Lu, 2010), peach (Lu and Peng, 2006), pear, kiwifruit, plum, tomato, zucchini, and cucumber (Qin and Lu, 2008). Since optical properties are wavelength-dependent, the interaction between the light and the fruit tissue provides a large amount of useful information about the biochemical and physical characteristics of the fruit. The migration of the light in the fruit is recorded by a camera, providing a backscattering image that has been used to analyze the optical properties of the fruit. The backscattering image was analyzed by the size of the scattering area (Peng and Lu, 2006), the histogram of intensities (Qing et al., 2007), the Lorentzian distribution function (Lu and Peng, 2006), the modified Lorentzian function (Peng and Lu, 2006) and the modified Gompertz function (Peng and Lu, 2007). Objective of the present study was to evaluate the potential of laser-induced light backscattering imaging for detecting CI in bananas.

2. Materials and Methods

2.1 Fruit samples

*Musa cavendishii* bananas in ripening stages two (R2), three (R3), four (R4), and five (R5) were obtained from a commercial banana ripening facility (FruchtExpress Import Export GmbH, Germany). Samples were evenly divided into two groups, i.e., the CI samples which were stored at a chilling temperature of 6 °C and the control samples which were stored at 13 °C. Both groups were stored for two days before taken out and exposed to ambient temperatures. Data collection was carried out at before storage (day 1), during storage (day 3) and after storage (day 4) by using backscattering imaging and visual assessment.

2.2 Image acquisition

Backscattering images of bananas were recorded using an in-house developed laser-induced backscattering imaging system in the Department of Horticultural Engineering, Leibniz Institute for Agricultural Engineering, Potsdam-Bornim (ATB), Germany. Each banana was placed under a CCD camera (JVC KY-F50E) with zoom lens (F2.5 and focal lengths of 18-108 mm). Laser diode with 1 mm size emitting at 660 and 785 nm with 45 mW maximal power was used as a light source. Backscattering images of sizes 720x576 pixels were acquired in a dark-room in order to obtain a good signal to noise ratio. A total of six images consisting of 3 images per side
of the banana were taken to obtain the average value of the backscattering for each fruit. The Lambertian cosine law was applied to adjust the intensity values of the surface captured by the CCD camera (Qing et al., 2007) on curved surfaces. In-house developed software was set-up in the computer to assist the image acquisition process.

The backscattering images were identified by the brightness of the light and the center of the profile was defined by the highest intensity of the illumination point (Fig. 1a). The brightness of the light decreased radially as the distance from the illumination point increased. The change in the intensity was fitted to a Lorentzian distribution function as shown in Fig. 1(b). The centre of the illumination point is marked by the zero value of distance (pixel).

![Image](image.png)

**FIGURE 1:** A backscattering image acquired from a banana using 785 nm wavelengths: (a) original backscattering image, (b) backscattering profile described by a Lorentzian distribution function.

### 2.3 Visual assessment

The visual assessment method using a browning scale as described by Nguyen et al. (2003) was performed immediately after the image acquisition. The browning scale was rated as follows: 1 = no chilling injury symptoms; 2 = mild chilling injury symptoms in which injury can be found in between the epidermal tissues; 3 = moderate chilling injury symptoms in which brown patches begin to become visible, larger and darker; 4 = severe chilling injury symptoms in which the brown patches are clearly visible and are larger and darker than at scale 3; 5 = very severe chilling injury symptoms in which the patches are relatively large on the surface.
2.4 Data analysis

Statistical analyses were carried out using Matlab (Math Work Inc., USA) and SAS statistical software. PLS_Toolbox 3.0 (Eigenvector Research, Inc. USA) was used for principal components analysis (PCA). Samples were classified into CI and control by using discriminant analysis. The performance of the classification was evaluated based on misclassification error of linear discriminant analysis (LDA) and quadratic discriminant analysis (QDA). Cross-validation error using leave-one-out method was carried out to check the robustness of the model.

3. Results and discussion

Score plots of PCA indicate that both the 660 and 785 nm wavelengths are capable of distinguishing samples according to their storage conditions (Fig. 2).

FIGURE 2: Score plots of the first and second principal components of backscattering profile after storage using: (a, b) 660 nm, (c, d) 785 nm considering storage temperature and ripeness stage.
The ascending order of ripening stages from R3 to R5 which arranged from left to right corresponding to interaction of samples to storage condition that strongly related to maturity level (Fig. 2b). However, R2 samples for both storage temperatures were mixed together and hardly distinguished by 660 nm. The overlapping of the data suggested that the R2 samples stored at 6 and 13 °C showed similar condition and not influenced by the storage condition although when the samples were placed at higher temperatures. In contrast, the distinction of the samples for 785 nm is clearer compared to 660 nm (Fig. 2c). The samples can be clustered perfectly according to their storage condition for each ripening stage indicating a clear different between samples stored at 6 and 13 °C.

Data taken at 785 nm gave 10% misclassification error when the samples were classified based on defective and normal (Table 1). The misclassification error for both wavelengths increases when the samples were classified based on the five browning scales. Meanwhile accuracy of classification for 660 nm reduced to 0.2 if using QDA.

### TABLE 1: Classification uncertainty of CI in bananas

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>LDA classification error</th>
<th>LDA Cross-validation error</th>
<th>QDA classification error</th>
<th>QDA Cross-validation error</th>
</tr>
</thead>
<tbody>
<tr>
<td>660 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>defective and control</td>
<td>0.409</td>
<td>0.413</td>
<td>0.207</td>
<td>0.209</td>
</tr>
<tr>
<td>Browning scale</td>
<td>0.560</td>
<td>0.562</td>
<td>0.328</td>
<td>0.334</td>
</tr>
<tr>
<td>785 nm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>defective and control</td>
<td>0.104</td>
<td>0.104</td>
<td>0.103</td>
<td>0.103</td>
</tr>
<tr>
<td>Browning scale</td>
<td>0.392</td>
<td>0.393</td>
<td>0.345</td>
<td>0.348</td>
</tr>
</tbody>
</table>

However, the misclassification error for 660 nm is still higher than 785 nm because of inconsistent ripening respond of R2 samples to storage condition also when the samples were placed at higher temperatures. Overall, QDA model obtained better classification result than LDA with lower misclassification error and consistent cross-validation values.

### Conclusions

Laser-induced backscattering imaging using 660 and 785 nm wavelengths were good candidates for non-destructive detection of CI in bananas. The technique successfully classified samples into defective and control ones after storing at ambient temperatures. Samples measured with the 785 nm wavelength showed better classification performance than those of the 660 nm. Although 660 nm has higher uncertainty than 785 nm, the results point out the capability of the system to detect the CI symptoms in bananas.
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References


