Bruise Detection Using NIR Hyperspectral Imaging for Strawberry

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Introduction

Background of Research

Strawberry Production of Japan

• An economically important fruit in Japan.
• Production area: 7,440 hectares in greenhouse
• Production volume: 208,600 tons for fresh fruits market only (2001).
• Operation: Manual
  Total labor input = 2000 hours per 0.1 ha
• Harvesting, sorting and packing operations
  = 1,200 hours (60% of Total Labor) per 0.1 ha

Research Focus on Two Main Areas

• Address the high labor costs
• Consumers demand for high product quality and food safety
Introduction

External Quality
- Size
- Shape
- Color

Internal Quality
- Taste
- Eating Experience
- Aroma
- Nutrient Content

High Quality Product

Safety
- Free of...
  - Defects
  - Bruises
  - Rot
  - Chemicals
Objectives of Research

To develop a technology based on NIR Hyperspectral imaging to detect bruises on fruits.

- To determine specific important wavelengths.
- To develop bruise detection algorithms.
- To determine the effects of storage time.
## Materials and Methods

### Strawberry Samples for Research

**Variety:** Akihime  
**Source:** A nearby greenhouse of a strawberry farmer from the university.

<table>
<thead>
<tr>
<th>Ripeness Maturity Levels</th>
<th>70-80%</th>
<th>Fully Ripe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions</strong></td>
<td>Length (mm), width (mm), breadth (mm), mass (gm)</td>
<td></td>
</tr>
<tr>
<td><strong>Bruising Force</strong></td>
<td>0 N, 0.5 N, 1.0 N, 1.5 N, 2.0 N, 3.0 N</td>
<td></td>
</tr>
<tr>
<td><strong>Spectral Imaging</strong></td>
<td>VIS/NIR Range 650 to 1000 nm at 5 nm interval</td>
<td></td>
</tr>
<tr>
<td><strong>Storage Time</strong></td>
<td>0 Day, 1 Day, 2 Days, 3 Days, 4 Days</td>
<td></td>
</tr>
</tbody>
</table>
**Materials and Methods**

**Taking of Spectral Images**

### Spectral Imaging Set-up

(a) Apogee AP2E camera  
(b) CRI VariSpec Liquid Crystal Tunable Filter  
(c) CRI Electronic Controller Box  
(d) Dolan-Jenner Fiber-Lite PL950  
(e) Cooler  
(f) Stage

<table>
<thead>
<tr>
<th>Camera</th>
<th>14-bit Apogee AP2E CCD camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter</td>
<td>CRI Varispec Liquid Crystal Tunable Filter (LCTF) VIS-NIR Model (650 to 1100 nm, 10 nm FWHM)</td>
</tr>
<tr>
<td>Illuminant</td>
<td>Dolan-Jenner Fiber-Lite PL950 DC regulated Illuminator 150-watt tungsten-halogen bulb</td>
</tr>
</tbody>
</table>
Materials and Methods

Application of Bruise

Orientec Universal Testing Machine
STA-1150
(Orientec Corporation, Japan)

25 mm ø
Materials and Methods

Data Acquisition, Image Processing, and Analysis

Apogee CCD Camera

Bruise Application

LCTF

Hyperspectral Imaging

Hyperspectral Image Cube

980nm (14-bit)

Pixel Masking

Spectral Profile Extraction

Randomization

Development Set

Validation Set

Statistical Analysis

Wavelength Selection

Flat Field Correction

\[ I_{\text{norm}}(x,y) = \frac{I_{\text{sample}}(x,y) - I_{\text{dark}}(x,y)}{I_{\text{reference}}(x,y) - I_{\text{dark}}(x,y)} \cdot m \]
## Results and Discussion

### VIS-NIR Spectral Images

<table>
<thead>
<tr>
<th></th>
<th>Orig. color</th>
<th>675 nm</th>
<th>750 nm</th>
<th>800 nm</th>
<th>900 nm</th>
<th>980 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-60% Ripe</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>70-80% Ripe</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
<tr>
<td>Full-Ripe</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
<td><img src="image16.png" alt="Image" /></td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Strawberry samples images at 50-60% ripe, 70-80% ripe and Full-ripe maturity levels in color and in monochrome at 675, 750, 800, 900, and 980 nm.
Results and Discussion

Spectral reflectance profile of bruised and non-bruised strawberries at two ripeness maturity stages.

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Results and Discussion

Visual Observation

<table>
<thead>
<tr>
<th>70-80% Ripe</th>
<th>RGB</th>
<th>980 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Strawberry" /></td>
<td><img src="image2.png" alt="RGB Image" /></td>
<td><img src="image3.png" alt="Infrared Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Full-Ripe</th>
<th>RGB</th>
<th>980 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4.png" alt="Strawberry" /></td>
<td><img src="image5.png" alt="RGB Image" /></td>
<td><img src="image6.png" alt="Infrared Image" /></td>
</tr>
</tbody>
</table>

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Results and Discussion

Bruise Development with Force Level

70-80% Ripe

Full-Ripe

0 N
1.5 N
3.0 N
## Results and Discussion

Classification efficiency (success in %) for bruised and non-bruised pixels using stepwise linear discriminant analysis

<table>
<thead>
<tr>
<th>Discriminant function wavelengths, nm</th>
<th>Model development</th>
<th>Model validation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-bruised</td>
<td>Bruised</td>
</tr>
<tr>
<td>980</td>
<td>96.0</td>
<td>88.4</td>
</tr>
<tr>
<td><strong>980, 825</strong></td>
<td><strong>99.4</strong></td>
<td><strong>90.7</strong></td>
</tr>
<tr>
<td>980, 825, 925</td>
<td>99.4</td>
<td>90.9</td>
</tr>
<tr>
<td>980, 825, 925, 680</td>
<td>99.6</td>
<td>91.3</td>
</tr>
<tr>
<td>980, 825, 925, 680, 650</td>
<td>99.5</td>
<td>91.8</td>
</tr>
</tbody>
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## Results and Discussion

### Bruise Detection with Force Level

<table>
<thead>
<tr>
<th>Force Level (N)</th>
<th>70-80% Ripe</th>
<th>Full-Ripe</th>
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<tbody>
<tr>
<td>0 N</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>1.0 N</td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>1.5 N</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
<tr>
<td>2.0 N</td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
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</table>
## Results and Discussion

### Detected Bruise Pattern with Storage Time

<table>
<thead>
<tr>
<th>980 nm</th>
<th>0 Day</th>
<th>1 Day</th>
<th>2 Days</th>
<th>3 Days</th>
<th>4 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>70-80% Ripe</td>
<td></td>
<td></td>
<td></td>
<td></td>
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Conclusion

- VIS-NIR range (650-1000 nm) hyperspectral imaging provides easier way to detect bruises.

- Through linear discriminant analysis best wavelengths were found at 825 and 980 nm.

- Detected bruises decrease with time.
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Thank You