New tools to fine-tune quality harvests: spectroscopy applications in viticulture

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1. Visible/NIR Spectroscopy of Grapes

- Interaction of matter with light (absorbance, reflectance) depends upon chemical composition
- Atomic and molecular energy levels (vibration, rotation, spin energy, etc.) are specific to quantum energy of a particular wavelength
- Spectral response pattern reveals aspects of chemical composition – “chemometrics”
- Estimate fruit quality, e.g., total solids (°Brix), titratable acidity, pH, phenolics, anthocyanins from spectral characteristic
The Electromagnetic Spectrum
Spectral absorption of some grape components...

- **Chlorophyll** absorbs **blue** and **red**, reflects **green**
- **Anthocyanins** – absorb **green**, reflect **blue** and **red**
- **Water** O-H bond peaks at 760, 970, 1450, 1940 nm

Brimrose Luminar 5030 NIR – “le Vigneron”
The Brimrose “le Vigneron” NIR System

• Portable handheld instrument scans one grape berry at a time in NIR spectrum
• Can be used in vineyard, or with fruit samples
• Season-to-season prediction has not been robust, needs re-calibration
• Requires contact with single berry, many berries must be sampled for representative values
• Expensive, time consuming but has shown good performance
Portable VIS/NIR Transflectance Probe

- Developed and tested in Chile
- Uses inexpensive Visible/NIR spectrometer with fibreoptic probe
- Good estimation of Brix, pH and anthocyanins ($R^2$ values were >0.85 with most above 0.90)
- *Probe measures one berry at a time, requires contact with fruit – time consuming, need many measurements*

From Herrera et al., 2003
1. Free-air VIS/NIR Spectroscopy Trials

• Why free-air?
  – Don’t have to be in contact with fruit
  – Larger field of view, more representative
  – Compatible with mounting on harvester

• Why VIS/NIR?
  – Inexpensive spectrometer, standard optics
  – Information from visible spectrum (colour)
Integrate VIS/NIR instrument with yield monitor?

OCE – Etech /U of Guelph project with Lakeview Vineyard Equipment Inc.
Free-air VIS/NIR setup used in 2008 (Wade Milton)

Laptop and USB fibreoptic spectrometer with halogen lamps used for composite sample reflectance
Collaborator: J-L Groux, Stratus Vineyard
(with K. Bailey, R. Blackadder, 2008-2010)

- Cab Sauvignon, Cab Franc, Syrah blocks sampled from early post-veraison to harvest
- Sample procedure (200-berry composite sample)
  - Sample front, back, top, bottom and shoulders of bunches, alternate on upper and lower wires, both sides of row
- Use inexpensive USB spectrometer for visible and NIR reflectance characteristics
- Scan entire composite sample (rapid, portable, more representative of vineyard block)
- Chemical analysis in Andy Reynolds lab at Brock
Partial least-squares regression for Brix using VIS/NIR and Unscrambler® 2008
### Predictions from Spectral Reflectance

<table>
<thead>
<tr>
<th>Substance</th>
<th>2008 Brimrose</th>
<th>2008 PLS VIS/NIR</th>
<th>2008 PLS/GA VIS/NIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar (° Brix)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.702</td>
<td>0.785</td>
<td>0.868</td>
</tr>
<tr>
<td>RMSEP</td>
<td>0.97</td>
<td>0.98</td>
<td>0.66</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.595</td>
<td>0.855</td>
<td>0.842</td>
</tr>
<tr>
<td>RMSEP</td>
<td>0.06</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>TA (g/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.595</td>
<td>0.696</td>
<td>0.848</td>
</tr>
<tr>
<td>RMSEP</td>
<td>0.73</td>
<td>0.64</td>
<td>0.84</td>
</tr>
<tr>
<td>Tartaric acid (mg/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.434</td>
<td>0.484</td>
<td>0.488</td>
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<tr>
<td>RMSEP</td>
<td>35.15</td>
<td>34.88</td>
<td>34.74</td>
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<tr>
<td>Phenolics</td>
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<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.484</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMSEP</td>
<td>34.88</td>
<td></td>
<td></td>
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<tr>
<td>Gallic acid</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R²</td>
<td>0.488</td>
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<td></td>
</tr>
<tr>
<td>RMSEP</td>
<td>34.74</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Setup for 2009-2010 reflectance measurements (Mike Fadock)

• Enclosure designed to exclude ambient light effects
• Non-reflective container allowed re-orientation of berries between measurements
• Repeat measurements after gentle shaking
Weekly Averaged Grape Reflectance – 2010

(weeks 2-11 shifted down to separate curves)
2009 PLS Predictions – Brix and pH

LOO BRIX prediction by 14 Component PLSR

LOO pH prediction by 7 Component PLSR
# Prediction of Berry Values from VIS/NIR Reflectance

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th></th>
<th></th>
<th>2010</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>R²</td>
<td>RMSEP</td>
<td>Range</td>
<td>R²</td>
<td>RMSEP</td>
</tr>
<tr>
<td>° Brix</td>
<td>16.3-24.0</td>
<td>.84</td>
<td>0.65</td>
<td>17.1-26.6</td>
<td>.89</td>
<td>0.65</td>
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<tr>
<td>pH</td>
<td>3.1-3.5</td>
<td>.58</td>
<td>0.05</td>
<td>3.1-3.8</td>
<td>.81</td>
<td>0.05</td>
</tr>
<tr>
<td>TA (g/L tartaric acid)</td>
<td>6.9-12.3</td>
<td>.56</td>
<td>0.59</td>
<td>5-13.8</td>
<td>.58</td>
<td>0.86</td>
</tr>
<tr>
<td>Phenols (mg/L gallic acid)</td>
<td>185-385</td>
<td>.27</td>
<td>31.7</td>
<td>110-275</td>
<td>.25</td>
<td>27.9</td>
</tr>
<tr>
<td>Anthocyanins (mg/L malvidin)</td>
<td>725-1370</td>
<td>.65</td>
<td>74.7</td>
<td>470-1130</td>
<td>.17</td>
<td>111</td>
</tr>
</tbody>
</table>
How robust is PLS model for prediction?

• Is spectral response consistent from year to year, and between similar varieties?

• Does system have to be re-calibrated each year?
  – Can we build on each previous dataset?
PCA Loadings – 2009 and 2010
(consistent year-to-year spectral contribution)

1st Component

3rd Component

2009  2010  2009  2010
2010 °Brix Prediction from 2009 Model
2010 pH Prediction from 2009 Model
Future of spectral methods for rapid fruit quality

• Currently *good results* for Brix, pH, TA
• Potential for rapid estimation of phenolics and anthocyanins
• Drawbacks to commercial equipment – expensive, need to calibrate, time consuming
• New technology for spectral sensing and information processing promises less expensive, more useful instruments soon…
Recent developments in fruit reflectance applications....

New Pellenc Spectron™ portable handheld vis/NIR spectrometer

– Based on research by Gilles Rabatel with “le tromblon” at Cemagref, Montpellier, France

2. Spectroscopy of leaves and canopy

- Visual assessment of vines (scouting) is important - disease, nutrition, water stress, etc.
- Other information may be there but we are limited to the visible spectrum
- Instrumental spectroscopy of canopy and leaves in ultraviolet (UV), visible, near-infrared (NIR) can be useful...
Leaf spectral reflectance and vine health...

- Good fruit quality starts with a healthy, well-balanced vine
- Plant stress shows up in the foliage – photosynthesis apparatus and other plant pigments affected
- These absorb and reflect in different parts of the spectrum, cause changes in leaf reflectance

Leafroll virus image courtesy CFIA
Leaf responses to physiological stress

- Environmental stress (e.g., ozone, powdery mildew) increased reflectance in 535-640 nm range, 670 nm unresponsive (Gregory Carter, 1993)

- Phylloxera-infested vines in California showed increased green reflectance (~550 nm) in remote sensing images (Lee Johnson, 1999)

- Anthocyanin biosynthesis in leaves from drought, extreme temperatures and light caused reduced green reflectance (Steele et al., 2009)

- NIR reflectance is relatively constant except under extreme water stress
Vegetation Reflectance Indices

- **Normalized Difference Vegetation Index (NDVI)** used in remote sensing is related to photosynthetically active biomass
  \[ \text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \]

- **Normalized Green-Red Reflectance (NGRR)** uses difference between green (550 nm) and red (670 nm) for detecting plant stress
  \[ \text{NGRR} = \rho_{\text{NIR}} - \frac{(\rho_{\text{GREEN}} - \rho_{\text{RED}})}{\rho_{\text{NIR}} + (\rho_{\text{GREEN}} - \rho_{\text{RED}})} \]
Can we use leaf reflectance to monitor vine status?

- 30-Bench Winemakers Riesling vineyard (Precision Viticulture project)
- Investigate single-leaf reflectance in situ and monitor vine and fruit performance
- Measure reflectance of fully-expanded leaves (5 per vine) monthly for ~ 500 sentinel vines
- Also determine soil moisture, vine water stress, harvest yield and quality
Taking leaf reflectance measurements at 30-Bench Winemakers vineyard
Normalized Green-Red Reflectance (NGRR) with Soil Moisture at 30-Bench Vineyard

Mean soil moisture

NGRR July 26, 2007

NGRR August 24, 2007
NGRR and °Brix at harvest - 2007
Leaf reflectance and fruit quality

• There is a relationship between plant stress (moisture, disease, etc.), leaf reflectance (NGRR) and subsequent fruit quality
• But relationship is complex, correlations are not reliable enough for easy direct prediction
• Other factors (crop load, weather, pruning) have large effects
• *Leaf reflectance has potential to map precision viticulture management zones – e.g., differential harvest*
Handheld instruments for leaf reflectance

Fieldscout CM1000 NDVI meter
Spectrum Technologies Inc.
www.specmeters.com/store/cm1000ndvi

CCM-200 chlorophyll meter
Opti-Sciences Inc.
www.optisci.com/ccm200.htm
Automated sensor for canopy reflectance

Greenseeker™

Images courtesy Ntech Industries, Inc.
Automated Sensors used for NDVI Mapping

GreenSeeker® NDVI Sensor on a quad bike

NDVI map from GreenSeeker® sensor

Images courtesy Ntech Industries, Inc.
Map of canopy reflectance (NDVI) used to make harvest decisions...

Mission Estate Vineyard
Mere Road, Hastings
Merlot and Syrah NDVI Survey

NDVI Range
- Merlot
  - < 0.569
  - 0.570 - 0.635
  - 0.636 - 0.699
  - 0.670 - 0.687
  - 0.688 - 0.696
  - 0.697 - 0.714
  - 0.715 - 0.748
  - 0.749 - 0.814
- Syrah
  - < 0.569
  - 0.570 - 0.635
  - 0.636 - 0.699
  - 0.670 - 0.687
  - 0.688 - 0.696
  - 0.697 - 0.714
  - 0.715 - 0.748
  - 0.749 - 0.814

Merlot
- Total Area: 4.63ha
- NDVI Avg.: 0.706
- NDVI Std. Dev.: 0.112

Syrah
- Total Area: 2.16ha
- NDVI Avg.: 0.680
- NDVI Std. Dev.: 0.080

Courtesy Caine Thompson, Spatial Solutions NZ
Is there potential for using vineyard canopy reflectance in Precision Viticulture?

- Greenseeker® and CropCircle® systems are commercially available
- Evidence that NDVI variation (biomass) is related to harvest quantity and quality
- May be more convenient than remote sensing to define management and harvest zones
- Need more research on linkages between vine balance, health and fruit quality
New tools to fine-tune quality harvests: spectroscopy applications in viticulture

Thank you!