Detection of Grapevine Viral Diseases Using Proximal Remote Sensing

Canh Nguyen[a] , Vasit Sagan[a] , Matthew Maimaitiyiming[b] , James Schoelz[b] , Misha T. Kwasniewski[b]

[a]Department of Earth and Atmospheric Sciences, Saint Louis University, St. Louis, MO 63108

[b]Division of Food Sciences, University of Missouri, Columbia, MO 65211

SAINT LOUIS UNIVERSITY™ Geospatial Institute

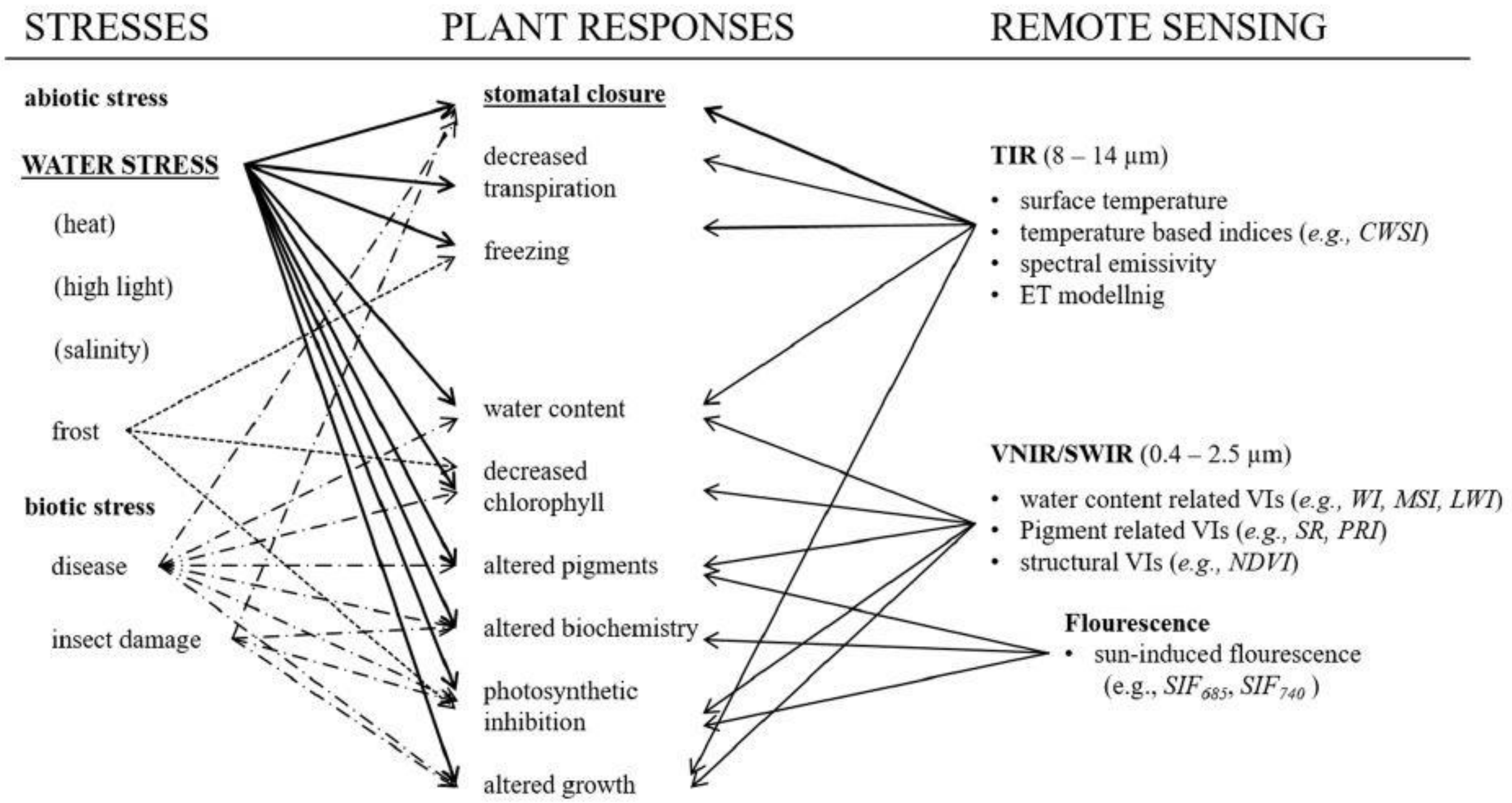
Introduction

- Disease-induced losses were estimated at $24 billion and $56 billion for soybean and corn respectively in the US between 2012 and 2016 (Crop Protection Network)
- Disease diagnostic at early stage is necessary for early intervention
- Plant pathogen detection by visual estimation by human raters, microscopic evaluation, or molecular technology
- Limitations: complex system, time consuming, and centralized laboratories

Remote Sensing

- Imaging techniques are reliable, cost effective, and nondestructive methods.
- Spectral sensors such as RGB, multispectral, hyperspectral, chlorophyll fluorescence, 3D Scanning.
- Hyperspectral imagery's advantages over others: hundreds of narrow and contiguous spectral bands
- Varying applications of hyperspectral: discovering salt stress, heavy metal, and explosives contamination in vegetation.

Why Remote Sensing ?



Jones & Vaughan (2010)

Literature Review

Table 1. Summary of studies of plant pathosystems and plant diseases using hyperspectral sensors

Crop	Disease / Pathogen	Reference
Barley	Net blotch (*Pyrenophora teres*), Brown rust (*Puccinia hordei*), Powdery mildew (*Blumeria graminis hordei*)	(Kuska et al. 2015; Wahabzada et al. 2015)
Wheat	Head blight (*Fusarium graminearum*), Yellow rust (*Puccinia striiformis f. sp. tritici*)	(Bauriegel et al. 2011; Bravo et al. 2003; Huang et al. 2007; Moshou et al. 2004)
Sugar beet	Cercospora leaf spot (*C. beticola*), Sugar beet rust (*U. betae*), Powdery mildew (*Erysiphe betae*), Root rot (*Rhizoctonia solani*), Rhizomania (*Beet necrotic yellow vein virus*)	(Bergstrasser et al. 2015; Hillnhutter et al. 2011; Mahlein et al. 2013; Mahlein et al. 2010; Mahlein et al. 2012b; Rumpf et al. 2010; Steddom et al. 2005; Steddom et al. 2003)
Tomato	Late blight (*Phytophthora infestans*)	(Wang et al. 2008)
Apple	Apple scab (*V. inaequalis*)	(Delalieux et al. 2007)
Tulip	Tulip breaking virus (TBV)	(Polder et al. 2014)
Sugar cane	Orange rust (*Puccinia kuehnii*)	(Apan et al. 2004)

Study Objectives

- Using hyperspectral images at proximal sensing scale to detect red blotch and grapevine vein-clearing viruses in grapevine.
- Why proximal?

spatial resolution of images was strongly influential on the disease detecting performance.

e.g., Soil-borne pathogens can be sensed by airborne imagery (Hillnhutter et al. 2011), single symptoms optimally detected proximal sensor platforms (West et al. 2003).

Grapevine red blotch Virus (GRBV)

Figure 1. Symptoms of GRBV in *Pinot noir* (left) (Courtesy R.R. Martin, USDA-ARS). Symptoms of Magnesium deficiency (right) (Courtesy R.P. Schreiner, USDA-ARS)

- Virus randomly creates blotches of red pigment, veins can remain green.
- Easily confused with leafroll viruses when leaves cup or roll, and those of abiotic stress (i.e., magnesium deficiency) or drought
- Polymerase chain reaction (PCR)-molecular test-is the only method and relatively expensive.

Grapevine Vein Clearing Virus (GVCV)

a b c

Figure 2. Translucent vein clearing on shoots (a), zig-zag internodes on shoots (b), and less dense canopy vine (c). Courtesy Wenping Qiu, Missouri State University

- First DNA virus found in grapevine (i.e., most grapevine viruses are RNA)
- Margins of new shoots become split and crinkled, Figure 2a.
- Veins look translucent in June and zig-zag internodes appear and become discernable in August, Figure 2b.
- Infected leaves misshaped and smaller, reducing vine size and less dense canopy, Figure 2c.
- Polymerase chain reaction (PCR)-molecular test-is the only method and relatively expensive.

Study Area and Data Collection

- An experiment at South Farm Research Center, Columbia, MO (38.92N, -92.28W).
- 2 grapevine groups: healthy and unhealthy/ infected, as other conditions were controlled.
- a hyperspectral sensor, SPECIM IQ (Oulu, Finland)

Table 2. Summary of Sample Size of Each Group and Each Date

	Number of healthy vines	Number of unhealthy vines	Total
August 7th	6	5	11
August 29th	4	5	9
September 19th	5	5	10
October 8th	5	5	10
Total	20	20	40

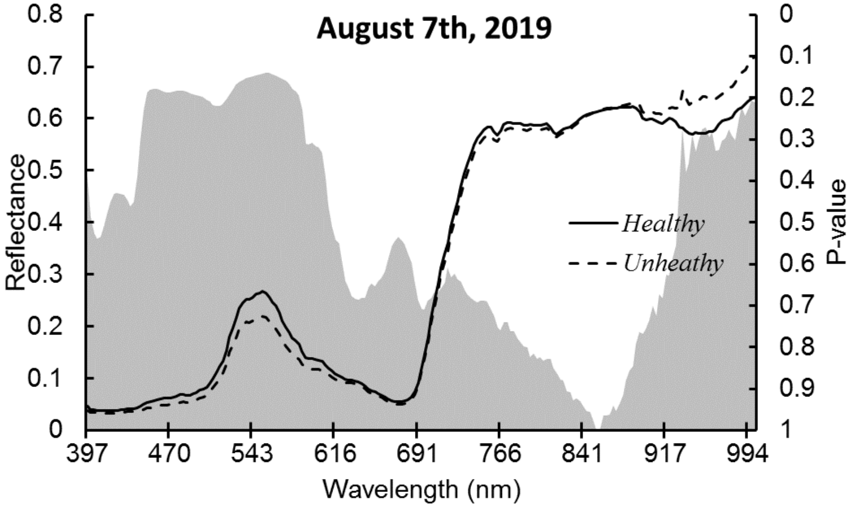
Data Pre-processing

- Wavelength: 397 nm to 1,004 nm with a resolution of 3nm
- Camera built-in functions to convert DN values to reflectance
- Region of Interests (ROIs) were extracted as pixel samples out of images of each vine.
- Spectral resolution: 203 bands

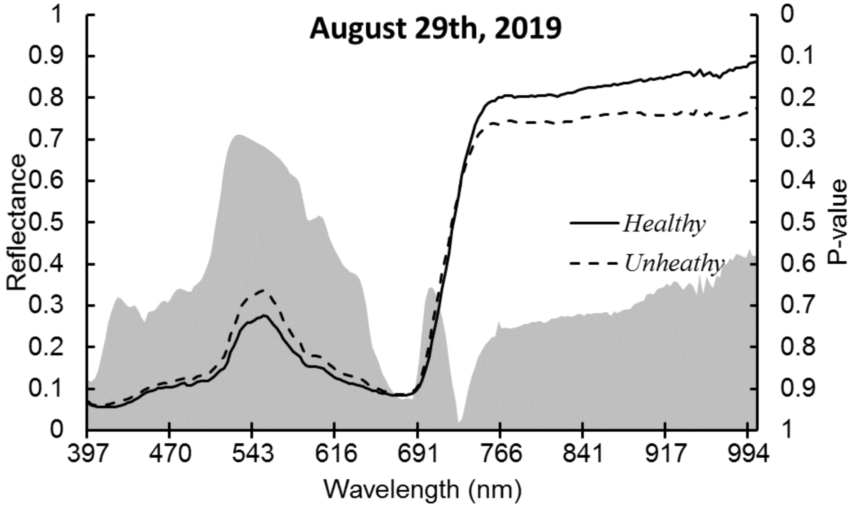
Methods

- Independent samples *t* tests for:
  - spectral reflectance of different growth stages
  - spectral reflectance of aggregated data
  - derivatives of spectral reflectance
- Vegetation indices
- Principal component analysis (PCA)

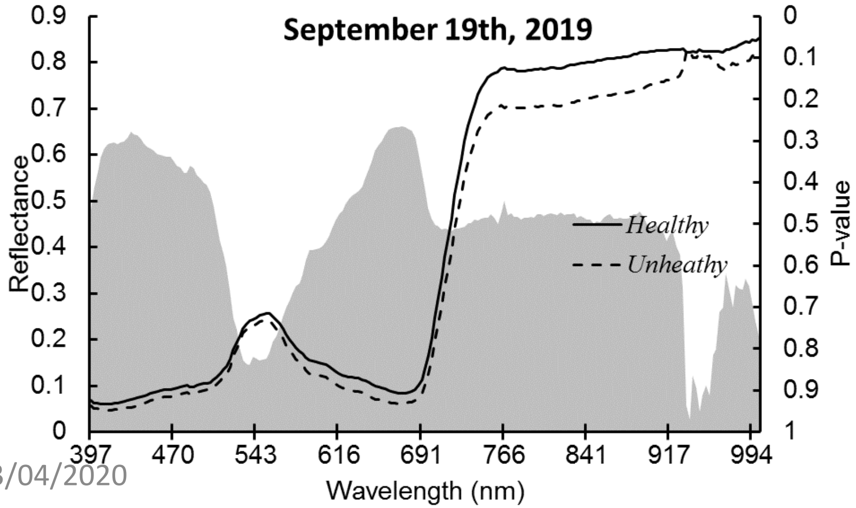
Results



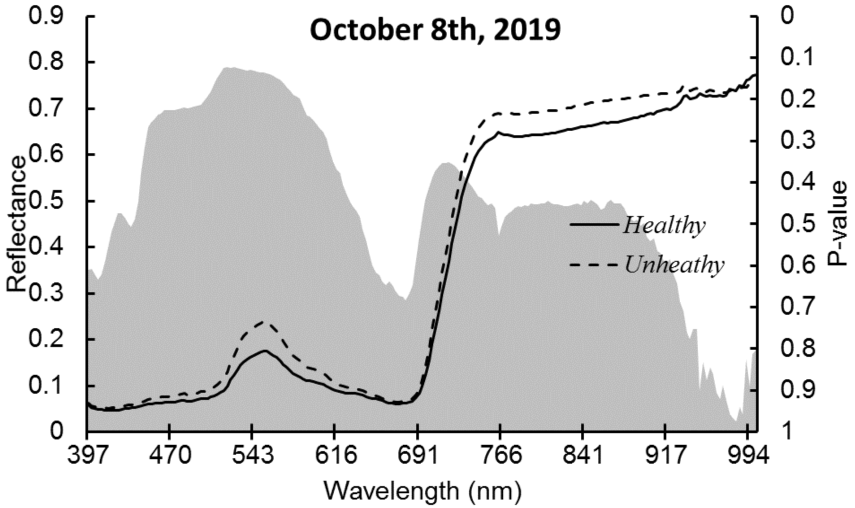
August 7th, 2019
Reflectance
P-value
Wavelength (nm)
Healthy
Unheathy



August 29th, 2019
Reflectance
P-value
Wavelength (nm)
Healthy
Unheathy



September 19th, 2019
Reflectance
P-value
Wavelength (nm)
Healthy
Unheathy



October 8th, 2019
Reflectance
P-value
Wavelength (nm)
Healthy
Unheathy

Healthy

Unhealthy/Infected

August 7, 2019

Healthy

Unhealthy/Infected

August 29, 2019

Healthy

Unhealthy/Infected

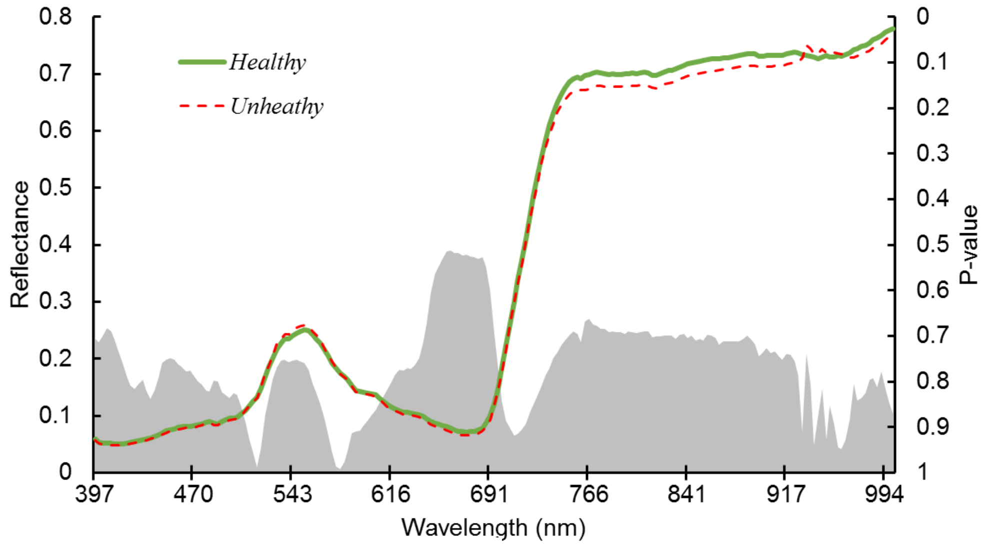
September 19, 2019

Healthy

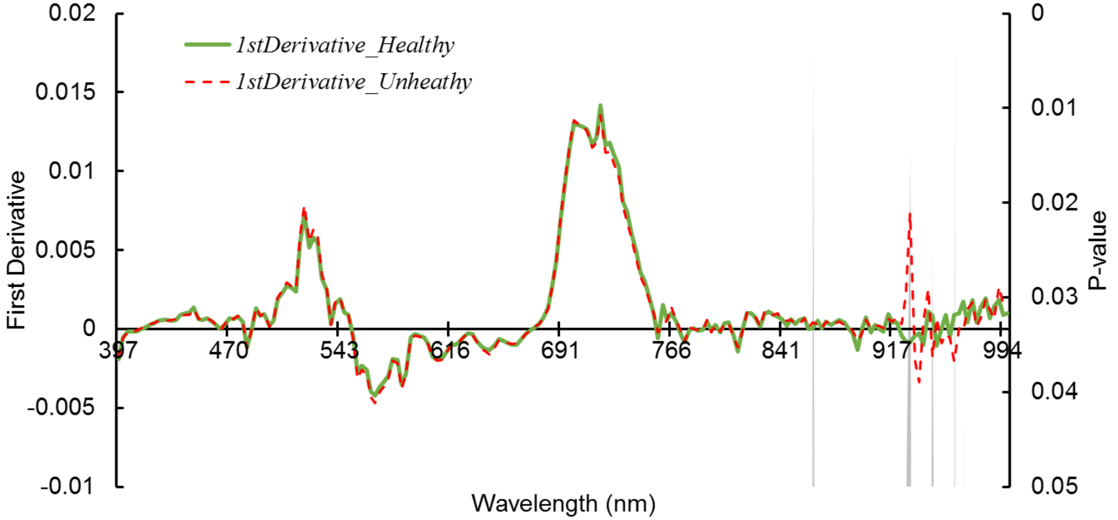
Unhealthy/Infected

October 8, 2019

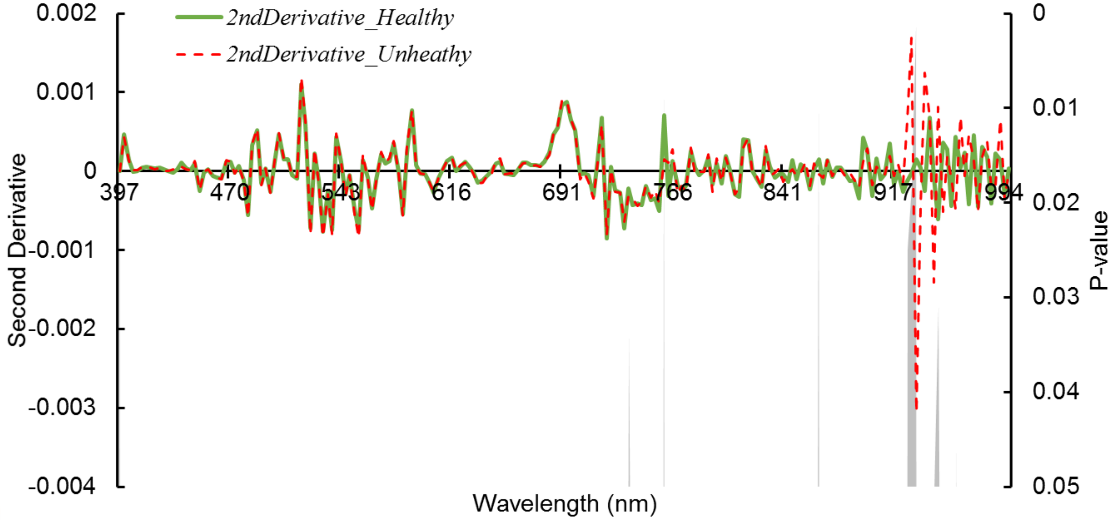
Results



Healthy
Unheathy
Reflectance
P-value
Wavelength (nm)
397 470 543 616 691 766 841 917 994



1stDerivative_Healthy
1stDerivative_Unheathy
First Derivative
P-value
Wavelength (nm)



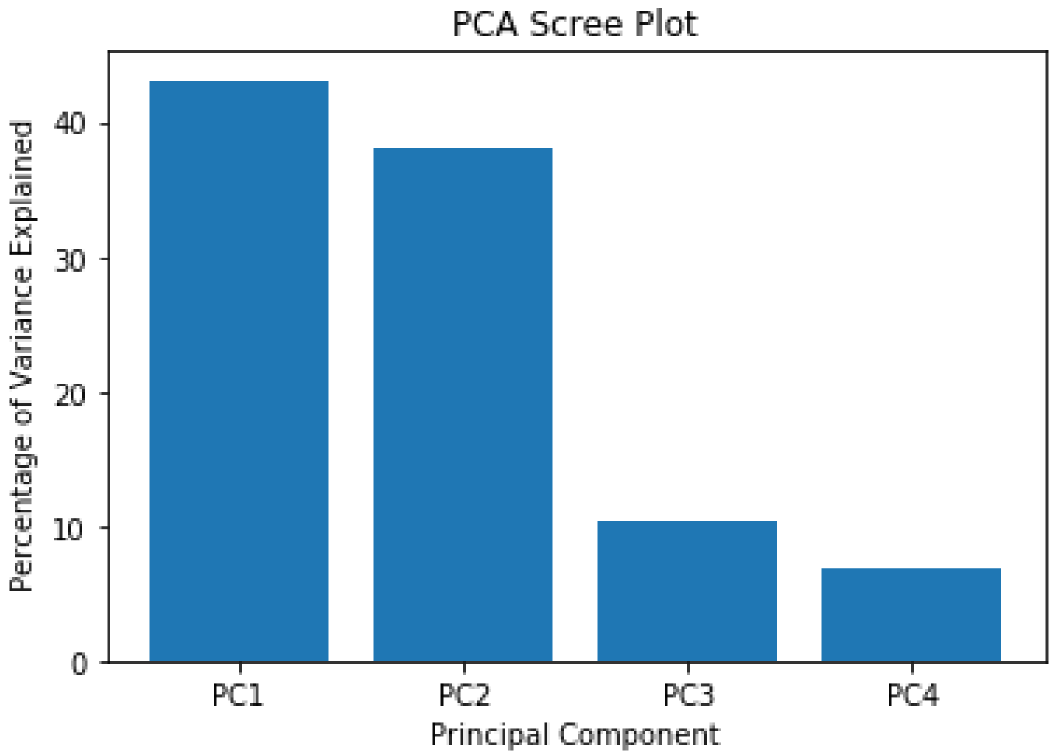
2ndDerivative_Healthy
2ndDerivative_Unheathy
Second Derivative
P-value
Wavelength (nm)

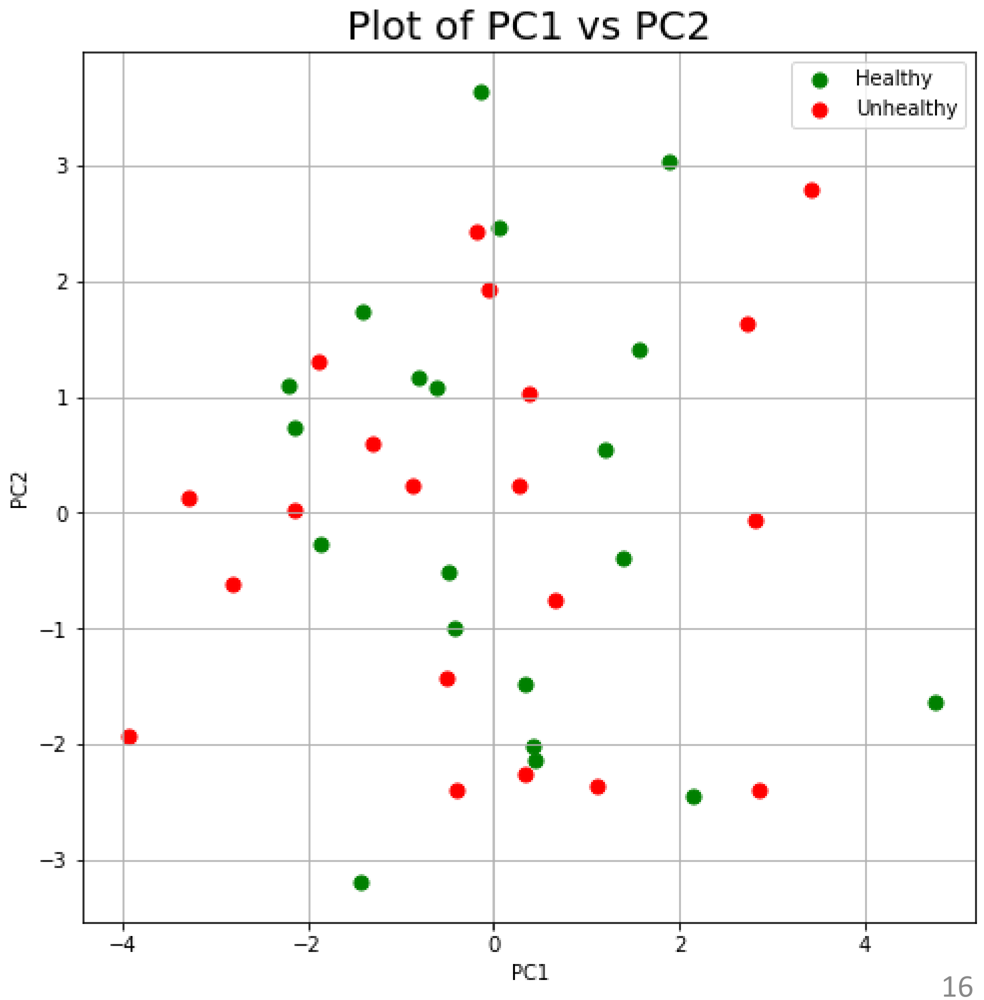
Vegetation Indices

Table 4. Summary of estimates of vegetation disease indices

Vegetation Indices	Mean of Healthy Vines	Mean of Unhealthy Vines	*t*-statistic
Normalized Difference Vegetation Index (NDVI)	0.817	0.824	-0.765 NS
Red-edge NDVI	0.455	0.447	0.348 NS
Simple Ratio Index (SRI)	10.141	10.682	-0.980 NS
Chlorophyll Index (CI)	0.455	0.447	0.348 NS
Scaled photochemical reflectance index (sPR)	0.518	0.523	-0.884 NS
Normalized phaeophytinization index (NPQI)	-0.074	-0.078	0.269 NS
Structure independent pigment index (SIPI)	0.825	0.827	-0.177 NS
Leaf rust disease severity index (LRDSI)	11.524	11.774	-0.228NS

Principal Component Analysis (PCA)





Conclusions

- Hyperspectral reflectance data and disease-centric indices were unable to discriminate two healthy and unhealthy grapevines.
- First and second derivatives of reflectance showed a significant difference at NIR region
- Plausible explanations:
  - Data proximally sensed at the incubation period of viruses.
  - Leaves were delayed to display symptoms.
  - Small sample sizes, only 20 samples on each vine group.

Q&A