SPECTRAL CHARACTERIZATION OF FUNGAL DISEASES ON *VITIS VINIFERA* LEAVES

Pâmela A. Pithan[1], Jorge R. Ducati[1]*, Lucas R. Garrido[2]

[1]Remote Sensing Center, Universidade Federal do Rio Grande do Sul, Av. Bento Goncalves 9500, 91501-970 Porto Alegre RS, Brazil
[2]Centro Nacional de Pesquisas em Uva e Vinho, EMBRAPA, Bento Goncalves RS, Brazil

*Corresponding author: ducati@if.ufrgs.br

Abstract

Aims: The aims of this study were to (1) detect alterations in the reflectance spectra of vines with fungal diseases, (2) map these alterations, and (3) determine the best wavelengths which may be used as early indicators of fungal diseases in vines.

Methods and Results: Cabernet Sauvignon vines grown in pots and kept in a greenhouse were inoculated with the pathogens causing mildew, powdery mildew, black-foot and Petri disease. In early stages of disease development, reflectance measurements were performed using a FieldSpec 3 spectroradiometer, which were compared with data from healthy plants. Additional measurements were performed with chlorophyll meters. The investigation began with discriminant analysis, which revealed that symptomatic plants are indeed separated from the control ones. Reflectance spectra were therefore further investigated, looking for alterations on the shape of the spectra, characteristic of each disease. The disease descriptors were based on ratios between spectral features internal to a spectrum, a procedure which allowed the derivation of parameters intrinsic to each disease. A set of thresholds, defined as the intensity ratios of reflectance at selected wavelengths, was derived for the studied diseases. The selected wavelength ratios were 443/496, 443/573, 443/695, 443/1900, 496/573, 496/695, 516/1900, and 1900/2435 (values in nanometers), for which the spectra from symptomatic plants present shape changes of as much as 20% with respect to healthy plants.

Conclusions: Spectral deformations were observed for the studied fungal diseases; they are larger for black-foot and powdery mildew, but some wavelength ratios are also indicators of downy mildew and Petri disease. Data from near-infrared in general carry more information compared with measurements at 1900 and 2435nm.

Significance and Impact of the Study: Since little is known on alterations of the reflectance spectra of vines, a better knowledge could be used in the development of sensors able to detect diseases through fast, non-destructive techniques. Early disease detection can lead to preventive actions which potentially can mitigate losses in grape yield and quality.

Keywords: Grapevine diseases, leaf reflectance, spectroradiometry, disease detection

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Methods and results: The study was made in year 2017 and again in 2018. Cabernet Sauvignon vines grown in pots and kept in a greenhouse were inoculated with the pathogens causing **mildew, powdery mildew, black-foot and Petri disease**. In early stages of disease development, reflectance measurements were performed using a FieldSpec 3 spectroradiometer, which were compared with data from healthy plants. Additional measurements were performed with chlorophyll meters. The investigation began with discriminant analysis, which revealed that symptomatic plants are indeed separated from the control ones. Reflectance spectra were therefore further investigated, looking for alterations on the shape of the spectra, characteristic of each disease. The disease descriptors were based on ratios between spectral features internal to a spectrum, a procedure which allowed the derivation of parameters intrinsic to each disease. A set of thresholds, defined as the intensity ratios of reflectance at selected wavelengths, was derived for the studied diseases. The selected wavelength ratios were 443/496, 443/573, 443/695, 443/1900, 496/573, 496/695, 516/1900, and 1900/2435 (values in nanometers), for which the spectra from symptomatic plants present shape changes of as much as 20% with respect to healthy plants.

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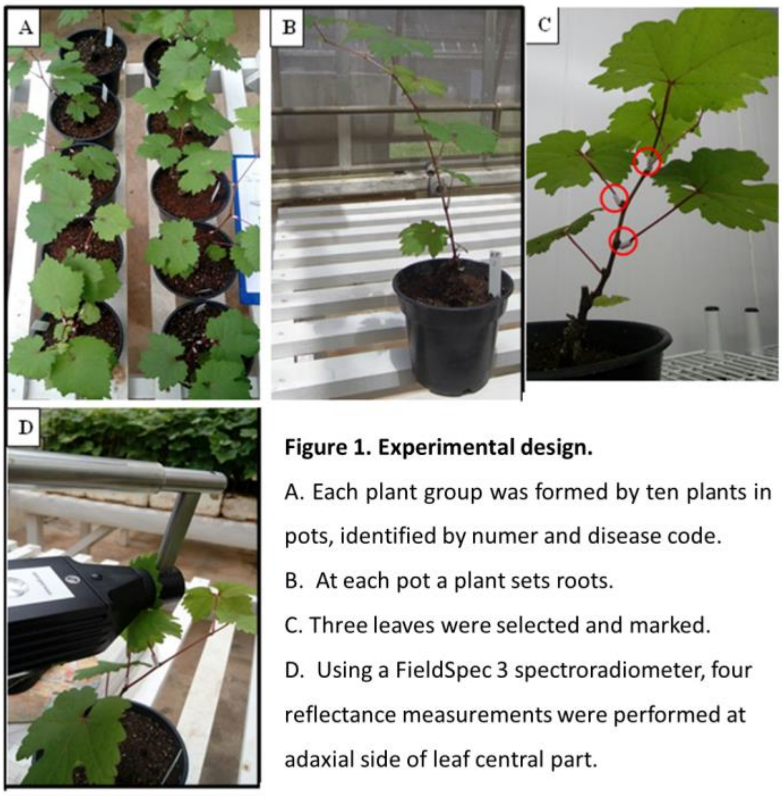

Figure 1. Experimental design.

A. Each plant group was formed by ten plants in pots, identified by numer and disease code.

B. At each pot a plant sets roots.

C. Three leaves were selected and marked.

D. Using a FieldSpec 3 spectroradiometer, four reflectance measurements were performed at adaxial side of leaf central part.

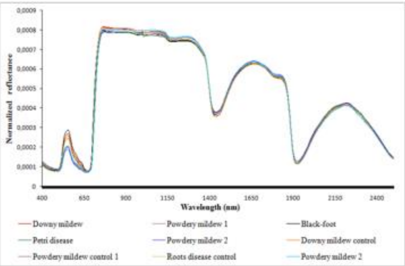

Figure 2. Examples of reflectance spectra of the studied diseases.

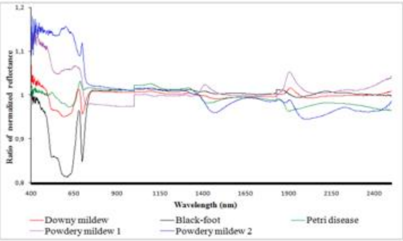

Figure 3. Original reflectance spectra of control plants were divided by spectra of sick plants, to reveal at which wavelengths spectral differences appear.

We performed a discriminant analysis using the spectral data set, and we were able to separate the diseases from the spectral information (Table 1)

Table 1. Confusion matrix (%) resulting from classification of leaf reflectance values from wavelengths selected for better separation between analyzed fungal diseases (excluding controls).

Disease	1	2	3	4	5	Σ
1	85.7	0	0	0	14.3	100
2	0	100	0	0	0	100
3	0	0	100	0	0	100
4	0	0	0	100	0	100
5	14.3	0	0	0	85.7	100

Legend: 1. Petri disease; 2. Downy mildew; 3. Powdery mildew 1; 4. Powdery mildew 2; 5. Black-foot.

When we divide reflectances values using the wavelengths revealed at Figure 3, we see that certain ratios are typical of specific diseases (Table 2)

	Downymildew		Black-foot		Petri disease		Powderymildew	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
443/496	1.01	0.03	0.97	0.03	1.02	0.04	1.08	0.01
443/573	0.44	0.03	0.39	0.03	0.45	0.06	0.60	0.06
443/695	0.55	0.03	0.47	0.04	0.56	0.06	0.71	0.05
443/1900	0.61	0.03	0.56	0.05	0.52	0.02	0.56	0.05
496/573	0.44	0.02	0.40	0.02	0.44	0.04	0.56	0.05
496/695	0.54	0.02	0.49	0.04	0.55	0.03	0.66	0.04
516/1900	1.04	0.09	1.09	0.16	0.88	0.13	0.75	0.06
1900/2435	0.71	0.01	0.72	0.02	0.73	0.01	0.75	0.01

Using the measurements made on control healthy plants on each year of the study, we were able to determine which wavelengths can be used as indicators of diseases in plants (Table 3).

Table 3 : Thresholds for the studied diseases derived for each year (2017 and 2018), calibrated by the control measurements acquired for each season.

	Downy mildew/ control		Black-foot/ control		Petri disease/ control		Powdery mildew/ control	
	2017	2018	2017	2018	2017	2018	2017	2018
443/496	0.98	1.00	0.94	0.86	0.99	0.96	1.05	0.99
443/573	0.94	1.06	0.83	0.81	0.97	1.01	0.92	0.97
443/695	0.92	1.04	0.83	0.82	0.98	1.05	0.91	0.96
443/1900	1.00	0.86	1.02	0.93	0.94	1.20	0.95	1.16
496/573	0.95	1.05	0.88	0.92	0.97	1.04	0.95	0.96
496/695	0.94	1.04	0.88	0.96	0.99	1.08	0.94	0.98
516/1900	1.06	0.74	1.18	1.03	0.95	1.06	1.01	1.09
1900/2435	0.98	1.03	1.00	1.02	1.00	0.99	0.98	1.01

Conclusions

The results of this study indicated that infections caused by the pathogens *P. viticola* , *U. necator*, *D. macrodidyma* and *Phaeoacremonium* ssp., after the inoculation of young plants of vines, when the symptoms are still in the initial stage, present changes in the spectral behavior of the leaves in the same spectral regions.

Accordingly, we presented here a methodology development aiming to the detection of some fungal diseases which affect vineyards. The method is based in spectral reflectance measurements of vine leaves, and produced a set of reflectance-related values, in the form of thresholds, that can be used in general measurements performed in field.

This work explored the potential of using spectroscopic observations to disease detection in plants, and was fully developed in laboratory controlled conditions.