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HYPERSPECTRAL CHARACTER ANALYSIS OF RICE LEAVES INFESTED BY BROWN PLANT-HOPPER (NILAPARVATA LUGENS)

ZHIYAN ZHOU[1], ZUOXI ZHAO[1], XIWEN LUO[1], YANFANG LI [2], YANG ZHANG[2], YING ZANG[1]

[1] Z. Zhou, Key Laboratory of Key Technology on Agricultural Machine and Equipment, Ministry of Education, College of Engineering, South China Agricultural University, Guangzhou 510642, China. zyzhou@scau.edu.cn
[1] Z. Zhao, zhao_zuoxi@yahoo.com.cn , corresponding author
[1] X. Luo, xwluo@scau.edu.cn
[2] Y. Li, Plant Protection Research Institute, Guangdong Academy of Agricultural Sciences, Guangzhou, China.
[2] Y. Zang, yingzang@scau.edu.cn

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ABSTRACT Rice Brown Plant-hopper (BPH) (Nilaparvata lugens) is one of the most serious infestations in rice production of China. To implement timely targeted pesticide applications, reducing input costs and benefiting the environment, an accurate early detection and quantification of damage caused by BPH infestation in rice plants is required. Currently, traditional methods, such as plant-flapping method, are the most common but subject to bias and can be inaccurate. Based on these imprecise and inaccurate detection systems and lack of damage evaluation data may cause costly errors to variable-rate spraying in Rice Precision Agriculture. A study was conducted to investigate: 1) the feasibility of using an ASD Fieldspec 3 radiometer to identify and discern differences of rice leaves with and without BPH infestation; and 2) the sensitive bands and the useful and optimum eigenvalues that extract from the spectral curves of the rice leaves. Reflectance data and derived vegetation indices from the radiometer were analyzed using statistical analysis procedure. Results show that it is possible to detect the stress caused by the BPH and to discriminate the rice leaves that were infested (I2PP, at a density of two BPHs per plant) and non-infested (NINP) by BPHs using remote sensing. The data provided evidence that 986nm may be most sensitive to BPHs infestation. The sensitive bands 550nm, 972-1000nm, 1250-1300nm, 666-673nm, 1919-1931nm, 758-790nm, which selected from hyperspectral spectrometry, have the potential to detect the infestation caused by BPHs in rice. The eigenvalues, such as the Trough Amplitude at 986nm, Difference of the Crest to the Trough (at 758~1063nm, 666~673nm; 758~1063nm, 972~1000nm; 758~1063nm, 1187~1300nm; 758~1063nm, 1919~1931nm; 1250~1314nm, 1919~1931nm), Difference of the Trough to the Trough (at 666~673nm, 972~1000nm; 972~1000nm, 1919~1931nm; 666~673nm, 1187~1300nm; 1187~1300nm, 1919~1931nm; 666~673nm, 1187~1300nm; 666~673nm, 1436~1455nm), Difference of the Crest (758~1063nm) to the Crest (1250~1314nm), Peak Area of the 1st Derivation at 670-790nm, NDVI at 550nm and 530nm, were found to be useful and optimum eigenvalues for differentiating the infested rice leaves caused by BPHs from non-infested rice leaves.

Keywords: Brown Plant-hopper (Nilaparvata Lugens), Remote sensing, Spectral reflectance, Vegetation indices, Rice leaves.

INTRODUCTION

Rice Brown Plant-hopper (BPH), Nilaparvata lugens (Stal)(Homoptera : Delphacidae), is small, soft bodied insect that obtain their nutrition by sucking sap from rice plants, has become the most serious insect pest of rice production in Asia, especially on cultivars(Zheng et al. 2007) . Rice plant-hopper feeding causes significantly lowered water content, chlorophyll content, leaf area, dry weight, aerial growth, and consequently the photosynthetic rate of plant. Feeding by large numbers of Rice plant-hopper lead to the death of infested leaf and then leaf drop, eventually, the whole plant lodging and death, which shows as hopperburn, result in greatly reduced yields (Backus et al. 2005) .

To improve rice production and protection, and to implement timely targeted pesticide applications, reducing input costs and benefiting the environment, an accurate early detection and quantification of damage caused by BPHs in rice plants is required. Currently, traditional methods, such as plant-flapping method (to investigate the population of BPHs by macroscopic observation, the tracking down rate is between 30% and 70%), are the most common but subject to bias and can be inaccurate (Nilsson 1995; Qi, Li Zheng et al 1995; Mirik et al. 2006a). These imprecise and inaccurate detection and damage evaluation data, however, may cause costly errors to variable-rate spraying in Precision Agriculture. Therefore, it is essential to have better methods for detecting stress timely and describing damage quantitatively and accurately.

Remote sensing is an alternative method for mapping the spatial distribution and severity of anomalies, including damage caused by crop insect-pests, that is consistent, nondestructive, noninvasive, unbiased, and precise(Riley 1989; Pinter et al. 2003; Fitzgerald et al. 2004; Mirik et al. 2006a; Mirik et al. 2006b). Crop plant under stress, i.e. stressed by water, disease, nutrient, weed and insect pests, etc., would causes canopy surface changes in leaf chemical concentrations, nutrient, cell structure, water content and potential, transpiration rate, and gas exchange, that can modify canopy reflectance characteristics compare with a healthy crop plant as for the differences in external feature of leaf, such as pigment and temperature. Many studies showed that crop plants under stress have a significant fluctuate in reflectance of the infrared band and the chlorophyll active band, a consequent shift of the red edge and vegetation indices (Shibayama and Akiyama 1989; Carter 1993; Shibayama et al. 1993; Carter and Miller 1994; Pinter et al. 2003; Yang et al. 2009). As a harmless, rapid, and cost-effective technology, remote sensing has been extensively used to study insect-pests caused stress by many researchers, such as aphid to wheat, cotton, tobacco and sorghum, etc. (Michels et al. 1999; Riedell and Blackmer 1999; Fitzgerald et al. 2000; Fitzgerald et al. 2004; Yang et al. 2005; Qiao, Hong-bo et al 2005; Reisig and Godfrey 2006; Mirik et al. 2006a; Mirik et al. 2006b; Elliott et al. 2007; Mirik et al. 2007; Reisig and Godfrey 2007; Yang et al. 2007; CHEN, Peng Cheng et al. 2007; QIAO, Hong Bo et al. 2007; Genc et al. 2008; Qiu, Bai Jing et al. 2008; Yang et al. 2009; SHI, Jing-jing et al. 2009) .

References which mentioned above show that insect-pests damaged to crops can be detected using remote sensing. To play an effective role in managing rice plant-hopper, relationships between spectral characters and symptoms of infestations must be adequately investigated based on ground studies before the development of the remote sensing algorithms and management schemes. The purpose of the current study was to identify wavelengths and relative spectral characteristics that are sensitive to BPH-infested rice plant leaves. Our experiments were geared towards the feasibility of spectral techniques in detecting BPH in rice and to build a scientific basis for accurate early detection of the rice paddy field insect-pests.

MATERIALS AND METHODS

A. Rice varieties and BPHs culture

This detection study was conducted in South China Agricultural University, the Key Laboratory of Key Technology on Agricultural Machine and Equipment, Ministry of Education, in Guangzhou city, China, at Longitude 113.3475 and Latitude 23.1574. Experiments were conducted during 27th September to 15th November 2009 using pot culture rice.

Seeds of Taichung Native (TN1) (BPH-susceptible) were sown in hills (seed spacing, 0.02m$\times$0.02m, for producing high vegetation cover to minimize soil influences) in 6 opaque plastic containers of red color with a diameter of 0.35m and a height of 0.4m on 27th September 2009. The soil was a paddy field loam. Six containers were randomly arranged in the greenhouse to minimize shading effects. After germination stage, all pots were watered once a day to keep the height of water layer between 0.01m and 0.03m, and fertilized using a composite fertilizer Batian (N-P-K=15-15-15, Shenzhen Batian Ecological Engineering Corp., China) once a week at a rate of 2g pot^{-1}.

BPHs that used in this study were obtained from Plant Protection Research Institute, Guangdong Academy of Agricultural Sciences (Guangzhou, China). The BPHs were reared in covered cages in a net room under natural temperature and photoperiod conditions. All experiments were conducted with natural temperature and photoperiod.

B. Selection of rice plants for detection

On 25th October 2009, twenty-eight days after sowing, when potted plants reached the tillering stage, six containers randomly divided into two groups, rice seedlings in three containers were infested with BPHs at a density of two BPHs (adults or fifth-instar nymphs) per plant (named I2PP), and rice seedlings in the other three containers were used as the control (non-infested, named NINP). After infested, three containers of I2PP were covered with nylon net cloth cages, let the BPHs spontaneous generation. The other three containers of NINP were also covered with nylon net cloth cages, and any insect-pests were removed by hand periodically to keep them free of BPHs. The purpose of covering the same nylon net cloth cages for all containers was to reduce the differences of temperature and photoperiod between I2PP and NINP.

Rice plants were selected from the containers both of I2PP and NINP on twenty days after infestation. The total numbers of spectra measurement rice plant samples in each groups were: infested with a density of two BPHs per plant (I2PP, n=21), non-infested (NINP, n=20).

C. Spectra measurement with hyperspectral spectrometry

Spectrum of each rice plant samples were measured using a FieldSpec® 3 Spectroradiometer (Analytical Spectral Devices, Inc., Boulder, Colorado, USA) fitted with a Pro Lamp Assembly (A128932). This spectroradiometer is specifically designed to acquire visible near-infrared (VNIR) and short-wave infrared (SWIR) spectra. It is a compact, field portable and precision instrument with a spectral range of 350-2500 nm and a rapid data collection time of 0.1 second per spectrum. The spectroradiometer detects 350-2500 nm continuous bands with spectral resolution: 3nm@350-1000nm, 7nm @1000-2500 nm; sampling interval: 1.4nm@350-1000nm, 2nm@1000-2500nm. The Pro Lamp Assembly, a 14.5 Volt 50 Watt Halogen Lamp, is tripod mountable for indoor lab diffuse reflectance measurements over the region 350-2500 nm.

The top first, second, and third leaves of each rice plant samples were selected for spectral measurement. All the measuring leaves were expanded and enclosed on a black rubber pad. At least ten consistent measurements were taken from the measuring leaves and each measurement was the mean of three consecutive individual full-range spectral scans.

D. Data analysis and pattern recognition

Spectra data were processed using MATLAB (The MathWorks, Inc., Natick, Massachusetts, USA). To identify bands and vegetation indexes that were sensitive to BPH infestation, 141 eigenvalues (listed in Table 1) of the spectral curves, such as crest position, trough position, edge position, values of its amplitude, and area of the edge, and the relative vegetation indexes, etc., was first extracted by calculate its first derivation. The derivation formula was showed as follows (Cho and Skidmore 2006):

$$\mathrm{DR}_{\lambda(i)} = (R_{\lambda(j+1)} - R_{\lambda(j)}) / \Delta\lambda \qquad (1)$$

Where *DR* is the first derivative reflectance at a wavelength *i*, midpoint between wavebands *j* and *j+1*, $R_{\lambda(j)}$ is the reflectance at the *j* waveband, $R_{\lambda(j+1)}$ is the reflectance at the *j+1* waveband, and $\triangle\lambda$ is the difference in wavelengths between *j* and *j+1*.

These eigenvalues was used to identify the sensitive bands subsequent to which there were significant differences between groups I2PP and NINP using ANOVA (Analysis of variance). Based on comparisons of these eigenvalues that were sensitive to infestation by BPHs could be initially determined according to the p-values.

Table 1. Various eigenvalues of the spectral curves.

Name	Abbreviation	Formula / wavelength	References
Crest Position	CP1-5	490-600nm, 730-1100nm, 1250-1370nm, 1570-1750, 2000-2350nm	The present study
Crest Amplitude	CA1-5		
Trough Position	TP1-5	600-700nm, 950-1030nm, 1130-1300nm, 1410-1510nm, 1890-2000nm	
Trough Amplitude	TA1-5		
Ratio of the Crest to the Trough	RVICT1-25	490-600nm, 730-1100nm, 1250-1370nm, 1570-1750, 2000-2350nm,	The present study

Ratio of the Crest to the Crest	RVICC1-10	600-700nm, 950-1030nm, 1130-1300nm, 1410-1510nm, 1890-2000nm	
Ratio of the Trough to the Trough	RVITT1-10		
Difference of the Crest to the Trough	DVICT1-25		
Difference of the Crest to the Crest	DVICC1-10		
Difference of the Trough to the Trough	DVITT1-10		
Ratio Vegetation Index	RVI1	R779/R558	(Qiu, Bai Jing et al. 2008)
	RVI2-3	R800/R450, R950/R450	(Yang et al. 2009)
	RVI4	R800/R694	(Yang et al. 2005)
	RVI5	R750/R705	(Sims and Gamon 2002)
	RVI6	R600/R502	
Lichtenthaler Index	LIC	R440/R690	(Lichtenthaler 1996)
Leaf Moisture Index	LMI	R1650/R830	(Yang et al. 2009)
Pigment Specific Simple ratio	PSSR1-3	R800/R680, R800/R470, R800/R635	(Blackburn 1999)
Water Band Index	WBI	R950/R900	(Riedell and Blackmer 1999)
Difference Vegetation Index	DVI1	DVI = R789−R663	(Tucker 1979)
Normalized Difference Vegetation Index	NDVI1	(R779-R558)/(R779+R558)	(Qiu, Bai Jing et al. 2008)
	NDVI2	(R750-R705)/(R750+R705)	(Sims and Gamon 2002)
	NDVI3	(R801-R670)/(R801+R670)	(Daughtry et al. 2000)
	NDVI4	(R789-R649)/(R789+R649)	(Rouse et al. 1974)
	NDVI5-6	(R747-R537)/(R747+R537), (R550-R530)/(R550+R530)	
Photochemical Reflectance Index	PRI	(R531-R570)/(R531+R570)	(Gamon et al. 1997; Thenot et al. 2002)
Normalized total Pigment to Chlorophyll Index	NPCI	(R680−R430)/(R680 + R430)	(Riedell and Blackmer 1999)
Structural Independent Pigment Index	SIPI	(R800−R450)/(R800−R680)	(Penuelas and Inoue 1999)
Aphid Index	AI	(R761-R908)/ (R712-R719)	(Mirik et al. 2006b)
Pigment Specific Normalized Difference	PSND1-3	(R800-R680)/(R800+R680), (R800-R635)/(R800+R635), (R800-R470)/(R800+R470)	(Blackburn 1999; Blackburn and Steele 1999)
Edge Position	EP1-10	490-550nm, 670-790nm, 1445-1660nm, 1925-2200nm, 550-670nm, 1100-1200nm, 1300-1445nm, 1660-1800nm, 1820-1925nm, 2200-2450nm	(Smith et al. 2004; Cho and Skidmore 2006; Mutanga and Skidmore 2007)
Edge Amplitude	EA1-10		
Peak Area of the 1st Derivation	PAR1-10		
Peak Abruptness of the 1st Derivation	PAB1-10		(WANG, Yuan-yuan et al. 2007)
Peak Asymmetry of the 1st Derivation	PAS1-10		

RESULTS AND DISCUSSION

A. Spectral reflectance characteristic

Figure 1 shows the comparison of spectral reflectance of rice leaves that were infested (I2PP) or non-infested (NINP) by Brown Plant-Hoppers (BPHs). Figure 2 shows the comparison of the first derivation of spectral reflectance of rice leaves that were infested (I2PP) or non-infested (NINP) by BPHs.

As can be seen from Figure 1 and Figure 2, reflectance was generally higher for NINP at 750-1300nm. The edges nearby the bands of 520nm, 570nm, 700nm, 1145nm, 1400nm, 1490nm, 1755nm, 1885nm, and 2000nm have higher slope degree for NINP, where their first derivative reflectances (absolute value) are usually higher. What's more, interestingly, there are double peaks in the green band for I2PP, where is a single peak for NINP (see Figure 1). The reasons for this phenomenon are complicated. Maybe the BPHs feeding on the rice plants significantly reduced nutrient uptake of roots (Wu et al. 2003; Wang et al. 2006), especially phosphorus (P) and potassium (K), then caused the nutrition changes of the plants, include a decrease water contents (about 1450nm, 1950nm, 2700nm are the absorption bands of water), a decrease in protein with (Zheng et al. 2007), etc., and these are the main facts.

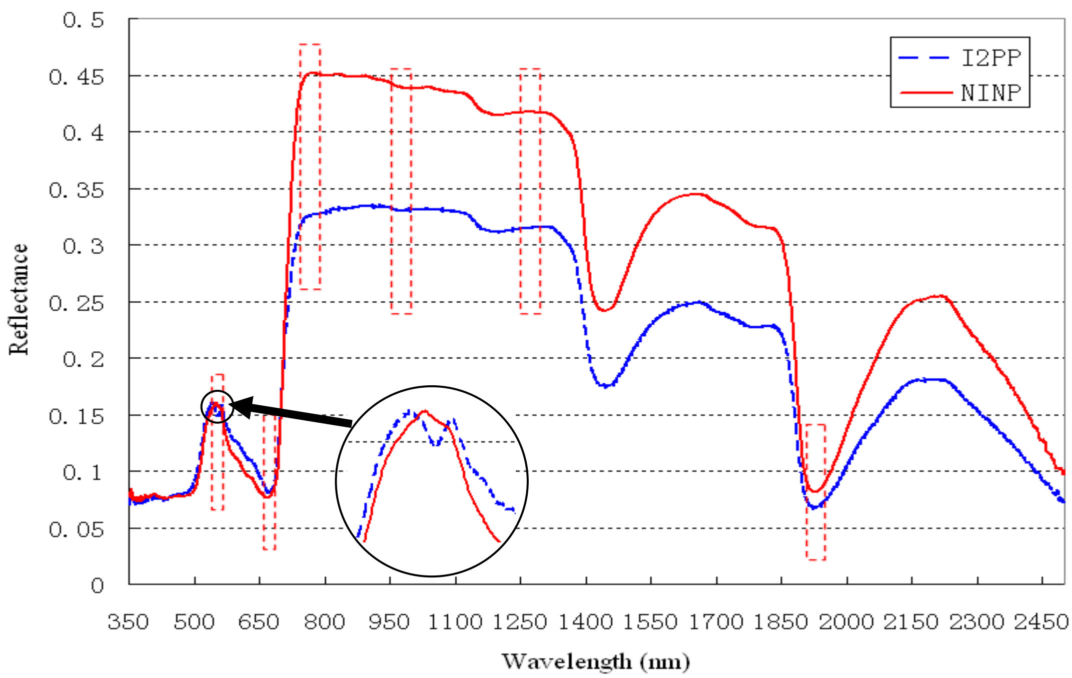


Figure 1. Comparison of spectral reflectance of rice leaves that were infested (I2PP, at a density of two BPHs per plant) and non-infested (NINP) by Brown Plant-Hoppers (BPHs). The red dashed line box showed the most sensitive bands to BPHs infestation.

Figure 2. Comparison of the first derivation of spectral reflectance of rice leaves that were infested (I2PP, at a density of two BPHs per plant) or non-infested (NINP) by Brown Plant-Hoppers (BPHs).

B. Eigenvalues of spectral curves and sensitive bands

To identify bands that were sensitive to BPH infestation, 141 eigenvalues of the spectral curves, such as crest position, trough position, edge position, values of its amplitude, and area of the edge, and the relative vegetation indexes, etc. was extracted by calculate its 1st derivation. After comparison their significant differences between groups I2PP and NINP using ANOVA, the useful and optimum eigenvalues were determined according to the P-values (Significant at the 0.01 level). Figure 3 shows the P-values that calculated from the ANOVA of 141 eigenvalues. According to the P-values (Significant at the 0.01 level), 48 optimum eigenvalues were selected (listed in Table 2).

As shown in Table 2, at the 0.01 significant levels, the useful and optimum eigenvalues are Crest Amplitude, Trough Amplitude, Difference of the Crest to the Trough, Difference of the Crest to the Crest, Ratio of the Crest to the Crest, Difference of the Trough to the Trough, Normalized Difference Vegetation Index at 550nm and 530nm, Edge Amplitude, Peak Area of the 1st Derivation, and Peak Abruptness of the 1st Derivation, respectively. As for the eigenvalues mentioned above involve so many bands, a histogram was used to determine the most sensitive bands. The histogram was showed in Figure 4.

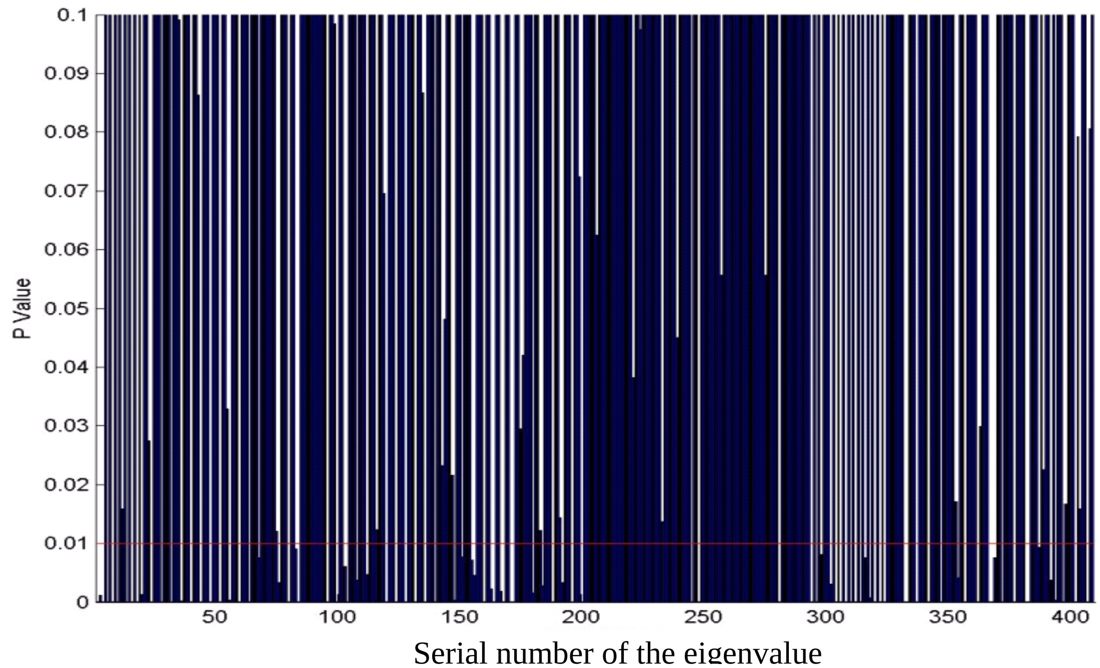


Figure 3. The P-values that calculated from the ANOVA of 141 eigenvalues. The red line shows the significant eigenvalues at the 0.01 significant levels.

Table 2. Various eigenvalues of the spectral curves.

No.	Eigenvalue Name	Abbreviation	Band(nm)	P-value
1*	Crest Amplitude	CA2	891	3.69325E-06
2*	Crest Amplitude	CA3	1305	9.19105E-06
3*	Crest Amplitude	CA4	1656	4.01304E-07
4*	Crest Amplitude	CA5	2210	4.20007E-07
5*	Trough Amplitude	CA2	986	9.14972E-06
6*	Trough Amplitude	CA3	1200	7.86609E-06
7*	Trough Amplitude	CA4	1446	8.45322E-07
8*	Difference of the Crest to the Trough	DVICT2	542~564nm, 972~1000nm	9.3951E-05
9*	Difference of the Crest to the Trough	DVICT3	542~564nm, 1187~1300nm	9.79267E-05
10*	Difference of the Crest to the Trough	DVICT6	758~1063nm, 666~673nm	8.9496E-07
11*	Difference of the Crest to the Trough	DVICT7	758~1063nm, 972~1000nm	2.47949E-10
12*	Difference of the Crest to the Trough	DVICT8	758~1063nm, 1187~1300nm	8.33552E-09
13*	Difference of the Crest to the Trough	DVICT10	758~1063nm, 1919~1931nm	1.78065E-06
14*	Difference of the Crest to the Trough	DVICT11	1250~1314nm, 666~673nm	2.44463E-06
15*	Difference of the Crest to the Trough	DVICT15	1250~1314nm, 1919~1931nm	4.9676E-06
16*	Difference of the Crest to the Trough	DVICT16	1646~1665nm, 666~673nm	3.71777E-08
17*	Difference of the Crest to the Trough	DVICT18	1646~1665nm, 1436~1455nm	4.51988E-06
18*	Difference of the Crest to the Trough	DVICT20	1646~1665nm, 1919~1931nm	6.27976E-08
19*	Difference of the Crest to the Trough	DVICT21	2144~2222nm, 666~673nm	1.00399E-08
20*	Difference of the Crest to the Trough	DVICT25	2144~2222nm, 1919~1931nm	1.69668E-08
21*	Difference of the Crest to the Crest	DVICC1	542~564nm, 758~1063nm	1.68355E-05
22*	Difference of the Crest to the Crest	DVICC2	542~564nm, 1250~1314nm	0.000112552
23*	Difference of the Crest to the Crest	DVICC5	758~1063nm, 1250~1314nm	8.3777E-10
24*	Ratio of the Crest to the Crest	RVICC8	1250~1314nm, 1646~1665nm	0.007717111
25*	Difference of the Crest to the Crest	DVICC10	1646~1665nm, 2144~2222nm	1.63809E-06

26*	Difference of the Trough to the Trough	DVITT1	666~673nm, 972~1000nm	2.58623E-06
27*	Difference of the Trough to the Trough	DVITT2	666~673nm, 1187~1300nm	1.99412E-06
28*	Difference of the Trough to the Trough	DVITT3	666~673nm, 1436~1455nm	1.65176E-08
29*	Difference of the Trough to the Trough	DVITT7	972~1000nm, 1919~1931nm	5.5023E-06
30*	Difference of the Trough to the Trough	DVITT9	1187~1300nm, 1919~1931nm	4.18328E-06
31*	Difference of the Trough to the Trough	DVITT10	1436~1455nm, 1919~1931nm	3.33292E-08
32*	Normalized Difference Vegetation Index	NDVI6	(R550-R530)/(R550+R530)	1.29563E-13
33*	Edge Amplitude	EA1	522	3.74731E-07
34*	Edge Amplitude	EA2	699	1.72496E-07
35*	Edge Amplitude	EA3	1488	9.17367E-07
36*	Edge Amplitude	EA4	2012	2.14139E-07
37*	Edge Amplitude	EA8	1682	1.14045E-05
38*	Edge Amplitude	EA9	1884	3.3133E-07
39*	Peak Area of the 1st Derivation	PAR1	490-550	7.84318E-09
40*	Peak Abruptness of the 1st Derivation	PAB1	490-550	9.09773E-05
41*	Peak Area of the 1st Derivation	PAR2	670-790	3.92593E-07
42*	Peak Area of the 1st Derivation	PAR3	1445-1660	4.59769E-06
43*	Peak Area of the 1st Derivation	PAR4	1925-2200	1.68757E-08
44*	Peak Area of the 1st Derivation	PAR5	550-600	2.61139E-10
45*	Peak Abruptness of the 1st Derivation	PAB5	550-600	2.03386E-11
46*	Peak Area of the 1st Derivation	PAR8	1660-1800	9.74387E-07
47*	Peak Area of the 1st Derivation	PAR9	1820-1925	7.46392E-08
48*	Peak Area of the 1st Derivation	PAR10	2200-2450	7.9133E-08

* Significant at the 0.01 level.

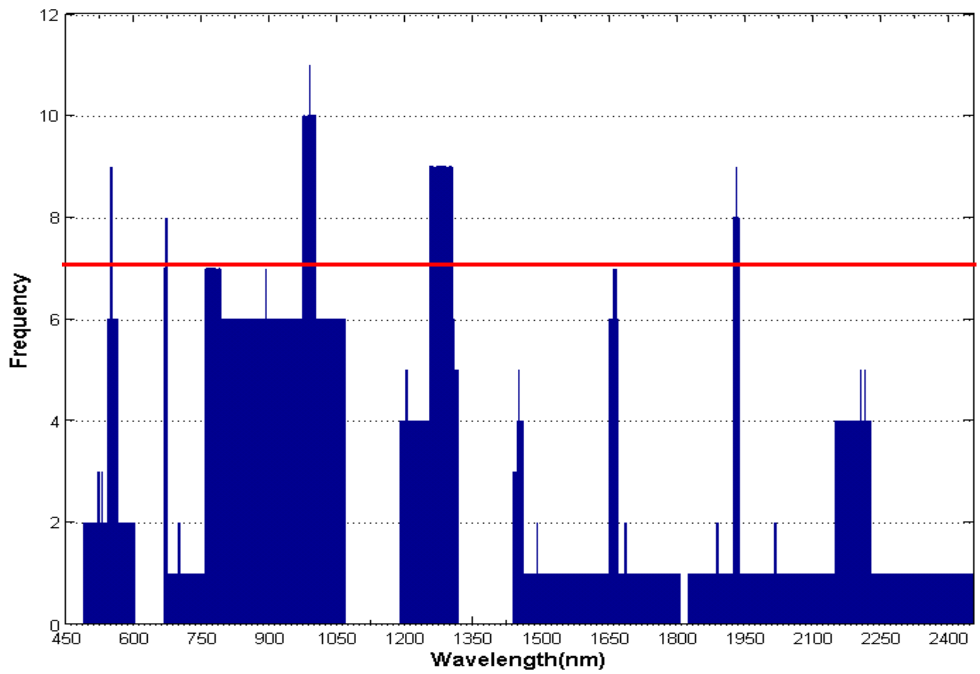


Figure 4. The histogram of the eigenvalues involved bands. The red line showed the higher frequency (>=7).

Compare to the frequency of each band appeared in the selected 48 eigenvalues (Figure 4), 986nm has highest frequency and thus it may be most sensitive to BPHs infestation. Analogously, 550nm, 972-1000nm, 1250-1300nm, 666-673nm, 1919-1931nm, 758-

790nm, have higher frequency (>=7, the red line showed in Figure 4) and thus they might be also more sensitive to BPHs infestation. The red dashed line box in Figure 1 showed the most sensitive bands to BPHs infestation.

Combined with Table 2 and Figure 4, Trough Amplitude at 986nm, Difference of the Crest to the Trough (at 758~1063nm, 666~673nm; 758~1063nm, 972~1000nm; 758~1063nm, 1187~1300nm; 758~1063nm, 1919~1931nm; 1250~1314nm, 1919~1931nm), Difference of the Trough to the Trough (at 666~673nm, 972~1000nm; 972~1000nm, 1919~1931nm; 666~673nm, 1187~1300nm; 1187~1300nm, 1919~1931nm; 666~673nm, 1187~1300nm; 666~673nm, 1436~1455nm), Difference of the Crest (758~1063nm) to the Crest (1250~1314nm), Peak Area of the 1st Derivation at 670-790nm, NDVI at 550nm and 530nm, are the most useful and optimum eigenvalues.

The selected of the most useful and optimum eigenvalues are explained using Difference of the Trough to the Trough (DVITT2, at 666~673nm, 1187~1300nm) and Peak Area of the 1st Derivation (PAR2, at 670-790nm) as examples. Figure 5 shows these two optimum eigenvalues and its P-values. As shown in Figure 5(a), DVITT2 of I2PP are mostly concentrated between -0.25~-0.18, while that of NINP are mostly concentrated between -0.39~-0.3. And in Figure 5(b), for NINP, the PAR2 at 670-790nm are mostly concentrated between 0.34~0.42, and for I2PP, mostly between 0.2~0.26. The others eigenvalues have the same significant difference to identify I2PP from NINP. They are all shown in Table 2.

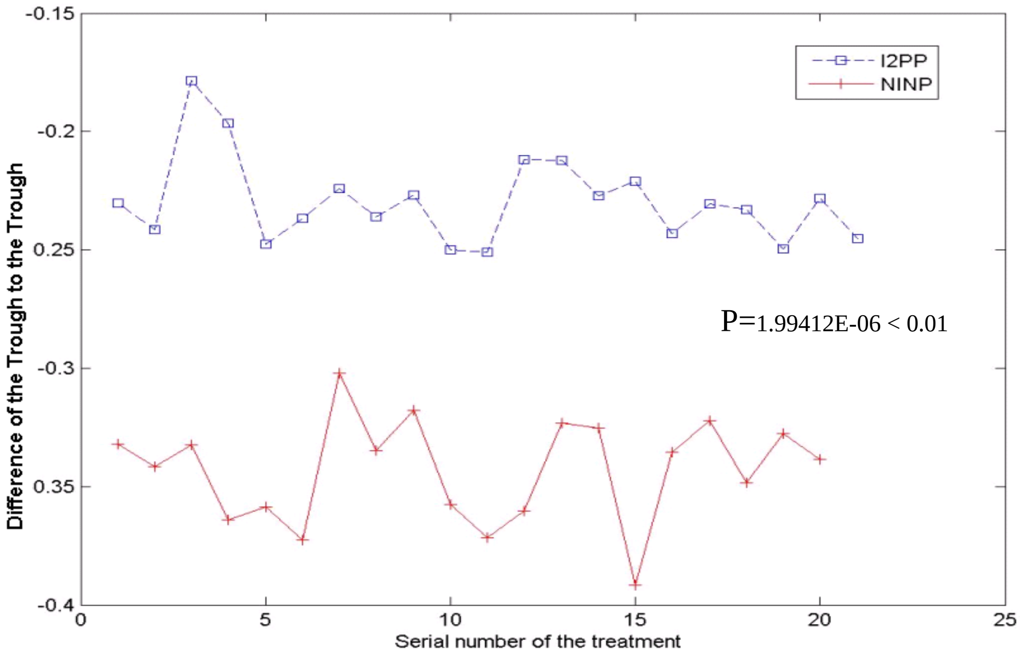
CONCLUSION

Based on the above results, it can be concluded that:

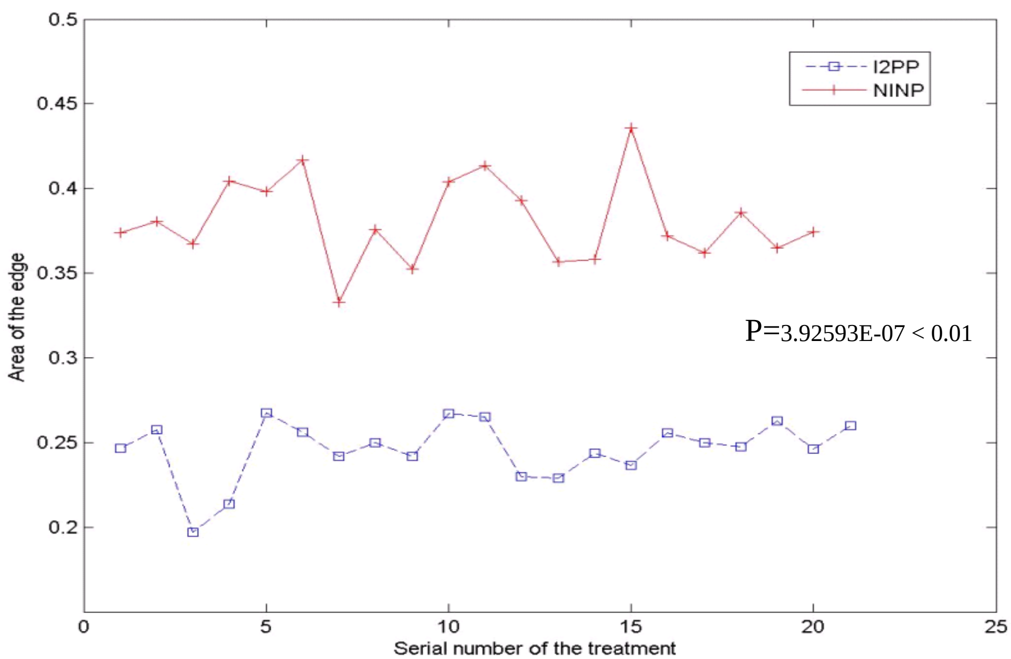
(1)The data provided evidence that 986nm may be most sensitive to BPHs infestation. The sensitive bands 550nm, 972-1000nm, 1250-1300nm, 666-673nm, 1919-1931nm, 758-790nm, which selected from hyperspectral spectrometry, have the potential to detect the infestation caused by BPHs in rice.

(2)The eigenvalues, such as the Trough Amplitude at 986nm, Difference of the Crest to the Trough (at 758~1063nm, 666~673nm; 758~1063nm, 972~1000nm; 758~1063nm, 1187~1300nm; 758~1063nm, 1919~1931nm; 1250~1314nm, 1919~1931nm), Difference of the Trough to the Trough (at 666~673nm, 972~1000nm; 972~1000nm, 1919~1931nm; 666~673nm, 1187~1300nm; 1187~1300nm, 1919~1931nm; 666~673nm, 1187~1300nm; 666~673nm, 1436~1455nm), Difference of the Crest (758~1063nm) to the Crest (1250~1314nm), Peak Area of the 1st Derivation at 670-790nm, NDVI at 550nm and 530nm,, which determined from the above mentioned sensitive bands, were found to be useful and optimum eigenvalues for differentiating the infested rice leaves caused by BPHs from non-infested rice leaves.

(3)Further studies are needed to identify bands and relative parameters that are most useful and sensitive to determined the damaged levels caused by BPHs in rice under field condition.



(a)



(b)

Figure 5. The selected optimum eigenvalues: (a) the Difference of the Trough to the Trough (DVITT2, at 666~673nm, 1187~1300nm) (b) the Peak Area of the 1st Derivation (PAR2, at 670-790nm). (I2PP: Infested by BPHs at a density of 2 BPHs per plant; NINP: non-infested.)

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