SPECTRAL DIFFERENCES OF OPPOSITE SIDES OF STRIPE RUST INFESTED WINTER WHEAT LEAVES USING ASD'S LEAF CLIP

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ABSTRACT

Stripe Rust, caused by *Puccinia striiformis* f. sp. *tritici*, has emerged as one of the most destructive foliar diseases of winter wheat (*Triticum aestivum* L.) and caused great yield loss. The primary objective of this study is to identify the stress characteristics of wheat leaves caused by such a disease. After performing artificial inoculation of stripe rust, hundreds of leaves with different infections were collected and leaf reflectance were conducted using ASD's (Analytical Spectral Devices) leaf clip probe. Based on the nonequivalent optical properties on the opposite side of a leaf, their spectral characteristics were specifically compared and the correlations between disease severity indices and water or chlorophyll were further analyzed. The final results indicated that, for the face and back sides of stripe rust infected wheat leaves, some obvious differences existed in the spectral reflectance and correlation curves between foliar disease severity indexes (*FDSIs*) and reflectance, especially with the increase of infections.

***Index Terms*—**Winter wheat, Stripe rust disease, Leaf reflectance measurement, ASD Leaf Clip, Foliar disease severity index (FDSI)

1. INTRODUCTION

Stripe rust, caused by *Puccinia striiformis* f. sp. *tritici*, has emerged as one of the most devastating foliar diseases of winter wheat (*Triticum aestivum* L.) and caused great yield loss. Over the past century, its prevalence has ever caused severe damage to China's wheat production for four times in 1950, 1964, 1990 and 2002. This disease can infect large areas of wheat primarily because it produces copious amount of airborne spores and consequently cause significant losses in yield [1]. Therefore, it is of significant importance to characterize and identify such a foliar wheat disease, especially in the early stage of serious outbreaks [2]. Since the emergence of remote sensing technology, it has been extensively applied in identification of various kinds of crop diseases and pests [3, 4]. In comparison with traditional on-farm diagnosis, remote sensing techniques, especially hyperspectral remote sensing, can load plenty of characteristic information of target crops [5, 6]. However, the interaction between electromagnetic radiation and plants varies by the variation of radiation wavelength. Depending on the level of health and or vigor, they will exhibit significant differences in the way they reflect light for the same plant leaves [7]. By analyzing spectral characteristic curves between healthy and diseased wheat leaves, diagnostic spectral bands and indices, sensitive to stripe rust, can be found out [8, 9].

Nevertheless, previous studies have been mainly focused on identifying an average reflectance for wheat leaves infected with stripe rust. The differences of optical properties for opposite sides of a leaf cannot be fully considered. In this study, ASD's Leaf Clip was used to characterize the spectral differences of striped rust infected winter wheat leaves.

2. MATERIALS AND METHODS

2.1 Experimental design

A field experiment was conducted in Xiaotangshan National Precision Agriculture Experimental Base, Changping District, Beijing (40°10′31″ N to 40°11′18″ N, 116°26′10″ E to 116°27′05″ E). The terrain of this base is very flat and it is an ideal venue for hyperspectral remote sensing experimental designs. Under normal water and nutrient management, stripe rust epidemics were initiated by artificial inoculation. At the heading (29 April 2011) stage, which is a key period to form wheat yield, wheat leaves with different infections were collected to identify the stress characteristics caused by stripe rust.

2.2 Artificial inoculation

In this study, the test wheat cultivar was Jing-9428 and wheat plants were inoculated under controlled conditions in different intensities with stripe rust spores. A spraying method was used to induce fungi into a living object. In the laboratory, stripe rust spores were firstly mixed with distilled water in two sprayers and two suspensions with two concentrations (0.45g spores and 6.0L water; 0.25g spores and 6.0L water) were prepared. Subsequently, the artificial inoculations were conducted in the wheat fields around 5:00 pm. Before spraying the suspensions, some water was firstly sprayed onto the wheat leaves to make it easier for the stripe rust spores to adhere to the leaves. Finally, the mixed suspensions were sprayed on the wheat canopies. After finishing spraying the entire target area, plastic membrane was covered on the wheat. On the next day, the plastic membrane was removed around 8:30 am. Additionally, normal treatment (CK) was designed near the inoculated stripe rust zones as a comparison standard.

2.3 Data acquisition and assessment of disease severity

There were totally 120 inverse third leaves to be randomly picked up and their reflectance measurements were conducted with an ASD Field Spectrometer (Analytical Spectral Devices, Inc., Boulder, Colorado, USA) with a leaf clip probe in the visible and near infrared (VNIR) and short-wave infrared (SWIR) ranges (350 to 2,500 nm). ASD's Leaf Clip is the ideal tool for non-destructive, one-handed functionality, and improved analysis of live vegetation and other thin heat sensitive targets. When collecting the leaf reflectance, ten replicate measurements were conducted from top to bottom of a leaf and the average spectrum was used as the final reflectance. After finishing the spectral measurements, the disease severity was determined through the proportion of a complete leaf covered by stripe rust spores. Afterwards, they were assigned a foliar disease severity index (FDSI) using the following equation. Consequently, four disease damage levels were generally classified: normal, light, moderate and serious.

$$FDSI = \frac{\sum_{i=1}^{n} S_{Di}}{S_L} \qquad (1)$$

where S_L is the total area of a certain leaf, S_{Di} is the area of spore, i is the number of spores.

3. RESULTS AND DISCUSSION

3.1 Comparison of spectral characteristics of opposite sides for a leaf

To comparatively analyze the spectral differences of opposite sides for healthy and diseased leaves, the reflectance curves of four disease damage levels were drawn as shown in Fig. 1. It could be evidently found that the spectral differences were increasingly enhanced, especially in the wavelength range of 750-1,360 nm with the increase of damage levels. The reason for such a phenomenon could be interpreted that stripe rust produced leaf lesions (pustules) in yellow color and tended to be grouped in patches. Once wheat leaves were infected, the tissue became brown and dry, and plants have a scorched, drouthy appearance. With the increase of narrow stripes, the reflectance showed a decreasing trend on the whole.

However, due to heterogeneous destruction of stripe rust pustules on the face and back sides for a leaf, the reflectance values were also different in different spectral ranges. For healthy wheat leaf, it generally shows high reflectance in the near infrared (NIR, 700-1,200 nm) because of multiple scattering at the air-cell interfaces in the leaf's internal tissue. The existence of disease pustules destroyed the cell structures, so corresponding reflectance decreased. As a result, NIR bands could be used to effectively discriminate different disease damage levels.

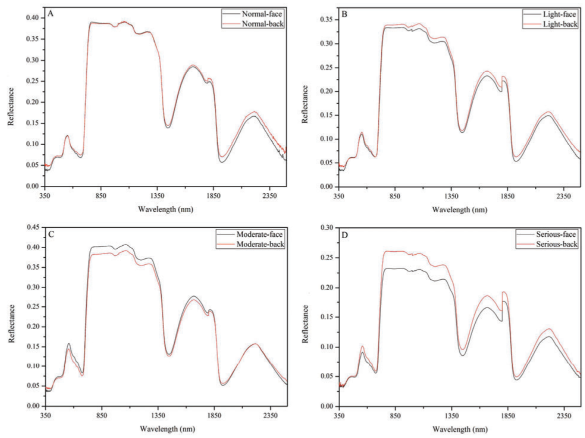

Fig. 1 Comparison of spectral curves of face and back sides of four disease damage levels (A: Normal level; B: Light level; C: Moderate level; D: Serious level)

3.2 Selection of spectral bands sensitive to stripe rust

On the basis of analyzing spectral differences, correlation analysis between FDSIs and reflectance values was further performed (the number of leaf samples was 120). Fig. 2 was their correlation analysis results of face and back sides of leaves. We could find that the correlation curves showed different change features for two sides. There was an obvious breaking point at around 740 nm to divide the two curves into two parts. In the wavelength of 350-740 nm, both curves had similar trends, while they showed an inverse trends ranging from 740 to 2,500 nm. For the face side, the sensitive spectral ranges with significant positive correlation to stripe rust were located in the ranges of 547-669 and 687-719 nm, while they were located in the ranges of 562-593 and 695-717 nm with significant positive correlation, and 389-496 and 1,885-2,500 nm with significant negative correlation for the back side. By selecting the peak values of these sensitive ranges, 610 and 702 nm were used as the sensitive bands for the face side and 575, 704, 421 and 1935 nm were the sensitive bands for the back side.

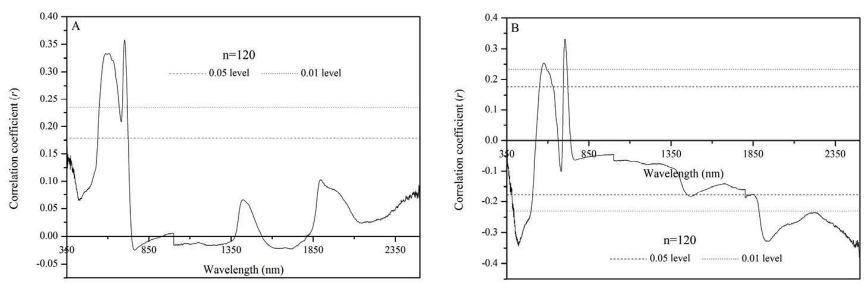

Fig. 2 Correlation analysis between the FDSIs and spectral reflectance of collected leaf samples in the wavelength range of 350-2,500 nm (A: Face side; B: Back side)

3.3 Identification of FDSIs

Spectral measurements provide an inexpensive and rapid diagnostic method for wheat stripe rust. Photochemical reflectance index (PRI) was used here to retrieve the disease severity using the face side as an example. This index was defined at the leaf and canopy levels in the early 1990s to assess the efficiency of a plant's use of absorbed photosynthetic active radiation (APAR) for photosynthesis (LUE) [10]. It was calculated using the reflectance values at 531 and 570 nm as follows.

$$PRI = \frac{R_{531} - R_{570}}{R_{531} + R_{570}} \qquad (2)$$

Fig. 3A was the built regression equation between PRI and FDSI using 70 wheat leaves and the coefficient of determination (R^2) reached 0.702. To validate the model, the other 50 samples were used to compare the measured and predicted values of FDSI (B). It was obvious that R^2 reached 0.817 which proved that the equation could be used to derive infections caused by stripe rust directly from reflectance values.

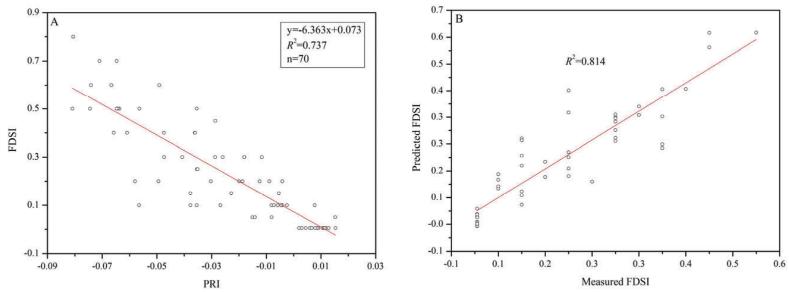

Fig. 3 Regression equation between PRI and FDSI (A) and comparison of measured and predicted FDSIs

4. CONCLUSION

The primary objective of this study was to compare spectral differences of opposite sides for a leaf infected with stripe rust. Corresponding analysis results indicate that the spectral data from ASD's Leaf Clip is feasible to identify stress characteristics caused by foliar disease of stripe rust. In comparison with ASD integrating sphere, the leaf clip is more flexible to be utilized in the field environment. By comparing the spectral differences, we can find that they have apparent between face and back sides of infected wheat leaves, especially with the increase of infections. Therefore, the spectral differences must be considered when studying the canopy spectral properties of diseased wheat.

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REFERENCES

[1] W. J. Huang, D. W. Lamb, Z. Niu, et al., "Identification of yellow rust in wheat using in-situ spectral reflectance measurements and airborne hyperspectral imaging." *Precision Agriculture*, vol. 8, no. 4-5, pp. 187-197, 2007

[2] C. Bravo, D. Moshou, J. West, et al., "Early disease detection in wheat fields using spectral reflectance." *Biosystems Engineering*, vol. 84, no. 2, pp. 137-145, 2003

[3] M. Hugh-Jones, "Applications of remote sensing to the identification of the habitats of parasites and disease vectors." *Parasitology Today*, vol. 5, no. 8, pp. 244-251, 1989

[4] M. S. Moran, Y. Inoue and E. M. Barnes, "Opportunities and limitations for image-based remote sensing in precision crop management." *Remote Sensing of Environment*, vol. 61, no. 3, pp. 319-346, 1997

[5] D. Moshou, C. Bravo, J. West, et al., "Automatic detection of 'yellow rust' in wheat using reflectance measurements and neural networks." *Computers and Electronics in Agriculture*, vol. 44, no. 3, pp. 173-188, 2004

[6] J. Li, J. B. Jiang, Y. H. Chen, et al., "Using hyperspectral indices to estimate foliar chlorophyll a concentrations of winter wheat under yellow rust stress." *New Zealand Journal of Agricultural Research*, vol. 50, no. 5, pp. 1031-1036, 2007

[7] J. S. West, C. Bravo, R. Oberti, et al., "The potential of optical canopy measurement for targeted control of field crop disease." *Annual Reviews of Phytopathology*, vol. 41, pp. 593-614, 2003

[8] R. J. Bryson, N.D. Paveley, W.S. Clark, et al., "Use of in-field measurements of green leaf area and incident radiation to estimate the effects of yellow rust epidemics on the yield of winter wheat." *European Journal of Agronomy*, vol. 7, no. 1, pp. 53-62, 1997

[9] R. Devadas, D. W. Lamb, S. Simpfendorfer, et al., "Evaluating ten spectral vegetation indices for identifying rust infection in individual wheat leaves." *Precision Agriculture*, vol. 10, no. 6, pp. 459-470, 2009

[10] J. A. Gamon, J. Peñuelas and C. B. Field, "A narrow-waveband spectral index that tracks diurnal changes in photosynthetic efficiency." *Remote Sensing of Environment*, vol. 41, no. 1, pp. 35-44, 1992