Vertical features of yellow rust infestation on winter wheat using hyperspectral imaging measurements

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***Abstract*—Yellow (stripe) rust *Puccinia striiformis* has caused severe losses on wheat in yield and grain quality in China. As the largest land area devoted to wheat production, China has also the largest area prone to yellow rust epidemics. Traditionally, the disease assessment was visually investigated in the field by experienced farmers or pathologists. The emergency of hyperspectral measurements has distinct advantages over conventional visual inspection, and they can collect the information repeatedly and automatically. In comparison with the hyperspectral measurements using a non-imaging spectrometer, the spectral and imaging features of pure yellow rust spores can be simultaneously collected. The study on monitoring the vertical features of yellow rust infestation on winter wheat was performed using ground-based imaging spectrometer. The results show that the infection severities generally show a gradual increasing trend from F-1 (F=Flag leaf) to F-3, while the relative chlorophyll shows an inverse change. The spectral reflectance gradually increases from F-1 to F-3 in the visible spectral region, while it is the very reverse in the near-infrared (NIR) region.**

Keywords—winter wheat; yellow rust; style; hyperspectral imaging; feature extraction; vertical infestation

I. INTRODUCTION

Wheat yellow (stripe) rust caused by *Puccinia striiformis* f. sp. *tritici* (PST) is one of the most devastating diseases of wheat worldwide [1]. In China, yellow rust has appeared in yearly epidemics since the widespread occurrence of the disease in the 1950s and has caused losses of more than 60 million tons [2]. Severe levels of infection can cause yield losses of more than 50% and significant reductions in grain quality. The three most important weather factors affecting epidemics of stripe rust are moisture, temperature, and wind [3]. When weather conditions are relatively appropriate, the disease can spread rapidly over very long distances. Infection can occur anytime from the one-leaf stage to plant maturity provided plants are still green. The pathogen causing yellow rust infects the green tissues of plants of cereal crops and grasses. Such a disease utilizes water and nutrients from the host plants, which weakens the plants and the wheat yield and quality have been greatly reduced.

To evaluate the symptoms and impact of wheat yellow rust, visual inspection and manual survey are usually used in traditional methods [4]. The destruction has been actually induced, although the symptoms cannot be observed visually, especially in the early stages of disease infection. Conversely, the biochemical components and organization structure inside wheat plant leaves would be induced to change which cause the changes of spectral features between healthy and infected wheat plants, which provides the monitoring basis for remote sensing techniques [5]. Many studies on leaf- and canopy-scale monitoring of plant diseases have been conducted using ground, aerial and space remote sensing technologies. The diseased plant leaves or canopies can be monitored by the spectral or texture differences between healthy and infected plant ingredient (e.g. leaf, stem, spike). For instance, yellow rust infestation on winter wheat can be detected in the field by means of a visual spectrograph in ambient lighting conditions [6]. For the implementation of site-specific fungicide applications, the spatio-temporal dynamics of crop diseases must be well known [7]. Mewes et al. [8] used a single airborne hyperspectral HyMap dataset to detect plant stress symptoms in wheat stands induced by a pathogen infection.

In comparison with multi-spectral image data, hyperspectral data has been shown to be highly suitable for the detection of crop growth anomalies, since they allow a detailed examination of stress-dependent changes in certain spectral ranges. In general, a non-imaging hyperspectral spectrometer (e.g. ASD) has been extensively used to detect the plant diseases and insect pests in ground-based in most previous studies [9-11]. The average spectra are usually acquired to analyze the healthy or diseased plant. It is obvious that the diagnosis accuracy and efficiency can be greatly affected due to the bad influence of mixed background (e.g. soil, water, non-target land feature). In our study, a hyperspectral imaging device was used to investigate the spectral and texture of pure disease spores and the vertical features of yellow rust infestation on winter wheat was further analyzed.

II. MATERIALS AND METHODS

A. Study Area

The field experiment was conducted at the National Experimental Station for Precision Agriculture of China

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(between 40°10′31″ and 40°11′18″ N and 116°26′10″ and 116°27′05″ E), in the north of Xiaotangshan Town, Changping District, Beijing. The terrain of this experimental site, with an area of approximately 167 ha, is flat and ideal for experiments in precision agriculture using hyperspectral remote sensing techniques (Fig. 1). The study site has a sub-humid continental monsoon climate (mean annual temperature of 11.8 °C and average annual rainfall of 550.3 mm).

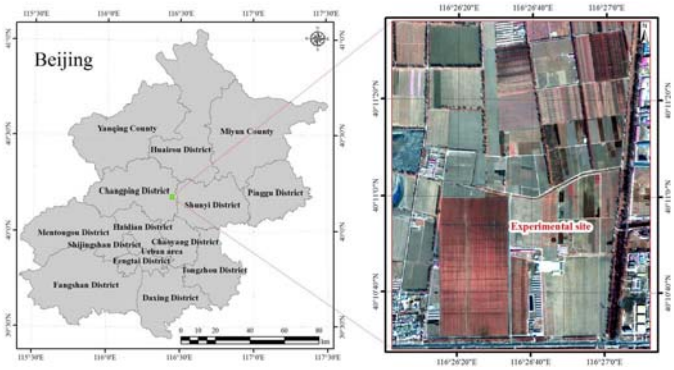

Fig. 1. Location map of the experimental site.

B. *Yellow Rust Inoculation*

To introduce yellow rust to the winter wheat plants, cultivar Jing-9428, susceptible to yellow rust was used for the artificial inoculation experiment. Two concentrations of uredospores of P. striiformis (0.45 g uredospores and 0.25 g uredospores in 6.0 L water, respectively) were prepared to form different infection severities by a spray-inoculating method. Inoculation in the wheat field was done at 1700 h. The following day the plastic membrane was removed at 0830 h. Yellow rust symptoms were found about 1 week after infection, and sporulation starts about 2 weeks after infection (Fig. 2).

Fig. 2. Comparison between yellow rust affected and healthy wheat canopy and leaf.

C. *Assessment of Disease Severity*

F-1, F-2, F-3 (F=flag leaf) were randomly collected from the inoculated and normal wheat fields. The disease severity for each leaf was determined by an experienced plant pathologist according to the percentage (Eq. 1). DISTRAIN (Version 1.0) was used to train the pathologist to estimate disease severity using variegated patterns of disease severity for eight common foliar diseases (including Disease 7–stripe rust) of cereals [12].

$$DS = \frac{\sum_{i=1}^{n} S_i}{S_L} \times 100\% \qquad (1)$$

where S_L is the area of a leaf, i is the number of spores and S_i is the area of a certain spore on the leaf.

D. *Acquisition of Hyperspectral Data Cubes*

There are mainly four steps to complete an experimental procedure: *i*. collecting the samples of wheat plants in the inoculated field, *ii*. measuring the chlorophyll content of leaves at different layers, *iii*. adhering the samples to the black cloth, and *iv*. collecting the hyperspectral data cubes (Fig. 3). Hyperspectral data cubes for the winter wheat plants infected by yellow rust pathogen were acquired using the Image-λ-V10-LU imaging spectrometer, with a wavelength range of 400-1000 nm and the hyperspectral reflectance were computed with the help of data acquired over a Spectralon calibration panel.

The ImSpector V10E imaging spectrometer consists of a Hamamatsu C8484-05G camera, a V10E spectrograph, a 1.9/35 mm C-mount zoom lens, and a mirror scanner. The Hamamatsu C8484-05G is a high spectral resolution digital camera. The V10E spectrograph has a slit size of 30 μm by 14.3 mm and can collect hyperspectral imagery in the wavelength range of 400-1000 nm with a spectral resolution of 2.8 nm. Together with the mirror scanner, the Hamamatsu C8484-05G collects the images in a push-broom manner and generates hyperspectral image cubes with effective pixels of 1392 (spatial axis) by 1040 (spectral axis). In this study, the image was binned 4 by 4 to improve the signal/noise ratio, which resulted in a final image size of 336 spatial by 256 spectral pixels. The angular field of view of the imaging spectrometer is 14° (horizontal) by 11° (vertical) by 18° (diagonal). The camera lens is 0.8 m away from the wheat plants.

Fig. 3. Structure of hyperspectral imaging spectrograph.

III. Results and Discussion

A. *Selection of Sensitive Spectral Bands*

Given that the entire spectrum covered by hyperspectral data is probably not needed for discrimination between healthy and stressed plants, the sensitive bands must be firstly explored. To identify the diseased areas quickly and accurately, it is necessary to know which spectral wavelengths are significantly affected by stress factors and which spectral resolution is needed [13]. To show the spectral differences accurately among different disease severities of leaf samples, the original hyperspectral data cubes must be first smoothed by filtering. Several ROIs (regions of interest) of three disease severities of healthy, mild and severe leaf samples were selected and the average spectra were derived from tip to the bottom the leaf sample (Fig. 4). We can find that the spectral reflectance increased with the increase of disease severities in the visible and near-infrared spectral regions. To identify the diseased leaf areas, two sensitive bands (558 nm and 856 nm) were selected from the wavelength ranges of 550-680 nm and 750-1300 nm. Both the bands and the combination can be used to analyze the leaf disease.

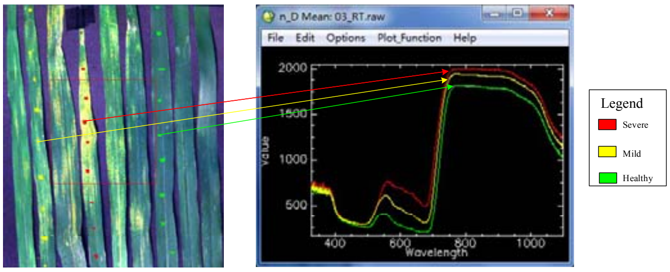

Fig. 4. Hyperspectral curves of three disease severities.

B. *Texture Features of Healthy and Diseased Leaf Areas*

In early stripe rust infection, the symptoms cannot be seen with the naked eye, but spores on mass are yellow- to orange-colored and powdery as the plants [14]. The pustules of yellow rust, which contain yellow to orange-yellow urediospores, usually form narrow stripes on the wheat leaves. The appearance of yellow rust spores changes the spectral and imaging features. In our study, the occurrence measures were used in ENVI (ENvironment for Visualizing Images) to apply any of five different texture filters that are based on occurrence measures [15]. The occurrence filters available are data range, mean, variance, entropy, and skewness (Fig. 5).

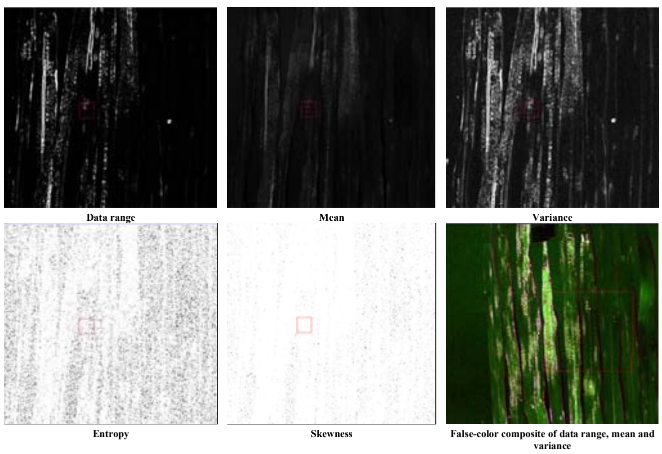

Fig. 5. Texture analysis of yellow rust in wheat leaf based on the occurrence measures.

It could be found that too much information of entropy and skewness images has been lost, so they were discarded in this study. The false-color composite could be very useful in identifying the yellow rust affected leaf areas, which was formed using the data range, mean, variance as red (R), green (G) and blue (B) bands. Nevertheless, some disturbance factors can affect the identification accuracy, e.g., the edges among different leaves and uninform luminance. The overall identification accuracy can reach 90.6% by a maximum likelihood supervised classification method in ENVI. To increase the classification accuracy, the object-oriented classification method (e.g. ENVI EX) is a better choice due to the extremely high spatial resolution of hyperspectral data cubes [16].

C. *Yellow Rust Infestation at Different Leaf Layers*

After investigating the differences of spectral and texture features of different disease severities, the vertical features of yellow rust infestation at different layers can be further discussed. It was obvious that the disease severity generally showed a gradually increasing trend from F-1 to F-3. The relative chlorophyll showed the trend: F-1>F-2>F-3 for the no. 2, no. 4, no. 6, but they showed the trend: F-1>F-3>F-2 for the no. 1 and no. 5 due to the measuring errors (Fig. 6a). We could conclude that the general trend of relative chlorophyll was F-1>F-2>F-3. Furthermore, the average hyperspectral reflectance were collected from tip to the bottom of a sample wheat plant. They showed that the reflectance values were gradually increased from F-1 to F-3 in the visible region, while they it was the very reverse in the near-infrared (NIR) region (Fig. 6b). Two wavelength ranges could be used to differentiate the three leaves in the visible (520-720 nm) and NIR (730-1000 nm) regions.

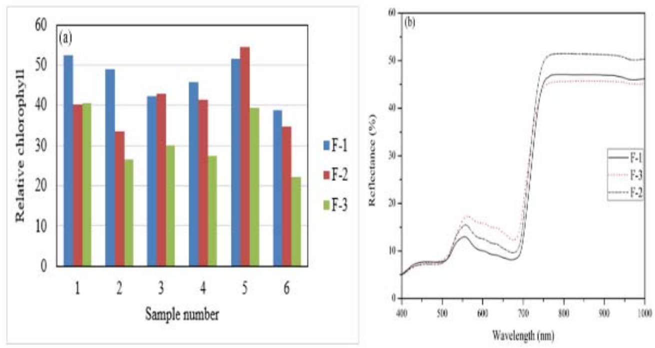

Fig. 6. Comparison of relative chlorophyll (a) and spectral reflectance (b) of three leaf layers.

IV. Conclusion

It is quietly necessary to carry out extensive studies on the epidemiology and management of yellow rust on winter wheat. Remote sensing has facilitated the more accurate monitoring and diagnosis of such a disease, especially the datasets acquired using the hyperspectral sensors. A hyperspectral imaging spectrometer is an extremely useful tool for accurately evaluating the wheat yellow rust. In comparison with non-imaging hyperspectral measurements, a hyperspectral data cube can simultaneously collect the spectral and imaging features of pure yellow rust spores. It is very useful to investigate the disease development for different leaf layers at several essential growth stages. The farmers and agricultural decision-making departments can immediately adopt measures to spray fungicides, especially at the early infestation period.

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