Detection of bacterial wilt disease (*Pseudomonas solancearum*) in Brinjal using hyperspectral remote sensing

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ABSTRACT:

Bacterial wilt disease (pathogen: *Pseudomonas solancearum*) is a major problem affecting brinjal crop. Infected leaves show yellowing, loss in turgidity, drying and ultimately the entire plant collapses. The study aims to examine the potential of hyperspectral remote sensing for detection of biotic stress caused due to bacterial wilt disease and identify best spectral band widths and hyperspectral indices indicative of disease infestation. This study was conducted in a farmer's plot at Alampur in Baruipur block, South 24 Pargana district, West Bengal. Canopy spectra (using ASD Fieldspec 2 Spectroradiometer), chlorophyll content (by Chlorophyll meter) and Leaf Area Index (LAI) (by plant canopy imager) were collected. The healthy plants had green and fully turgid leaves whereas diseased plants had lower chlorophyll content and LAI. The reduction in chlorophyll content lowered reflectance in green region and internal leaf damage in near-infrared region. A correlation analysis was carried out between reflectance at specific bandwidths and hyperspectral indices with chlorophyll content and LAI of healthy and stressed plants. Bandwidths of 528-531 nm, 550-570 nm, 710-760 nm, and single bands such as 800 nm and 920 nm and indices viz. Greenness index, Modified Chlorophyll Absorption in Reflectance Index (MCARI), Transformed Chlorophyll Absorption in Reflectance Index (TCARI), Triangular Vegetation Index (TVI), Simple Ratio Pigment Index (SRPI), Photochemical Reflectance Index (PRI 2), Lichtenthaler Indices (LIC1, LIC2), Structure Intensive Pigment Index (SIPI) etc. were found to have strong positive correlation (R^2>0.9) with plant parameters. These specific bandwidths and indices can be helpful in biophysical parameter estimation and early detection of crop stress, crop growth and disease monitoring.

1. INTRODUCTION

Brinjal (*Solanum melongena*) or eggplant is considered as one of the important vegetable crops after potato,onion and tomato. According to an estimate, in India, about 1.4 million small and marginal farmers grow brinjal crop for a regular and steady income (Choudhary *et al*., 2009). West Bengal state of India has the highest area (about 160 thousand hectares) under Brinjal cultivation in India with a production of approximately 3000 thousand tonnes. The major brinjal producing belts in the state are South 24-Paraganas, Cooch Behar, Jalpaiguri, Nadia, Murshidabad and Malda. Bacterial wilt disease (pathogen: *Pseudomonas solancearum*) has been widely reported for causing severe problems in brinjal cultivation in the tropical, sub tropical and warm temperate regions of the world.

Several researchers have reported the occurrence of this devastating disease from India, and especially, West Bengal (Das *et al*., 1955; Chatterjee *et al*., 1997; Samaddar *et al*., 1998; Mondal *el al*., 2004b). It has been reported that brinjal crops transplanted during summer months are more prone to get infected with this disease (Mondal *et al*., 2014). Wilting is generally observed in the reproductive stage of the crop growth, caused by infection in the vascular system of the plant. The pathogen enters the water-conducting xylem vessels of a plant, then proliferates within the vessels, causing water blockage. Infected leaves show yellowing, loss in turgidity, drying and ultimately the entire plant collapses.

Several attempts have been made in developing techniques for crop visual monitoring and quantification of stress induced by pathogenic diseases. Several authers (Thomas *et al*., 1972; Toler *et al*., 1981; Blazquez *et al*., 1983; Kurschner *et al*., 1984; Blakeman, 1990) have reported that the spectral reflectance of green vegetation in the red band (0.6–0.7 µm) is most sensitive to leaf chlorophyll and pigment contents while the near infrared (NIR) band (0.7–0.9 µm) is most sensitive to biomass and leaf area index. It has been observed that the stressed plants have lower absorption of red light and higher absorption of NIR radiation (Lillesand and Kiefer, 1994; Guyot, 1990; Hatfield *et al*., 1993). These spectral characteristics of green plants can be used to evaluate the stresses of various crops (Chapelle *et al*., 1992; Shibayama *et al*., 1993; Zhang *et al*., 2002; Fitzgerald *et al*., 2004).

Empirical relationships can be established between the factors that cause plant stress and the variations observed in the resulting reflectance signatures (Jacquemoud *et al*., 2001). Many researchers have examined vegetation pigment levels using reflectance data at specific wavelengths or by creating ratios of reflectance data values at several specific wavelengths (Gitelson *et al*., 2006; Gitelson *et al*., 2002; Blackburn, 1998a; Blackburn, 1998b; Serrano *et al*., 2002; Haboudane *et al*., 2008) or at the red-edge (Jones *et al*., 2010). Zhang *et al*. (2002) demonstrated the ability to distinguish healthy tomato plants from late blight infected plants using PCA, cluster analysis, and spectral ratio analysis in several fields of tomatoes with varying levels of infection. Kumar *et al*. (2010) reported that spectral indices like Normalized Difference Vegetation Index (NDVI),

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Ratio Vegetation Index (RVI), Aphid Index (AI) and Structure Insensitive Pigment Index (SIPI) had significant correlation with aphid infestation in mustard crop. Ray *et al*. (2011) investigated the utility of hyperspectral reflectance data for potato late blight disease detection. The differences between the vegetation indices for plants at different levels of disease infestation were found to be highly significant. The optimal hyperspectral wavebands to discriminate the healthy from disease infested plants were 540, 610, 620, 700, 710, 730, 780 and 1040 nm, whereas up to 25% infestation could be discriminated using reflectance at 710, 720 and 750 nm. Though, it is difficult to visually quantify the nature of stress, these responses affect the amount and quality of electromagnetic radiation reflected from plant canopies (Sahoo *et al*., 2015). Spectral reflectance data provides a means for detection of disease infestation to help reduce potential production losses, restrain environmental risk, and decrease the cost of farming. Irrespective of whether or not high value crops are infected with a disease, growers typically apply pesticides as insurance to diminish the risk of losing large amounts of their crop. Agricultural producers spray chemicals uniformly over entire fields to prevent or control disease, which is unnecessarily costly since disease infestation is predominately concentrated in patches around original foci where disease originates (Moshou et al., 2004), with large areas of fields free from disease at any stage of infestation (Bravo et al., 2003). In addition to higher production costs, repeated application of pesticides increases the risk of pests adapting to the pesticides, rendering the pesticides virtually ineffective. Excessive pesticide application may also increase the amount of toxic residues contaminating ground water, making targeted pesticide placement at the correct time an important goal. To prevent overuse of chemicals, growers need a remote sensing system that can provide timely detection of diseases (Zhang et al., 2005).

In this backdrop, this study aims to examine the potential of hyperspectral remote sensing for detection of biotic stress caused due to bacterial wilt disease and identify the best spectral band widths and hyperspectral indices indicative of disease infestation.

2. METHODOLOGY

2.1 Study Area

This study was conducted in Brinjal growing fields of farmers in Alampur at Baruipur block of South 24 Pargana district, West Bengal (Figure 1). The district of south-24 Parganas encompasses the moribund, mature as well as active parts of the Ganga delta, bounded by the great Sunderbans mangrove forest at its south-western side. The Baruipur block is located in the northern inland tracts of the district. Its land surface is flat with an elevation of only 3-5 m above mean sea level and the soils are mainly alluvial in nature and predominantly clay loam, hence very favourable for agriculture. The normal annual rainfall in this district is of the tune of 1800 mm. The district is characterized by hot and humid climate. It receives adequate rainfall from North-East and South-West monsoons which set in the later half of June and withdraw by the middle of October. Pre-monsoon rains are received during March-April. May is the hottest month with temperature as high as 40°C and and January is the coldest month with temperature as low as 10°C.

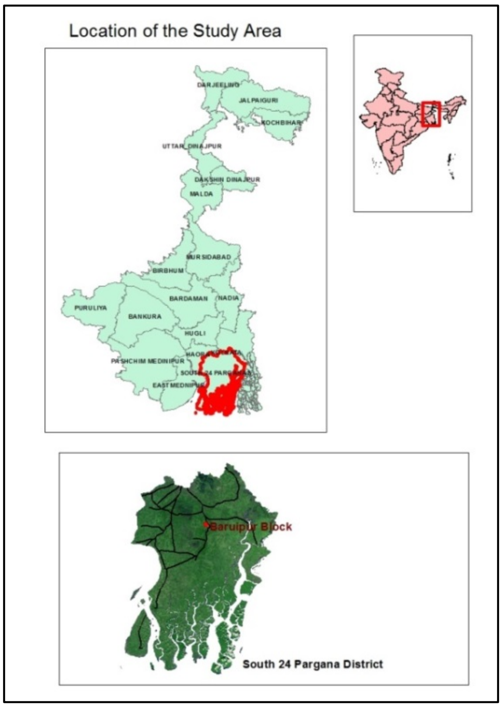


Figure 1. Study Area

2.2 Data Collection

2.2.1 Hyperspectral Data:

Hyperspectral reflectance data of healthy and diseased brinjal were collected, using ASD Fieldspec Handheld 2 Spectroradiometer. Data was captured between 11:00 am and 1:00 pm to maximize sunlight. Gathering spectra at a given location involves optimizing integration time (typically set at 17 ms), providing foreoptic information, recording dark current, collecting white reference reflectance and obtaining the target reflectance. The target reflectance is the ratio of energy reflected off the target (eg. crop) to energy incident on the target (measured using BaSO4 white reference plate called Spectralon). Since the dark current varies with time and temperature, it was gathered for each integration time (virtually new for each plot). Reflectance measurements were made about one meter above the crop canopy with the sensor facing the crop and oriented normal to the plant using 25^0 FOV (ASD Inc, 2010).

Hyperspectral Data Preprocessing: A window based software, View Spec Pro was used for viewing, analyzing and exporting the spectral data into ASCII format. The continguous spectral profile contained reflectance data in the spectral range of 325 to 1075 nm with 1 nm interval. Earlier studies (Apan et al., 2005) have shown that bands in close proximity has redundant information and there is high levels of noise between 350 to 400nm It was found that keeping a bandwidth of 5–10 nm is optimum for crop stress studies (Ray et al., 2006). The spectral data was preprocessed accordingly at a bandwidth of 10 nm in the VNIR (400 to 1075 nm) spectrum.

2.2.2 Biophysical Data :

Chlorophyll content in the leaves of healthy and diseased Brinjal plants were sampled using the instrument, Chlorophyll meter (MC-100). The instrument gives chlorophyll concentration reading i.e. CCI, by calculating the ratio of transmittance at 931 nm to transmittance at 653 nm. A CCI measurement near 1 indicates similar transmittance of red and NIR radiation, thus little to no chlorophyll in the leaf sample. A CCI measurement greater than one indicates less transmittance of red radiation relative to near infra-red radiation (Apogee Instruments Inc, 2013). Leaf Area Index (LAI) data was collected using plant canopy imager Model No CI-110. Its value ranges from 0-10, with 0 representing no canopy or bare ground and 10 representing a dense conifer forest canopy (CID Bioscience Inc, 2014).

2.2.3 Ancillary Data :

Crop condition and management practices followed at the site, were recorded using the ground truth performas. Geo-tagged field photographs was collected using android based smart phone (Asus Zenphone 2).

2.3 Computation of Narrow Band Indices

Different vegetation indices were computed which includes **structural indices**: NDVI; **Chlorophyll indices**: Greenness Index, MCARI (Modified Chlorophyll Absorption Reflectance Index), TCARI (Transformed Chlorophyll Absorption Reflectance Index),TVI (Triangular Vegetation Index), SIPI (Structural Insensitive Pigment Index), Normalized Phaeophytinization Index (NPQI), NPCI (Normalized Pigment Chlorophyll Index), PRI (Photochemical Reflectance Index), SRPI(Simple Ratio Pigment Index), Carter Indices, Lichtenthaler Indices and **Red edge indices**: Vogelmann Indices, ZTM (Zarco Tejada and Miller),GM1 and GM2. Details are given in Table 1.

Index	**Formula**	**Source**
Greeness index (G)	R554/R677	-
Modified Chlorophyll absorption in Reflectance Index (MCARI)	((R700-R670)-0.2*(R700-R550))*(R700/R670)	Daughtery *et al.* (2000)
Transformed CARI (TCARI)	3*((R700-R670)-0.2*(R700-R550)*(R700/R670))	Haboudane *et al.* (2002)
Triangular Vegetation Index (TVI)	0.5*(120* (R750-R550)-200*(R670-R550))	Broge and Leblane (2000)
Zarco-Tejada & Miller (ZM)	R750/R710	Zarco-Tejada *et al.* (2000)
Simple Ratio Pigment Index (SRPI)	R430/R680	Penuelas *et al* (1995)
Normalized Phaeophytinization Index (NPQI)	(R415- R435)/(R415+R435)	Barnes *et al.* (1992)
Photochemical Reflectance Index 1 (PRI1)	(R528- R567)/(R528+R567)	Gamon *et al.* (1992)
Photochemical Reflectance Index 2 (PRI2)	(R531- R570)/(R531+R570)	Gamon *et al.* (1992)
Normalized Pigment Chlorophyll Index (NPCI)	(R680- R430)/(R680+R430)	Penuelas *et al* (1994)
Carter Index 1 (Ctr1)	R695/R420	Carter (1994)
Carter Index 2 (Ctr2)	R695/R760	Carter *et al.* (1996)
Lichtenthaler Index 1 (LIC1)	(R800-R680)/(R800+R680)	Lichtenthaler *et al.* (1996)
Lichtenthaler Index 2 (LIC2)	R440/R690	Lichtenthaler *et al.* (1996)
Structure Intensive Pigment Index (SIPI)	(R800-R450)/(R800+R650)	Penuelas *et al.* (1995)
Vogelmann Index 1 (Vog1)	R740/R720	Vogelmann *et al.* (1993)
Vogelmann Index 2 (Vog2)	(R734-R747)/(R715+R726)	Vogelmann *et al.* (1993)
Vogelmann Index 3 (Vog3)	(R734-R747)/(R715+R720)	Vogelmann *et al.* (1993)
Gitelson and Merzlyak 1(GM1)	R750/R550	Gitelson and Merzlyak (1997)
Gitelson and Merzlyak 2(GM2)	R750/R700	Gitelson and Merzlyak (1997)
Normalized Difference Vegetation Index (NDVI)	(R920-R696)/(R920+R696)	

Table 1. Formulas used for computation of various hyperspectral vegetation indices

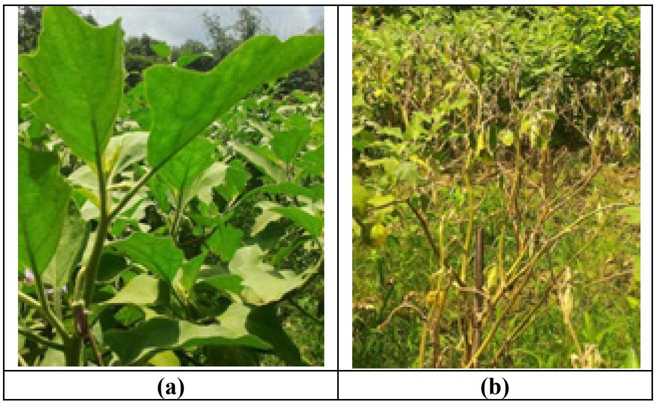
2.4 Correlation Analysis

Correlation analysis was carried out between reflectance at specific bandwidths and hyperspectral indices with biophysical parameters like chlorophyll content and LAI of healthy and stressed plants.

3 RESULTS AND DISCUSSIONS

3.1 Effect of disease on hyperspectral reflectance of crops

The effect of disease on Brinjal can be clearly seen in Figure 3a, with green and fully turgid leaves and in Figure 3(b) there was a decrease in chlorophyll content and change in the internal leaf structure due to their shrivelling and curling.



(a) (b)

Figure 3(a) Healthy Brinjal plant, (b) Diseased Brinjal plant

The reflectance spectral curve (Figure 4) also shows a significant difference between diseased and healthy brinjal plants. In diseased and severly diseased brinjal there is a decrease in reflectance in the green region due to reduction in chlorophyll content and in near-infrared reflectance due to internal leaf damage. When a plant suffers from a stress factor such as pest or disease infestation, normal chlorophyll production diminishes, followed by a decrease in absorption and an increase in reflectance in the blue and red visible regions (Yang et al., 2010). Reflectance is also reduced in the NIR wavebands because as the mesophyll layer of the plants leaves is affected by the pathogen invasion, their internal reflective capacity diminishes, causing a reduction in reflection of NIR energy.

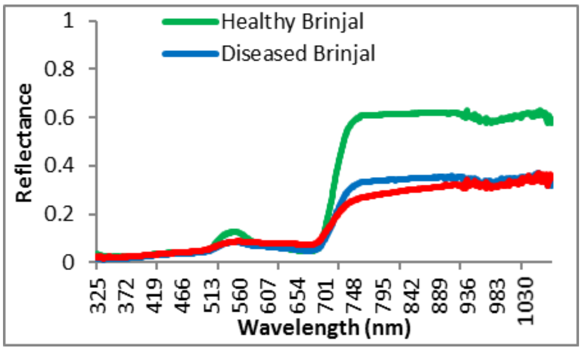


Figure 4 Comparison between spectra of normal and diseased Brinjal in Baruipur, West Bengal

3.2 Correlation Results

From the figures 5 and 6, it has been observed that bandwidths of 528-531 nm, 550-570 nm, 710-760 nm, and single bands such as 800 nm and 920 nm shows strong positive correlation (R^2>0.9) with Chlorophyll Concentration Index (CCI) and Leaf Area Index (LAI).

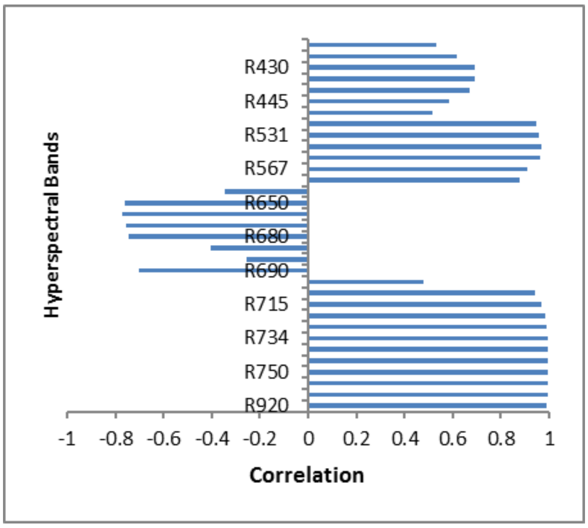


Figure 5. Correlation between chlorophyll content and Reflectance in narrow bands

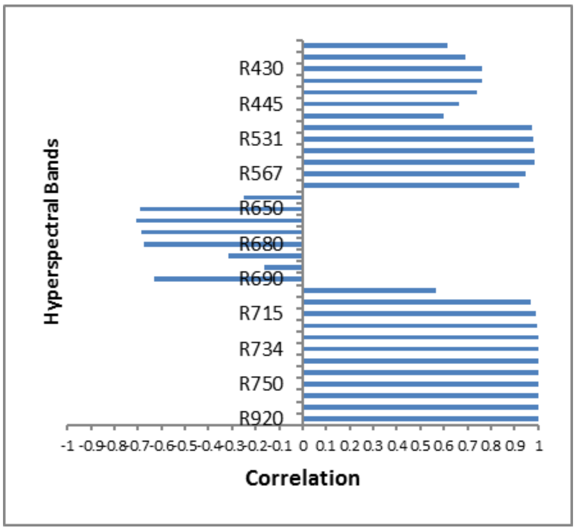


Figure 6. Correlation between Leaf Area Index and Reflectance in narrow bands

Indices viz. Greenness index, Modified Chlorophyll Absorption in Reflectance Index (MCARI), Transformed Chlorophyll Absorption in Reflectance Index (TCARI), Triangular Vegetation Index (TVI), Simple Ratio Pigment Index (SRPI), Photochemical Reflectance Index (PRI 2), Lichtenthaler Indices (LIC1, LIC2), Structure Intensive Pigment Index (SIPI) etc. were found to have strong positive correlation (R^2>0.9) with above biophysical parameters.

4. CONCLUSION

Optical remote sensing techniques are well known for objective and reliable automated diagnosis and detection of plant diseases. Vegetations suffering from any kind of biotic stress show decrease in chlorophyll production and reduction of absorption in the red and blue visible region. The amount of reflectance in these regions on the other hand increases. The present study also confirms the same.

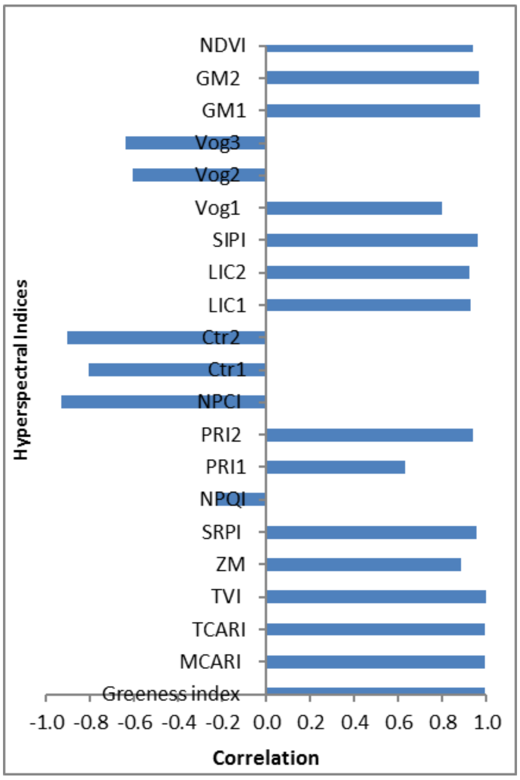


Figure 7 Correlation between chlorophyll content and Hyperspectral indices

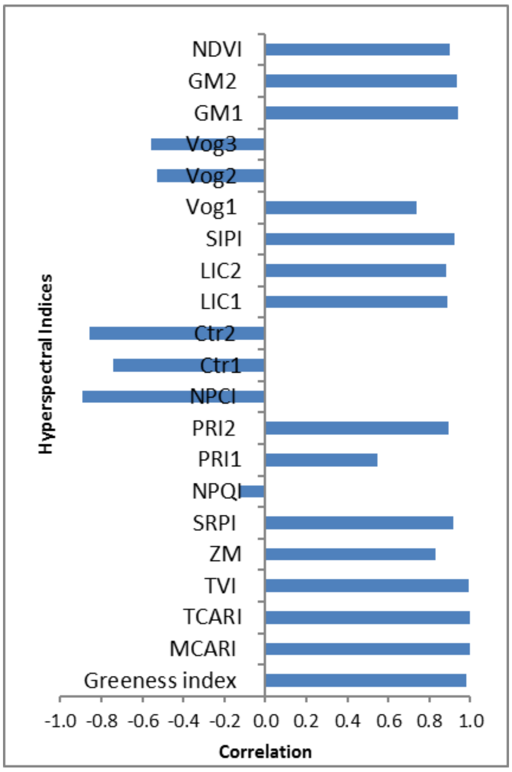


Figure 8 Correlation between Leaf Area Index and Hyperspectral indices

Bandwidths of 528-531 nm, 550-570 nm, 710-760 nm, and single bands such as 800 nm and 920 nm and indices viz. Greenness index, Modified Chlorophyll Absorption in Reflectance Index (MCARI), Transformed Chlorophyll Absorption in Reflectance Index (TCARI), Triangular Vegetation Index (TVI), Simple Ratio Pigment Index (SRPI), Photochemical Reflectance Index (PRI 2), Lichtenthaler Indices (LIC1, LIC2), Structure Intensive Pigment Index (SIPI) etc. were found to have strong positive correlation (R^2>0.9) with biophysical parameters. These specific bandwidths and indices can be helpful in regional biophysical parameter estimation through corresponding satellite derived band data and early detection of crop stress, crop growth and disease monitoring.

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