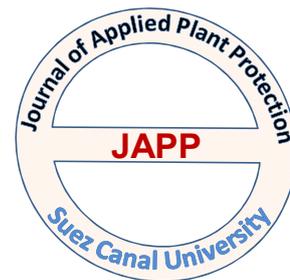




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# Monitoring and Managing Rice Pest Infestation through Hyperspectral Remote Sensing Technology under Field Conditions

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**Abstract:** Timely assessment of infestation symptoms in crops is critical for pest control and precision farming. The use of non-contact, highly-efficient, and affordable methods such as hyperspectral data for detecting and monitoring plant pests could greatly facilitate plant protection management. A field experiment was carried out during season of 2018 at Al-Qurien city, Sharkia Governorate, Egypt. The exploratory objectives were: (i) to establish a monitoring method for the damages caused by rice leaf folder (RLF), *Cnaphalocrocis medinalis* (Guenée), and yellow stem borer (YSB), *Scirpophaga incertulas* (Walker), of rice (*Oryza sativa* L.) variety (Giza177) based on hyperspectral data, and (ii) to manage the RLF and YSB of rice eco-friendly using Azadirachtin 0.15% EC. Spectral reflectances from rice at different stages in various bands were recorded using field portable hyperspectral radiometer (FPHR). The vegetation indices (VIs) were calculated and correlated with pest damage, sensitivity analysis of spectral bands, and red edge position to estimate the extent of damage caused by each pest. The results showed that spectral reflectance of rice hills damaged by studied pests was different from that of the undamaged hills. In the damaged hills, there was a decrease in near infrared (NIR) reflectance (760 to 900 nm) while the green (520 to 600 nm) and red reflectance (630 to 690 nm) increased compared to undamaged hills treated with Azadirachtin 0.15% EC. The mean percent reflectance values (of all days of observation) in the red region in RLF and YSB damaged hills were  $2.41 \pm 0.86$  and  $9.31 \pm 3.96$ , respectively, while the treated hills with Azadirachtin 0.15% EC recorded  $1.53 \pm 0.40$  and  $5.80 \pm 2.09$ . The percent reflectance values in NIR region were  $36.37 \pm 7.93$  (RLF) and  $37.80 \pm 10.22$  (YSB) in untreated hills while treated ones recorded  $39.70 \pm 7.80$  for RLF and  $43.74 \pm 8.74$  for YSB. The red reflectance had significant positive correlation with both pests while green and NIR reflectance recorded non-significant changes due to pest damage on all days of observation. On the basis of a comprehensive analysis of the hyperspectral data, significant spectral indices such as the normalized difference vegetation index (NDVI), simple ratio (SR), and green red vegetation index (GRVI) values were explored to provide an accurate and robust assessment of rice infestation by studied pests. Among the vegetation indices, SR had the highest sensitivity compared to NDVI and GRVI. Linear regression equations were adopted for studied crop ages for estimating RLF and YSB damage based on NDVI and SR values. The results demonstrated the operational applicability of ground-based hyperspectral measurements for diagnostic mapping of pest symptoms. Considering the efficacy and eco-friendly nature of Azadirachtin it could be considered as effective botanicals in successful management of the pests RLF and YSB of rice. It has a great potential in detecting early pest infestation for precision farming.

**Keywords:** Hyperspectral remote sensing, band selection, rice leaf folder (RLF), Yellow Stem Borer (YSB)

## INTRODUCTION

Rice (*Oryza sativa* L.) is an important crop for global food security. Monitoring infestation is critical for growth diagnosis, precision management to generate higher yield and better grain quality and minimize adverse environmental impacts (Krishna *et al.*, 2019). Rice contains protein name gluten (8.1%), vitamins, minerals, fibers (2.2%) and lots of carbohydrates (77.1%) with a total of 349 calories (Singh *et al.*, 2017). Rice crop is highly sensitive for several insect pests (Oerke, 2006; Strange and Scott, 2005; Krishna *et al.*, 2019). About 300 species of insects have been reported to attack rice crop, of which 20 were found to be major pests causing 21-51% yield loss (Singh and Dhaliwal, 1994). Among the serious major insect pests are yellow stem borer- YSB, *Scirpophaga incertulas* (Walker), and the rice leaf folder- RLF, *Cnaphalocrocis medinalis* (Guenée) (Krishna *et al.*, 2019); causing a yield loss over the world (Prashad, 2003). The presence of YSB in our fields is easily identified by “dead heart” or “white ear” in hills at vegetative stage and panicle at reproductive stage (Prakash *et al.*, 2014). The RLF is also observed during both stages and feed inside the

leaves make a fold. At vegetative phase, crops can generally recover from damage but during the reproductive phase the damage can be economically important (Sulagitti *et al.*, 2018). The attack of YSB is obvious after 45 days of transplantation, while that of RLF was at the time of reproductive phase (Bisen *et al.*, 2019).

Early detection of insect pest infestation is an essential step to take up timely management measure. Remote sensing can be useful in detecting crop damage over a large area in a short time period (Yue *et al.*, 2018; Huang *et al.*, 2007; Zhang *et al.*, 2012). Damage evaluation of diseases has been largely done by visual inspections and quantification but visual quantification of plant pest and diseases with accuracy and precision is a tough task (Mahlein, 2015). Utilization of remote sensing techniques are based on the assumption that plant pest and disease stresses interfere with physical structure and function of plant and influence the absorption of light energy and therefore changes the reflectance spectrum of plants (Zhang *et al.*, 2015). Recent advances in the field of spectroscopy offer much needed technology of hyperspectral remote sensing

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(Shakoor *et al.*, 2017). Hyperspectral remote sensing for disease detection can help in monitoring the diseases in plants with the help of different plant spectral properties at the visible, near infrared and shortwave infrared regions ranging from 350 – 2500 nm, which develops specific signatures for a specific stress for a given plant (Huang *et al.*, 2007). It has been effectively used in assessment of disease in agricultural crops like wheat, rice, tomato etc across the world facilitating the precision spray in field for pest control (Yang *et al.*, 2010), support high throughput put phenol typing of plants (Furbank and Tester, 2011; Shakoor *et al.*, 2017) or loss assessment in agricultural insurance investigations (Zhang *et al.*, 2015). Remote and local sensors can be applied to monitor plant nutrient and moisture needs, soil conditions, and plant health (including insect and infestation detection).

Hyperspectral remotely sensed data provide hundreds of contiguous narrow spectral bands, forming spectral curves of the scene components of interest (Huang *et al.*, 2007; Thomas *et al.*, 2018; Su *et al.*, 2019). Analyses of the shapes of these spectra allow discrimination of the scene component (Thomas *et al.*, 2018). The utility of hyperspectral data to diagnose pests can improve detection speed and provide opportunity for non-destructive sampling (Su *et al.*, 2019). Another area of application of the spectral signatures of crop stresses is precision farming (Liaghat and Balasundram, 2010). Precision farming is based on such information intensive sources and attempts to address the site-specific needs with spatially variable application (Furbank and Tester, 2011). To establish a reliable and wide foundation for precision agriculture, there is a desperate need for data with high spatial resolution, wide thematic range and high thematic resolution (Liaghat and Balasundram, 2010; Shakoor *et al.*, 2017). The ground-based hyperspectral spectroradiometer technique involves recording of spectral reflectance at canopy level and comparing the data obtained from healthy and pest infested plants (Apan *et al.*, 2004; Chen *et al.*, 2007). The reflectance data from different spectral bands namely blue, green, red and near infrared (NIR) from healthy and infested plants are subjected to mathematical analysis to calculate vegetation indices which can also help in detecting and estimating the crop damages (Mirik *et al.*, 2006).

In fact, a few studies have been made to identify damages caused by rice pests through remote sensing techniques (Yang *et al.*, 2007; Liaghat and Balasundram 2010; Zhou *et al.*, 2010). These studies have been made to find out the spectral bands reflecting damage caused by individual pests such as Brown Plant-hopper (*Nilaparvata lugens*). Hence a detailed analysis of the spectral reflectance characteristics of damages caused by rice pests under field conditions can help to diagnose pests, discriminate among them, estimate the level of loss and thus help to devise better management strategies in precision farming (Liaghat and Balasundram, 2010).

The biochemical Neem seed kernel extract is known to suppress the feeding, growth and reproduction

of insects (Natarajan and Sundaramurthy, 1990). Its products could be recommended for many programs; on integrated pest management (Juan *et al.*, 2000; Calvo and Molina, 2003). Considering the efficacy and eco-friendly nature of Neem extracts it could be considered as effective botanicals in successful management of (YSB), in rice fields (Mahfujur, 2020).

The application of non-destructive methods to detect plant infestation at an early stage of its development is very important for pest management in commercially important crops. Earlier some studies have been done to characterize reflectance spectra of pests, nutrient stress nitrogen deficiency, and irrigation management for rice but very few literatures are available regarding characterization of spectral reflectance to study RLF and YSB infestations. Therefore, the primary objectives of the present study are: (i) to monitor changes in the spectral reflectance characteristics of undamaged and damaged rice crop due to RLF and YSB insects, (ii) to establish the most sensitive wavebands to the studied pest infestation and (iii) to manage the RLF and YSB insects eco-friendly by using the bio-pesticide (Azadirachtin 0.15% EC).

## MATERIALS AND METHODS

### Field experiment and pest infestation

A field experiment was conducted at Al-Qurien city, Sharkia Governorate, Egypt during season 2018. Rice plant (Giza 177) was grown in four plots with duration of 125 days. Soil at the site was clay. Rice leaf folder (RLF), *C. medinalis*, and yellow stem borer (YSB), *S. incertulas* were selected as major rice pests for the current study. The observation period was 40 to 70 days for RLF and 80 to 110 days for YSB. Leaf characters and susceptibility to insect pests were chosen for the experiment.

The naturally occurring pest infestation was studied in four plots each of dimension 5×10 m<sup>2</sup> demarcated as T1 (RLF damaged), T2 (undamaged), T3 (YSB damaged), T4 (undamaged) in existing rice crop. In the plot marked healthy or undamaged, the hills were protected from insect damage by spraying Azadirachtin 0.15% EC periodically. In the plots marked RLF and YSB damaged, no plant protection measures were taken up against RLF and YSB so as to allow natural buildup of RLF and YSB. However, both the plots were kept free from plant diseases by careful monitoring and spraying fungicide/ bactericide whenever necessary. A view of studied rice field experiment in which observations were recorded is provided in Plate 1a. Ten hills were tagged to represent healthy (undamaged) and damaged categories in the protected and unprotected plots. The ten tagged hills served as replications on each pest.

The field observations were recorded at 10 days interval during active infestation by RLF and YSB in each hill from ten tagged hills, (percent leaf damage caused by RLF and percent spectral reflectance). The observations during active RLF infestation were recorded in the field on 40, 50, 60 and 70 DAT. While the field observations during active YSB infestation were on 80, 90, 100 and 110 DAT.

### Percent damage calculation

The procedure for calculation of percent leaf damage and percent white ear heads were adopted from Heinrichs *et al.* (1985) using the following formula

$$\% \text{ leaf damage} = \frac{\text{number of damaged leaves}}{\text{total number of leaves}} \times 100$$

$$\% \text{ white ear} = \frac{\text{No. of panicles with white ear}}{\text{No. of productive tillers}} \times 100$$

Folding and scrapping symptoms of leaves caused by RLF vegetation stage presented at (Plate 1b).

The panicles that have turned fully chaffy, unfilled, white in color and that stand erect caused by YSB damage was taken as white ear symptom (as shown in Plate 1c; healthy panicles are shown in Plate 1d). The mean and SD of percent damage of 10 tagged hills were worked out.

### Ground-based hyperspectral measurements

The GER 1500 model is a field portable hyperspectral radiometer (FPHR) covering the UV, Visible, and NIR wavelengths from 276 nm to 1093 nm (Plate. 2). It uses a diffraction grating with a silicon diode array. The silicon array has 512 discrete detectors that provide the capability to read 512 spectral bands. The Spectroradiometer includes memory for standalone operation as well as capability for computer assisted operation through its COM2, RS232 serial port.



**Plate (1):** Spectral properties of tested rice crop with different infestation symptoms and undamaged plants.

a) Studied rice field experiment view, b) Folding and scrapping symptom of leaves caused by RLF at vegetative stage, c) White ear symptom damaged by YSB at milky stage, d) Treated with Azadirachtin 0.15% EC (undamaged rice plants).

The leaf spectral data were collected by pointing the instrument at a distance of 30 cm above the leaf on clear sunny days between 10 am and 1 pm local time. The instrument was optimized and calibrated before the first measurement and after every five minutes onwards to adapt to the changing atmospheric conditions as mentioned by Luther and Carroll (1999) and Abdel-Rahman *et al.* (2010). The incident spectrum was periodically obtained from the light reflected by a barium sulphate standard panel before each set of measurements. The percent reflectance spectrum was calculated as the ratio between the reflected spectra from target and the incident spectra (reference) of the canopy using the following formula

$$\% \text{ Reflectance} = \frac{\text{Reflectance from target (plant canopy)}}{\text{Reflectance from reference (panel)}} \times 100$$

The spectral reflectance data, both absolute and percent reflectance values were transferred from the Spectroradiometer to a personal computer as ASCII files utilizing specific software supplied with the instrument. These files were later opened in a spreadsheet program and further analyses were carried out. The 512 values of percent spectral reflectance at approximately 1.5 nm bandwidth intervals starting from 276 to 1093 nm were obtained for each hill, and for 10 hills in the treatment.

Furthermore, the reflectance in green, red, and near-infrared (NIR) bands were selected due to their most sensitive wavelengths to plant parts and calculated for each hill by taking mean of reflectance values in the wavelengths ranges of 520-600 nm, 630-690 nm and 760-900 nm, respectively, to match the bands in the Landsat Thematic Mapper (TM) sensors. From the reflectance values calculated for green, red and NIR bands, various vegetation indices that would reflect the crop condition were worked out.

### Spectral vegetation indices

Vegetation Indices (VIs) are combinations of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. They are derived using the reflectance properties of vegetation described in plant foliage. Each of the VIs is designed to accentuate a particular vegetation property. All VIs requires high-quality reflectance measurements from either multispectral or hyperspectral sensors.



**Plate (2):** Field Portable Hyperspectral Radiometer (FPHR): Model- GER 1500

Normalized difference vegetation index (NDVI) is the normalized difference of reflectance in NIR and red bands (Sellers, 1985; Sims and Gamon, 2002; Mirik *et al.*, 2006; Yang *et al.*, 2009). NDVI is used to detect plant stress. Its values range from -1 to 1. NDVI can saturate at high leaf area index (LAI).

$$\text{NDVI} = \frac{(\text{RNIR} - \text{RRED})}{(\text{RNIR} + \text{RRED})}$$

**Where:**  $R_{\text{RED}}$  and  $R_{\text{NIR}}$  are spectral reflectance values in red and NIR bands, respectively.

### Analytical Methods

The indices and pest damage data were subjected to the following mathematical and statistical analyses to get meaningful interpretation. They are mean and standard deviation (SD), correlation and linear

regression studies, red edge position (REP) analysis, band sensitivity and vegetation index sensitivity analyses, and linear correlation intensity analysis.

The mean and SD were worked out for the following parameters, for 10 hills in each damaged and undamaged category. They are percent leaf damage in RLF affected hills, percent white ear in YSB affected hills, percent reflectance in green, red and NIR, and vegetation indices namely NDVI, SR and GRVI.

The correlation between reflectances in various spectral bands (namely red, green, and NIR), vegetation indices (namely NDVI, GRVI, and SR) and the percent leaf damage and white ears caused by RLF and YSB were worked out. Ten tagged hills which had varying levels of pest infestation and the corresponding vegetation indices worked out for each hill based on spectral reflectance studies were used in working out the correlation coefficient ( $r$ ) and the coefficient of determination ( $R^2$ ). The mean value of spectral indices of ten tagged control hills was also included in calculation of correlation coefficient. The test of significance of the correlation coefficient was done as suggested by Rangaswamy (1995). A linear regression of the percent damage on each of the vegetation indices was fit based on the varying levels of pest infestation in the ten tagged hills and the corresponding vegetation indices.

The REP is defined by the wavelength of the maximum first derivative of the reflectance spectrum in the region of the red edge. The first derivative was calculated using a first-difference transformation of the reflectance spectrum (Dawson and Curran, 1998) as follows:

$$FDR(\lambda_i) = \frac{(R_{\lambda(j+1)} - R_{\lambda(j)})}{\Delta\lambda}$$

*Where* FDR 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  $\Delta\lambda$  is the difference in wavelengths between  $j$  and  $j+1$ .

The FDR of wavelengths in the range of 690 to 740 were worked out for successive changes in the wavelength in hyperspectral data and the wavelength corresponding to maximum FDR value was taken as the REP. The REP of healthy and infested plants was calculated to find the shift in REP known as the red shift. The REP analysis was performed for reflectance data obtained from field studies.

Sensitivity at a given wavelength or band was computed by using the following formula (Carter, 1993).

$$\text{Band sensitivity} = \frac{R_{inf} - R_{ctrl}}{R_{ctrl}} \times 100$$

*Where:*  $R_{inf}$  - canopy reflectance of infested plants,  $R_{ctrl}$  - canopy reflectance of control plants.

Similarly, sensitivity for given vegetation index was calculated by using the following formula:

$$\text{Vegetation index sensitivity} = \frac{VI_{inf} - VI_{ctrl}}{VI_{ctrl}} \times 100$$

*Where:*  $VI_{inf}$  - vegetation index of infested plants;  $VI_{ctrl}$  - vegetation index of control plants. The band sensitivity and VI sensitivity analyses were performed for data obtained from field studies.

Linear correlation intensity analysis was done to find out the wavelengths whose reflectance values had the maximum positive and negative correlation with pest damage. The correlation between pest damage and spectral reflectance in each of the 512 wavelength bands ranging from 350 to 1050 nm were worked out and these correlation values were plotted as a graph against the wavelengths to get the linear correlation intensity analysis graph as suggested by Yang and Cheng (2004) and Luedeling *et al.*, (2009). Similar to the band sensitivity analysis, this study will help to locate wavelengths most sensitive to pest damage.

## RESULTS AND DISCUSSION

The results of the field experiment conducted on detection and estimation of damage caused by insect pests of rice using hyperspectral radiometry are presented here under.

### Percent leaf damage by RLF and percent white ear caused by rice YSB

The percent leaf damage caused by rice RLF in ten tagged hills was  $18.9 \pm 8.8$  on 40 days after planting (DAT) which coincided with the beginning of RLF incidence (Table 1). The damage increased to  $32.4 \pm 14.3$  on 60 DAT and later decreased. In undamaged tagged hills the percent leaf damage was nil throughout the period of observations from 40 to 70 DAT.

**Table (1):** Percent damage leaves caused by RLF damaged rice hills and percent white ear damage caused by YSB damaged rice hills in field

Rice Leaf Folder	
DAT	Percent damaged leaves*
40	$18.9 \pm 8.8$
50	$26.8 \pm 11.7$
60	$32.4 \pm 14.3$
70	$29.1 \pm 15.1$
Yellow Stem Borer	
DAT	Percent white ear damaged *
80	$18.7 \pm 8.1$
90	$21.1 \pm 7.2$
100	$24.5 \pm 15.8$
110	$26.8 \pm 10.5$

\* Mean and standard deviation of 10 tagged hills; (DAT): Days after transplanting; White ear symptoms observed 80 DAT (milky stage) onwards; In undamaged plots, nil damage was recorded.

The mean percent white ear caused by rice YSB in the ten tagged hills was  $18.7 \pm 8.1$  on 80 DAT. The white ear symptoms started appearing 85 DAT onwards (Table 1). The percent damage increased to  $26.8 \pm 10.5$  on 110 DAT and later vanishes. In undamaged tagged hills, the percent white ear damage was nil during the entire period of observation.

### Spectral reflectance in RLF and YSB damaged hills

The percent reflectance in green, red and near infrared (NIR) regions in the damaged hills was different from that of the undamaged hills. In general, in the RLF damaged hills, there was a decrease in NIR reflectance while the green and red reflectance increased compared to undamaged hills. On 40 DAT, the percent reflectance values in the red region in damaged hills were  $1.83 \pm 0.99$  while undamaged hills recorded  $1.43 \pm 0.22$ . The percent reflectance in green region was  $3.64 \pm 1.45$  in damaged hills while undamaged hills recorded  $3.19 \pm 0.96$ . The reflectance in NIR region decreased to  $35.38 \pm 7.88$  in damaged hills as compared to undamaged ones which recorded  $36.11 \pm 6.78$  (Table 2 and Fig. 1). Similar trend was noticed in observations recorded on other days namely 50, 60 and 70 DAT. There was an increase in green and red reflectance and a decrease in NIR reflectance in YSB damaged hills showing white ear symptom compared to undamaged hills. On 80 DAT, the percent reflectance values in the red region in YSB damaged hills were  $7.66 \pm 2.08$  while undamaged hills recorded  $4.65 \pm 2.35$ . The percent green reflectance was  $9.68 \pm 2.16$  in damaged hills compared to  $7.35 \pm 3.10$  in undamaged hills. The percent reflectance in NIR region was  $44.86 \pm 7.60$  in damaged hills while undamaged ones recorded  $42.25 \pm 8.32$  (Table 2 and Fig. 2). The red reflectance had significant positive correlation with RLF and YSB damage while green and NIR reflectance recorded non-significant changes due to pest damage.

### Detection and estimation of damages caused by RLF and YSB by hyperspectral radiometry

The rice damaged by RLF showed increased reflectance in red region and decreased reflectance in near infrared (NIR) region. The mean percent red reflectance increased from 1.53 in undamaged hills (Azadirachtin 0.15% EC treated) to 2.41 in RLF damaged hills and the NIR reflectance decreased from 39.70 to 37.93 (Table 2). Among the bands, the red reflectance was significantly positively correlated with RLF damage on all days of observation. The increase in red reflectance in RLF damaged hills is attributed to the loss of chlorophyll pigment due to scrapping by insects. That is in with the findings of Carter (1993); Riedell and Blackmer (1999), who reported that the stressed plants have a lower reflectance in NIR region (700–1300 nm), a higher reflectance in the far-red region of the spectrum, and a consequent shift of the red edge.

The spectral reflectance curve of late stage crop (above 80 DAT) when white ear heads appeared due to YSB damage) was much different from that of the early stage crop (40 to 80 DAT - when RLF incidence was found). There was a pronounced increase in reflectance of visual bands namely green and red bands in both healthy and pest infested crops in the late stage compared to early stage of crop. This could be related to the presence of panicles in late stage which reflect electromagnetic radiation in a different pattern compared to reflectance from leaves in early stage. However, the reflectance curve of YSB damaged hills expressing white ear head symptom differed from healthy hills. The percent green reflectance was 7.55 in

undamaged hills while it was 9.50 in YSB damaged hills (Table 2). There was a non-significant correlation between YSB damage and green reflectance. The red reflectance increased from 5.80 in undamaged to 9.31 in damaged hills. The NIR reflectance decreased from 37.80 to 43.74 in damaged hills. The YSB damage significantly positively correlated with red and non-significantly negatively with NIR reflectance. While perusing the literature, no information was available on detection of rice YSB through remote sensing techniques. However, results obtained from similar pests on other crops or other pests on rice crop could help understand the pattern obtained with this pest. In case of rice RLF, the spectral reflectivity increased significantly at 610-700 nm (red region), but decreased at 530-570 nm (green region) and 700-1050 nm (NIR region) as the rate of damaged leaves increased (Huang *et al.*, 2010). The results of research on canopy reflectance of tobacco damaged by the tobacco aphid *M. persicae* and the chlorophyll content showed that the reflectance decreased due to the damage of tobacco aphid, especially in the NIR band. The reflectance in light, moderate and severe aphid infestations decreased to 12, 27, 52 percent and 15, 20, 38 percent in green and NIR band respectively compared to the healthy (Qiao *et al.*, 2007; Su *et al.*, 2019). However in our results with rice YSB, there was a significant increase in red and non-significant changes in green and NIR regions were noticed.

### Sensitivity of spectral bands to RLF and YSB damage

The sensitivity percent of spectral bands can provide information on usefulness of the band for detecting pest damage. The higher the magnitude of the sensitivity irrespective of the sign (positive or negative), the higher will be the effect explained by the band. The sign indicates if the reflectance in the given band increases or decreases with increase in damage by pest. The sensitivity percent of red band, on 70 days after transplanting (DAT) was +58.8 percent while that of NIR and green bands were -13.5 and +35.8; indicating that red band is more sensitive to damage by RLF (Table 3, Fig. 3). Similar report has been made by Huang *et al.* (2010) who found that spectral reflectance of rice leaf decreased in the green (520-600 nm) and NIR (760-900 nm) wave-length regions with the increase of the damage degree whereas it increased in the red wave-length region (630-690 nm).

The sensitivity percent in YSB infestation of red band, on 90 DAT was +113.5 percent while that of NIR and green bands were -14.5 and +33.4 which indicate that red band is more sensitive to white ear symptom caused by YSB (Table 4 and Fig. 4). These were the periods when active damage was caused by YSB in these two crops. The values beyond 100 DAT were influenced by senescence of the crop and hence may not reflect the effect of pest damage.

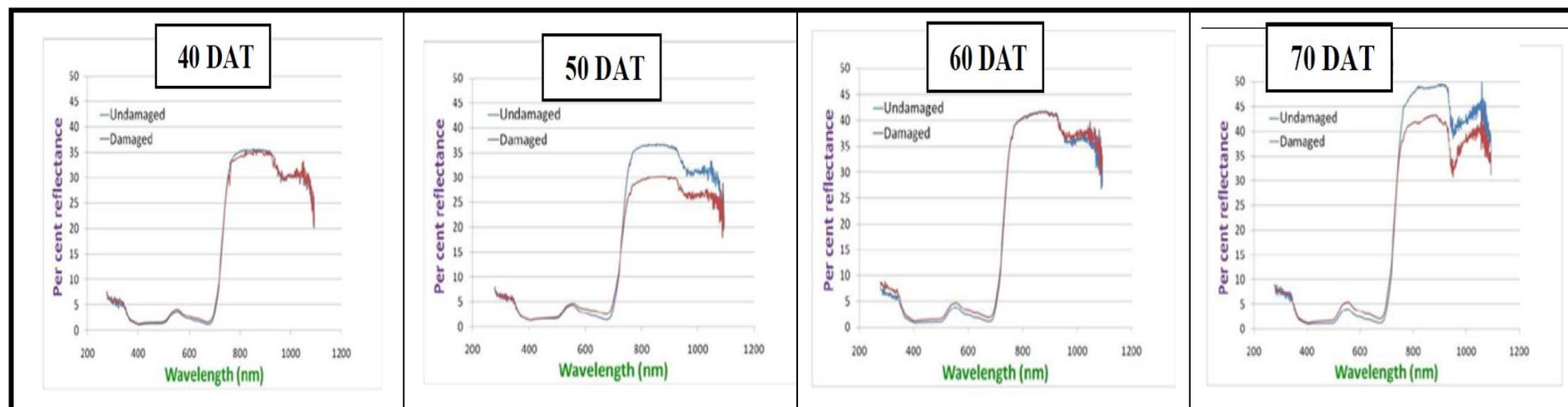
### Sensitivity of vegetation indices to RLF and YSB damage

Apart from the amplitude of reflectance and transformed spectral bands, various forms of vegetation indices (VIs) are widely used in detecting and monitoring plant diseases and pests (Zhang *et al.*, 2019).

**Table (2):** Correlation coefficient between leaf damage by tested pests and reflectance spectra at each band wavelengths

DAT	Percent reflectance at green band				Percent reflectance at red band				Percent reflectance at NIR band			
	Damaged hills**	Undamaged hills**	Correlation with percent damage		Damaged hills**	Undamaged hills**	Correlation with percent damage		Damaged hills**	Undamaged hills**	Correlation with percent damage	
			r	R <sup>2</sup>			r	R <sup>2</sup>			r	R <sup>2</sup>
<b>Leaf Folder (RLF)</b>												
40	4.89 ± 1.55	3.24 ± 1.02	0.71	0.51*	1.83 ± 0.99	1.43 ± 0.22	0.70	0.52*	33.87 ± 7.87	35.12 ± 6.80	0.04	0.00 ns
50	5.21 ± 1.09	3.35 ± 0.99	0.56	0.23	2.95 ± 1.13	1.50 ± 0.44	0.78	0.58*	28.88 ± 6.92	35.01 ± 6.81	-0.06	0.00 ns
60	5.11 ± 1.12	3.01 ± 0.51	0.41	0.18	2.29 ± 0.68	1.54 ± 0.38	0.74	0.54*	40.01 ± 8.74	40.79 ± 4.12	-0.14	0.03 ns
70	6.71 ± 1.61	3.17 ± 1.81	0.33	0.11	2.55 ± 0.63	1.63 ± 0.54	0.69	0.44*	42.72 ± 8.20	47.86 ± 13.45	-0.36	0.15 ns
Mean	5.48 ± 1.34	3.19 ± 1.08	-	-	2.41 ± 0.86	1.53 ± 0.40	-	-	36.37 ± 7.93	39.70 ± 7.80	-	-
<b>Yellow Stem Borer (STB)</b>												
80	9.68 ± 2.16	7.35 ± 3.10	0.20	0.04 ns	7.66 ± 2.08	7.55 ± 2.04	0.68	0.46*	44.86 ± 7.60	42.25 ± 8.32	-0.53	0.28 ns
90	9.06 ± 3.09	6.74 ± 2.82	0.56	0.31*	8.82 ± 3.90	4.18 ± 1.92	0.74	0.54*	40.33 ± 8.65	45.92 ± 8.54	-0.19	0.04 ns
100	9.21 ± 4.57	7.66 ± 3.81	0.32	0.10 ns	9.71 ± 5.53	5.04 ± 2.34	50.5	0.31*	35.16 ± 14.30	44.87 ± 8.26	-0.40	0.16 ns
110	10.06 ± 3.51	8.44 ± 2.55	0.42	0.17 ns	11.04 ± 4.31	6.42 ± 2.06	0.67	0.44*	30.84 ± 10.33	41.96 ± 8.86	-0.16	0.03 ns
Mean	9.50 ± 3.33	7.55 ± 3.07	-	-	9.31 ± 3.96	5.80 ± 2.09	-	-	37.80 ± 10.22	43.74 ± 8.47	-	-

\*\*Mean and standard deviation of 10 tagged hills (azadirachtin 0.15% EC treated); \* Significant at the level of 0.05; # Green: 520 to 600 nm, Red: 630 to 690 nm, NIR: 760 to 900 nm; (DAT): Days after transplanting.

**Fig. (1):** Spectral reflectance curves of RLF damaged and undamaged (azadirachtin 0.15% EC treated) rice hills

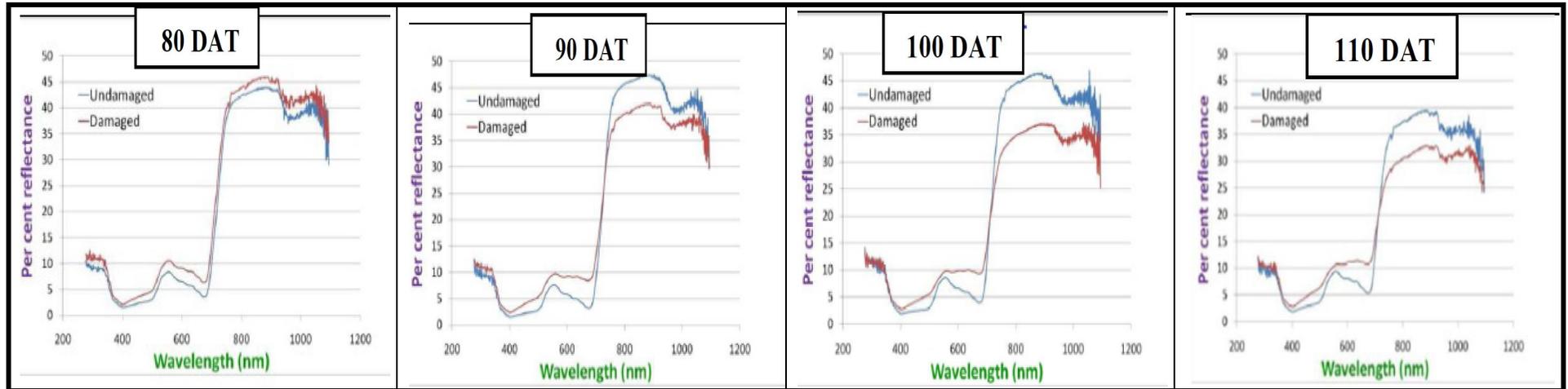


Fig. (2): Spectral reflectance curves of ten rice hills mean showing white ear symptom (caused by YSB) in comparison with undamaged hills (azadirachtin 0.15% EC treated)

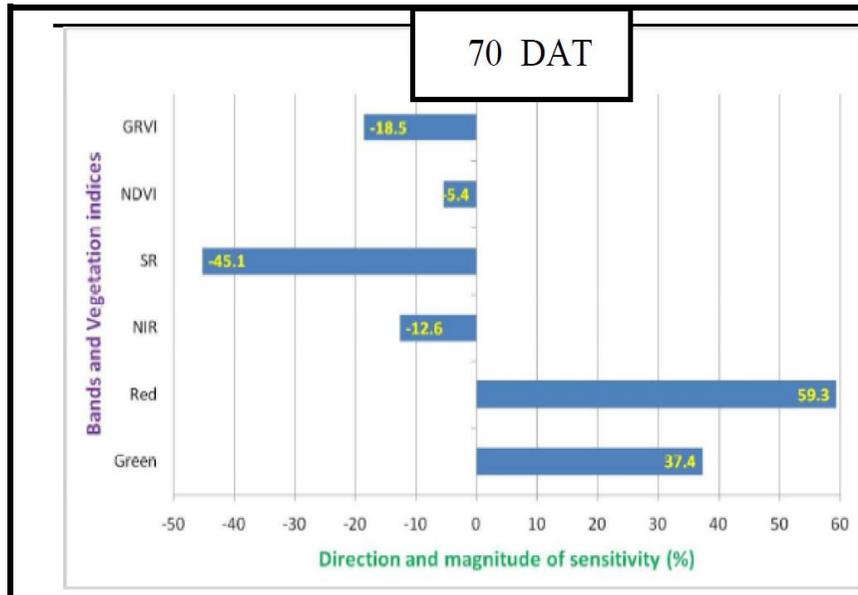


Fig.(3): Sensitivity\* of spectral bands and vegetation indices to RLF damage in rice  
\* Calculated from mean of ten plants

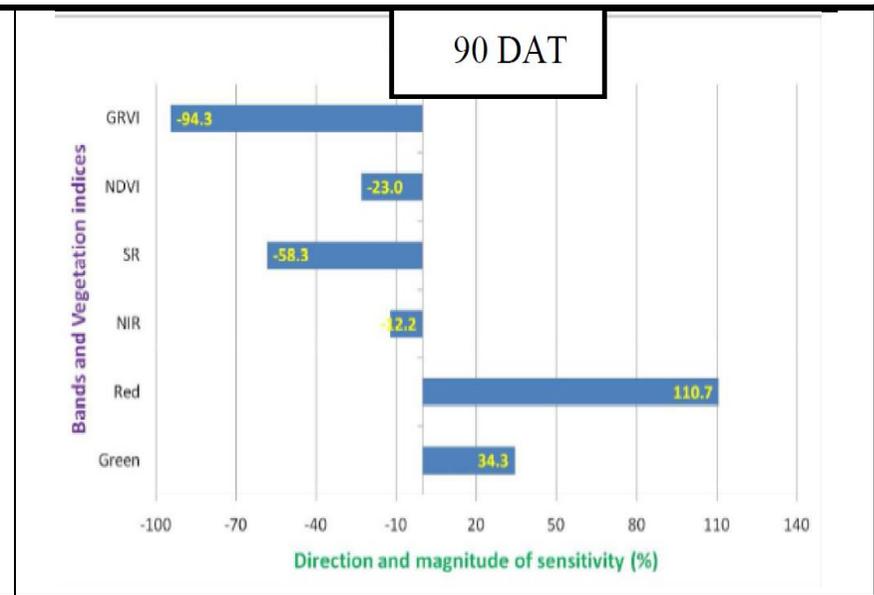


Fig.(4): Sensitivity\* of spectral bands and vegetation indices to YSB damage in rice  
\* Calculated from mean of ten plants

The sensitivity percent of three vegetation indices namely simple ratio (SR), normalized difference vegetation index (NDVI) and green red vegetation index (GRVI) to RLF damage in rice crop was worked out. On 70 DAT, these three indices were in respective -42.3, -6.5 and -19.3, indicating the usefulness of SR which was highest in magnitude irrespective of the sign (Table 3 and Fig. 3). On 90 DAT the sensitivity percent of vegetation indices namely SR, NDVI and GRVI to YSB damage was -56.4, -23.3 and -99.2 respectively; indicating the usefulness of GRVI which was highest in magnitude followed by SR and NDVI (Table 4 and Fig. 8). Similar trends were observed on most days of

observation in both varieties except at stages beyond 100 DAT when crop attained senescence which affected the usefulness of these indices in pest detection. Motohka *et al.* (2010) found that GRVI decreased in response to the changes in canopy vegetation even in the middle of the growing period when the apparent change of leaf colors and leaf density were small. GRVI kept changing during the entire growing period, whereas NDVI stopped changing in the middle of the growing period at a saturation value. This suggests that GRVI is better for detecting subtle disturbance in the middle of the growing period.

**Table (3):** Sensitivity of spectral reflectance bands and vegetation indices to leaf damage

DAT	Percent sensitivity to damage <sup>##</sup>					
	Spectral bands			Vegetation indices		
	Green <sup>#</sup>	Red <sup>#</sup>	NIR <sup>#</sup>	SR <sup>*</sup>	NDVI <sup>*</sup>	GRVI <sup>*</sup>
<b>Leaf Folder</b>						
40	11.2	25.1	-2.1	-21.7	-2.4	-15.3
50	12.2	56.2	-18.4	-47.8	-9.0	-46.4
60	25.0	52.1	-0.4	-34.5	-3.91	-24.1
70	35.8	58.8	-12.6	-42.3	-6.5	-19.3
<b>Yellow Stem Borer</b>						
80	29.5	59.3	4.0	-34.7	-11.4	-44.8
90	33.4	113.5	-14.5	-56.4	-23.3	-99.2
100	20.2	92.8	-21.6	-59.4	-28.9	-112.6
110	19.2	72.0	-18.2	-52.5	-33.3	-134.3

<sup>#</sup> Green: 520 to 600 nm, Red: 630 to 690 nm; (NIR): Near infrared 760 to 900 nm; <sup>##</sup> Calculated from mean of 10 tagged hills; <sup>\*</sup> (SR): Simple Ratio; (NDVI): Normalized Difference Vegetation Index; (GRVI): Green Red Vegetation Index; (DAT): Days after transplanting

#### Normalized Difference Vegetation Index (NDVI) in RLF and YSB damaged hills

The NDVI values in the pest damaged hills were comparatively lower than undamaged hills (Azadirachtin 0.15% EC treated). Among the damaged hills, there was a proportionate decrease in NDVI values as the percent damaged increased. In case of RLF damage, there was a significant negative correlation between pest damage and NDVI values on all days of observation ( $R^2$  values ranged from 0.71 to 0.92). On 40 DAT, the NDVI in undamaged hills was  $0.916 \pm 0.016$  while damaged hills recorded only  $0.895 \pm 0.030$ . The correlation coefficient (r) and coefficient of determination ( $R^2$  values) were -0.88 and 0.77 respectively (Table 4 and Fig. 5). Observations recorded on other days revealed similar trend. On 40 DAT, the intercept (a) and slope (b) of linear regression of pest damage (y) on NDVI (x) were -331.03 and 314.46 respectively. On 60 DAT, a and b values were -433.26 and 435.54 respectively. The slope and intercept of other days were also worked out. It was found that as the age of the crop increased the slope and intercept values of NDVI increased.

Regarding to YSB symptoms, there was a significant negative correlation between white ear symptom caused by YSB damage and NDVI values on

all days of observation ( $R^2$  values ranged from 0.77 to 0.95). On 80 DAT, the NDVI in undamaged hills was  $0.808 \pm 0.071$  while damaged hills recorded only  $0.706 \pm 0.075$ . The correlation coefficient (r) and coefficient of determination ( $R^2$  values) were -0.88 and 0.77 respectively (Table 4). On 80 DAT, the intercept (a) and slope (b) of linear regression of YSB damage (y) on NDVI (x) were -117.39 and 101.76 respectively. On 90 DAT, the values a and b were -74.45 and 69.39 respectively.

#### Simple Ratio (SR) in RLF and YSB damaged hills

The SR values in the RLF damaged hills were relatively lesser compared to undamaged hills (Azadirachtin 0.15% EC treated). In the damaged hills, there was a corresponding decrease in SR values as the percent damage increased. There was a significant negative correlation between pest damage and SR values on all days of observation ( $R^2$  values ranged from 0.72 to 0.82). On 40 DAT, the SR in undamaged hills was  $23.69 \pm 6.18$  while in case of damaged hills it was recorded only  $19.96 \pm 5.89$ . The correlation coefficient (r) and coefficient of determination ( $R^2$  values) were -0.89 and 0.80 respectively (Table 4 and Fig. 6). On 40 DAT, the intercept (a) and slope (b) of linear regression of pest damage (y) on SR (x) were -1.76 and 52.56 respectively. On 60 DAT, a and b values

were -2.49 and 75.11 respectively. Similar values were obtained on other days of observation. As the age of the crop increased the slope and intercept values of SR increased.

Significant negative correlation existed between YSB damage and SR values on all days of observation ( $R^2$  values ranged from 0.74 to 0.94). On 80 DAT, the SR in undamaged hills was  $10.69 \pm 4.10$  while damaged hills, it was  $6.09 \pm 1.60$ . The correlation coefficient ( $r$ ) and coefficient of determination ( $R^2$  values) were -0.97 and 0.94 respectively (Table 4 and Fig. 7). The intercept (a) and slope (b) of linear regression of YSB damage (y) on SR (x) were -4.88 and 49.86 respectively. On 90 DAT, a and b values were -2.75 and 36.98 respectively.

### Green Red Vegetation Index (GRVI) in RLF and YSB damaged hills

The pest damaged hills recorded comparatively lesser GRVI values than undamaged hills. GRVI decreased as the percent damaged increased. There was a significant negative correlation between pest damage and GRVI values on all days of observation except 40 DAT ( $R^2$  values ranged from 0.31 to 0.66). On 60 DAT, the GRVI in undamaged and damaged hills was  $0.374 \pm 0.074$  and  $0.269 \pm 0.079$  respectively. The correlation coefficient ( $r$ ) and coefficient of determination ( $R^2$  values) were -0.81 and 0.66 respectively (Table 4). The slope and intercept values of GRVI was not found to be related to crop age.

It was found that a significant negative correlation existed between YSB damage and GRVI values on all days of observation ( $R^2$  values ranged from 0.43 to 0.81). On 80 DAT, the GRVI in undamaged hills was  $0.242 \pm 0.086$  while damaged hills recorded only  $0.120 \pm 0.089$ . The correlation coefficient ( $r$ ) and coefficient of determination ( $R^2$  values) were -0.90 and 0.81 respectively (Table 4 and Fig. 8). The intercept (a) and slope (b) of linear regression of YSB damage (y) on GRVI (x) were -110.69 and 32.88 respectively on this day of observation. On 90 DAT, the a and b values were -84.91 and 24.46 respectively.

### Estimation of RLF and YSB damage based on vegetation indices

The regression analysis of SR and NDVI provided possibilities of estimating RLF damage, as strong correlation existed between these parameters and RLF damage. NDVI values even though found to show lesser deviation in sensitivity analysis had significant negative correlation with RLF damage ( $R^2$  values above 0.70 on all days of observation) (Table 4). Similarly, SR also had significant negative correlation with pest damage ( $R^2$  above 0.71 on all days of observation and not on all days of observation) (Table 4). The GRVI even though found to show higher level of sensitivity to RLF damage could not be used to estimate damage as correlation was not significant on all days. Further research would be needed to find if GRVI represents the current active damage status (which is difficult to find out through normal sampling methods) while NDVI and SR reflect the cumulative damage in the crop by RLF (which we normally assess through sampling methods).

The regression analysis of SR, NDVI and GRVI provided possibilities of estimating YSB damage, as significant correlation existed between these parameters and YSB damage. NDVI values even though found to show lesser deviation in sensitivity analysis had significant negative correlation with YSB damage ( $R^2$  values above 0.77 on all days of observation - Table 4). Similarly, SR also had significant negative correlation with pest damage ( $R^2$  above 0.72 on all days of observation - Table 4). The GRVI was also significantly negatively correlated with YSB damage on all days of observation even though the  $R^2$  values declined at later stages of crop towards senescence (Table 4). Chen *et al.* (2010) found that a model of (R589-R648)/(R589+R648) had the best estimation precision to estimate severity levels of leaves infested by aphid.

### Sensitive wavelength to RLF and YSB damage

Based on sensitivity analysis of spectral bands recorded on different days of pest incidence, the wavelength having highest sensitivity (positive value) to damage caused by RLF was found to lie in red band in the wavelength range from 675 to 679 nm in variety studied. The most negative value in the sensitivity analysis curve was situated in NIR band with a wavelength range of 759 to 764 nm (Table 5 and Fig. 9) (Huang *et al.*, 2010; Zhang *et al.*, 2015) reported that the regions of 530-564 nm, 614-695 nm and 706-1050 nm were the sensitive wave-length bands which could reflect the damage to rice leaf by the rice RLF. The maximum diagnostic accuracy belonged to the model based on the reflectivity at 741 nm.

Based on sensitivity analysis of spectral bands recorded on different days of pest incidence, the most positive wavelength sensitive to damage caused by YSB ranged from 678 to 675 nm in both varieties studied. The most negative value in the sensitivity analysis curve was situated in NIR band with a wavelength range of 760 to 768 nm (Table 5 and Fig. 10).

### Red edge position shift due to RLF and YSB damage

Prominent among new hyperspectral remote sensing products is the wavelength of maximum slope in the red-NIR transition or red-edge (670-780 nm). This wavelength point is known as the red-edge position (REP) (Horler *et al.*, 1983; Clevers *et al.*, 2002; Du *et al.*, 2018). Increases in the amount of chlorophyll causes a broadening of the major chlorophyll absorption feature centered around 690 nm (Buschmann and Nagel, 1993; Dawson and Curran, 1998; Krishna *et al.*, 2019), causing a shift in the red edge slope and REP towards longer wavelengths. Low leaf chlorophyll concentrations cause shifts of the red-edge slope and REP towards the shorter wavelengths. These characteristic shifts in the REP have been used as a means to estimate foliar chlorophyll content and also as an indicator of vegetation stress (Clevers *et al.*, 2002; Lamb *et al.*, 2002; Smith *et al.*, 2004; Shakoore *et al.*, 2017). An advantage of the REP over the NDVI is that it is less sensitive to varying soil and atmospheric conditions, and sensor view angle (Curran *et al.*, 1995; Clevers *et al.*, 2001; Zhang *et al.*, 2019).

**Table (4):** Relationship of vegetation indices with percent damage in RLF and YSB infested rice hills

DAT	Values <sup>#</sup>		Correlation ** with percent leaf damage		Regression ** of percent damage (y) on vegetation index (x)	
	Damaged hills**	Undamaged hills**	r	R <sup>2</sup>	Slope (b)	Intercept (a)
<b>Normalized Difference Vegetation Index (NDVI):</b>			<b>Leaf Folder</b>			
40	0.898 ± 0.033	0.915 ± 0.015	-0.88	0.75*	-331.05	314.52
50	0.824 ± 0.055	0.914 ± 0.013	-0.91	0.83*	-196.28	186.39
60	0.890 ± 0.029	0.927 ± 0.017	-0.84	0.71*	-457.16	425.54
70	0.883 ± 0.024	0.934 ± 0.018	-0.96	-0.92*	-562.34	524.60
Mean	0.874 ± 0.035	0.923 ± 0.016	-	-	-	-
<b>Normalized Difference Vegetation Index (NDVI):</b>			<b>Yellow Stem Borer</b>			
80	0.706 ± 0.075	0.808 ± 0.071	-0.88	0.77*	-117.39	101.63
90	0.647 ± 0.122	0.838 ± 0.064	-0.91	0.82*	-74.45	69.39
100	0.559 ± 0.145	0.806 ± 0.062	-0.97	0.95*	-107.64	86.00
110	0.476 ± 0.119	0.713 ± 0.060	-0.91	0.83*	-95.15	71.75
Mean	0.597 ± 0.115	0.791 ± 0.064	-	-	-	-
<b>Simple Ratio (SR):</b>			<b>Leaf Folder</b>			
40	19.96 ± 5.89	23.69 ± 6.18	-0.89	0.80*	-1.76	52.56
50	12.27 ± 7.31	23.16 ± 5.82	-0.85	0.72*	-1.38	41.42
60	18.38 ± 5.21	27.71 ± 5.94	-0.90	0.80*	-2.49	75.11
70	16.77 ± 3.74	31.19 ± 7.41	-0.90	0.82*	-2.56	71.76
Mean	16.85 ± 5.54	26.44 ± 6.34	-	-	-	-
<b>Simple Ratio (SR):</b>			<b>Yellow Stem Borer</b>			
80	6.09 ± 1.60	10.69 ± 4.10	-0.97	0.94*	-4.88	49.86
90	5.51 ± 3.04	12.99 ± 5.18	-0.94	0.89*	-2.75	36.98
100	4.08 ± 1.90	10.38 ± 4.17	-0.86	0.74*	-5.67	49.77
110	3.00 ± 0.95	6.21 ± 1.35	-0.89	0.80*	-9.41	55.47
Mean	4.67 ± 1.87	10.07 ± 3.70	-	-	-	-
<b>Green Red Vegetation Index (GRVI):</b>			<b>Leaf Folder</b>			
40	0.287 ± 0.040	0.343 ± 0.045	-0.14	0.02 ns	-	-
50	0.183 ± 0.097	0.331 ± 0.039	-0.77	0.59*	-93.20	41.41
60	0.267 ± 0.079	0.374 ± 0.074	-0.81	0.66*	-153.57	70.67
70	0.281 ± 0.087	0.336 ± 0.068	-0.55	0.31*	-105.22	55.48
Mean	0.255 ± 0.076	0.346 ± 0.057	-	-	-	-
<b>Green Red Vegetation Index (GRVI):</b>			<b>Yellow Stem Borer</b>			
80	0.120 ± 0.089	0.242 ± 0.086	-0.90	0.81*	-110.69	32.88
90	0.034 ± 0.099	0.238 ± 0.045	-0.90	0.80*	-84.91	24.46
100	-0.015 ± 0.080	0.208 ± 0.099	-0.81	0.66*	-137.45	24.17
110	-0.039 ± 0.073	0.140 ± 0.056	-0.78	0.64*	-123.69	21.60
Mean	0.025 ± 0.085	0.207 ± 0.072	-	-	-	-

<sup>#</sup>Mean and standard deviation of 10 tagged hills (azadirachtin 0.15% EC treated); \* Significant at p=0.05; \*\*Calculated for 10 hills with varying degrees of infestation in comparison with 10 undamaged hills; (DAT): Days after transplanting

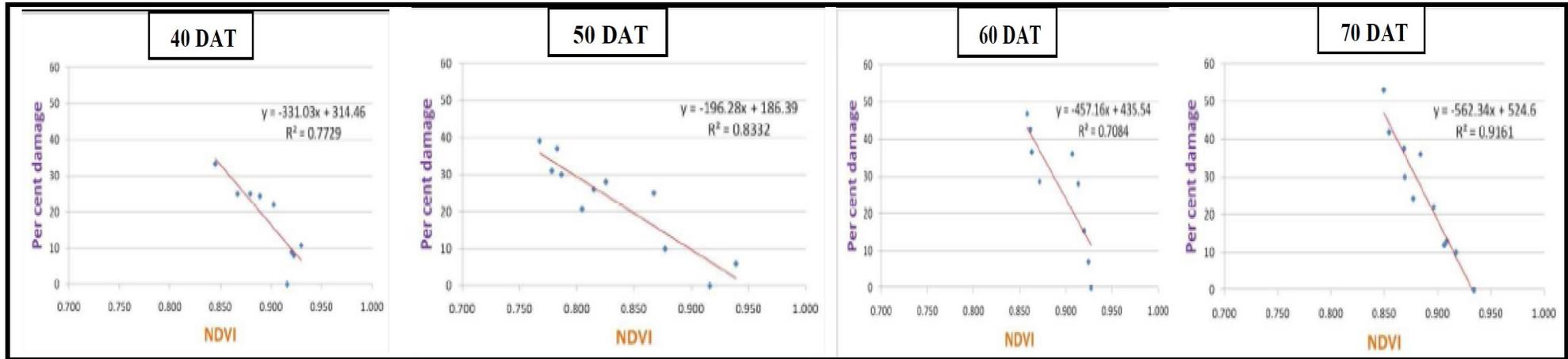


Fig. (5): Relationship (Mean of ten hills) between NDVI and percent leaf damage caused by RLF in rice hills

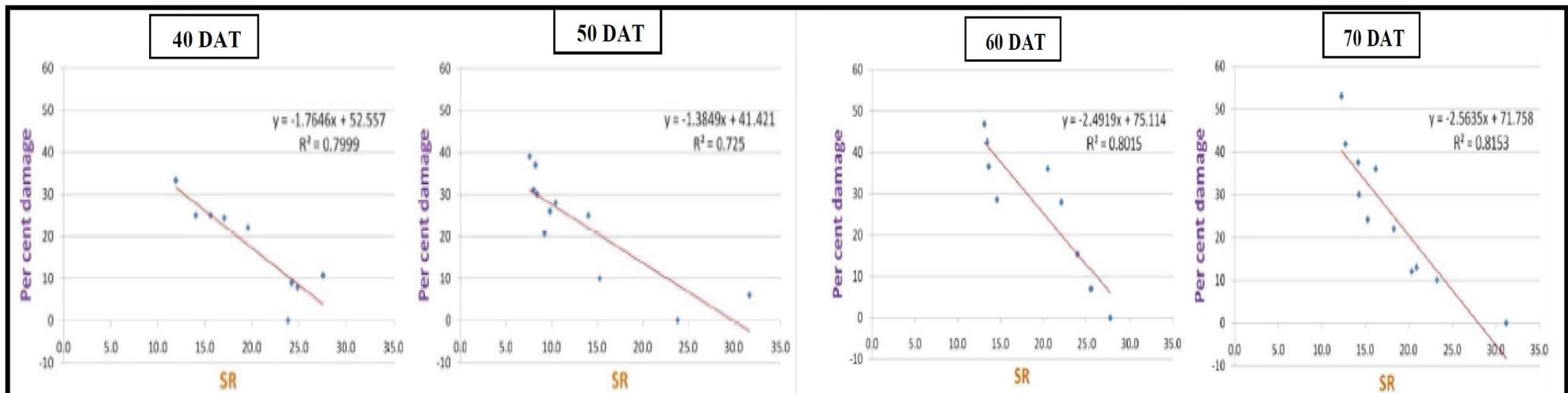


Fig. (6): Relationship (Mean of ten hills) between SR and percent leaf damage caused by RLF in rice hills

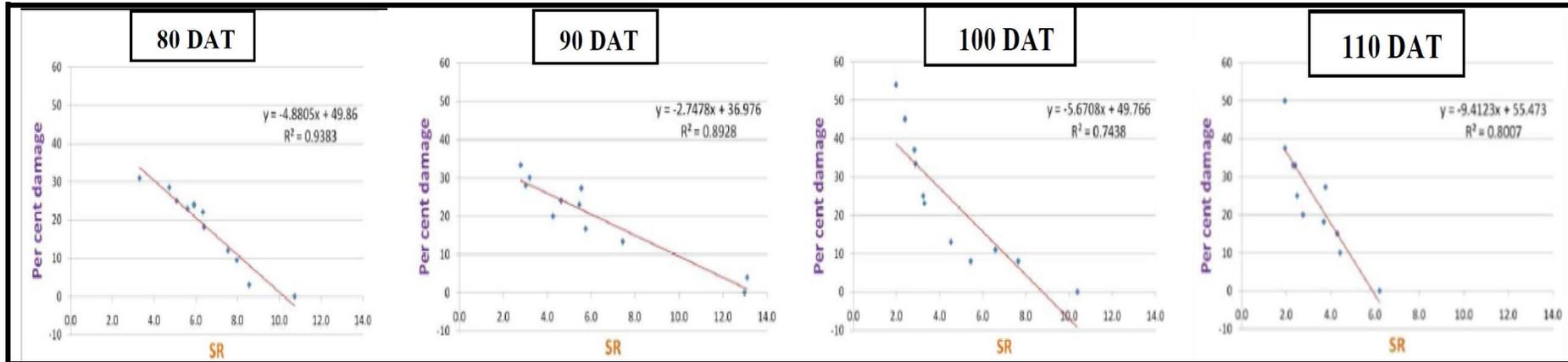


Fig. (7): Relationship (Mean of ten hills) between SR and percent white ear caused by YSB in rice hills

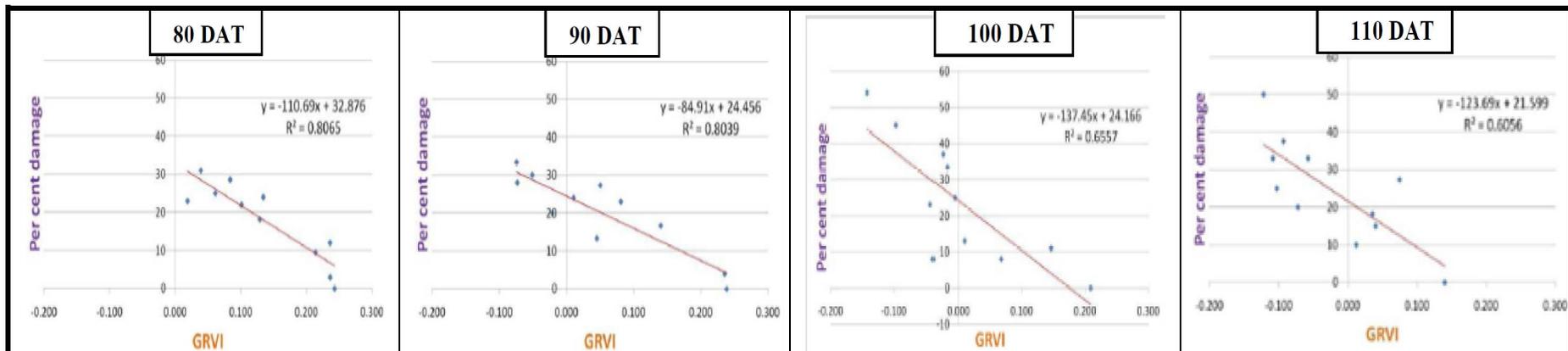
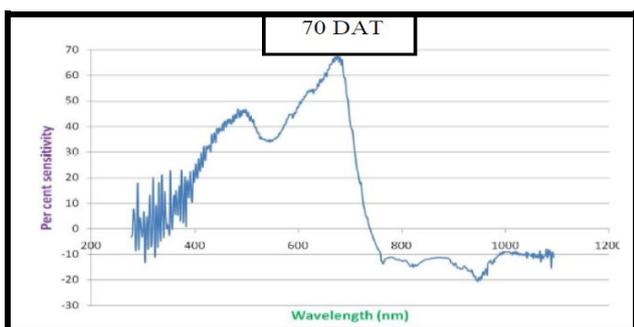


Fig. (8): Relationship (Mean of ten hills) between GRVI and percent white ear caused by YSB in rice hills

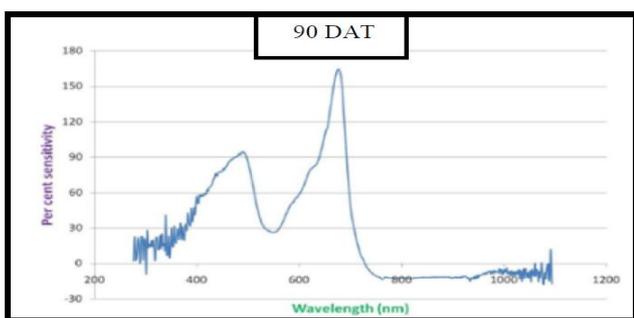
**Table (5):** Most sensitive wavelength (nm) of rice for RLF and YSB damage in rice

DAT	Positive side		Negative side	
	Wave length (nm)	Percent sensitivity	Wave length (nm)	Percent sensitivity
<b>Rice Leaf Folder (RLF)</b>				
40	679.93	34.31	759.60	-9.60
50	679.93	73.58	759.60	-18.03
60	678.34	68.40	759.60	-1.16
70	675.64	67.39	764.26	-13.82
<b>Yellow Stem Borer (YSB)</b>				
80	678.34	77.28	762.15	1.63
90	678.34	163.21	761.71	-13.69
100	673.57	130.97	769.47	-23.43
110	675.75	105.01	768.92	-19.56

The calculated wavelengths were from mean of 10 hills; (DAT) Days after transplanting



**Fig. (9):** Sensitivity\* of reflectance at different wavelengths to RLF damage in rice



**Fig.(10):** Sensitivity\* of reflectance at different wavelengths to YSB damage in rice

\*Calculated from mean of ten plants

The REP of RLF infested hills shifted towards lower wavelength. On 40 DAT, the red edge of undamaged hills was 725.35 while in damaged hills it shifted to 718.45 (Table 6). Similar trend was observed on all days of observation. From 40 to 70 days, in undamaged hills, the red edge increased with age of crop due to increased canopy. However, in RLF damaged hills, the increase of red edge with age was not

very pronounced which could be due to the stress caused by pest (Abdel-Rahman *et al.*, 2010; Thomas *et al.*, 2018). The red edge position of YSB infested hills shifted towards lower wavelength. On 100 DAT, the red edge of undamaged hills was 718.45 while in damaged hills it shifted to 708.66 (Table 6). Similar trend was observed on all days of observation. From 80 to 110 days, in undamaged hills, the red edge decreased with age of crop due to decreased chlorophyll content in older leaves. In YSB damaged hills also, the decrease of red edge with age was observed. However, the red edge in affected hills was much lesser than that of healthy hills of same age which can be attributed to the fact that healthy hills had high amounts of chlorophyll in the boot leaf while the YSB affected hills had no chlorophyll.

**Table (6):** Red edge position wavelengths (nm) and red shift in the spectral curves of tested insects

DAT	Red edge position		Red shift
	Damaged hills	Undamaged hills*	
<b>RLF</b>			
40	718.45	725.35	7.86
50	718.45	725.35	7.86
60	725.76	733.61	7.85
70	721.05	735.17	14.12
<b>YSB</b>			
80	719.47	727.33	7.9
90	725.76	727.33	1.6
100	708.66	718.45	12.6
110	702.28	718.45	17.2

DAT - Days after transplanting ; \* The calculated wavelengths from mean of 10 hills; Azadirachtin 0.15% EC treated)

**CONCLUSIONS**

The spectral reflectance curve of rice hills damaged by pests namely rice leaf folder (RLF) and yellow stem borer (YSB) was different from that of the treated with Azadirachtin 0.15% EC (undamaged hills). In general, in the RLF damaged hills, there was a decrease in near infrared (NIR) reflectance (760 to 900 nm) while the green (520 to 600 nm) and red reflectance (630 to 690 nm) increased compared to treated hills. The red reflectance had significant positive correlation with RLF damage while green and NIR reflectance recorded non-significant changes due to pest damage on all days of observation. The sensitivity percent of red band to RLF damage was the highest when compared to green and NIR on most of the days of observation in both the varieties studied. The red reflectance had significant positive correlation with YSB damage while green and NIR reflectance recorded non-significant changes due to pest damage on all days of observation. The wavelength having highest sensitivity (positive value) to damage caused by RLF was recorded in red band in the wavelength range from 675 to 679 nm. The most negative value in the sensitivity analysis curve was situated in NIR band with a wavelength range of 759 to 764 nm. The Red Edge Position (REP) of RLF infested hills shifted towards lower wavelength. On 40 DAT, the

red edge of treated hills was 725.35 nm while it shifted to 718.45 nm in the untreated hills with a red shift of 7.86 nm. There was a significant negative correlation between RLF damage and normalized difference vegetation index (NDVI), simple ratio (SR) and green red vegetation index (GRVI) values on all days of observation ( $R^2$  values of NDVI, SR and GRVI ranged from 0.72 to 0.90, 0.73 to 0.84 and 0.33 to 0.65 respectively). The REP of YSB infested hills shifted towards lower wavelength. On 100 DAT, the red edge of undamaged hills was 718.45 nm while in damaged hills it shifted to 708.66 nm with a red shift of 12.6 nm. Similar shifts were found in REP in most of the days of observation. There was a significant negative correlation between YSB damage and NDVI, SR and GRVI values on most of the days of observation ( $R^2$  values of NDVI, SR and GRVI ranged from 0.78 to 0.95, 0.75 to 0.96 and 0.64 to 0.83 respectively). Among the vegetation indices, GRVI had the highest sensitivity compared to SR and NDVI. On 90 DAT, the percent sensitivity of SR, NDVI and GRVI to YSB damage was -56.4, -23.3 and -99.2 respectively.

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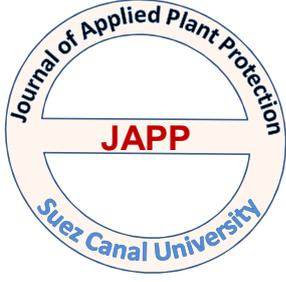
## رصد ومكافحة الإصابة بأفات الأرز من خلال تقنية الاستشعار عن بعد فائق الأطياف تحت الظروف الحقلية

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يعتبر محصول الأرز من أهم محاصيل الحبوب الاستراتيجية، وهو أحد محاور الأمن الغذائي المصري. تحديد الأصابة مبكراً من أهم العوامل الحرجة لنجاح وإدارة الزراعة الدقيقة. إستهدفت الدراسة الحقلية رصد وتشخيص كلاً من البؤر المصابة ببعض آفات محصول الأرز وغير المصابة (المعاملة بالاذناركتين ١٥% EC) باستخدام بيانات الاستشعار عن بعد فائق الأطياف من خلال جهاز الهيبرسبيكترو راديومتر الحقل المحمول (Field Portable Hyperspectral Radiometer (FPHR) ومن ثم مكافحة الإصابة مبكراً من أجل زيادة الإنتاج وتحسين جودة المنتج. يعتبر هذا الجهاز من التقنيات الحديثة في أجهزة علم الاستشعار من بعد فائق الأطياف Hyperspectral Remote Sensors ، فهو أحد مكونات الزراعة الدقيقة الذي يعطي تفاصيل أكثر لتمييز وتشخيص المكونات المختلفة بكل سهولة وبسرعة فائقة وبكفاءة عالية حيث له القدرة على تسجيل ٥١٢ قراءة (قناة طيفية) للعينة الواحدة (سواء مصابة أو غير مصابة) في مدى من الأطوال الموجية يتراوح من ٢٧٦ إلى ١٠٩٣ نانومتر. تم اختيار عدد من أهم الآفات الحشرية التي تصيب محصول الأرز (صنف جيزة ١٧٧) في مصر وهم: rice leaf folder و yellow stem borer، تم إجراء التجربة بأحد الحقول التابعة لمدينة القرين، محافظة الشرقية، مصر، وتم تقسيم الأرض لأربع معاملات وكل معاملة لها خمس مكررات وهم، معاملة للقطعة المصابة بـ rice leaf folder وأخرى معاملة بالاذناركتين ١٥% EC (خالية من الإصابة)، والثالثة لتقدير الإصابة بـ yellow stem borer والرابعة معاملة أيضاً بالاذناركتين ١٥% EC (خالية من الإصابة)، ومن ثم تمت ملاحظة نسبة الإصابة بكل معاملة وتسجيل النتائج خلال ٥-١٠ أيام من الإصابة بكل حشرة ، سُجّلت الانعكاسات الطيفية Spectral reflectance حقلياً سواء للنباتات المعاملة بالاذناركتين ١٥% EC (غير المصابة) أو للنباتات المصابة غير المعاملة بالاذناركتين ١٥% EC ، بكل أفة وعلى فترات نمو مختلفة على حدة بجهاز الهيبرسبيكترو راديومتر FPHR على مسافة ٣٠ سم من النبات في يوم صحو مشمس خالي من الغيوم، ومن ثم حساب النسب المئوية لهذه الانعكاسات. كما تم إجراء التحليلات الإحصائية لمعرفة مدى معنوية الارتباط بين مدى تواجد الإصابة من جهة والانعكاسات الطيفية المسجلة بالجهاز من جهة أخرى وذلك من خلال حساب معاملات الارتباط والانحدار للانعكاسات الطيفية لكل معاملة بكل أفة على حدة. تم حساب عدد من الأدلة الطيفية (vegetation indices) مثل (NDVI) ، (SR) ، (Green red vegetation index) ، (GRVI). أوضحت النتائج أن منحني الانعكاسات الطيفية للنباتات المعاملة بمستخلص النيم ١٥% EC كان مختلفاً تماماً عن النباتات المصابة غير المعاملة بمستخلص النيم ١٥% EC. كما وجد أن هناك ارتباط وثيق بين النسب المئوية للانعكاسات الطيفية وبين أعراض الإصابة بكل نوع من الآفات المستخدمة، حيث تم تمييز الإصابة بكل وضوح على فترات مختلفة من الزراعة من خلال الانعكاسات الطيفية والتي تماشت بصورة معنوية مع التشخيص الحقلية للإصابة. كما أشارت التحليلات الإحصائية بين الانعكاسات الطيفية وأعراض الإصابة إلى أن معامل الارتباط Correlation Coefficient كان معنوياً سواء سلبياً أو إيجابياً بناءً على خصائص الانعكاس والإمتصاص للنبات أثناء مراحل نموه المختلفة وكذلك كونه مصاباً أو غير مصاباً، وبناءً عليه، فقد تم إختيار بعض الانعكاسات الطيفية من المدى الطيفي المذكور أعلاه، على أساس الأطوال الموجية لحساب القنوات الطيفية (Bands) وهي: (Blue, Green, Red, Near-infrared (NIR) والتي كانت أكثر حساسيةً وارتباطاً بأعراض الإصابة المختلفة مقارنة بالنباتات غير المصابة والمعاملة بمستخلص النيم ١٥% EC. فقد وجد أن القناة الطيفية الحمراء هي الأكثر حساسيةً لتشخيص الإصابة بكل نوعي الآفات تحت الدراسة وذلك بالمقارنة بالقنوات الطيفية الأخرى، وكذلك فقد وجد أن دليل SR هو أكثر الأدلة ارتباطاً بنوع ومعدل الإصابة عن باقي الأدلة، وفي النهاية، تم عرض النتائج من خلال منحنيات الانعكاسات الطيفية مع أعراض الإصابة لكل حشرة، والتي تضمنت معادلات الانحدار Regression Equations للتشخيص الكمي لهذه الأعراض. التوصية: أكدت هذه الدراسة قدرة تكنولوجيا الاستشعار من البعد كثير الأطياف FPHR على تشخيص أعراض الإصابة بالآفات تحت الدراسة بصورة مبكرة مما يسهل مقاومتها قبل تدهور المحصول، كما أوضحت الدراسة فعالية الاذناركتين ١٥% EC في مكافحة آفات الأرز محل الدراسة بصورة آمنة بيئياً.

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