Madras Agric. J., 103 (7-9): 242-249, September 2016
https://doi.org/10.29321/MAJ.10.001028

Hyperspectral Radiometry for Detection and Estimation of Infestation Caused by Major Sucking Pests in Brinjal

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Studies were carried out on detection and estimation of infestation caused by sucking pests of brinjal using hyperspectral radiometry in potted plants grown in green house during 2013 - 14 at Department of Remote Sensing and GIS, Tamil Nadu Agricultural University (TNAU), Coimbatore. The results revealed that the spectral reflectance curve of brinjal plants infested by redspider mites, mealybugs and aphids were different from that of the healthy plants. The Red Edge Position (REP) of mites infested plants with medium (25 - 50%), high (>50 %) level of damage (10 - 25 %) and plants with high infestation of mealybug, shifted from 720.26 to 707.64 nm, 701.33 nm and 718.68 nm, respectively. Whereas, REP of aphid infested plants were same as that of healthy plants (720.26 nm). There was a significant negative correlation between damages caused by sucking pests and vegetation indices (VIs) namely, normalized difference vegetation index (NDVI), simple ratio (SR), green red vegetation index (GRVI) and soil adjusted vegetation index (SAVI) values. Linear regression equations were developed for estimating pest damages based on NDVI, SR and GRVI values. SR, NDVI and SAVI were more sensitive to sucking pest infestation in brinjal. The respective per cent sensitivity of SR, NDVI, GRVI and SAVI were - 60.1, -35.4, -5.3 and -38.6, for mite infestation; – 48.6, -39.2, -8.8 and -24.1, for mealybug infestation and - 43.3, -31.7, -8.9 and -12.3, for aphid infestation indicating the usefulness of SR and NDVI, which were the highest in magnitude irrespective of the sign. Thus, it was found that detection, estimation and discrimination of infestation caused by sucking pests of brinjal could be done using hyperspectral radiometry.

Key words: Hyperspectral radiometry, Brinjal, Mites, Mealy bug, Vegetation index, Red edge position

Brinjal, *Solanum melongena* L., also known as eggplant or aubergine is a common and popular vegetable crop grown in the subtropics and tropics. Brinjal is essentially a warm weather crop, which is grown extensively in India, Bangladesh, Pakistan, China, Japan, and the Philippines. It is also popular in Egypt, France, Italy, and the United States. According to the 2013 FAO Production Yearbook, the world eggplant production area was 1.871 million ha, and the total production was 49.50 million tonnes (FAO, 2015). In India eggplant was grown in an area of 6.8 lakh ha with the production of 11.89 million metric tonnes. Eggplant can be grown in almost all parts of India all the year round except in higher altitudes. In the tropics, eggplant production is severely constrained by several insect and mite pests. The major pests include eggplant fruit and shoot borer, leafhopper, whitefly, thrips, aphid, spotted beetles, leaf roller, stem borer, blister beetle, red spider mite, and little leaf disease (Srinivasan, 2009). Growers rely heavily on chemical pesticides to protect their crop. In Bangladesh, some farmers spray about 180 times during a cropping season (SUSVEG-Asia 2007). Pesticide misuse has adverse effects on the environment and human health and also increases the cost of production. The main reason for misuse of pesticide is non availability of effective pest monitoring and detection system.

Thus, the detection and assessment of pest damage symptoms is essential in commercial agriculture. Traditionally, pest and disease damage assessment in plants is being done by visual approach, *i.e.* relying upon the human eye and brain to assess the incidence of pest in crops. However, the problems with the traditional approaches is that they are often time-consuming and labour intensive (Lucas, 1998). Therefore, there is a need to develop different approaches that can enhance or supplement traditional techniques. Remote sensing has been used in agriculture for many decades (Moran*, et al.,* 1997). One of its earliest applications was on crop pest and disease assessment. Reflectance data was found to be capable of detecting changes in the biophysical properties of plant leaf and canopy associated with insect pests. Additionally, remote sensing may provide a better means to quantify pest stress than visual assessment methods and it can be used to collect sample measurements repeatedly, non-destructively and non-invasively. Hyperspectral sensing, a technique that utilizes sensors operating in hundreds of narrow contiguous spectral bands, offers potential to improve the assessment of crop pests. Many studies have shown that the basis for distinguishing healthy and stressed plants using optical remote sensing technique is their differences in reflectance in different spectral regions.

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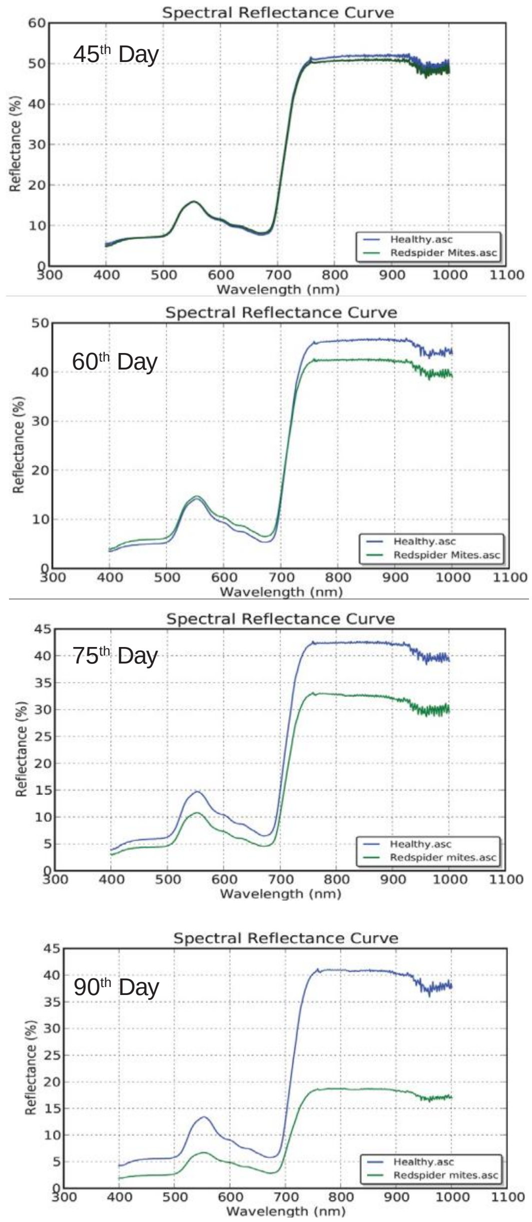
Healthy plant often has a high reflectance in the near-infrared (NIR) region determined by cellular and subcellular structures and a low visible reflectance due to strong pigment absorption (Riedell and Blackmer, 1999). Changes in pigment concentrations as well as internal leaf structure are strongly related to the physiological status, and consequently, spectral features of plant (Blackburn, 1998; Mirik *et al.,* 2007). 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 (Carter, 1993; Malthus and Madeira, 1993; Shibayama *et al*., 1993). 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. The utility of hyperspectral remote sensing technique to diagnose pests can improve detection speed and provide opportunity for non-destructive sampling. With the advent of remote sensing techniques, plant protection scientists have used these techniques to detect crop damages caused by insect pests and diseases in various crops such as rice, cotton, wheat, sugarcane, pulses and vegetables (Chen *et al.,* 2007; Mageshwaran, 2012; Ranjitha, 2013). With this background information, studies were carried out on detection and estimation of damage caused by sucking pests of brinjal using hyperspectral radiometry techniques.

Materials and Methods

Two pot culture experiments with variety Co 2 were conducted to study the spectral reflectance characteristics of healthy and pest damaged brinjal crop and compile a spectral library of damage symptoms caused by pests in brinjal plants. Studies were carried out on detection and estimation of damage caused by redspider mites (*Tetranychus urticae* Koch), mealybugs (*Phenacoccus solenopsis* Tinsley) and aphids (*Aphis gossypii* Glover) in brinjal using hyperspectral radiometry at Department of Remote Sensing and GIS, Tamil Nadu Agricultural University (TNAU), Coimbatore during 2013 - 2015. The natural occurrence of pest infestation was studied in ten pots each of T1 (mite damaged), T2 (mealybug damaged), T3 (aphids damaged) and T4 (Healthy) in pot culture experiment. In the pot marked healthy, the plants were protected from insect damage by spraying suitable insecticides periodically. No plant protection measures were taken up against redspider mites and other pests in order to allow natural build up. However, all the plots were kept free from plant diseases by careful monitoring and spraying fungicide/ bactericide whenever necessary. The spectroradiometer can read the plant canopy surface and detect damage caused by insect pests in terms of spectral reflectance and derived indices. It would be more scientific to estimate pest damage rather than pest population from spectral indices through correlation and regression studies. Hence, the pest damage was recorded from 5 leaves at the top of the plant based on visual scoring at 15 days interval during active damage stage starting from 45, 60, 75 and 90 days after transplanting (DAT). Ten potted plants served as replications for each treatment. Based on score [healthy (undamaged), low (less than 25 per cent damage), medium (25 to 50 per cent damage) and high (more than 50 per cent damage)] plants were identified to take spectral reflectance data.

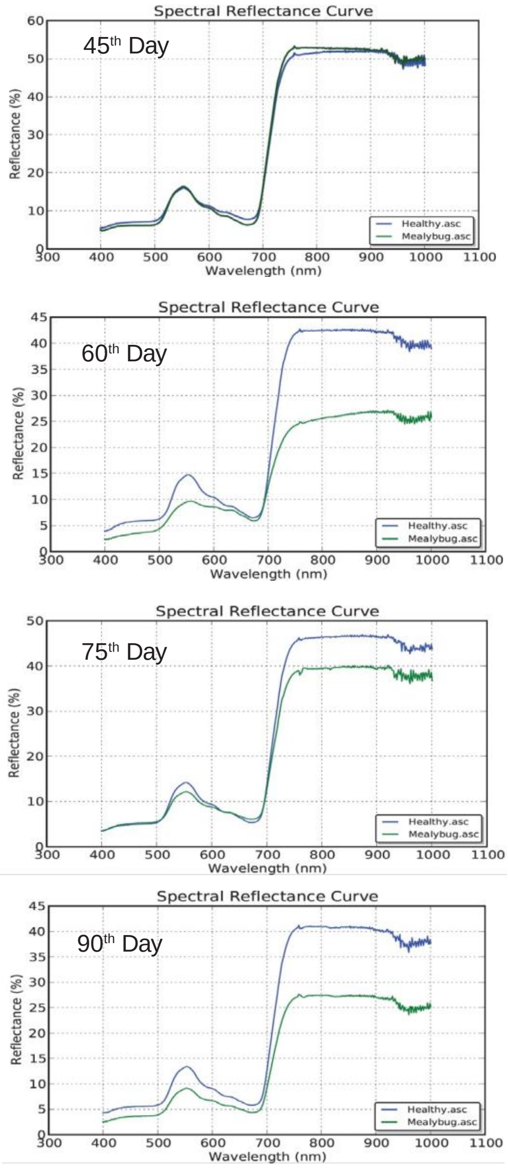
Fig 1. Spectral reflectance curves of pest infested and healthy brinjal plants at different time interval

Redspider mites



Field experiment was conducted at Orchard, Horticulture College and Research Institute, Tamil Nadu Agricultural University (TNAU), Coimbatore. The naturally occurring pest infestation was studied in two plots each of dimension 20 × 10 sq.m demarcated as healthy and pest damaged in existing CO 2 brinjal crop. In the plot marked healthy or undamaged, the plants were protected from insect damage by spraying suitable insecticides periodically. In the plot marked pest damaged, no plant protection measures were taken up so as to allow natural build up of pests. However, both the plots were kept free from plant diseases by careful monitoring and spraying fungicide/ bactericide whenever necessary. The observations were recorded in the ten randomly selected plants to represent healthy, low, medium and high level of redspider mites, mealybugs and aphids infestation categories at 15 days interval during 45, 60 and 75 DAT.

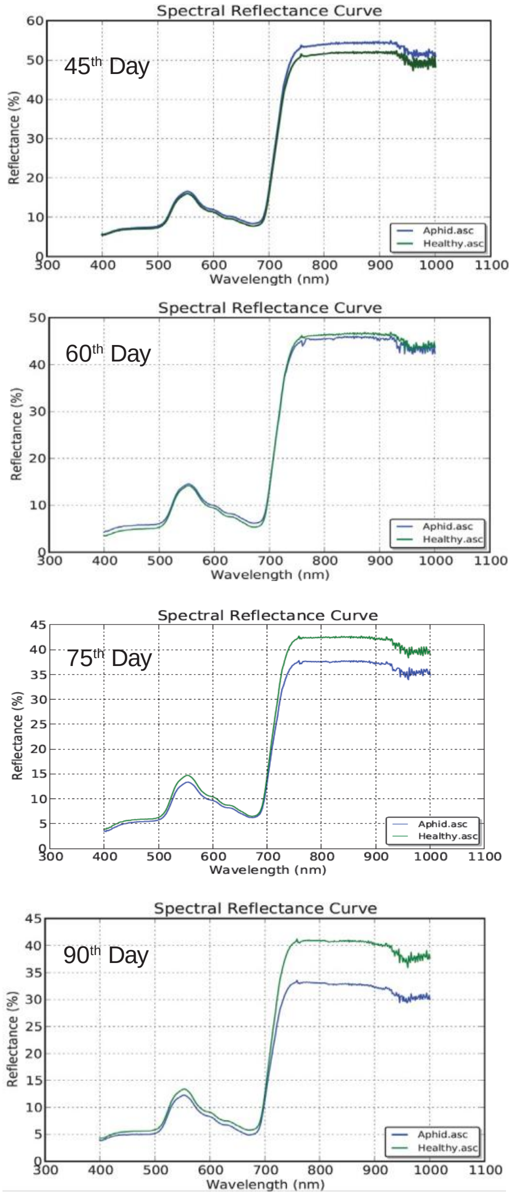
Mealybug



Per cent spectral reflectance in various bands *viz.,* blue (450-520 nm), green (520-590 nm), red (620-680 nm) and NIR (770-860 nm) regions of electromagnetic spectrum was also recorded using Hyperspectral Spectroradiometer (GER 1500). The technique involves recording of spectral reflectance at canopy level using hyperspectral spectroradiometer and comparing the data obtained from healthy and pest infested plants. The spectral signature for the damage symptoms caused by aphids, mites and mealy bugs in brinjal plants were developed. The Red Edge Position (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:

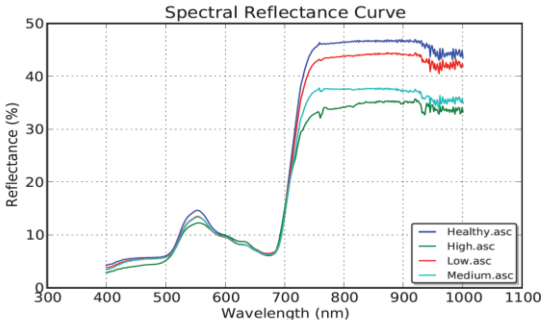
$$FDR_{(\lambda i)} = \frac{[R_{\lambda(j+1)} - R_{\lambda(j)}]}{\Delta_{\lambda}}$$

Aphid

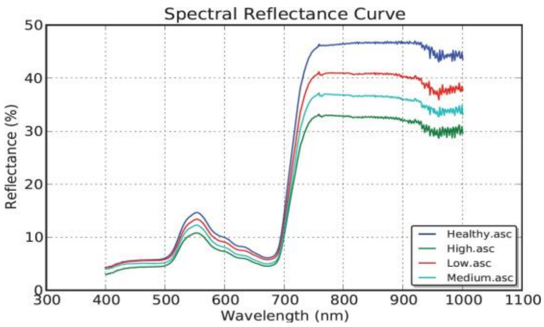


Where, FDR is the first derivative reflectance at a wavelength i, midpoint between wavebands j and j+1, Rλ(j) is the reflectance at the j waveband, Rλ(j+1) is the reflectance at the j+1 waveband, and rλ is the difference in wavelengths between j and j+1. The FDR of wavelengths in the range of 680 to 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.

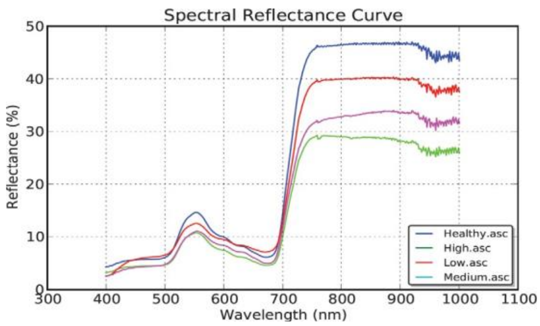
Fig 2. Spectral reflectance of varying levels of infestation of pests and healthy brinjal plants at different infestation level



Aphid



Redspider mites



Mealybugs

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 require high-quality reflectance measurements from either multispectral or hyperspectral sensors. Normalized Difference Vegetation Index (NDVI) is the normalized difference of reflectance in NIR and red bands (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).

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

Where, RRED and RNIR are spectral reflectance values in red and NIR bands, respectively.

Simple Ratio (SR) is the ratio of the highest reflectance and absorption bands of chlorophyll. As with the NDVI, it can saturate in dense vegetation, when LAI becomes very high. The value of this index ranges from 0 to more than 30 (Sims and Gamon, 2002; Mirik *et al*., 2006).

$$\text{SR} = \frac{\text{RNIR}}{\text{RRED}}$$

Where, RRED and RNIR are spectral reflectance values in red and NIR bands, respectively.

Motohka *et al.* (2010) suggested a new index called green red vegetation index, GRVI, which can show small changes in vegetation condition during crop growth. GRVI does not saturate at high LAI.

$$\text{GRVI} = \frac{\text{RGREEN - RRED}}{\text{RGREEN + RRED}}$$

Where, RRED and RGREEN are spectral reflectance values in red and green bands, respectively.

Results and Discussion

The spectral reflectance curve, Red Edge Position (REP) and vegetation indices (VIs) namely normalized difference vegetation index (NDVI), simple ratio (SR), green red vegetation index (GRVI) and soil adjusted vegetation index (SAVI) values for healthy brinjal plant were given in the Table 1. The Red Edge Position (REP) of healthy plant was 720.26 nm irrespective of the stage of the plant. SR, SAVI,

Table 1. Relationship of vegetation indices with healthy brinjal plants

Mean of ten observations

DAT	REP	SR	SAVI	NDVI	GNDVI	GRVI
45	720.26	7.826	1.260	0.846	0.701	0.283
60	720.26	7.578	1.230	0.826	0.654	0.274
75	720.26	7.284	1.156	0.781	0.629	0.265
90	720.26	7.121	1.130	0.759	0.633	0.261

DAT – Days After Transplanting; REP – Red Edge Position, SR – Simple Ratio; SAVI – Soil Adjusted Vegetation Index; NDVI – Normalized Difference Vegetation Index; GNDVI – Green Normalized Difference Vegetation Index; GRVI –Green Red Vegetation Index.

NDVI, GNDVI and GRVI for healthy plants on 45th DAT were 7.826, 1.260, 0.846, 0.701 and 0.283; on 60th day were 7.578, 1.230, 0.826, 0.654 and 0.274; on 75th day were 7.284, 1.156, 0.781, 0.629 and 0.265 and on 90th day were 7.121, 1.130, 0.759, 0.633 and 0.261, respectively. The correlation and regression analysis performed between per cent damage caused by the different pests with vegetation indices at different stage of the crop revealed that, the REP of aphid infested plants and healthy plants were same (720.26 nm) irrespective of the stage of the crop (Table 2). SR, SAVI, NDVI, GNDVI and GRVI for aphid damaged plants on 45th DAT were 7.126, 1.238, 0.839, 0.790 and 0.223; on 60th day were 6.823, 1.228, 0.825, 0.637 and 0.204; on 75th day were 5.927, 1.119, 0.766, 0.644 and 0.197 and on 90th day were 5.463, 1.051, 0.706, 0.579 and 0.189, respectively. Among vegetation indices, SR was significantly correlated with the per cent aphid incidence at 0.01 % level. The shifting of REP was observed in the red spider mite damaged plants and mealy bug damaged plants (Table 2). In red spider mite damaged plants REP was shifted from 720.26 to 707.65 on 75 DAT and 701.33 in 90 DAT whereas, in mealy bug damaged plants REP was shifted to 708.68 on 75 as well as 90 DAT. The vegetation indices *viz.,* SR, SAVI, NDVI, GNDVI and GRVI for red spider mite and mealy bug damaged plants were 6.437, 1.233, 0.828, 0.739, 0.217 and 7.092, 1.229, 0.826, 0.701, 0.228, respectively on 45 DAT; 5.621, 1.188, 0.798, 0.646, 0.197 and 6.247, 1.130, 0.760, 0.611, 0.192, respectively on 60 DAT; 4.822, 1.062, 0.715, 0.578, 0.190 and 5.481, 1.048, 0.706, 0.576, 0.182, respectively on 75 DAT; 4.037, 0.965, 0.661, 0.454, 0.172 and 4.834, 1.004, 0.676, 0.563, 0.177, respectively on 90 DAT (Table 2).

Table 2. Relationship of vegetation indices with varying levels of pest infestation in brinjal

Particulars (DAT)	Percent Infestation	REP	SR	SAVI	NDVI	GNDVI	GRVI
Aphid damage							
45	3.96	720.26	7.126	1.238	0.839	0.790	0.223
60	10.61	720.26	6.823	1.228	0.825	0.637	0.204
75	20.58	720.26	5.927	1.119	0.766	0.644	0.197
90	28.84	720.26	5.463	1.051	0.706	0.579	0.189
Correlation co-efficient (r)	-	-	- 0.99**	- 0.98*	- 0.98*	- 0.86	- 0.95*
Regression co-efficient (R^2)	-	-	0.99**	0.96*	0.97*	0.75	0.90*
Intercept (a)	-	-	105.21	154.17	154.76	85.87	161.65
Slope (b)	-	-	- 14.08	- 119.22	- 176.99	- 105.47	- 716.59
Red spider mite damage							
45	5.79	720.26	6.437	1.233	0.828	0.739	0.217
60	14.36	720.26	5.621	1.188	0.798	0.646	0.197
75	41.90	707.65	4.822	1.062	0.715	0.578	0.190
90	78.33	701.33	4.037	0.965	0.661	0.454	0.172
Correlation co-efficient (r)	-	-	- 0.97*	- 0.99*	- 0.98*	- 0.98*	- 0.94
Regression co-efficient (R^2)	-	-	0.93*	0.97*	0.96*	0.95*	0.88
Intercept (a)	-	-	194.99	330.22	350.44	195.92	355.55
Slope (b)	-	-	- 30.57	- 265.40	- 420.18	- 266.17	- 1651.84
Mealy bug damage							
45	9.78	720.26	7.092	1.229	0.826	0.701	0.228
60	35.27	720.26	6.247	1.130	0.760	0.611	0.192
75	60.79	718.68	5.481	1.048	0.706	0.576	0.182
90	85.48	718.68	4.834	1.004	0.676	0.563	0.177
Correlation co-efficient (r)	-	-	- 0.99**	- 0.98*	- 0.98*	- 0.93	- 0.91
Regression co-efficient (R^2)	-	-	0.99**	0.97*	0.97*	0.87	0.83
Intercept (a)	-	-	245.35	406.54	410.73	347.71	300.53
Slope (b)	-	-	- 33.40	- 325.29	- 489.08	- 489.40	- 1297.59

DAT – Days After Transplanting; ** – Significant at the 0.01 level; * – Significant at the 0.05 level; REP – Red Edge Position, SR – Simple Ratio; SAVI – Soil Adjusted Vegetation Index; NDVI – Normalized Difference Vegetation Index; GNDVI – Green Normalized Difference Vegetation Index; GRVI –Green Red Vegetation Index.

The results of field trial, indicated that the spectral reflectance curve of brinjal plant damaged by aphids were different from that of the healthy plants (Table 3). The Red Edge Position (REP) of aphid infested plants and healthy plants were the same (720.26 nm). There was a significant negative correlation between damages caused by mites and vegetation indices (VIs) namely, normalized difference vegetation index (NDVI), simple ratio (SR) green red vegetation index (GRVI) and soil adjusted vegetation index (SAVI) values (Table 3). Linear regression equations were developed for estimating pest damages based on NDVI, SR and GRVI values. SR and NDVI were more sensitive to aphid infestation in brinjal. The per cent sensitivity of SR, NDVI GRVI and SAVI were - 43.3, -31.7, -8.9 and -12.3, respectively indicating the usefulness of SR, which was the highest in magnitude irrespective of the sign.

The spectral reflectance curve of brinjal plant damaged by mites was different from that of the healthy plants (Table 3). In general, in the damaged plants, there was a decrease in reflectance at green (520 to 590 nm) red (620 to 680 nm) as well as near infra red (NIR) (770 to 860 nm) wavelength regions when compared to healthy plants. REP of mites infested plants with medium and high level of damage shifted to 720.26 to 707.64 nm and 701.33 nm, respectively than the healthy crop (720.26 nm). There was a significant negative correlation between damages caused by mites and vegetation indices (VIs) namely, normalized difference vegetation index (NDVI), simple ratio (SR) green red vegetation index (GRVI) and soil adjusted vegetation index (SAVI) values (Table 3). Linear regression equations were developed for estimating pest damages based on NDVI, SR and GRVI values. SR, NDVI and SAVI were more sensitive to mite infestation in brinjal. The per cent sensitivity of SR, NDVI GRVI and SAVI were - 60.1, -35.4, -5.3 and -38.6, respectively indicating the usefulness of SR which was highest in magnitude irrespective of the sign.

The spectral reflectance curve of brinjal plant damaged by mealybugs was different from that of the healthy plants (Table 3). The negative value in the sensitivity analysis curve was situated in NIR band. REP of mealybug infested plants shifted towards lower wavelength. Plants with low level of damage have the same REP as that of healthy plants (720.26). Whereas, plants with medium and high level of damage, red edge position shifting was observed from 720.26 to 718.68 nm. There was a significant negative correlation between damages caused by mealybugs and vegetation indices (VIs) namely, normalized difference vegetation index (NDVI), simple ratio (SR) green red vegetation index (GRVI) and soil adjusted vegetation index (SAVI) values (Table 3). Linear regression equations were developed for SR, NDVI, GRVI and SAVI and were more sensitive to mealybug infestation in brinjal. The per cent sensitivity of SR, NDVI GRVI and SAVI were – 48.6, -39.2, -8.8 and -24.1, respectively indicating the usefulness of SR, which was the highest in magnitude irrespective of the sign.

Table 3. Relationship of vegetation indices with major infestation of sucking pests in brinjal

Name of the index	Level of damage				Correlation co-efficient (r)	R2 Value	Intercept (a)	Slope (b)
	Healthy	Low	Medium	High				
Aphid damage								
REP	720.26	720.26	720.26	720.26	-	-	-	-
SR	7.068	6.810	6.553	6.193	0.98*	0.97*	4.332	-0.743
NDVI	0.752	0.706	0.695	0.677	0.99**	0.94**	1.294	-0.529
GRVI	0.265	0.236	0.221	0.211	0.91NS	0.88NS	0.837	-0.093
SAVI	1.119	1.050	1.032	1.005	0.98**	0.96**	2.927	-0.212
Red spider mite damage								
REP	720.26	720.26	707.65	701.33	-	-	-	-
SR	7.068	6.082	5.431	4.173	0.98*	0.98**	8.022	-0.933
NDVI	0.752	0.718	0.689	0.613	0.99**	0.95**	0.804	-0.044
GRVI	0.265	0.252	0.230	0.235	0.84NS	0.81NS	0.273	-0.011
SAVI	1.119	1.066	1.019	0.903	0.99**	0.95**	1.20	-0.069
Mealy bug damage								
REP	720.26	720.26	718.68	718.68	-	-	-	-
SR	7.068	6.518	5.667	5.085	-0.94NS	0.98NS	15.70	-2.508
NDVI	0.752	0.716	0.669	0.617	-0.98*	0.99*	0.916	-0.049
GRVI	0.265	0.238	0.217	0.208	-0.96NS	0.92NS	0.376	-0.052
SAVI	1.119	1.089	1.011	0.972	-0.98*	0.97*	1.366	-0.074

NDVI- normalized difference vegetation index, SR- simple ratio, GRVI - green red vegetation index, SAVI - soil adjusted vegetation index, *Significant at the 0.05 levels, **Significant at the 0.01 levels, ^{NS} Non significant.

This is in accordance with the findings of Carter (1993); Shibayama *et al*. (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. Mirik *et al*. (2007) reported that Russian wheat aphid infested wheat canopies had significantly lower reflectance in the NIR region and higher in the visible range of the spectrum when compared with non-infested canopies. 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 (Horler *et al*., 1983; Clevers *et al*., 2002).

Increases in the amount of chlorophyll causes a broadening of the major chlorophyll absorption feature centred around 680 nm (Buschmann and Nagel, 1993; Dawson and Curran, 1998), 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 concentration/content and also as an indicator of vegetation stress (Horler *et al*., 1983; Curran *et al*., 1995; Clevers *et al*., 2002; Lamb *et al*., 2002; Smith *et al*., 2004). 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). Thus, it was found that detection, estimation and discrimination of damage caused by sucking pests of brinjal could be done using hyperspectral radiometry.

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Received after revision: September 24, 2016 ; Accepted: September 30, 2016