Red Edge Position (REP), an Indicator for Crop Stress Detection: Implication on Rice (*Oryza sativa* L)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Crop stresses due to both biotic and abiotic are the major factors affecting crop productivity. The need of the hour is to minimize the yield losses due to these stresses. Early detection can help to reduce the impact of stresses on crop growth and yield. Remote sensing techniques have been shown to be timely, non-destructive and provide spatial estimates for quantifying and monitoring crop stress as compared to direct field techniques. In this study we tested the possibility of detecting impact of abiotic stresses, mainly Nitrogen (N) and elevated CO_2 and Temperature on growth and yield of rice crops based on the spectral reflectance data in the red edge position (REP). Spectral reflectances of crop canopyi from 350 to 2500 nm acquired using SVC spectroradiometer under clear sky condition between 11:00 and 13:00 IST. The results thus obtained indicate that REP is a good indicator of crop stress detection as healthy crops always are at longer wavelength as compared to crop under stress. The research work done also elucidates that REP can lead to the development of real-time management tool for crop stress detection, thereby reducing the yield losses due these stresses.

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1. INTRODUCTION

Stress causes crops to grow below their potential and this affects the physiological functioning of the plants leading to some injury. Recently Hyperspectral imaging in physiological attributes is considered as an important and precise tool for the identification of stress which gives us timely monitoring of plant biogeochemical processes which may provide accurate estimation of plant health status. Many of these plant responses are difficult to quantify visually with acceptable levels of precision and promptness. However, these responses also affect the amount and quality of electromagnetic radiation reflected from plant canopies. Relationship between chlorosis and necrosis was given by Curran [1] on the remote sensing of foliar chemistry by spectral measurements. Collins [2] had shown that transition region of red-NIR, commonly known as Red Edge brings out sudden change in vegetation reflectance between 680 to 780 nm. According to Portigal et al. [3], information contained in the first derivative of red edge (680-730nm) reflectance values has shown to be useful for discrimination of vegetation. Leaf reflectance in the red edge region between 680 to 780 nm due to the combined effects of strong chlorophyll absorption in the red wavelengths and high reflectance in the NIR wavelengths due to internal leaf scattering [4]. Many studies using rice spectral reflectance data has been done to estimate its product and health condition at red edge region [5,6,7]. Some parameters such as chlorophyll content, nitrogen, LAI, biomass and relative water content were studied in the first derivative reflectance curve in the red edge region [8].

Based on the fact that stresses interfere with photosynthesis and physical structure of the plants and affect absorption of light energy and reflectance spectrum of plants, hyperspectral remote sensing was found to be able to identify different stresses [9]. Evaluation of the stress level to which plants are subjected is therefore critical information required both for the quantification of consequences on production and for taking action for their mitigation. Use of non-destructive methods to detect crop stress at an early stage of its development holds great promise for management in commercially important agricultural crops [10]. However, spectral characteristics and damage symptoms need to be aptly correlated based on ground truth prior to development of any management schemes. Thus a study has been carried out to assess the crop conditions based on changes in spectral properties cause by various abiotic stresses such as environmental stress (elevated CO_2 and Temperature) and Nutrient (N) stress to facilitate quick detection of stress.

2. METHODOLOGY

The present investigation was carried out in the Department of Crop Physiology, Assam Agricultural University (AAU), Jorhat, Assam. The rice experiment was conducted with four local genotype namely Inglongkiri, Banglami, IET22238 and Bash to the induced elevated CO_2 and temperature stress, in Carbondioxide Temperature Gradient Tunnel (CTGT) to simulate elevated CO_2 concentration and temperature viz. AMB: Ambient CO_2 and temperature, CTGT I : CO_2 level of 400 ppm and a temperature of 2^oC greater than ambient, CTGT (II) a CO_2 level of 550 ppm and a temperature of 4^oC greater than ambient and CTGT (III) a CO_2 level of 750 ppm and a temperature of 6^oC greater than ambient was maintained; and nitrogen stress viz. N_1: No applied N (N: P: K @ 0: 20: 20 kg ha^{-1}), N_2: low N (N: P: K @ 20: 20: 20 kg ha^{-1}) and N_3: RDF N (N: P: K @ 40: 20: 20 kg ha^{-1}).

The field spectral measurement were collected using HR 1024 spectroradiometer over visible to shortwave infrared wavelength range (300-2500 nm) keeping observation window strictly at 11:00 to 13:00 IST under clear sky condition. Several processing techniques were applied before statistical analysis that includes signature file overlap/matching, Savitzky and Golay [11] (SG) filtering, reflectance normalization and the first derivative of the reflectance. The SG filtered spectra were transformed into first order derivative spectra as the prediction accuracy of the foliar bio-chemicals improves with transformed spectra [12].

The first derivative curve in the range of red edge wavelengths i.e. 660nm-780nm was calculated and the highest value obtained in this range as the maximum possible slope is determined as the red edge position [13] for each of the genotype under different treatments.

$$FDR_\lambda = \frac{R_{\lambda+1} - R_\lambda}{\Delta\lambda}$$

Where,

FDR: First Derivative at λ wavelength, R: Reflectance

Physiologically active leaves were taken to record various plant parameters. The total chlorophyll content was determined by the formula as suggested by Arnon [14] and expressed as mg g^{-1} leaf fresh weight. The chlorophyll stability index (CSI) was estimated by following the method of Chetty et al. [15].

3. RESULTS AND DISCUSSION

In the present investigation the response of rice genotypes to the interaction of elevated CO_2 and temperature and nitrogen stress were characterized using spectral information. Several processing techniques such as smoothing, normalization and first derivatives were applied on spectral data before statistical analysis as shown in Fig. 1. Field crop reflectance actually was a kind of mixed reflectance, influenced not only by rice canopy but also by soil. Reflectance spectra may suffer from background signals and albedo effects. In contrast, derivatives were shown to be less sensitive to variations of soil background, illumination, and surface albedo [16]. The first derivative was calculated using a

first difference transformation of the reflectance spectrum (FDR) [17].

The first derivative Curve in the range of red edge wavelengths calculated (Fig. 2) and the highest value obtained in this range as the maximum possible slope is determined as the red edge position for each of the genotype under different treatment (Fig. 3).

The red edge position of all genotype observed in present investigation higher at ambient condition followed by CTGT II, CTGT I and CTGT III. The REP of Inglongkiri was the highest wavelength followed by Banglami in ambient condition. The REP of IET was the lowest wavelength at CTGT III. Literatures proved the relationship between chlorophyll and red edge position so that with increasing chlorophyll and nitrogen concentration the REP moves towards the longer wavelengths [18]. Here, a positive correlation with R^2= 0.70 at 95 % confidence was obtained between total chlorophyll and REP of rice genotype at different treatment (Fig. 4).
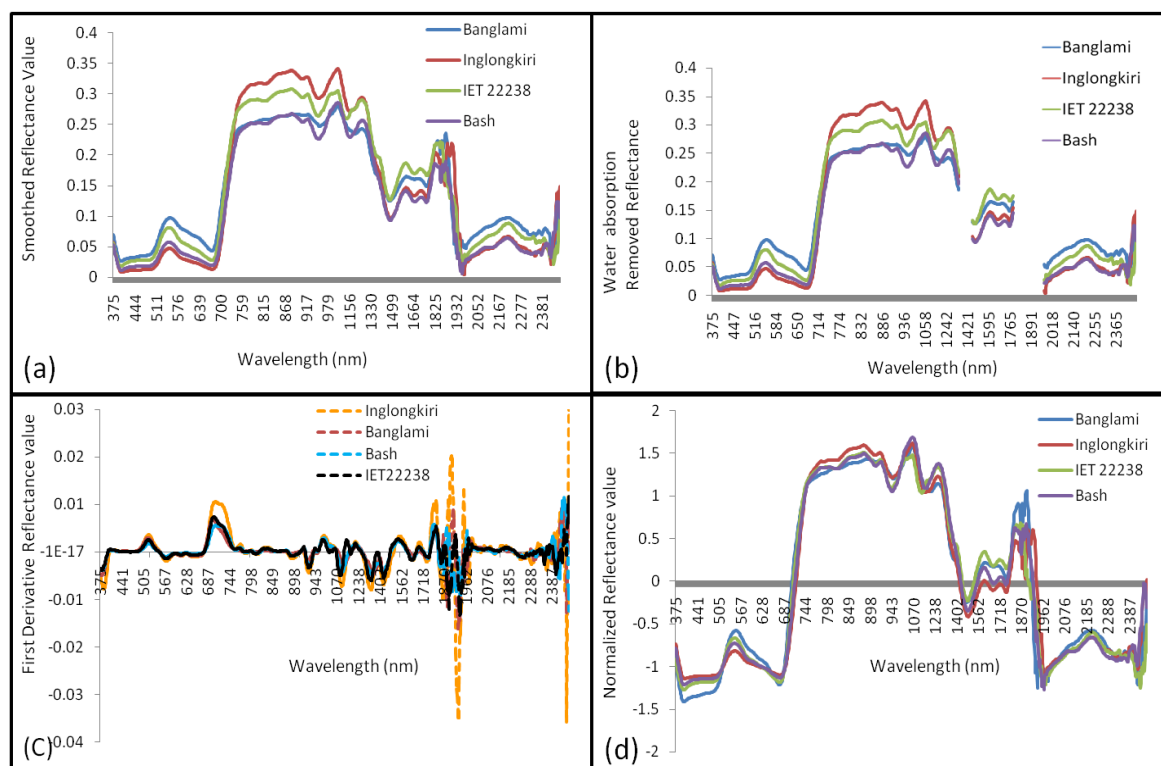

Fig. 1. Reflectance of leaf of selected rice genotype (a) Smoothed Reflectance (SR), (b) water absorption removed reflectance, (c) First Derivative of the Reflectance (FDR) and (d)Normalized Reflectance (NR)
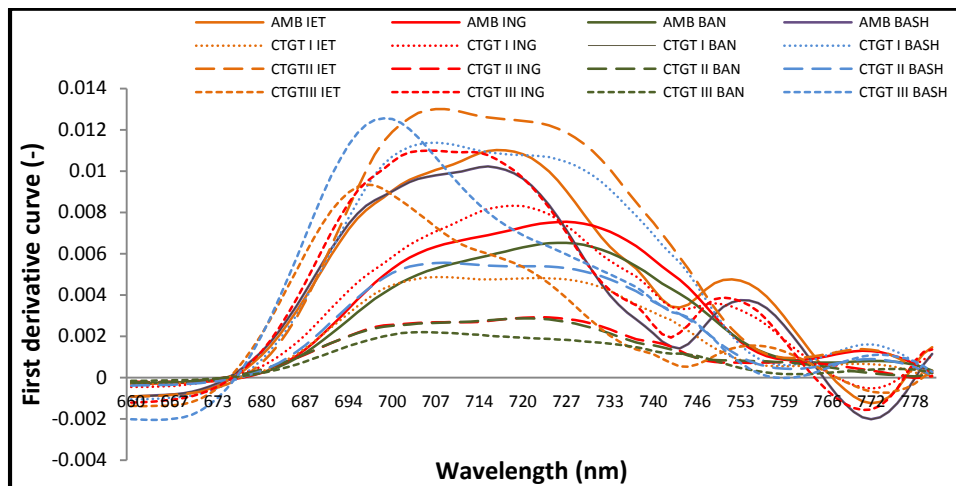
Fig. 2. The first derivative spectral reflectance curves of rice genotype under different treatment at red edge region (660-780 nm)
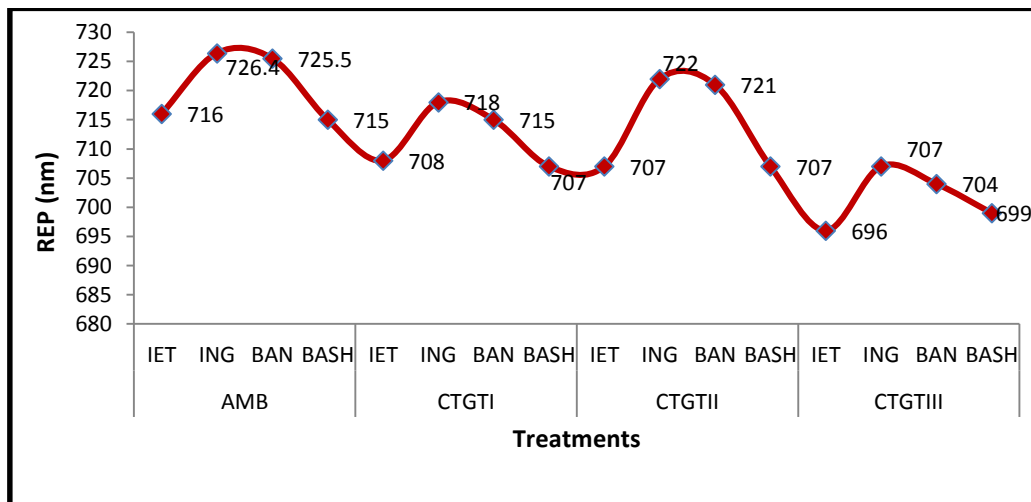

Fig. 3. Red edge position (REP) obtained for each rice genotype under different treatment
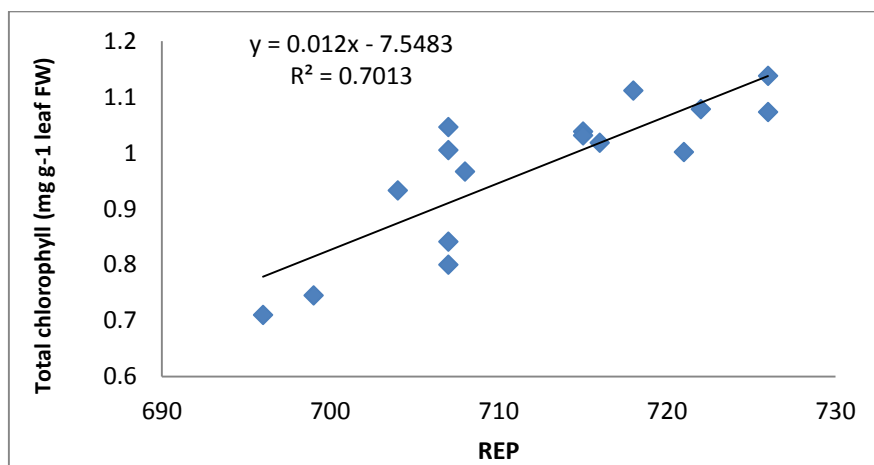

$y = 0.012x - 7.5483$
$R^2 = 0.7013$

Fig. 4. Relationship between total chlorophyll (mg g-1 leaf FW) and REP(nm) under different treatment

In present investigation highest total chlorophyll content was recorded in ambient followed by CTGT-I, indicating CO_2 and temperature has greater effect on chlorophyll concentration leaves of rice (Table 1). There was variability of reduction rate of chlorophyll among genotypes under the different treatment (Fig. 5).

Less reduction of total chlorophyll contents of leaves were recorded in Inglongkiri followed by Banglami in CTGT-II may due to slow degradation of chlorophyll under elevated CO_2 as it evident from our result that higher level chlorophyll stability index (CSI) was maintained in this condition by theses genotypes (Fig. 6). The chlorophyll stability index indicates a plant's tolerance to environmental stresses. The higher the CSI, the lower the amount of stress impact on chlorophyll content of the plants. A higher CSI values signifies a plant's ability to withstand stress through greater stability of chloroplast membranes leading to higher rates of photosynthesis, more dry matter production, and

higher productivity [19]. This result was in conformity with result of present investigation. Present study also demonstrated that CSI was significantly affected in rice leaves under CTGTIII. Reduction of CSI attributed that high temperature stress adversely affected the chlorophyll concentration in leaves; therefore, CSI was adversely affected in susceptible genotypes such as Bash and IET-22238 however, reduction in the chlorophyll content was ameliorated by the CO_2 enrichment at CTGT II there by plat maintained the CSI.

Furthermore, the red edge position of all genotype was observed higher at N3 with recommended dose of nitrogen fertilization followed by N2 and N1 (Fig. 7). The REP of Inglongkiri and Banglami (tolerant genotypes) were observed highest wavelength at 724 nm followed by IET and Bash at 722 nm and 720 respectively at N3. The REP of Bash was the lowest wavelength at 698nm followed by IET (699nm) at N1.

Table 1. Interactive Effect of CO_2 and Temperature on total chlorophyll (mg g^{-1} leaf FW) (Treatment × Genotype)

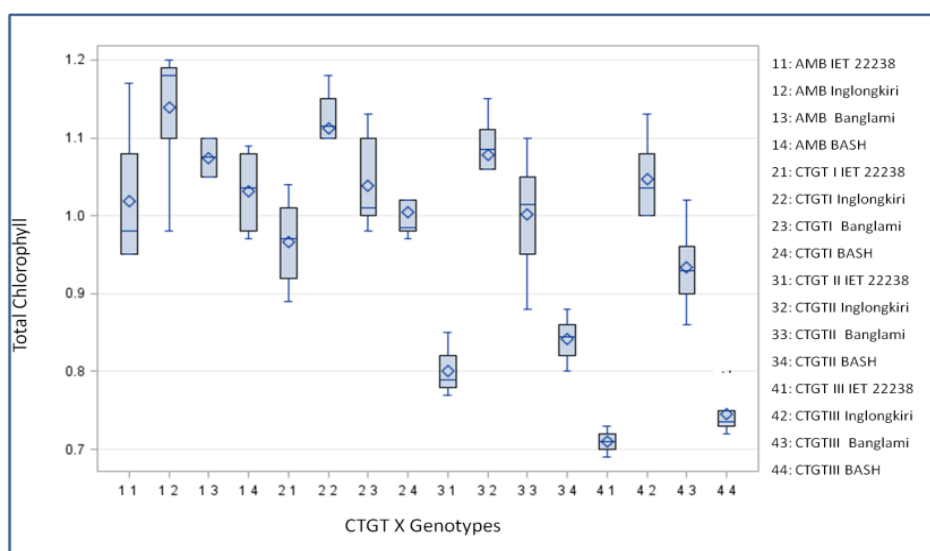| G / T	1st YR				2nd YR				Pooled			
	IET	ING	BAN	BASH	IET	ING	BAN	BASH	IET	ING	BAN	BASH
Ambient	1.03	1.12	1.03	1.02	1.00	1.10	1.05	1.04	1.02	1.11	1.04	1.03
CTGT I	0.97	1.09	1.00	1.00	0.96	1.08	1.02	1.01	0.97	1.08	1.01	1.01
CTGT II	0.80	1.05	0.96	0.83	0.80	1.04	0.98	0.85	0.80	1.05	0.97	0.84
CTGT III	0.72	1.03	0.93	0.74	0.70	1.00	0.88	0.75	0.71	1.02	0.90	0.75
S. Ed.	0.03				0.02				0.02			
CD(0.05%)	0.07				0.05				0.03			

Fig. 5. Box plot of total chlorophyll ((mg g^{-1} leaf FW) under Interactive effect of Treatment and Genotype
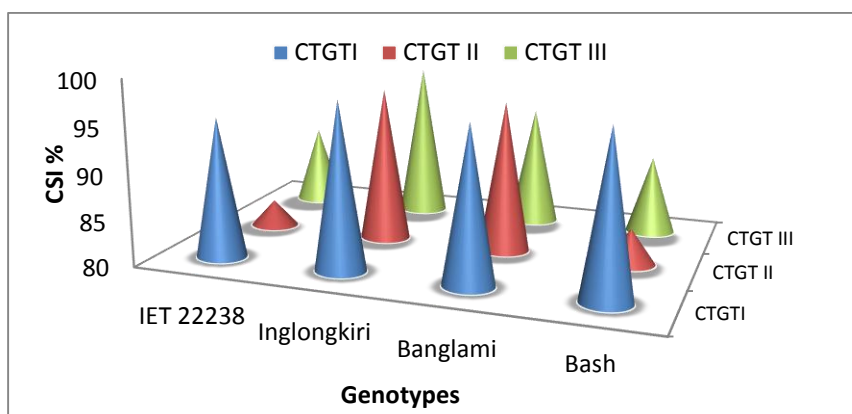
Fig. 6. Chlorophyll stability index (CSI) under varying level of CO$_2$ and temperature
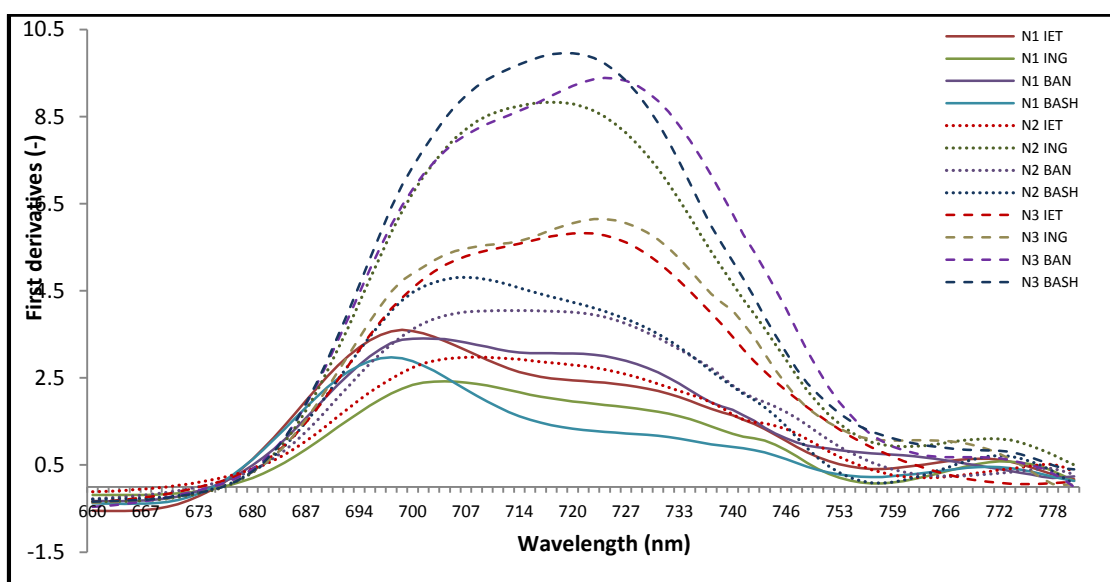

Fig. 7. The first derivative spectral reflectance curves of rice genotype under different levels of Nitrogen fertilizer at red edge region (660-780 nm)
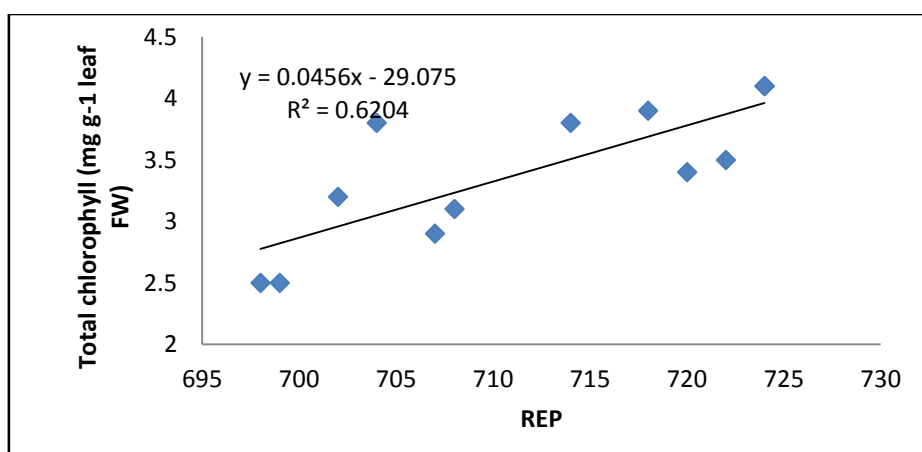

$$y = 0.0456x - 29.075$$
$$R^2 = 0.6204$$

Fig. 8. Relationship between total chlorophyll (mg g-1 leaf FW) and REP (nm) at different Nitrogen fertilizer

Table 2. Impact of varying level of nitrogen on total chlorophyll (mg g^{-1} leaf FW) (Treatment × Genotype)

G \ T	1st YR				2nd YR				Pooled			
	IET	ING	BAN	BASH	IET	ING	BAN	BASH	IET	ING	BAN	BASH
N1	2.66	3.66	3.63	2.82	2.35	3.87	3.81	2.23	2.51	3.77	3.72	2.53
N2	3.07	3.82	3.77	3.08	3.03	4.01	3.87	2.87	3.05	3.91	3.82	2.97
N3	3.46	4.09	4.05	3.55	3.49	4.17	4.08	3.27	3.48	4.13	4.06	3.41
S. Ed.	0.06				0.15				0.17			
CD(0.05%)	0.14				0.32				0.36			
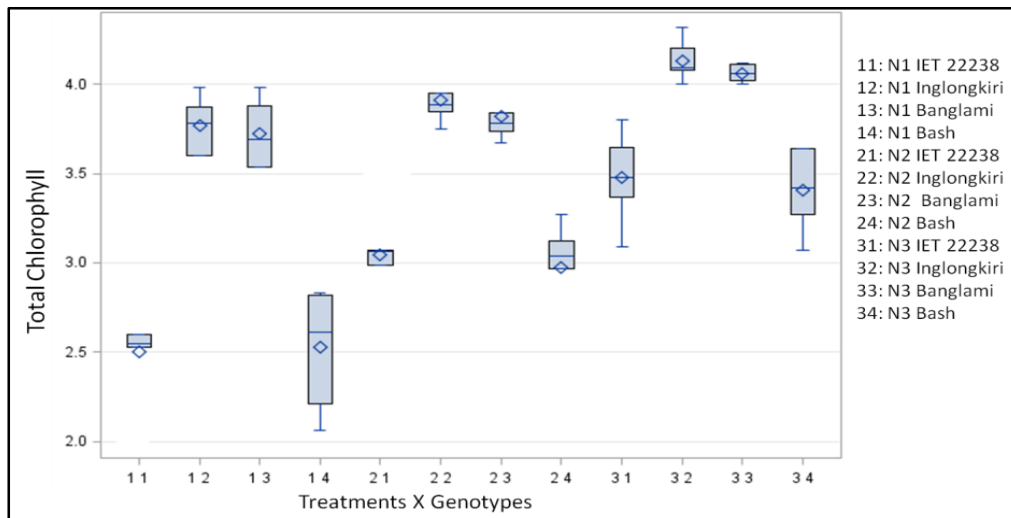
Fig. 9. Box plot of total chlorophyll (mg g^{-1} leaf FW) under Interactive effect of Treatment and Genotype

Similarly, Significant variation was also recorded in total chlorophyll content under the varying level of N application and total chlorophyll content increased with subsequent increased of N treatment (Table 2). A positive correlation with R^2= 0.62 at 95 % confidence was obtained between total chlorophyll and REP of rice genotype at different treatment (Fig. 8). Highest chlorophyll content was recorded in Inglongkiri and Banglami under all the treatment (Fig. 9). Similar results have been reported in Maize by Mc Cullough et al. [20] who reported that new maize hybrids were more tolerant than earlier hybrids to limited N supply during the early vegetative phase with respect to chlorophyll content. Another similar finding demonstrated that REP of Hybrid rice varieties shifted towards longer wavelength, and they were predicted as more productive rice varieties [13].

4. CONCLUSION

Spectral reflectance at red edge position of all genotype observed in present investigation higher at ambient condition followed by CTGT II.

The REP of tolerant genotype was the highest wavelength whereas REP of susceptible genotype was the lowest wavelength at CTGT III which indicates REP at longer wavelengths with higher foliar chlorophyll content. Furthermore, the variability among the genotypes under varying level of Nitrogen fertilizer can easily monitored using spectral responses at red edge position. REP in tolerant genotypes was found in comparatively longer wavelength at 40Kg of N which is due to higher foliar chlorophyll content. It has reveals from the study that when a plant is healthy with high chlorophyll content, the red edge position shifts toward the longer wavelengths; when it suffers from stress or chlorosis and low chlorophyll content, it shifts toward the shorter wavelengths. Ferwerda and Skidmore [12] have demonstrated that differential shift in the red edge position towards shorter wavelengths for different nutrient elements under study.

The rise of CO$_2$ between 700 and 1000 ppm by the end of this century [21] due to global warming will effectively influence the productivity of crop

plants. Again nitrogen is a limiting nutrient in most of the agricultural soils. Hence REP provides a very sensitive and quick indicator for a variety of stress such as environmental and nutrient stress which would help farmers/ scientists to select genotype as well as management practices responsive to adjust in this type of environmental as well as changes in soil nutrient level.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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