Effect of UV-B radiation on physiological and phenological plasticity in rice (*Oryza sativa* L.)

By

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(2012-11-197)

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THESIS

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DEPARTMENT OF PLANT PHYSIOLOGY

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2015

DECLARATION

I hereby declare that this thesis entitled **"Effect of UV-B radiation on physiological and phenological plasticity in rice (*Oryza sativa* L.)"** is a bonafide record of research work done by me during the course of research and that it has not been previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that the thesis entitled **"Effect of UV-B radiation on physiological and phenological plasticity in rice (*Oryza sativa* L.)"** is a record of research work done independently by **Mr. Wagh Yogesh Sahebrao** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship to him.

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We, the undersigned members of the advisory committee of **Mr. Wagh Yogesh Sahebrao,**a candidate for the degree of **Master of Science in Agriculture** with major field in **Plant Physiology,** agree that the thesis entitled **"Effect of UV-B radiation on physiological and phenological plasticity in rice (*Oryza sativa* L.)"** may be submitted by **Mr. Wagh Yogesh Sahebrao,** in partial fulfilment of the requirement for the degree.

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Wagh Yogesh Sahebrao

Dedicated to my Beloved Parents and Teacher

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Introduction

1. INTRODUCTION

Global warming has resulted in climate change all over the world by increasing ambient temperature and CO_2 and changing rainfall pattern. This has caused severe impact in agriculture. Since climate itself is an input in the agricultural production system the farming sector is seriously affected by change in climate. Chemical profile of atmosphere has changed during last few decades due to anthropogenic activities. Despite advanced technologies such as improved varieties, genetically modified organisms and irrigation system, abiotic stresses like drought, high temperature and salinity have become serious threat to agriculture, reducing productivity of the major crops (Wang, 2003).

There has been a considerable concern over the stratospheric ozone layer during last few decades as a result of anthropogenic pollutants like halogenated hydrocarbons and other ozone depleting chemical reaching the stratosphere. A decrease in the ozone layer has lead to a significant increase in ultraviolet-B radiation (280-320 nm) reaching earth surface and the phenomenon is to continue in future (McKenzie 2007).

Ultraviolet (UV) radiation constitutes small part of solar radiation (10%). The amount of UV radiation reaching the earth's surface depends on energy output of sun and the transmission properties such as stratospheric ozone of atmosphere. UV radiation divides into three group of radiation UV-C (100 to 280), UV-B (280 to 320 nm) and UV-A (320 to 400 nm). Among these the UV-B region has received most attention because it is absorbed by the stratospheric ozone layer. Though UV-B is only a minor components of total solar radiation (less than 0.5%), due to its high energy, it's potential for causing biological damage is very high.

It is reported that India lies in a low ozone belt and receives more UV-B radiation than those of temperate region with higher altitude (Singh, 1993). It is a

known fact that UV-B radiation is the highest in tropical region where rice is grown as the major food crop.

Rice is the most important crop of India and it occupies 23.3 percent of gross cropped area of the country. It is gown in about 42.5 million ha with a production of 93 mt contributing 45 percent to total food grain production and 46 percent of total cereal production of India. Various reports indicate rice is highly sensitive to UV-B radiations though varietal variation in sensitivity exists.

In crop plants UV-B influences an array of physiological and biochemical parameters like reduced photosynthetic rate, CO_2 uptake, stomatal conductance, dark respiration and alteration in protein, carbohydrate and pigment composition of plant tissues. UV-B radiation has direct and indirect effects on rice production. The indirect effects include other components of rice ecosystem such as weeds, disease and nitrogen fixing cyanobacteria (Jansen *et al.,* 1998; Sharma, 2001).

Some of the studies conducted in Kerala indicated that decrease in ozone layer taking place in some areas where sun burns are reported in human beings (Nishanth *et al.,* 2011). Further decline in rice yield during puncha season (Dec-March) with an increase in flavanoid content also gives an indication on the effect of UV-B radiation on rice yield (Nandini *et al.,* 2014). Failure of rice crop in puncha season has lead to abandoning of double cropping in productive rice ecosystem like the kole lands of Kerala. Physiological changes induced in rice due to deviation from normal climate lead to low productivity. A detailed investigation is necessary to come up with realistic recommendations in farm management practices to overcome such situations. All this warrants a detailed study on the effect of UV-B radiation on rice in Kerala. Hence the present project was proposed with the following objective.

Objective:

- To understand the effect of Ultraviolet-B (UV-B) radiation on various morphological changes in rice.
- To study the effect of UV-B radiation on phonology of rice.
- To understand the effect of Ultraviolet-B (UV-B) radiation on various physiological and biochemical changes in rice.

Review of Literature

2. REVIEW OF LITERATURE

The solar energy of sun is essential to support the life on our planet *via.* the process of photosynthesis. Photosynthetically relevant solar radiation that reaches the surface of earth is divided into two main spectrums. Ultraviolet radiation (UV) (100 to 400 nm) and photosynthetically active radiation (PAR) (400 to 700 nm). UV radiation contains three group of radiation UV-C (100 to 280), UV-B (280 to 320 nm) and UV-A (320 to 400 nm). Among these the UV-B region is selectively attenuated by the stratospheric ozone layer (Green, *et al.,* 1974). In contrast, the UV-A and PAR radiation are affected by light scattering. The most biologically damaging wavelength UV-C is absorbed almost completely by the atmosphere and therefore, not a significant factor for biological processes under natural conditions (Vass, 1997).

During the last few decades, there has been considerable concern over the depletion of stratospheric ozone as a result of manmade ozone depleting pollutants, such as halogenated hydrocarbon and other chemicals (Kerr, 1988). A decrease in ozone layer could lead to a significant increase in incoming ultraviolet-B (UV-B) radiation (280-320 nm) and shift in the spectral UV composition reaching the surface of earth (WMO, 2003; Ajavon *et al*., 2006; UNEP, 2010; WMO, 2014), which is predicted to continue in the future (Lee *et al*., 2002; Hadjinicolaou and Pyle, 2004; McKenzie, 2007).

Bhattacharya (2012) and his co-workers studied annual variability and distribution of ultraviolet index (UVI) in India over several locations (Srinagar, New Delhi, Bhopal, Ahmadabad, Kolkata, Mumbai, Pune, Hyderabad and Chennai) for the period of July 2002 to June 2012. They found that UVI is high from September to March and the timing of enhanced UVI has some practical importance. Nishanth *et al*. (2011) made a study during 2000 to 2010 in Kerala including two districts Kannur and Palakkad by correlating UV irradiation with Total Ozone Column (TOC) by using Ozone Monitoring Instrument (OMI). They

observed that the UV at Kannur has increased consistently from 2000 to 2010. The TOC was very low during 2010 at Kannur and Palakkad which may be the prime reason for the sunburn reported in these two locations.

All living organism of the earth are exposed to UV-B radiation at intensities that vary with the solar angle and the thickness of the stratospheric ozone layer. Though UV-B is a minor component of total solar radiation due to its high energy its potential for causing biological damage is exceptionally high and an even small increase could lead to significant biological damage (Zlatev *et al.,* 2012). Ambient solar UV-B affects plant growth and development in various ways (Pal *et al.,* 1997).

In this chapter attempt has been made to review the relevant literature available at national and international level on various aspects pertinent to the present study under the following heading.

2.1 Effect of UV-B on morphological and phenological characters

2.2 Effect of UV-B on physiological traits

2.3 Effect of UV-B on biochemical characters

2.4 Effect of UV-B on yield parameters

2.1 Effect of UV-B on morphological and phenological characters

2.1.1 Plant height

Plant height is an important agronomic trait related to plant status and yield potential of rice. Morphological changes in rice seedlings exposed to UV-B treatment by simulating 5% depletion of stratospheric ozone in the Philippine lead to reduced plant height, leaf blade and leaf area (Barnes *et al*., 1993). Dai *et al*. (1994) tested 188 rice cultivars from various rice growing regions and ecosystem under elevated UV-B radiation for 3 weeks and observed that around 143 rice cultivars had significantly reduced in plant height.

Exposure to UV-B radiation decreased plant height, leaf area and plant dry weight and increased auxiliary branching and leaf curling in rice (Dai *et al*., 1995a), in higher plant (Greenberg *et al*., 1997) and in weeds (Furness *et al*., 1999). Greenhouse trials with rice cv. IR74 showed that enhanced UV-B radiation reduced plant height significantly (Dai *et al*., 1995b).

Feng *et al*. (2002) reported that UV-B radiation decreased plant height and dry weight of stem of two soybean cultivars. The different doses of UV-B radiation applied to the two species *Avena fatua* and *Setaria viridis* induced changes in leaf and plant morphology such as decrease of plant height, biomass of leaves, shoots and roots as well as leaf area (Zuk-Golaszewska *et al*., 2003). Mohammed *et al*. (2007) carried out study in two different rice cultivars under two conditions i.e. sub-ambient and ambient levels of UV-B for 29 days and 87 days in two different experiments. They found that plant height was significantly reduced in ambient UV-B condition by 5%.

Jun *et al*. (2010) observed decrease in plant height, green leaf number, total leaf area and biomass (root and shoot) under enhanced UV-B radiation in barley, which varied with different growth stages.

In order to understand the effects of enhanced ultraviolet-B (UV-B) radiation on soybean yield components and seed growth characteristics, three determinate soybean cultivars, Hai339 (H339), Heinong35 (HN35) and Kennong18 (KN18) were grown for 2 years in a field experiment exposed to enhanced UV-B radiation. Enhanced UV-B radiation decreased plant height, dry weight of individual stem and yield per plant of all soybean cultivars (Liu *et al*., 2013).

2.1.2 Number of tillers

Sixteen rice cultivars from seven different geographical regions were grown in greenhouse with and without supplemental UV-B radiation and a significant reduction in tiller number in all rice cultivars were observed (Teramura

et al., 1991). Lewis and Teramura (1992) carried out the study in two rice cultivars IR-36 and Fujiyama-5, they found that UV-B radiation reduced the tiller number in IR-36 at elevated CO_2 whereas it was increased in Fujiyama-5.

To determine the interspecific variation in sensitivity of rice to enhanced UV-B radiation Dai *et al.* (1994) tested 188 rice cultivars collected from various rice growing region and ecosystem and observed that 41 cultivars had less tiller number under elevated UV-B radiation. Greenhouse trials with rice cv. IR74 showed that enhanced UV-B radiation resulted in reduced number of tillers (Dai *et al*., 1995a).

Kumagai *et al*. (2001) had done an investigation on exposure of Japanese lowland rice to UV-B radiation in a cool rice-growing region by using two cultivars Sasanishiki and Norin-1 for four cropping seasons from 1994 to 1997. In both cultivars significant decreases in tiller number as a result of supplemental UV-B radiation were observed during the tillering stage in all cropping season.

Hidema *et al*. (2005) examined effect of elevated UV-B radiation under sunlight on rice in cool rice-growing region (Japan) in 1999, 2001 and 2002, and observed a significant decrease in tiller number under elevated UV-B radiation in 2001 and 2002. Mohammed *et al*. (2007) had carried out study in two different rice cultivars under two condition i.e. sub- ambient and ambient for 29 days and 87 days in two different experiments and reported significant decrease in vegetative tiller production (25%) under sub-ambient UV-B radiation condition.

2.1.3 Leaf thickness

In response to increase in concentration of UV-B plant increase leaf thickness. Changes in these leaf character could prevent UV-B radiation from penetrating deeper into the inner leaf tissue, thereby reducing the amount of UV-B-induced damages to photosynthetic organelles (Teramura *et al*., 1991). In UV-B sensitive plant species, generally leaf thickness increased with enhanced UV-B radiation (Johanson *et al.,* 1995; Rozema *et al.,* 1997). Activation of leaf

thickening and auxiliary branching are regarded as typical UV-B induced responses (Jansen *et al*., 1998; Jansen, 2002; Krizek, 2004).

Increase in leaf thickness due to UV-B was common (Bornman and Vogelman, 1991), but in some cases a decrease in leaf thickness along with an increase in number of palisade layers was observed as in cotton (Kakani *et al*., 2003a). Supplemental UV-B radiation was also found to increase the thickness of palisade parenchyma in *Populus trichocarpa* and *Q. rubra* growing in a greenhouse, but did not induce any leaf epidermal changes (Nagel *et al*., 1998).

Thick leaves were seen associated with increase in the thickness of the upper epidermis, spongy parenchyma and also spongy intercellular space. In outdoor experiments, leaves of oak saplings (*Quercus robur* L) exposed to UV-B treatment had thicker and smaller leaves relative to those exposed to ambient levels of radiation (Antonelli *et al.,* 1998; Newsham *et al.,* 1999). Solar UV-B radiation seemed to delay plant growth in all species examined (four *Acacia* and two *Eucalyptus* species) although it did not affect photosynthetic activity significantly. However, a reduced specific leaf area (SLA) and an increased leaf thickness and size of epidermis were observed in plants exposed to UV-B radiation (Liu *et al.,* 2005).

Klem *et al.* (2012) carried out studies on the combined effect of UV-B and PAR on two barley varieties. They found that leaf length and leaf area decreased, whereas leaf thickness was increased by the [UV+PAR] treatment. Plant species differed in their anatomical responses to UV-B radiation. Berli *et al*. (2013) reported that grapevines exposed to high solar UV-B and reduced UV-B, leaf thickness increased in the former treatments.

2.1.4 Number of productive tillers

A rice hill with 3 to 5 plants will produce 30 to 40 tillers under favourable growth condition and out of these only 15 to 16 will produce panicles which are called as productive tillers. Usually these productive tillers have to compete with

unproductive tillers for photosynthetic assimilates nutrients and solar energy under normal growing environmental condition (Khush, 1990). Hence any stress situation which aggravates the competition between productive and unproductive tillers for photoassimilates and solar energy may reduce number of productive tillers in rice plants. Productive tillers per unit ground area spikelet sterility and grain weight are important component of yield and are negatively affected by elevated UV-B radiation (Teramura, 1991; Hidema, *et al.,* 1995)

2.1.5 Flag leaf angle

Flag leaf angle has an important effect on increasing rice grain yield. Grain yield is a function of optimum distribution of photoassimilates and arrangement of leaves for better light penetration and utilization. The top three leaves especially flag leaf contributes most to grain yield (Ray *et al*., 1983; Misra, 1986). The morphological traits of flag leaf such as size and shape, leaf angle and physiological traits of flag leaf such as chlorophyll content and photosynthetic capacity have been considered to be the important determinants of grain yield in cereals (Hirota *et al*., 1990; Chen *et al*., 1995). Narrow leaves with vertical orientation resulted in lower attenuation of the incoming solar UV-B compared with plants having wider leaves and horizontal leaf orientation resulted in greater attenuation of incoming UV-B radiation (He *et al.*, 1993).

In rice, the flag leaf is metabolically active and has been a subject of study by number of investigators. The leaf angle could be affected crop physiological activity. There was positive correlation between flag leaf angle and photosynthetic material translocation and spikelet fertility increase. For increasing grain yield in rice, flag leaf must be wide and vertical (Dutta *et al.,* 2002). Kobayashi *et al.* (2006) reported flag leaf traits such as flag leaf length, width and angle are inherited quantitatively and are influenced largely by growing environment. The flag leaf morphology, significantly affects yield, grain quality, maturity, pest preference and absorption of plant growth regulators and other important production parameters in cereals including rice (Fan *et al*., 2007).

2.1.6 Panicle length

The length of rice panicle decides the number of grain it can hold and consequently rice yield. It is therefore one of the important trait which contributes to yield in rice because it determines the number of spikelets that will be produced per panicle. Mohammed and Tarpley (2009) observed a decrease in main stem panicle length and number of primary branches per panicle in rice plants exposed to UV-B radiation of 0, 8 and 16 kJ m^{-2} day^{-1}. Same trend was observed in wheat by Yuan *et al.* (1998) when exposed to supplemental level of UV-B radiation. In contrast Ramakrishnan and Kulandaivelu (2014) reported an increase in panicle length in UV-B treated plantlets for 10 minutes in an *invitro* regenerated rice cv. ADT 43.

2.1.7 Days to heading

Heading time is an important phenological character in rice. Ramakrishnan and Kulandaivelu (2014) carried out study on *in vitro* regenerated rice (*Oryza sativa* cv. ADT 43) plantlets under two sets of ultraviolet-B radiation, low (10 min d^{-1}) and high (30 min d^{-1}). They found that there was no difference in UV-B treated and UV-B untreated plantlets in time taken for heading.

2.1.8 Days to 50 percent flowering

Survival of many plant species depends on setting seeds well in advance of seasonal environmental extremes including frost, heat or drought. Synchrony of flowering is also beneficial especially for out breeding species which must time their reproduction to coincide with flowering of other individuals or genotypes and often with the presence of insect and bird pollinators. The natural light and temperature provides much of the seasonal information essential for control of flowering time.

The earlier studies conducted using artificial UV lamps by investigators demonstrated the delay in the onset of flowering in crops (Ziska *et al.,* 1992;

Musil, 1995). Saile and Tevini (1997) conducted studies on different cultivars of bush bean (*Phaseolus vulgaris* L.) with UV-B treatment and they observed that flowering was delayed under intense UV-B in several cultivars.

Rajendiran and Ramanujan (2004) studied the effect of elevated UV-B radiation (12.2 kJ m^{-2} d^{-1}) against the ambient level (10 kJ m^{-2} d^{-1}) on flowering in green gram (*Vigna radiata* L.). They observed that flowering initiation and achievement of 50 % flowering was delayed by 3.5 days in UV-B stressed plant.

In another study with trichome mutants of *Arabidopsis thaliana* An *et al.* (2012) reported a notable delay in flowering time in all mutants and wild types exposed to UV-B.

2.1.9 Days to harvestable maturity

The rice crop usually harvested when grain moisture content is between 20-25% on wet basis and when 80-85% of the grain are straw coloured. Little is known about the effect of UV-B on harvestable maturity and hence references on harvestable maturity in relation to UV-B are limited.

Environmental stresses like high temperature decreased duration from panicle emergence to physiological maturity by 6-8 days in rice cultivars (Prasad *et al.,* 2005). Water stressed plant took longer time to flower and to mature as compared to plants that were well watered (Sikuku *et al.,* 2010)

2.2 Effect of UV-B on physiological traits

2.2.1 Photosynthesis rate

The response of rice crop to high dose of UV-B radiation in terms of net photosynthesis is complicated since growth stages, canopy reaction and levels of visible radiation before and during treatment, cultivar differences and other factors have to be considered. The most common consequences of exposure to enhanced UV-B radiation on photosynthetic functions are decreased CO_2 fixation

and oxygen evolution (Renger *et al.,* 1989; Allen *et al*., 1997), impairment of photosystem II and to a lesser extent of photosystem I (Vass *et al*., 2005), reduction in dry weight, secondary sugars, starch and chlorophyll (Fiscus and Booker, 1995), decrease in Rubisco activity (Strid *et al*., 1990; Allen *et al*., 1998), inactivation of ATP synthase (Zhang *et al*., 1994) and loss in integrity of the thylakoid membranes (Swarna *et al*., 2012).There is a variety of UV-B radiation targets in plant, where the photosynthetic apparatus is the prime action site of UV-B, and its damage contributes significantly to the overall UV-B effects (Vass *et al*., 2005).

Xiaoqin and Qing (2006) investigated physiological response of mono maple seedlings with two levels of UV-B treatments (ambient UV-B, 11.02 KJ m^{-2} day^{-1}; enhanced UV-B, 14.33 KJ m^{-2} day^{-1}). They found that enhanced UV-B caused a marked decline in net photosynthetic rate.

The responses of the photosynthetic pathways to UV-B radiation depends on various experimental growth conditions and plant growth stages, flow rate and the ratio of PAR to UV-B radiation, UV-B dosage as well as on the interaction with other environmental stresses like cold, drought, mineral availability etc. (Jenkins, 2009).

Few studies have focused on the molecular mechanism underlying UV-B sensitivity of photosynthesis. Changes in gene expression in response to supplementary UV-B include reduction in expression and synthesis of key photosynthetic proteins including Rubisco (Jordan *et al*., 1992), the Chlorophyll a/b binding proteins (Lhcb) and the D1 polypeptide of photosystem II (psb A) (Mackemess *et al*., 1997). Casoti and Walbot (2003) conducted a field experiment on maize plants and documented a significant down-regulation of genes associated with photosynthesis under elevated UV. UV radiation can inhibit photosynthesis by altering photosynthetic gene expression and also by detrimentally affecting UV-sensitive parts of the photosynthetic machinery (Caldwell *et al*., 2007).

The oxidative damage of proteins, lipids and pigments (Hollosy, 2002; Vass *et al*., 2005), contributes to the decrease in thylakoid membrane function and alterations in the organization of the membrane complexes. Swarna *et al*. (2012) reported that UV-B affects PS II photochemistry (68% loss) and this inhibition is closely related to the extent of lipid peroxidation of thylakoid membranes in maize primary leaves.

The deleterious effects of UV-B radiation on photosynthesis and photosynthetic productivity of plants are reviewed by Kataria *et al*. (2014). The sites of damage include oxygen evolving complex, D1 and D2 reaction centre proteins and other components on the donor and acceptor sides of PS II. Mn cluster of water oxidation complex is the most important primary target of UV-B stress whereas D1 and D2 proteins, quinone molecules and cytochrome b are the subsequent targets of UV-B. In addition, photosynthetic carbon reduction is also sensitive to UV-B radiation which has a direct effect on the activity and content of Rubisco.

2.2.2 Stomatal conductance

Stomatal regulation is another important process limiting leaf photosynthesis. Dai *et al*. (1995b) studied the effect of UVB radiation on stomatal density and opening in four cultivars of rice (*Oryza sativa L.)*. Ten-day-old seedlings of IR45 and IR74 (UV-B sensitive), and IR64 and IR30 (UV-B less sensitive), were subjected to UV-B radiation in a glasshouse for 6 h d^{-1} for 4 weeks. The unweighted UV-B radiation was 1·94 Wm^{-2} for UV-B treatment and 0·15 Wm^{-2} for control. Results showed that a 2-week UV-B treatment had significantly reduced stomatal density and opening in IR45 and IR74. Under 4-week UV-B exposure, stomatal density decreased in all cultivars, except in IR64. Greater reduction of stomata on the adaxial surface than on the abaxial surface under 3 and 4 weeks of UV-B exposure suggests a direct effect of UV-B radiation on stomatal physiology.

Stomatal closure by enhanced UV-B and increased leaf diffusive resistance has been demonstrated with the action spectrum peaking below wavelength of 290 nm (Tevini and Teramura, 1989). It is assumed that stomatal closure is generated by a loss of turgor pressure with ion leakage from the guard cells. Nogues *et al*. (1999) investigated the effect of UV-B radiation on stomatal conductance in pea (*Pisum sativum* L.), commelina (*Commelina communis* L.), and oilseed rape (*Brassica napus* L.) plants. Plants were grown in a greenhouse with three different ratios of UV-B active radiation. They found pea plants grown in the highest UV-B exhibited a substantial decrease of adaxial and abaxial stomatal conductance.

Several studies have also shown that reduction in CO_2 assimilation is caused by UV-induced reduction in stomatal conductance (Jansen and Noort, 2000; Lu *et al*., 2009). Takeuchi *et al*. (2002) reported that once stomata were exposed to UV-B radiation, they were unable to readjust their aperture in response to environmental stimuli and speculated that UV-B may impact reactions that make possible the solute fluxes leading to stomatal opening. Reductions in CO_2 assimilation rate may be further mediated through reduction in light-harvesting complexes, disruption of thylakoid membrane integrity and degradation and inactivation of Rubisco.

Treatment with UV-B can affect stomatal conductance, altering the rate of water loss by transpiration and uptake rate of CO_2 for photosynthesis (Yao and Liu, 2006). Yun and Zhong (2009) studied three species of herbaceous climbing plants (*Luffa cylindrica, Trichosanthes kirilowii and Dioscorea opposita*) and they found that in all species stomatal conductance was decreased.

Reddy *et al.* (2013) reported that though internal CO_2 concentration was not affected significantly by UV-B radiation, the stomatal conductance and transpiration decreased to some extent at higher UV-B treatment in corn hybrids.

2.2.3 Transpiration rate

Enhanced UV-B radiation increased the stomatal diffusion resistance and decreased the transpiration rate in *Trichosanthes kirilowii* (Liu *et al*., 2003), soybean and wheat (Mirecki and Teramura, 1984; Zheng *et al*., 1995; Teramura *et al*., 1980).

Yun and Zhong (2009) measured diurnal changes in transpiration rate and stomatal conductance in three species of herbaceous climbing plants (*Luffa cylindrica, Trichosanthes kirilowii and Dioscorea opposita*) exposed to two intensities of UV-B radiation (3.0 μw cm^{-2} and 8.0 μw cm^{-2}) under ambient growth conditions. They found that the transpiration rates decreased under both treatments in all species and stomatal conductance was lower in 3.0 μw cm^{-2}. In another study in sweet almond (*Prunus dulcis* (Miller) D. Webb) it was found that enhanced UV-B radiation at 7.32 and 9.36 kJ m^{-2} causes significant inhibition of photosynthetic rate accompanied by a reduction in stomatal conductance and transpiration rate (Ranjbarfordoei and Damme, 2010).

A field experiment was conducted by YunSheng *et al*. (2011) to investigate effects of enhanced UV-B radiation on physiological characteristics of different cultivars of barley. Results showed that enhanced UV-B (14.4 $kJm^{-2}d^{-1}$) depressed the photosynthesis and transpiration in all the barley cultivars. Similar study conducted on summer rape (*Brassica napus*) under UV-B level of 1 $kJm^{-2}d^{-1}$ revealed a significant decrease in transpiration rate (Januškaitienė, 2013).

Basahi *et al*. (2014) reported that enhanced UV-B radiation negatively and significantly affected the process of photosynthesis including CO_2 assimilation, stomatal conductance to water vapour and transpiration rate in lettuce (*Lactuca sativa* L. cv Romaine) under field condition.

2.2.4 *Canopy temperature depression (CTD)*

Canopy Temperature Depression (CTD) is usually expressed as canopy temperature minus air temperature, and this value is higher and a positive number in a well irrigated crop, net radiation, air temperature and wind speed have slight effects on CTD (Smith *et al*., 1986). Increase in CTD might have occurred due to increased respiration and decreased transpiration resulting from stomatal closure (Siddique *et al*., 2000). CTD also affected by biological and environmental factors like water status of soil, wind, evapotranspiration, cloudiness, conduction systems, plant metabolism, air temperature, relative humidity and continuous radiation (Reynolds *et al*., 2001). Munjal and Rena (2003) have reported that cool canopy during grain filling period in wheat is an important physiological principle for high temperature stress tolerance.

2.3 Effect of UV-B on biochemical characters

2.3.1 Chlorophyll content

Chlorophyll reduction on exposure to UV-B in major crop species ranged from as low as 10% (Pal *et al*., 1999) to as high as 70% (He *et al*., 1993) and the reduction was higher among the dicot species (10-78%) compared to that in monocot species (0-33%). The differential responses between these two groups can be attributed to the orientation of leaves.

Reduction in chlorophyll content is mainly due to a breakdown of the structural integrity of chloroplasts on exposure to UV-B radiation. The chlorophyll components, thylakoids and grana were sensitive to the incoming solar radiation (He *et al*., 1994; Cassi-Lit *et al*., 1997).

UV-B radiations have an indirect damaging effect on plants. It is found that both chlorophyll ‘a’ and ‘b’ contents of leaves dropped in *Phaseolus vulgaris* leaves grown under UV-B stress (Michaela *et al*., 2000). Under UV-B exclusion, chlorophyll content of *Fagus sylvestris* leaves was higher but the

chlorophyll a/b ratio was lower in leaves under the ambient level of UV-B radiation (Laposi *et al*., 2002). An increase in UV-B radiation resulted in rupture of the thylakoids and grana due to the disintegration of the membranes (Kakani *et al*., 2003b).

The research on effect of enhanced UV-B radiation on chlorophyll content of two wild sugarcane (*Saccharum spontaneum*) clones 92-11 and 93-25 for two consecutive years in field condition. Revelled that chlorophyll content of clone 92-11 decreased while that of clone 93-25 increased (HaiYan *et al*., 2006). The impact of the combined stress factors of heavy metals and UV-A+B radiation in *Pisum sativum* was investigated by Saleh (2007), the result showed significant decrease in total chlorophyll under UV-A+B radiation.

Surabhi *et al*. (2009) conducted study on three varieties of cowpea (*Vigna unguiculata* L.) with three level of UV-B radiation under controlled environmental condition. They observed total chlorophyll concentration decreased significantly in all the three cowpea cultivars with increase in UV-B radiation. Aiamla-or *et al*. (2010) investigated effect of UV-B radiation on chlorophyll degradation on broccoli florets. Broccoli florets were irradiated with three UV-B doses and kept at 15 °C in darkness. They found that a UV-B dose of at least 8.8 kJ m^{-2} efficiently decrease the contents of chlorophylls *a* and *b*. In a field experiments with *Vigna radiate* and *Indigofera tinctoria* L. an initial increase and subsequent decrease in chlorophyll content was observed under UV-B radiation. (Ravindran *et al*., 2010).

In the study by Singh *et al*. (2011) on bean (*Dolichos lablab*) under supplemental UV-B total chlorophyll content were affected significantly. Total chlorophyll and chlorophyll a/b ratio decreased significantly in UV-B treated plants. Total chlorophyll content reduced by 27.8 and 5.3% at 15 and 30 days after germination. Lidon and Ramalho (2011) conducted study on rice (*Oryza sativa* L.) under UV-B condition, treated plants showed a decline in values of chlorophyll ‘a’, total chlorophyll and ratio of chlorophyll a: b. Salama *et al*.

(2011) carried out studies on some annual desert plants, they observed that the chlorophyll ‘a’, ‘b’, and total contents were decreased with enhanced UV-B radiation when compared with the control values.

Petrulova *et al*. (2014) investigated response of two cultivars of *Matricaria chamomilla* plants on UV irradiation and found that short time UV dose decreases chlorophyll ‘a’ and ‘b’ indicating the impact on photosynthesis.

2.3.2 Flavanoid content

Accumulation of the UV-B-absorbing pigments is one of the ways by which plants alleviate the harmful effect of UV-B light (Caldwell *et al.,* 1983; Beggs *et al.,* 1986). The UV-B light-absorbing flavonoids are implicated as protective pigments in shoots and leaves exposed to UV-B light and their specific location in epidermal layer protects internal cell layers by attenuating the impinging UV-B radiation at the epidermis (Tevini *et al.,* 1991; Braun *et al.,* 1993). In the case of UV-B exposure, key components of the acclimation response are the increased capabilities of photorepair and the accumulation of UV-B absorbing flavonoids and other phenolics. Key flavonoid biosynthesis genes are regulated by UV-B. It has been argued that the main protective role of these phenolics is associated with their antioxidative capabilities (Agati and Tattini, 2010). This fits the observation that flavonoids can be found in tissues not directly exposed to UV-B but also in subcellular domains as far apart as chloroplasts, vacuoles, nuclei and roots and leaves. Flavonoids accumulates in a range of cellular compartments, including cell walls, vacuoles, chloroplasts, nucleus, trichomes and epidermal cells to protect underlying tissues by absorbing UV-B photons (Jansen *et al*., 2012; Schreiner *et al*., 2014).

Information on UV-B absorbing pigments and their role in ameliorating the harmful effect of UV light in rice is scanty. Investigators have reported that UV-B treatment increases the amount of UV-absorbing pigments in some rice cultivars (Ziska and Teramura, 1992; Dai *et al*., 1992). In another study Shao Bai *et al*. (1998) observed that when two Rice cv. IR68 and Dular exposed to UV-B

level of 13.0 and 19.1 kJ m^{-2} day^{-1} for 2 and 4 weeks, increased the flavanoid content.

Barely cultivars (*Hordeum vulgare* L. cvs Giza 121 and Sahrawy) were grown under controlled conditions in growth chamber with and without UV-B radiation. The levels of flavonoids were significantly greater with UV-B exposed leaves in both varieties as compared with control (Nasser, 2001).Yuan *et al*. (2010) studied the effects of UV-B (2.5 kJm^{-2}, 5.0 kJm^{-2} and 7.5 kJm^{-2}) radiation on flavonoid contents in seedling of two rice (*Oryza sativa* L.) cultivars ("Huangkenuo" and "Hexi 41") under pot experiment. Flavonoid contents of "Huangkenuo" seedling significantly increased under 2.5 $kJ.m^{-2}$ and 5.0 $kJ.m^{-2}$ UV-B radiations and in "Hexi 41" increased under enhanced UV-B radiation from 2.5 $kJ.m^{-2}$ to 7.5 $kJ.m^{-2}$.

2.3.3 Catalase activity

Most physiological stress including UV-B enhansment disturb plant metabolism and cause oxidative injury by enhancing the production of reactive oxygen species (Takeuchi *et al.,* 1996; Dai *et al.,* 1997; Hideg *et al.,* 1997; Kubo *et al*., 1999). The generation of ROS causes direct or indirect oxidative damage to DNA, proteins, membranes, lipids, etc. (A-H-Mackerness, 2000; Booij-James *et al*., 2000). Karpinski *et al*. (1997) reported that an increased H_2O_2 level is detected simultaneously with the inhibition of photosynthesis by UV-B radiation, suggesting that the UV-B induced oxidative burst of H_2O_2 is associated with the damage and degradation of the D1 and D2 proteins of the photosystem-II reaction centre.

The metabolism of reactive oxygen species depends on low molecular antioxidant system as well as enzymes such as superoxide dismutase, peroxidase, polyphenoloxidase, catalase and phenylalanine ammonialyase (Asada, 1999; A-H-Mackerness, 2000). Some studies have showed similarities between response to UV-B radiation and other oxidative stress such as ozone treatment (Rao *et al*., 1996; Savenstrand *et al*., 2002).

Catalase is found predominantly in the peroxisome and has low substrate affinity. An alternative mode of H_2O_2 destruction is via peroxidase which is found throughout the cell (Jimenez *et al*., 1997).Catalase activity was increased when rice seedlings were exposed to UV-B radiation in environmentally controlled growth chamber (JwaKyung *et al*., 2005).

In the study of Xu *et al*. (2008) two soybean cultivars were grown in field condition with and without natural levels of UV-B, they found that solar UV-B radiation caused oxidative stress in both cultivars and increased the activities of catalase. In contrast to this Ravindran *et al*. (2010) reported that 22.7% decrease in catalase activity under supplemental UV-B treatment in *Indigofera tinctoria* L. seedlings.

Reshmi and Rajalakshmi (2012) conducted experiment to investigate effect of UV and drought stresses in *Spilanthes acmella* (toothache plant). The results showed that during drought condition, the catalase activity decreased as compared with the control plant where as UV treated plants showed increase in the catalase activity.

Fedina *et al*. (2010) investigated the response of three rice cultivars to UV-B radiation. They observed the enhancement of catalase activity after UV-B treatment. In the study of Yongmei *et al*. (2014) different levels of UV-B radiation was given to two rice cultivars in paddy field, they found that catalase activity were increase by 42.3% to 58.4 % in leaf. Takshak and Agrawal (2014) found increase in catalase activity in *Withania somnifera* under supplemental UV-B, and the increase was higher in the roots as compared to shoot.

2.3.4 Indole-3-acetic acid (IAA) content

UV-B radiation interferes with indole acetic acid (IAA) metabolism, possibly via photooxidation of IAA, resulting in hormonal imbalances that would certainly induce morphogenic effects (Ros and Tevini, 1995). However the studies were under lab conditions that might not directly relate to environmentally

relevant conditions. In field trials with relevant doses of UV-B, some of the observed morphological alterations (i.e. branching) resembled that of known IAA effects (Jansen *et al*., 1998).

Olszyk *et al*. (1996) investigated IAA content in two rice cultivars exposed to UV-B. They found that two weeks of exposure resulted in a decrease in IAA content for IR74 to a similar extent with 6, 13, or 19.1 $kJm^{-2}d^{-1}$ UV-B compared to 0-UV-B. However, a variety Naizersail had significant decrease in IAA only with 19.1 $kJm^{-2}d^{-1}$ UV-B compared to 0-UV-B. Four weeks of exposure resulted in a decrease in IAA contents for both cultivars at all enhanced UV-B levels.

In a study, rice cultivars IR68 and Dular were exposed to UV-B irradiation at 13 and 19.2 kJ $m^{-2}d^{-1}$ for two and four weeks. Plant IAA contents in the leaves significantly decreased as UV-B level increased (ShaoBai *et al*., 1997). Huang *et al*. (1997) reported the decrease in IAA content and increase in peroxidase and IAA oxidase activities of UV-B treated rice cultivars IR68 and Dular when compared to ambient condition.

Jansen *et al*. (2001) studied the mechanism of UV protection in two duckweed species by exploiting the UV radiation sensitivity. The findings showed that UV-tolerant ecotype had significantly higher indole-3-acetic acid (IAA) levels than a UV-sensitive ecotype.

The response of pea (*Pisum sativum* L., *cv.* Scinado) plants to low UV-B radiation was studied by Katerova and Prinse (2008), they found that IAA decreased after 10 days at the UV-B level of 0.3 kJ m^{-2} d^{-1}.

Yuan *et al*. (2010a) conducted study on 10 cultivars of wheat with enhanced UV-B radiation (5.00 kJm^{-2}) under field condition. The finding of this study revealed that of 6 cultivars out of 10 showed significant decrease in IAA content.

2.3.5 Phenol content

In plants, exposure to UV light is expected to be a comparatively mild stimulus for the synthesis of phenolic compound. Induction of the general phenylpropanoid pathway consequent accumulation of phenolic compound (Logemann *et al*., 1999). Increased accumulation of phenolic compounds is one of the main responses to UV-B radiation, which filter out UV-B photons before they reach sensitive molecules. In *Brassica napus,* approximately 20 distinct UV absorbing pigments were produced in response to UV-B radiation, their synthesis occurring mainly in the epidermal cell layer (Greenberg *et al*., 1996). A greater increase in the leaf UV-B absorbing compounds i.e. phenolic compounds occurred when the plants were grown in relatively low PAR/UV-B (Alexieva *et al*., 2001).

In *Aeschynomene aspera* L. UV-B significantly increased phenolic compound (Ramya and Balakrishnan, 2013). In another study when *Artemisia annua* L. plants were irradiated with UV-B radiation (2.8 Wm^{-2}) for 1, 2, 3 and 4 hrs duration, the phenolic content enhanced under 3 hrs treatment(Pandey and Pandey-Rai, 2014). MiJa *et al*. (2014) observed that when mushrooms (*Lentinus edodes*) treated with UV-B irradiation (25 kJm^{-2}) under in *vitro* systems, showed significantly higher total phenolic content.

2.3.6 Polyphenoloxidase (PPO) activity

Polyphenoloxidase is also responsible for the oxidation of phenolic compounds in plants. The stress mechanism in plants includes polyphenoloxidase activities which participate in protection *via* phenolic compounds. These enzymes can mitigate the UV-induced damage by protecting the photosynthetic pathway and cellular components (Rao *et al*., 1996; Balakrishnan *et al*., 2005; Reshmi and Rajalakshmi, 2012).

Balakrishnan *et al*. (2005) reported that polyphenoloxidase activity was increased in UV-B treated *Crotalaria juncea* L. seedlings as compared with untreated seedling. Ravindran *et al.* (2010) studied the impact of UV-B radiation

on *Indigofera tinctoria* L. seedlings and they found that polyphenoloxidase increased by 39.9%. He further observed that the increase in PAL activity stimulates the synthesis of flavanoid and anthocyanin.

Agarwal (2007) studied *Cassia auriculata* L. seedlings irradiated with UV-B in an environment-control chamber with two doses, UV-B stress led to significant increases of the peroxidase and polyphenoloxidase activity.

Tasgin and Nadaroglu (2013) investigated combined effect of UV-B and butylated hydroxanisol (BHA) on wheat seedling and observed an increased in the activity of polyphenoloxidase in wheat seedling.

2.3.7 Phenylalanine ammonialyase (PAL) activity

Phenylalanine ammonialyase is an important enzyme in regulating flavonoid biosynthesis and transcriptionally induced by UV-radiation. Increase in phenylalanine ammonialyase activity stimulates the synthesis of flavonoid and anthocyanin (Ravindran *et al*., 2010). Morales *et al*. (2010) reported strong positive correlations between phenylalanine ammonialyase expression and accumulation of flavonoid under UV treatments in silver birch seedlings. Meiling *et al*. (2012) observed that activity of phenylalanine ammonialyase increased with the increased content of total flavonoid in a shrub (*Caryopteris mongolica*) after UV-B treatment.

Rice seedlings when exposed to UV-B radiations expressed a four fold increased in phenylalanine ammonialyase (PAL) activity (Sarma and Sharma, 1999). Wheat seedling when exposed to the UV-B radiation to analyse activity of polyphenol enzymes, also showed enhancement in phenylalanine ammonialyase activity (Hao and Rong, 2009).

Jóźwiak-żurek *et al*. (2011) carried out the investigation on combined effect of two stresses (UV-B radiation and allelochemical stress induced by Ferulic acid) on cucumber. The activity of phenylalanine ammonialyase was

increased in cucumber plants, whereas the effect of Ferulic acid was not significant.

The effects of UV-B radiation was studied in *Aeschynomene aspera* L. by, Ramya and Balakrishnan (2013) they found that phenylalanine ammonialyase enzyme activity was increased in plants after UV-B treatment. MinJeong *et al*. (2013) carried out experiment on medicinal plant sowthistle (*Ixeris dentata* Nakai), they observed UV radiation increased the activity of phenylalanine ammonialyase in plant.

A study focused on the effect of supplemental UV-B radiation on response of mash-bean (*Vigna mungo* L. Hepper) showed that phenylalanine ammonialyase (PAL) activity was increased markedly as a result of UV-stress in the beginning, subsequently, it declined (Shaukat *et al*., 2013).

2.4 Effect of UV-B on Yield parameters

A yield component refers to the structure of rice crop that directly translate in to yield. These include number of panicles per hill, number of spikelets per panicle, per cent filled grain per panicle and 1000 grain weight.

If assimilates supply to rice grain is restricted by some unfavourable environmental conditions in the first ten days of the grain filling period the yield may be profoundly affected (Yoshida, 1981).

The UV-B effect on the crops can be of more dreadful consequences that the UV-B radiation reduces the economic yield of crop plants. Moreover it can also affect the quality of nutrition which would have indirect impact on human population through alterations in the food supply. Several agricultural crops including varieties of important crops such as rice (Hidema *et al.,* 1997) have shown susceptibility to increases in UV-B radiation.

Solar UV-B radiation exclusion studies have indicated that ambient levels of solar UV-B radiation reduce biomass accumulation and grain yield in

cucumber (Krizet *et al*., 1997), lettuce (Krizet *et al*., 1998), barley (Mazza *et al*., 1999) and soybean (Mazza *et al*., 2000).

Kumagai *et al*. (2001) investigated the effects of supplementary UV-B radiation on the yield of Japanese rice cultivars in a paddy field over a 5-year period. They found that supplementary UV-B radiation inhibited yield and grain development. Hidema *et al*. (2005) observed that tiller number, dry mass, panicle number, grain yield and grain size significantly decreased under supplemental UV-B radiation in rice.

Yuan *et al*. (1998) conducted a study on wheat grown in the field for two seasons under ambient and supplemental level of UV-B radiation. They found that enhanced UV-B radiation reduced significantly the spike number, grain number per spike, spike length and thousand grain weights. Harvest index (HI) also decreased under enhanced UV-B condition.

In the study of Mohammed and Tarpley (2009), rice plants were exposed to UV-B radiation of 0, 8 and 16 kJ m^{-2} day^{-1}. By the increase in UV-B radiation there was increase in spikelet sterility.

Three soybean cultivars, H339, HN35 and KN18 were grown for 2 years in a field experiment exposed to enhanced UV-B radiation. There was significant decrease in pod number per plant and seed number per pod under enhanced UV-B radiation (Liu *et al*., 2013).

Material and Methods

3. MATERIALS AND METHODS

The present study was conducted at the Department of Plant Physiology, College of Horticulture, Vellanikkara, during December 2013 to April 2014. The details of materials used and methods adopted are presented in this chapter.

3.1 General details

3.1.1 Location

The experiment was conducted at College of Horticulture Vellanikkara. The geographical co-ordinates of the location of the College are $10^0$32' N and $76^0$16 E with an altitude of 22.5 m above MSL.

3.1.2 Season

The crop period was from December 2013 to April 2014.

3.2 Experimental detail

Experiment was laid out in a Completely Randomised Design (CRD) in pots with 6 treatments and 7 replications with 5 pots in each replication. Six treatments comprised of three levels of solar radiation and two varieties of paddy. Three levels of solar radiation are:

1. T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

2. T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

3. T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

Two varieties of rice used are:

1. V_1- Jyothi
2. V_2- Uma

3.2.1 Details of UV-B condition

The experiment was conducted in ventilated polyhouse of size 42.75 m^2 to produce UV reduce and enhanced condition. The side of polyhouse covered with insect proof net (40 mesh). The polyhouse was compartmentalized in two parts of equal size. Roof of one compartment was claded with 0.13 mm thick polyester filter which transmitted 85% full spectrum radiation excluding UV-B which provided UV-B reduced condition as UV-B – 0 (T_2) (280-320 nm). The other compartment roof was covered with UV transparent polyethylene sheet (0.25mm thickness) which transmitted 85 per cent full spectrum but including UV-B which served as T_3. Further to enhance UV-B, in this chamber 4 number of UV-B fluorescent tubes (TL-D18W/52 2G- Made in Holland) were installed on an adjustable frame perpendicular to the potted plants which exhibit its emission more than 230 nm to maximum 312 nm. The lamps were switched on from 10 am to 2 pm (4 hrs daily) which is considered as the biologically active photoperiod. The average UV-B radiation provided by lamps was measured as 0.16 Wm^{-2} at canopy level. The height of lamps was adjusted throughout growing period to maintain the distance 50 cm above canopy. T_1 condition was provided by exposing the crops to 100 per cent natural solar radiation.

3.2.2. Varietal Details

The details of two rice varieties used in the study are given below

3.2.2.1 Jyothi (V_1)

The rice variety Jyothi (PTB 39) is a red kernelled with long bold grains, short duration of 110-115 days. Jyothi developed from Regional Agriculture Research Station Pattambi. The variety is suitable for direct seeding and

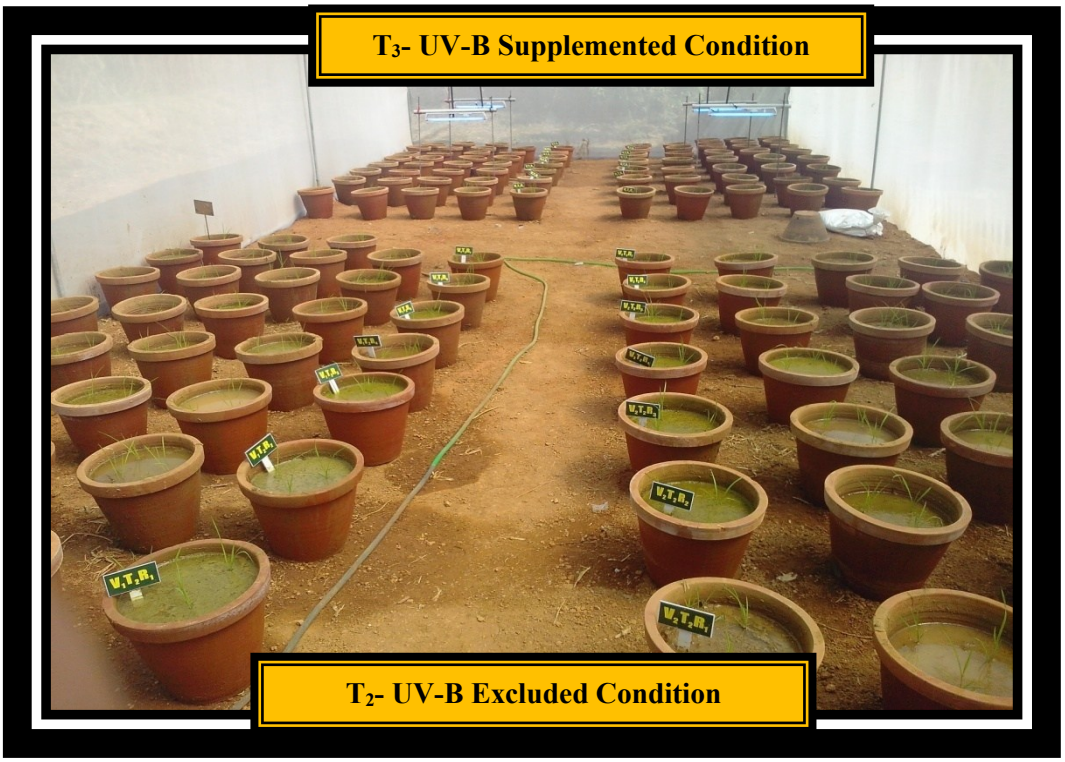


Plate 1: View of the experimental plot

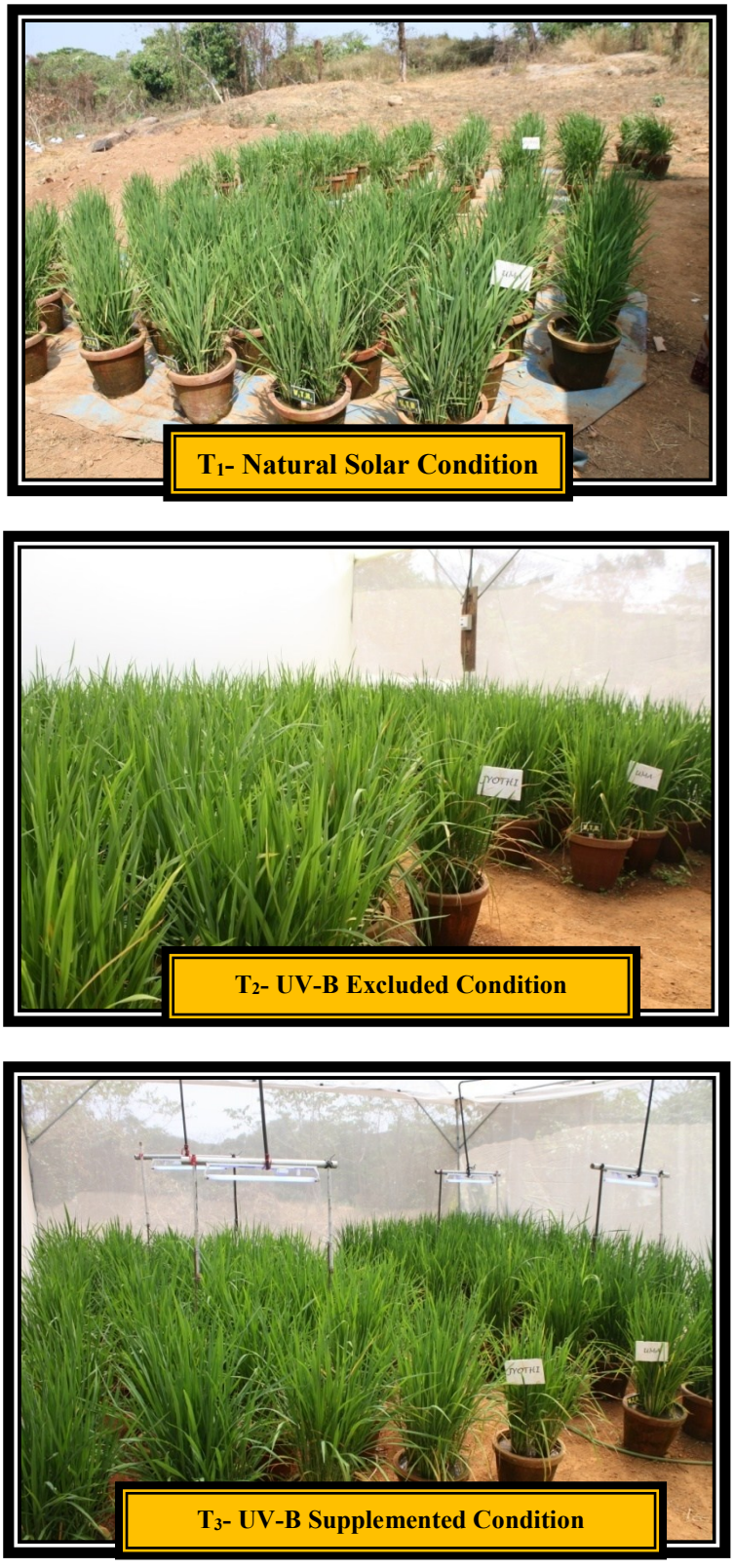


Plate 2: Rice crop grown under different levels of UV-B

a. UV-B meter

b. UV meter and Quantum light meter

c. LI-6400 Portable Photosynthesis system

d. Infrared thermometer

Plate 3: Various instruments used during the study

transplanting during both first (*Virippu*) and second crop (*Mundakan*) seasons. It is tolerant to BPH and rice blast disease, moderately susceptible to sheath blight and capable of yielding over 8 t ha^{-1} under favourable situations and gives moderate yields even under adverse conditions.

3.2.2.2 Uma (V_2)

The variety Uma (Mo. 16) is a red kernelled with medium bold grains, medium duration of 115-120 days. Uma is most popular rice variety of the Kerala State developed by Rice Research Station, Moncompu. It is non lodging, resistant to BPH and GM bold biotype-5 and having dormancy up to 3 weeks. Uma is suited for three seasons, especially to additional crop season of *Kuttanad* and capable of producing a yield of over 5 t ha^{-1} under favourable situations.

3.2.3 Raising of crop and management

The crop was raised in mud pot of size 12 inch all pots were filled with clay loam soil collected from paddy field of Agriculture Research Station, Mannutty (ARS, Mannuthy). 21 days old rice seedling transplanted at the rate of two seedling per hill and three hills per pot and exposed to different treatments. The fertilizer management were adapted as per the POP 2013 of KAU. Each pot received the manurial schedule at 5 tonnes FYM as basal which was incorporated at the time of filling pots. The crop was applied with N, P and K at the rate 70:35:45. Out of this 50 per cent N, 100 per cent P and 50 per cent K was given as basal at the time of transplanting. 25 per cent N was given at the time of active tillering stage and remaining 25 per cent N and 50 per cent K was given at maximum tillering stage. Urea, rock phosphate and MOP were used as the fertilizer material.

3.2.4 UV-B and PAR (Photosynthetically Active Radiation) measurement

The UV-B radiation inside and outside of polyhouse was measured using UV-B meter (Model-3414F, Field scout, Spectrum technology, Icn. USA) from

10 am to 4 pm daily throughout the growing period at two hours interval (10 am, 12 noon, 2 pm and 4 pm) and expressed as Wm^{-2}.

Photosynthetically active radiation (PAR) was also measured from 10 am to 4 pm daily throughout growing period. Using instrument Model-3415F, Field scout, Spectrum technology, Icn.USA. The intensity of PAR is referred as PPFD (Photosynthetic Photon Flux Density) which is measured in unit $\mu mol\ m^{-2}s^{-1}$.

3.3 Observations recorded

3.3.1 Morphological and phenological observation

a) Plant height

Three plants were selected randomly from each replication and tagged to measure height of the plant. The plant height was recorded at tillering and flowering stage of crop from ground level to tip of longest leaf of plant and expressed in centimetre.

b) Number of tillers per hill

Three hills from each replication were selected randomly and tagged for taking tiller count. Number of tiller was counted at tillering and flowering stage and mean value expressed in number per hill.

c) Leaf thickness

Leaf thickness was recorded as leaf dry weight per unit leaf area which expressed as mg/cm^2 at both tillering and flowering stages (Yoshida *et al.*, 1969).

d) Number of productive tillers per hill

Number of productive tillers per hill was counted just before harvesting the crop from the same sample hills used for counting number of tillers per hill. The average value worked out and expressed as the number of productive tillers per hill.

e) Flag leaf angle

Flag leaf angle was measured near the collar as the angle of attachment between the flag leaf blade and the main panicle axis using protractor vertically at tillering and flowering stage of crop (Yoshida *et al.,* 1969) and is measured as degree.

f) Panicle length

Twelve panicles were selected at random in each treatment and length was measured from the base to the tip of the top most spikelet. The average length is worked out and expressed in centimetre.

g) Days to heading

Days to heading was recorded when 50% panicle tip emerged from the flag leaf sheath in each pot in every replication and expressed in days from the date of transplanting.

h) Days to 50 percent flowering

Number of days taken for 50 per cent flowering was counted from transplanting in both varieties and recorded in days.

i) Days to harvestable maturity

Number of days taken for harvestable maturity from transplanting was determined at the maturity stage when 50 per cent plants in a treatment matured and recorded in days in both varieties.

3.3.2 Physiological observations

The physiological parameters were recorded at tillering and flowering stage as detailed below:

3.3.2.1 Leaf gas exchange parameters

Leaf gas exchange measurements were performed using portable photosynthesis system (PPS) (Model - LI-6400 of ICOR inc. Lincoln, Nebraska, USA). Totally three measurements were taken in the same leaf for each plant and three plant were observed in each replication. Leaf was inserted in leaf chamber and leaf area was adjusted at 2.5 cm^2. Reading was taken between 9.00 to 10.30 am using this instrument. The following gas exchange parameters were recorded and the unit expressed in parenthesis.

a) Photosynthesis Rate (μ mol CO_2 m^{-2} s^{-1})
b) Stomatal Conductance (mol H_2O m^{-2} s^{-1})
c) Transpirational Rate (mmol H_2O m^{-2} s^{-1})

3.3.2.2 Canopy Temperature Depression (CTD)

CTD was measured by using Infrared thermometer (Model-6110L AGRI-THERM III^{TM} Infrared thermometer by Everest Interscience INC. Tuscon, USA) at morning from 09-11 am from three treatments at tillering and flowering stage of crop.

3.3.3 Biochemical observation

The biochemical parameters were recorded at tillering and flowering stage as detailed below:

a) Chlorophyll content

The chlorophyll a, Chlorophyll b and total chlorophyll were estimated by method suggested by Hiscox and Israelstam (1979). For chlorophyll estimation 100 mg leaf sample was added to 10 ml DMSO (Dimethyl Sulphoxide) and kept in dark for overnight. Then final volume made up to 25 ml after filtering in the next day. The chlorophyll content was estimated in spectrophotometer (Model-4001/4 ThermoSpectonic, Thermo Electron Corporation, USA) at two wavelength

645 nm and 663 nm and expressed as milligram g^{-1} fresh weight of plant tissue. The calculation done by using following formulae.

Chlorophyll 'a' = [(12.7 x A663) – (2.69 x A645)] x V/1000 x W

Chlorophyll 'b'= [(22.9 x A645) – (4.68 x A663)] x V/1000 x W

Total chlorophyll = [(20.2 x A645) + (8.02 x A663)] x V/1000 x W

Where,

A = Absorption at given wavelength

V = Total volume of sample in extraction medium

W = Weight of sample

b) Flavanoid content

Flavanoid were extracted and quantified by the method suggested by Mirecki and Teramara (1984). For flavanoid estimation 500 mg of leaves were placed in 80 per cent acidified methanol (methanol:water:HCl 79:20:1) for 12 hours in dark to extract flavanoid and the absorbance was read at 300 nm and expressed as A_{300} g^{-1} fresh weight of plant sample by the following formula.

$$Y = 16.05 \times A$$

Where,

Y = Concentration of UV-B absorbing compound equivalent to Coumaric acid.

A = Absorbance at 300 nm.

c) Catalase activity

Catalase activity was assayed by the method suggested by Barber (1980). The fresh leaves (0.5 g) were ground in 20 ml of cold potassium phosphate buffer and centrifuged at 15,000 rpm for 15 min. The enzyme extract was brought up to 25 ml. with the potassium phosphate buffer. One ml (1 ml.) of enzyme extract, 2 ml. of 0.1 M H_2O_2 and 3 ml. of potassium phosphate buffer were placed in a test tube. After 5 min. the reaction in test tube was stopped by adding 1 ml. of 0.7 N concentrated sulphuric acid. The test tube was incubated for 5 min. at 27^0C and the residual hydrogen peroxide in the test tube was titrated against 0.01 M $KMnO_4$ until a faint purple colour persisted for at least 15 second. The amount of H_2O_2 destroyed by catalase was calculated by the formula given below:

$$\frac{25 \times 0.85}{2} \times \frac{V}{W}$$

Where,

W = weight of sample

V = Volume of $KMnO_4$ utilized (Titer value)

The activity of the catalase was expressed as enzyme units. One unit of catalase was defined as that amount of enzyme, which breaks down 1 µ mol. of H_2O_2/ min g^{-1}freshweight.

d) Indole-3-acetic acid (IAA) content

IAA (Indole-3-acetic acid) was estimated by the method suggested by Parthasarathi *et al.* (1970) with little modification using Garden Weber reagent. The IAA was expressed in µg of free Auxin g^{-1} fresh weight.

e) Phenol content

Phenol content was estimated by the method suggested by Malick and Singh (1980). For phenol content estimation 0.5 g of plant sample homogenated in 10 ml of 80 per cent ethanol and centrifuged at 10,000 rpm for 20 minutes. Supernatant was collected and evaporated to dry. Then 5 ml of distilled water was added from that 0.2 ml of sample placed in a test tube and made up to volume 3 ml. Later 0.5 ml of folin-Ciocalteau reagent were added and after 3 minutes, 2 ml of 20 % Na_2CO_3 solution was added and absorbance measured at 650 nm using spectrophotometer (Model-4001/4 Thermo Spectonic, Thermo Electron Corporation, USA). The phenol content was expressed as mg g^{-1} of fresh weight.

Standard solution was prepared with catechol and absorbance taken at 650 nm. Calculation carried out by the given formula.

$$\frac{\text{Test sample absorbance}}{\text{Standard solution absorbance}} \text{ X } \frac{\text{Concentration of standard solution}}{\text{Weight of sample}}$$

f) Polyphenoloxidase activity

Polyphenoloxidase activity was assayed by the method of Esterbaner *et al.* (1977). The assay mixture containing 0.5 g plant leaves 50 mM Tris- HCl, (*p*H 7.2), 0.4 M Sorbitol and 10 mM NaCl (3 ml: 1 ml: 1 ml) was centrifuged at 20,000 rpm for 10 minutes and supernatant (enzyme extract) was used for enzyme assay. In cuvette 2.5 ml. of 0.1 M phosphate buffer (*p*H 6.5) and 0.3 ml. of catechol solution (0.01 M) was added and the spectrophotometer (Model-4001/4 ThermoSpectonic, Thermo Electron Corporation, USA), was set at 495 nm. Then 0.2 ml. of enzyme extract was added in cuvette and absorbance recorded at every 30 second up to 5 min. The activity of Polyphenoloxidase was estimated by the formula given below:

$$K \times (\Delta A / min)$$

Where,

K = 0.272 (catechol oxidase)

ΔA = Initial value of absorbance – Final value of absorbance

The Polyphenoloxidase activity was expressed as enzyme unit (EU) g^{-1} fresh weight.

g) Phenylalanine ammonialyase activity (PAL)

Phenylalanine ammonialyase was determined by following the method of Bruseke (1980). For Phenylalanine ammonialyase activity 500 milligram fresh leaves were homogenized in 5 ml. of cold 25 mM borate buffer containing 5 mM mercaptoethanol and centrifuged at 12,000 rpm for 20 minutes. The supernatant (enzyme extract) was used for assay. The enzyme extract (0.2 ml) of was added to 0.5 ml borate buffer (0.2 M) and 1.3 ml distilled water. The reaction was initiated by adding 1ml of L- phenylalanine (0.1 M) and incubated for 30-60 minute at 32ºC. After incubation the reaction was terminated by adding 0.5 ml 1 M trichloro acetic acid and the absorbance was read at 290 nm in UV- VIS spectrophotometer against blank. The PAL was expressed as the concentration of µ mol t- cinnamic acid formed g^{-1} fresh weight as determined from t-cinnamic acid standard graph.

3.3.4 Yield parameters

a) Number of panicles per hill

Number of panicles was counted from three hills all pots in each replication after harvesting and average expressed as number of panicle per hill.

b) Number of spikelet per panicle

Numbers of spikelet per panicle was counted from randomly selected twelve panicles from each replication and the mean number for single panicle was worked out.

c) Filled grain per panicle

Grains were selected from randomly selected 12 panicles and separated in to filled grains and chaff grains. The number of filled grain was counted and expressed as percentage to total filled grain.

d) Spikelet sterility

Number of sterile spikelet counted from randomly selected twelve panicles and average number of sterile spikelet for single panicle was worked out.

e) 1000 grain weight

One thousand grains were randomly selected from the each treatment and their weight was recorded in grams using electronic balance (Model- CB-10, ConTech, Instrument Company, Mumbai, India).

f) Grain and straw yield per pot

Crop was harvested manually from each pot in every replication and grain and straw were separated. The weight of grain and straw from each pot was recorded (using electronic balance Model- CB-10, ConTech, Instrument Company, Mumbai, India) separately at 14 % moisture and expressed in gram per hill.

f) Harvest Index (HI)

The proportion of economic yield was represented over biological yield, using the formula (Donald and Hamblin, 1976) and expressed as Harvest Index (HI).

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Economic yield + Biological yield}} \text{ X } 100$$

3.4 Statistical analysis

Data were analysed using MSTATC package. Analysis of variance was done for each parameter under observation and critical difference (CD) computed.

Results

4. RESULTS

Results of observation on the morphological, phenological, physiological, biochemical and yield parameters of two rice varieties Jyothi and Uma grown under three levels of UV-B radiations i.e. natural solar UV-B condition (T_1), UV-B excluded condition (T_2) and UV-B supplemented condition (T_3) are presented in this chapter. The data recorded were tabulated and analysed statistically. The results obtained are presented below. The mean data are presented in the relevant tables and depicited by appropriate figures.

4.1 UV-B analysis

The mean data on UV-B radiation recorded from 10 am to 4 pm at 2 hrs interval during the growth period (Dec-13 to April-14) of crop are given in Table 1 and 2.

Under UV-B excluded condition (T_2) this radiation was totally blocked and hence the value recorded is zero.

The UV-B recorded was significantly higher in natural solar UV-B condition (T_1) when compared to UV-B supplemented condition T_3 (Table 1) in all the months of observation. Under T_1 condition UV-B radiation was significantly higher in the month of March-14 when compared to other months. The lower value was recorded during Dec-13 under both situations (T_1 and T_3). UV-B was higher under natural solar UV-B condition, irrespective of time of observation.

Temporal observation of the UV-B measured from time to time showed a gradual increase from 10 am to 12 noon and a decrease from 12 noon to 4 pm in both situations of T_1 and T_3. The maximum value was recorded at 12 noon in both the situations (Table 2).

The daily observation recorded at 2 hrs intervals from 10 am to 4 pm showed maximum value of UV-B at12 noon during March-14 (3.581Wm^{-2}) and

Table 1: Data on UV-B radiation taken at different treatment

DECEMBER	**10 am**	**12 noon**	**2 pm**	**4 pm**
T_1	2.4503	3.2483	2.6822	1.3036
T_2	0	0	0	0
T_3	0.1187	0.1726	0.1301	0.0511
t-Value	22.246	88.592	15.335	14.115
JANUARY				
T_1	2.0994	3.2913	2.7056	1.3331
T_2	0	0	0	0
T_3	0.1319	0.1960	0.1620	0.0693
t-Value	29.403	25.867	13.989	17.536
FEBRUARY				
T_1	1.9579	3.0207	2.8594	1.44469
T_2	0	0	0	0
T_3	0.1270	0.1872	0.1519	0.0721
t-Value	16.763	14.920	17.060	20.290
MARCH				
T_1	2.1895	3.5811	3.2416	1.6714
T_2	0	0	0	0
T_3	0.1599	0.2555	0.1842	0.0814
t-Value	24.027	29.516	28.917	29.007
APRIL				
T_1	1.7421	2.8220	2.5218	1.3407
T_2	0	0	0	0
T_3	0.1749	0.2770	0.2008	0.0863
t-Value	7.930	9.481	9.288	25.387

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T_2-** Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T_3-** 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

Table 2: Data on UV-B radiation taken at different time

DECEMBER	**T_1**	**T_2**	**T_3**
10 am	2.450	0	0.119
12 noon	3.248	0	0.173
2 pm	2.682	0	0.130
4pm	1.304	0	0.051
CD	0.3266	0	0.0296
JANUARY			
10 am	2.127	0	0.136
12 noon	3.274	0	0.194
2 pm	2.688	0	0.161
4pm	1.331	0	0.069
CD	0.3049	0	0.0468
FEBRUARY			
10 am	1.958	0	0.127
12 noon	3.021	0	0.187
2 pm	2.859	0	0.152
4pm	1.447	0	0.072
CD	0.3880	0	0.0277
MARCH			
10 am	2.189	0	0.160
12 noon	3.581	0	0.255
2 pm	3.242	0	0.184
4pm	1.671	0	0.081
CD	0.2494	0	0.0277
APRIL			
10 am	1.742	0	0.0175
12 noon	2.822	0	0.277
2 pm	2.522	0	0.201
4pm	1.341	0	0.086
CD	0.5820	0	0.0554

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T_2-** Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T_3-** 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

minimum of 2.822 Wm^{-2} was recorded during April-14 in T_1 condition. The lowest value of UV-B ranged from 1.304 Wm^{-2} to 1.671 Wm^{-2} at 4 pm in all the months observed in open condition. There was significant variation in UV-B radiation from 10 am to 4 pm in all the months throughout growing period (Table 2). In T_3 the mean value ranged from 0.1187 to 0.1749 Wm^{-2}, 0.1726 to 0.2770 Wm^{-2}, 0.1301 to 0.2008 Wm^{-2} and 0.0511 to 0.0863 Wm^{-2} during 10 am, 12 noon, 2 pm and 4 pm respectively.

4.2 Morphological and phenological characters

The data on the morphological and phenological characters observed at tillering and flowering stages of crop are given below in appropriate sub heading.

4.2.1 Plant height

The mean data on plant height observed at tillering and flowering stages showed significant variation between the varieties Jyothi (V_1) and Uma (V_2) (Table 3). Among the two, Uma recorded the tallest height of 46.31 cm at tillering stage, Jyothi recorded tallest height of 94.63 cm at flowering stage.

Under different UV-B levels, UV-B excluded situation (T_2) resulted in significant tallest plant height of 54.14 cm and 98.61 cm at tillering and flowering stages, respectively. The shortest plant height was recorded under T_1 condition as 37.49 cm and 74.18 cm at the above stages, respectively. T_3 condition recorded 39.51 cm at tillering and 87.99 cm at flowering stage.

Both the varieties produced significantly taller plants when subjected to reduced UV-B situations when compared to other UV-B condition under tillering stage. However this was not reflected in flowering stage and all the varieties had statistically similar stature irrespective of UV-B situation.

Jyothi plants with height of 54.40 cm and Uma with 53.87 cm under reduced UV-B situation at tillering stage were highly significant over others. At

Table 3: Mean Plant height (cm), Number of tillers per hill and leaf thickness (mg/cm^2) of two rice varieties at different UV-B levels.

Tillering stage				Flowering stage			
	Plant height (cm)	**No. of tillers/ plant**	**Leaf thickness/ mg/cm^2**		**Plant height (cm)**	**No. of tillers/ plant**	**Leaf thickness/ mg/cm^2**
V_1	41.11	7.9	4.80	**V_1**	94.63	25.8	4.67
V_2	46.31	8.6	4.23	**V_2**	79.21	22.8	4.63
Significance	**S**	**NS**	**S**	**Significance**	**S**	**S**	**NS**
T_1	37.49	7.5	4.64	**T_1**	74.18	25.4	5.15
T_2	54.14	10.0	4.44	**T_2**	98.61	25.0	4.26
T_3	39.51	7.3	4.36	**T_3**	87.99	22.4	4.54
CD	**3.41**	**0.9**	**NS**	**CD**	**8.33**	**NS**	**0.45**
V_1T_1	38.27	7.2	4.97	**V_1T_1**	78.36	27.3	5.20
V_1T_2	54.40	8.9	4.51	**V_1T_2**	105.29	25.9	4.53
V_1T_3	30.66	7.9	4.67	**V_1T_3**	100.26	24.1	4.27
V_2T_1	36.70	7.8	4.30	**V_2T_1**	70.00	23.6	5.10
V_2T_2	53.87	11.2	4.36	**V_2T_2**	91.93	24.1	4.54
V_2T_3	48.36	6.8	4.04	**V_2T_3**	75.71	20.7	4.24
CD	**4.84**	**1.3**	**NS**	**CD**	**NS**	**NS**	**NS**

V_1- Jyothi

V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

flowering stage the varieties performed similarly without responding to changing UV-B situation.

4.2.2 Number of tillers per hill

Among the varieties the number of tillers per hill observed was found non-significant at tillering stage. However it was significant at flowering stage (Table 3). The highest numbers of 25.8 tillers per hill at flowering stage was recorded by the variety Jyothi, significantly more than Uma.

UV-B situation showed remarkable influence on tiller production only at tillering stage. The higher numbers of tillers per hill were observed in T_2 (10.0) and lowest recorded in T_3 (7.3). However this effect was not carried over to flowering stage, where in the UV-B treatments did not influence tiller production.

The number of tillers per hill produced by the varieties Jyothi and Uma significantly varied under different UV-B situation only at tillering stage. The variety Uma produced significantly higher tiller number (11.2) followed by Jyothi (8.9) for T_2 situation compared to other situations. Both varieties showed non-significant variation for tiller number between T_1 and T_3 conditions. The interactive effect of varieties and UV-B situation was not visible significantly at flowering stage.

4.2.3 Leaf thickness

The mean data on leaf thickness at tillering and flowering stage are given in Table 3.

Varieties expressed significant variation in leaf thickness at tillering stage. The leaf thickness was more in variety Jyothi (4.80 mg/cm^2) when compared to Uma (4.23 mg/cm^2) at tillering stage. But this variation was not observed at flowering stage.

Table 4: Mean number of productive tillers per hill, flag leaf angle (^{0}) and panicle length (cm) of two rice varieties at different UV-B levels.

	No. Of Productive tillers/ Hill	**Flag leaf angle (^{0})**	**Panicle length (cm)**
V_1	16.2	18.11	20.58
V_2	14.7	15.80	20.08
Significance	**S**	**NS**	**S**
T_1	16.9	12.91	18.64
T_2	15.1	23.33	21.82
T_3	14.2	14.75	20.52
CD	**1.0**	**3.30**	**0.52**
V_1T_1	17.5	12.46	18.36
V_1T_2	15.6	26.42	22.15
V_1T_3	15.9	15.71	21.23
V_2T_1	16.3	13.36	18.93
V_2T_2	14.6	20.24	21.49
V_2T_3	13.0	13.80	19.81
CD	**NS**	**NS**	**0.74**

V_1- Jyothi

V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

Leaf thickness both at tillering and flowering stage was not influenced by UV-B levels. Condition T_1 recorded the highest leaf thickness (5.15 mg/cm^2) followed by T_3 (4.54 mg/cm^2) and T_2 (4.26 mg/cm^2) at flowering stage.

The variation in leaf thickness due to interactive effect of varieties and UV-B situations was not observed at both stages of observation.

4.2.4 Number of productive tillers per hill

The mean data on number of productive tillers per hill is given in Table 4.

The number of productive tillers per hill varied significantly between varieties. The variety Jyothi recorded 16.2 productive tillers per hill whereas, Uma recorded 14.7 productive tillers per hill.

The different levels of UV-B radiations also caused significant variation in number of productive tillers per hill. The more number of productive tillers per hill (16.9) was recorded under T_1 condition followed by T_2 (15.1) and T_3 (14.2). There was no significant difference in number of productive tillers produced under T_2 and T_3 levels of UV-B radiation.

The interactive effect of varieties and UV-B levels could not produce any significant variation in number of productive tillers per hill.

4.2.5 Flag leaf angle

The mean data on flag leaf angle from vertical cones observed at 50 per cent flowering is given in Table 4. There was no significant variation in flag leaf angle between both varieties.

But there was significant variation in flag leaf angle between treatments T_2 had the highest angle (23.33^0) followed by T_3 (14.75^0) and the lowest value for flag leaf angle recorded in T_1 (12.91^0). Flag leaf angle was remarkably enhanced under UV-B excluded condition.

Between variety and treatment there was non-significant difference in flag leaf angle.

4.2.6 Panicle length

The mean data on panicle length are given in Table 4.

Panicle length showed significant difference between varieties Jyothi (V_1) and Uma (V_2). The highest length was recorded in variety V_1 (20.58 cm) followed by V_2 (20.08 cm).

The different levels of UV-B radiation also recorded significant variation in panicle length. The panicle length was highest (21.82 cm) under UV-B excluded condition (T_2) followed by T_3 (20.52 cm). The lowest was recorded inT_1 (18.64 cm) condition when the crop was exposed to 100 per cent natural solar UV-B radiation.

The different levels of UV-B radiation showed significant variation for panicle length for both varieties. Both the varieties recorded highest panicle length under UV-B excluded condition i.e. T_2 followed by T_3. Under natural solar condition the UV-B radiation reduced the panicle length in both Jyothi and Uma. The reduction in panicle length was 17.10 per cent and 11.90 per cent for Jyothi and Uma respectively when compared to UV-B excluded condition.

4.2.7 Days to heading

Days to heading recorded significant variation between varieties V_1 and V_2 (Table 5). The variety V_2 recorded more days to heading (73.79) than V_1 (66.90).

Under different levels of UV-B radiation T_1 recorded more number of days for heading (73.46) than T_2 (69.27) and T_3 (68.31). There was no significant difference between T_2 and T_3 for the same character.

The interactive effect of variety and treatment for days to heading recorded non-significant variation.

Table 5: Mean Days to heading, Days to 50% flowering and Days to harvestable maturity of two rice varieties at different UV-B levels.

	Days to heading	**Days to 50% flowering**	**Days to harvestable maturity**
V_1	66.90	73.90	103.90
V_2	73.79	80.79	110.79
Significance	**S**	**S**	**S**
T_1	73.46	80.46	110.46
T_2	69.27	76.27	106.27
T_3	68.31	75.31	105.31
CD	**1.79**	**1.79**	**1.79**
V_1T_1	69.97	76.97	106.97
V_1T_2	65.51	72.51	102.51
V_1T_3	65.23	72.23	102.23
V_2T_1	76.94	83.94	113.94
V_2T_2	73.03	80.03	110.03
V_2T_3	71.40	78.40	108.40
CD	**NS**	**NS**	**NS**

V_1- Jyothi

V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

4.2.8 Days to 50 per cent flowering

The mean data are on days to 50 per cent flowering recorded is given in Table 5.

Days to 50 percent flowering was observed significantly different between varieties V_1 and V_2. Variety Jyothi completed 50 per cent flowering earlier (73.90) than Uma (80.79).

Crop reached fifty per cent flowering significantly earlier when crop was subjected to T_2 (76.27) and T_3 (75.31) situation than the T_1 condition (80.46). However, days to 50 per cent flowering was not significantly different between T_2 and T_3. Further combinations of varieties and UV-B situations did not cause significant difference in days to 50 per cent flowering.

4.2.9 Days to harvestable maturity

Significant variation was observed in both varieties for days to harvestable maturity (Table 5). More days were taken by variety Uma (110.79) followed by Jyothi (103.90).

Under different treatment there were significant difference observed. The longest days were taken under the situation T_1 (110.46) followed by T_2 (106.27) and least days taken by T_3 (105.31).

Days to harvestable maturity were not significantly different among combination of variety and UV-B situation.

4.3 Physiological characters

The result of the physiological characters observed at tillering and flowering stages of crop are given below on appropriate heading.

4.3.1 Photosynthetic rate

The mean data on photosynthetic rate are given in Table 6.

The two varieties did not differ significantly in photosynthetic rate during tillering stage. However during flowering stage Jyothi recoded higher photosynthetic rate (27.70 µmol CO_2 $m^{-2}s^{-1}$) than Uma (24.31 µmol CO_2 $m^{-2}s^{-1}$). The photosynthetic rate showed a decrease from tillering to flowering stage in both varieties.

Plants grown in UV-B excluded condition (T_2) recorded significantly higher photosynthetic rate than plants grown under natural solar condition (T_1) and UV-B supplemented condition (T_3) both at tillering and flowering stages. Higher photosynthetic rate observed under T_2 condition at tillering stage was 34.69 µmol CO_2 $m^{-2}s^{-1}$ and flowering stage was 28.01µmol CO_2 $m^{-2}s^{-1}$. This was followed by T_3 and the rate was 27.51 µmol CO_2 $m^{-2}s^{-1}$ and 25.30 µmol CO_2 $m^{-2}s^{-1}$ respectively under tillering and flowering stages and the lowest photosynthetic rate was under T_1 (23.41 µmol CO_2 $m^{-2}s^{-1}$) at tillering stage and T_1 (24.70 µmol CO_2 $m^{-2}s^{-1}$) at flowering stage. T_3 and T_1 were identical at flowering stage.

The interactive effect on varieties and treatments indicated significant variation in photosynthetic rate for variety Jyothi under all UV-B levels only at tillering stage. Both varieties Jyothi and Uma produced significant photosynthetic rate only under T_2 condition. The other situations reflected lower photosynthetic rate for both varieties.

4.3.2 Stomatal conductance

The mean data on stomatal conductance is given in Table 6.

Varieties did not show significant difference in stomatal conductance at tillering stage. But at flowering stage the variety Jyothi recorded significantly higher conductance (0.38 mol H_2O m^{-2} s^{-1}) than Uma (0.32 mol H_2O m^{-2} s^{-1}).

The stomatal conductance was significantly higher when crop was grown under excluded UV-B radiation (T_2) at both tillering and flowering stages. Stomatal conductance was 0.55 mol H_2O $m^{-2}s^{-1}$ and 0.40 mol H_2O $m^{-2}s^{-1}$ at

Table 6: Mean Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1}), Stomatal conductance (mol H_2O m^{-2} s^{-1}), Transpiration rate (mmol H_2O m^{-2} s^{-1}) and Canopy temperature depression (^0C) of rice varieties under different UV-B levels.

Tillering stage					Flowering stage				
	PN. Rate	**Stoml. Cond.**	**Trasp. Rate**	**CTD**		**PN. Rate**	**Stoml. Cond.**	**Trasp. Rate**	**CTD**
V_1	29.83	0.40	4.21	-2.26	**V_1**	27.70	0.38	4.13	-2.77
V_2	27.25	0.38	4.21	-2.90	**V_2**	24.31	0.32	3.94	-2.70
Significance	**NS**	**NS**	**NS**	**S**	**Significance**	**S**	**S**	**NS**	**NS**
T_1	23.41	0.27	3.66	-2.07	**T_1**	24.70	0.32	3.83	-1.81
T_2	34.69	0.55	4.91	-3.04	**T_2**	28.01	0.40	4.25	-3.51
T_3	27.51	0.35	4.06	-2.64	**T_3**	25.30	0.33	4.03	-2.89
CD	**3.34**	**0.09**	**0.36**	**0.25**	**CD**	**2.61**	**0.04**	**NS**	**0.47**
V_1T_1	22.23	0.26	3.56	-1.79	**V_1T_1**	26.57	0.34	3.70	-1.93
V_1T_2	36.17	0.56	4.76	-3.21	**V_1T_2**	28.92	0.42	4.28	-3.23
V_1T_3	31.10	0.38	4.30	-2.12	**V_1T_3**	27.60	0.37	4.42	-3.16
V_2T_1	23.93	0.32	3.82	-2.36	**V_2T_1**	21.80	0.27	3.63	-1.69
V_2T_2	33.21	0.54	5.06	-3.50	**V_2T_2**	27.10	0.37	4.21	-3.87
V_2T_3	24.60	0.28	3.75	-2.86	**V_2T_3**	24.03	0.33	3.97	-2.56
CD	**4.73**	**NS**	**NS**	**0.36**	**CD**	**NS**	**NS**	**NS**	**0.68**

V_1- Jyothi; V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

tillering and flowering stages respectively. This was significantly higher than T_3 and T_1 at both stages. T_1 and T_3 condition did not significantly between them in case of stomatal conductance both at tillering and flowering stages.

The interactive effect between varieties and different conditions did not produce significant variation at both the stages.

4.3.3 Transpiration rate

The mean data on transpiration rate is given in Table 6.

The rate of transpiration was found to be decreased from tillering to flowering stage in both varieties. Varieties did not show any significant difference in transpiration rate at both tillering and flowering stages.

Under different levels of UV-B, transpiration rate was significantly different, at tillering stage whereas it was non-significant at flowering stage. The highest rate of (4.91 mmol H_2O $m^{-2}s^{-1}$) transpiration was recorded under UV-B excluded condition (T_2), followed by T_3 (4.06 mmol H_2O $m^{-2}s^{-1}$) and significantly the least at T_1 (3.66 mmol H_2O $m^{-2}s^{-1}$) all at the tillering stage.

The interactive effect of varieties and different levels of UV-B radiation did not cause any significant variation in the transpiration rate at the both stages.

4.3.4 Canopy temperature depression (CTD)

The mean data on canopy temperature depression is given in Table 6.

CTD, which is the differential of air and canopy temperatures showed significant difference between the varieties only at tillering stage and was non-significant at flowering stage. Variety Uma showed more canopy cooling (-2.90 ^{0}C) than Jyothi (-2.26 ^{0}C) at tillering stage.

The different UV-B levels situation caused variation in CTD. Significantly more canopy cooling i.e. highest temperature depression, was observed under

UV-B excluded (T_2) condition at tillering (-3.04 ^{0}C) and flowering stages (-3.51 ^{0}C). This was followed by T_3 and the values were -2.64 ^{0}C and -2.89 ^{0}C at the above stages, respectively. The crop grown under natural solar condition (T_1) recorded significantly the lower temperature difference and the values were -2.07 ^{0}C and -1.81 ^{0}C at tillering and flowering stages, respectively.

There was significant variation in interactive effect of varieties and UV-B situations both at tillering and flowering stages. UV-B excluded situation (T_2) at both the stages for both the varieties Jyothi and Uma caused significant canopy cooling more than other combinations. Variety Uma recorded a significant CTD value of -3.50 ^{0}C and Jyothi with value of -3.21 ^{0}C at tillering stage, whereas the corresponding values were -3.87 ^{0}C and 3.23 ^{0}C for the respective varieties at flowering stage.

4.4 Biochemical characters

The result of the biochemical characters observed at tillering and flowering stages are given in Table 6, 7 and 8 and are discussed under the following heading.

4.4.1 Chlorophyll content

Chlorophyll 'a'

The mean data on chlorophyll 'a' are given in Table 7. Chlorophyll 'a' was found significantly different among the varieties both at tillering and flowering stages. Uma recorded significantly higher values of 3.36 mg g^{-1} fr.wt. and 2.31 mg g^{-1} fr.wt. at tillering and flowering stages, respectively. Corresponding values for Jyothi are 2.70 mg g^{-1} fr.wt. and 1.85 mg g^{-1} fr.wt.

Chlorophyll 'a' content showed a decrease from tillering to flowering stage in all the three conditions. Significant difference for chlorophyll 'a' content was found at both stages under three different UV-B situation. Both at tillering and flowering stage crop grown under T_2 recorded highest value of chlorophyll 'a'

Table 7: Mean Chlorophyll 'a' (mg g^{-1} fr.wt.), Chlorophyll 'b' (mg g^{-1} fr.wt.) and Total chlorophyll (mg g^{-1} fr.wt.) of two rice varieties under different UV-B levels.

Tillering stage				Flowering stage			
	Chl 'a'	**Chl 'b'**	**Total chl**		**Chl 'a'**	**Chl 'b'**	**Total chl**
V_1	2.70	0.90	3.62	**V_1**	1.85	0.55	2.41
V_2	3.36	1.01	4.34	**V_2**	2.31	0.62	2.95
Significance	**S**	**NS**	**S**	**Significance**	**S**	**NS**	**S**
T_1	2.78	1.04	3.83	**T_1**	1.76	0.45	2.21
T_2	3.23	0.87	4.05	**T_2**	2.33	0.62	2.95
T_3	3.07	0.97	4.06	**T_3**	2.16	0.69	2.87
CD	**0.23**	**NS**	**NS**	**CD**	**0.24**	**0.12**	**0.24**
V_1T_1	2.73	0.98	3.48	**V_1T_1**	1.60	0.39	1.98
V_1T_2	2.88	0.80	3.82	**V_1T_2**	2.08	0.54	2.63
V_1T_3	2.49	0.93	3.56	**V_1T_3**	1.88	0.73	2.61
V_2T_1	2.84	1.09	3.83	**V_2T_1**	1.92	0.52	2.44
V_2T_2	3.59	0.93	4.53	**V_2T_2**	2.58	0.70	3.28
V_2T_3	3.65	1.01	4.65	**V_2T_3**	2.43	0.65	3.13
CD	**0.32**	**NS**	**0.68**	**CD**	**NS**	**NS**	**NS**

V_1- Jyothi

V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

as 3.23 and 2.33 mg g^{-1} fr.wt. respectively. The chlorophyll 'a' content under T_3 situation was statistically similar to it. Lowest values recorded in T_1 condition at tillering and flowering stages respectively are 2.78 and 1.76 mg g^{-1} fr.wt.

Interactive effect of varieties and treatments showed a significant difference in chlorophyll 'a' only at tillering stage. It was non-significant at flowering stage. In general Uma variety had higher chlorophyll 'a' content. At tillering stage the higher chlorophyll 'a' content was recorded in variety Uma under the conditions of T_2 and T_3 which was more than Jyothi under similar situation. Uma recorded lower chlorophyll 'a' content at T_1 condition whereas Jyothi at T_3 condition.

Chlorophyll 'b'

The mean data on chlorophyll 'b' are given in Table 7. Chlorophyll 'b' recorded non-significant variation between Jyothi and Uma at tillering and flowering stage.

Different UV-B levels expressed significant variation in chlorophyll 'b' only at flowering. Chlorophyll 'b' was significantly higher under UV-B enhanced condition T_3 (0.69 mg g^{-1} fr.wt.), followed by T_2 (0.62 mg g^{-1} fr.wt.) and lower under treatment T_1 (0.45 mg g^{-1} fr wt.) at flowering stage.

Chlorophyll 'b' content due to combinations of variety and levels of UV-B radiation was non-significant at tillering and flowering stage.

Total chlorophyll

The mean data on total chlorophyll content is given in Table 7. The total chlorophyll content decreased from tillering to flowering stages in both varieties. Significant differences were observed between both varieties at tillering and flowering stages. Variety Uma recorded highest total chlorophyll at both stages as 4.34 and 2.95 mg g^{-1} fr.wt. respectively than Jyothi.

Results showed non-significant variation in total chlorophyll content due to UV-B levels at tillering stage but caused significance variation at flowering stage. At flowering stage treatment T_2 recorded more content of total chlorophyll (2.95 mg g^{-1} fr.wt.) but was on par with T_3 (2.87 mg g^{-1} fr.wt.). T_1 recorded significantly lower total chlorophyll content of 2.21 mg g^{-1} fr.wt. at flowering stage.

There was significant variation between varieties and levels of UV-B for total chlorophyll content at tillering stage but was non-significant at flowering stage. Uma recorded highest chlorophyll content under T_3 condition (4.65 mg g^{-1} fr.wt.) which was on par with T_2 (4.53 mg g^{-1} fr.wt.). Jyothi (V_1) recorded highest chlorophyll content (3.82 mg g^{-1} fr.wt.) in UV- B excluded condition (T_2) but was lower than Uma.

4.4.2 Flavonoid content

The mean data on flavonoid content recorded at tillering and flowering stages is given in Table 8.

Varieties, different UV-B situations and its interactive effect could not produce a significant variation in flavonoid content at tillering stage. But there was significant variation in flavonoid content between variety and treatments at flowering stage. Jyothi recorded significantly more flavonoid content of 52.14 A_{300} g^{-1} fr.wt. than Uma (49.25 A_{300} g^{-1} fr.wt.) at flowering stage.

Under different levels of UV-B treatments, natural solar condition i.e. T_1 showed significantly very high level of flavonoid content (55.90 A_{300} g^{-1} fr.wt.) followed by UV-B supplemented condition T_3 (49.20 A_{300} g^{-1} fr.wt.) and lowest level of flavonoid content was recorded under UV-B excluded condition T_2 (46.97 A_{300} g^{-1} fr.wt.).

Table 8: Mean Flavanoid (A_{300} g^{-1} fr.wt.), Catalase (1µ mol of H_2O_2 per min g^{-1} fr.wt.) and IAA (µg g^{-1} fr.wt.) of two rice varieties under different UV-B levels.

Tillering stage				Flowering stage			
	Flavanoid	**Catalase**	**IAA**		**Flavanoid**	**Catalase**	**IAA**
V_1	43.01	8.63	2.02	**V_1**	52.14	10.18	3.16
V_2	41.36	9.98	1.87	**V_2**	49.25	17.24	1.75
Significance	**NS**	**S**	**S**	**Significance**	**S**	**S**	**S**
T_1	43.19	10.07	1.90	**T_1**	55.90	17.30	2.31
T_2	40.90	8.75	1.99	**T_2**	46.97	11.63	2.56
T_3	42.46	9.11	1.94	**T_3**	49.20	12.19	2.50
CD	**NS**	**1.02**	**0.07**	**CD**	**1.53**	**3.01**	**0.08**
V_1T_1	44.27	10.22	1.93	**V_1T_1**	57.53	6.56	2.92
V_1T_2	41.45	7.79	2.10	**V_1T_2**	48.22	10.62	3.38
V_1T_3	43.33	7.89	2.01	**V_1T_3**	50.65	13.36	3.20
V_2T_1	42.11	10.32	1.79	**V_2T_1**	54.27	16.70	1.71
V_2T_2	40.36	9.71	1.94	**V_2T_2**	54.73	13.76	1.80
V_2T_3	41.60	9.92	1.89	**V_2T_3**	47.75	21.25	1.75
CD	**NS**	**1.45**	**0.10**	**CD**	**NS**	**NS**	**0.12**

V_1- Jyothi

V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

4.4.3 Catalase activity

The mean data on catalase activity at tillering and flowering stages is given in Table 8.

The catalase activity was found significantly different between varieties both at tillering and flowering stages. The catalase activity increased from tillering to flowering stage. Variety Uma recorded significantly more activity of catalase enzyme i.e. 9.98 and 17.24 µmol of H_2O_2 min^{-1} g^{-1} fr.wt. at tillering and flowering stages respectively. Respective values for Jyothi are 8.63 and 10.18 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.

Under different levels of UV-B radiation also the catalase activity was found significantly different at both stages. At tillering stage natural solar condition (T_1) recorded highest catalase activity (10.07 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.) which was significantly higher than T_2 (8.75 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.). There was no significant difference in catalase activity between T_1 and T_3. The treatments T_2 and T_3 also recorded non-significant variation for this enzyme activity. At flowering stage also the catalase activity was more under T_1 condition (17.30 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.) followed by T_3 (12.19 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.) the lowest enzyme activity of 11.63 µmol of H_2O_2 min^{-1} g^{-1} fr.wt. was recorded under T_2.

The variety Jyothi recorded the highest catalase activity (10.22 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.) and Uma (10.32 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.) at tillering stage under T_1. Other variety and UV-B combinations expressed statistically similar values expect variety Jyothi at T_2 & T_3 situations. Jyothi at T_3 (7.89 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.) and T_2 (7.79 µmol of H_2O_2 min^{-1} g^{-1} fr.wt.) has least catalase activity. At the tillering stage there was 31.42 per cent increase in catalase activity under T_1 condition than T_2 whereas it was 29.48 per cent increase under T_1 than T_3. The variety Uma recorded 6.12 per cent increase in catalase activity under T_1 than T_2. But the increasing catalase activity was only 4.07 per

cent under T_1 than T_3. These interactive effects were not evident at flowering stage.

4.4.4 Indole-3-Acitic Acid (IAA) content

The mean data on indole-3-acetic acid (IAA) content is given in Table 8.

The IAA content was significantly different among varieties at both stages. Variety Jyothi recorded 2.02 μ g^{-1} fr.wt. and 3.16 μ g^{-1} fr.wt. of IAA at tillering and flowering stage respectively. The respective values for Uma are 1.87 and 1.75 μ g^{-1} fr.wt.

Under different UV-B levels the endogenous IAA content significantly decreased under T_1 condition both at tillering and flowering stages compared to T_2 condition. The highest value for IAA content was observed under T_2 condition in both stages (1.99 and 2.56 μ g^{-1} fr.wt. respectively). IAA content at T_3 situation both at tillering and flowering stage was similar to T_2 situation.

The interactive effect of varieties and UV-B situations recorded significant difference in IAA content both at tillering and flowering stages. Variety Jyothi recorded significantly higher IAA content at T_2 (2.10 μ g^{-1} fr.wt.) and T_3 (2.01 μ g^{-1} fr.wt.) at tillering stage. Jyothi also recorded significantly high level of IAA content at T_2 (3.38 μ g^{-1} fr.wt.) and T_3 (3.20 μ g^{-1} fr.wt.) at flowering stage. Uma recorded significantly lower values than Jyothi at similar situations both at tillering and flowering stages.

4.4.5 Phenol content

The mean data on phenol content is given inTable 9.

Varieties showed significant difference in phenol content both at tillering and flowering stage. Jyothi recorded high phenol content of 1.76 and 1.94 mg g^{-1} fr.wt. at respective stages. Both varieties expressed increase in phenol content from tillering to flowering stage.

Table 9: Mean Phenol (mg g^{-1} fr.wt.), Polyphenoloxidase (PPO) (EU g^{-1} fr.wt.) and Phenylalanine ammonialyase (PAL) (µ mol t-cinnamic g^{-1} fr.wt.) of two rice varieties under different UV-B levels.

Tillering stage				Flowering stage			
	Phenol	**PPO**	**PAL**		**Phenol**	**PPO**	**PAL**
V_1	1.76	0.03	0.76	**V_1**	1.94	0.03	0.40
V_2	1.24	0.03	0.57	**V_2**	1.58	0.01	0.38
Significance	**S**	**NS**	**S**	**Significance**	**S**	**S**	**NS**
T_1	1.98	0.04	0.87	**T_1**	2.32	0.03	0.49
T_2	1.21	0.01	0.56	**T_2**	1.47	0.01	0.28
T_3	1.31	0.03	0.57	**T_3**	1.50	0.02	0.41
CD	**0.14**	**NS**	**0.06**	**CD**	**0.28**	**0.02**	**0.07**
`V_1T_1	2.25	0.04	1.04	**V_1T_1**	2.39	0.02	0.59
V_1T_2	1.49	0.01	0.62	**V_1T_2**	1.67	0.01	0.14
V_1T_3	1.55	0.02	0.63	**V_1T_3**	1.77	0.01	0.41
V_2T_1	1.71	0.05	0.70	**V_2T_1**	2.24	0.05	0.42
V_2T_2	0.94	0.01	0.50	**V_2T_2**	1.16	0.02	0.38
V_2T_3	1.07	0.03	0.49	**V_2T_3**	1.34	0.02	0.41
CD	**NS**	**NS**	**0.09**	**CD**	**NS**	**NS**	**0.10**

V_1- Jyothi

V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

Crop grown in natural solar condition (T_1) recorded high phenol content at tillering (1.98 mg g^{-1} fr.wt.) and at flowering (2.32 mg g^{-1} fr.wt.) stages compared to other situations T_2 and T_3 at both the stages and were on par. The lowest phenol content was observed under T_2 condition at tillering (1.21 mg g^{-1} fr.wt.) and flowering (1.47 mg g^{-1} fr.wt.) stage.

The interactive effect between varieties and situations could not produce a significant difference in phenol content at both stages.

4.4.6 Polyphenoloxidase (PPO) activity

The mean data on polyphenoloxidase activity is given in Table 9.

PPO, which is responsible for oxidation of phenolic compounds, was found increased due to more UV-B radiation under open condition (T_1) when compared to T_2 and T_3. There was no significant difference in PPO activity due to varieties, different situations and interactive effect of varieties and treatments at tillering stage. However it was significantly different between varieties and treatments at flowering stage Jyothi recorded the highest PPO activity of 0.03 EU g^{-1} fr.wt. than Uma (0.01 EU g^{-1} fr.wt.) at flowering stage.

At flowering stage T_1 condition recoded significantly higher activity of PPO (0.03 EU g^{-1} fr.wt.) than T_2 (0.01 EU g^{-1} fr.wt.) and T_3 (0.02 EU g^{-1} fr.wt.).

4.4.7 Phenylalanine ammonialyase (PAL) activity

The mean data on phenylalanine ammonialyase activity is given in Table 9.

The activity of PAL was observed significantly different at tillering stage in varieties whereas, it was non-significant at flowering stage. At tillering stage highest PAL activity of 0.76 µ mol t-cinnamic g^{-1} fr.wt. was recorded by Jyothi followed by Uma (0.57 µ mol t-cinnamic g^{-1} fr.wt.).There was a decrease in PAL activity from tillering to flowering stage in both varieties.

Under different UV-B levels significant variation in PAL activity at tillering and flowering stages was observed. T_1 recorded highest PAL activity at both stages; 0.87 µ mol t-cinnamic g^{-1} fr.wt. at tillering stage and 0.49 µ mol t-cinnamic g^{-1} fr.wt. at flowering stage. These were significantly more when compared to T_2 and T_3. PAL activity was not significantly affected due to T_2 and T_3 situations at tillering stage.

The variety Jyothi recorded significantly higher PAL activity in natural solar condition (T_1) at both the stages compared to Uma in T_1 condition. The lowest PAL activity was observed under T_2 condition for both varieties at tillering stage. Both the varieties recorded non-significant difference for this character under T_2 and T_3 condition at tillering stage.

4.5 Yield and yield parameter

The results of yield and yield parameters are given under the following headings.

4.5.1. Number of panicle per hill

The mean data on number of panicle per hill is given in Table 10.

The panicle number per hill varied significantly between varieties. The variety Jyothi recorded 16.2 panicles per hill whereas, Uma recorded 14.7 panicle per hill.

The different levels of UV-B radiations also caused significant variation in panicle number. More number of panicles per hill (16.9) was recorded under T_1 condition than T_2 (15.1) and T_3 (14.2).

The interactive effect of varieties and treatments could not produce any significant variation in number of panicle per hill.

Table 10: Mean Number of panicle per hill, Number of spikelets per panicle, Filled grain per panicle and spikelet sterility (%) of two rice varieties under different UV-B levels.

	No. Of Panicle/ Hill	**No. Spikelets / panicle**	**Filled grain/ Panicle**	**Spikelet sterility (%)**
V_1	16.2	90.9	65.1	35.05
V_2	14.7	121.2	74.2	42.99
Significance	**S**	**S**	**S**	**S**
T_1	16.9	71.6	23.9	66.76
T_2	15.1	138.3	110.6	19.63
T_3	14.2	108.3	74.3	30.66
CD	**1.0**	**9.0**	**8.3**	**4.83**
V_1T_1	17.5	54.9	17.9	67.21
V_1T_2	15.6	118.8	98.9	16.96
V_1T_3	15.4	99.0	78.4	20.98
V_2T_1	16.3	88.2	29.9	66.31
V_2T_2	14.6	157.7	122.3	22.31
V_2T_3	13.0	117.6	70.2	40.35
CD	**NS**	**NS**	**11.77**	**6.83**

V_1- Jyothi

V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

4.5.2 Number of spikelet per panicle

The mean data on number of spikelet per panicle was computed and given in Table 10.

The number of spikelet per panicle varied significantly between the variety Jyothi and Uma. The more number of spikelet per panicle was recorded in Uma (121.2) whereas, Jyothi recorded only 90.9 spikelet per panicle.

Significant variation was also observed in number of spikelet per panicle under different treatments. More number of spikelet per panicle (138.3) was recorded under T_2 followed by T_3 (108.3) and less number of spikelet was recorded under T_1 (71.6), where crop was exposed to natural solar radiation.

The interactive effects between varieties and UV-B situations were not significant.

4.5.3 Filled grain per panicle

The mean data on number of filled grain per panicle is given in Table 10.

Both varieties Jyothi and Uma recorded significant difference in number of filled grain per panicle. Uma recorded more number of filled grains per panicle (74.2) followed by Jyothi (65.1).

The different levels of UV-B radiation also caused significant variation in number of filled grains per panicle. The highest number of filled grains per panicle (110.6) was observed under T_2 condition followed by T_3 condition which recorded 74.3 filled grains per panicle. The lowest number (23.9) was recorded under T_1.

The interactive effect of varieties and treatments also registered significant difference in number of filled grains per panicle. The crop exposed to natural solar UV-B radiation recorded the lowest value of 17.9 and 29.9 for both the variety Jyothi and Uma, respectively. The highest number of filled grain per panicle was

recorded under UV-B excluded condition (T_2) for Jyothi and Uma (98.9 and 122.3), among which, Uma registered significant number of filled grain panicle.

4.5.4 Spikelet sterility

The mean data on spikelet sterility percentage is given in Table 10.

The highest spikelet sterility percentage (42.99 %) was observed in the variety Uma and lowest (35.05 %) percentage was observed in the variety Jyothi.

The different UV-B radiation could cause a significant difference in spikelet sterility percentage. The lowest spikelet sterility was observed under T_2 condition (19.63 %) followed by T_3 (30.66 %) whereas, highest spikelet sterility percentage was observed under T_1 condition (66.76 %).

Both varieties Jyothi and Uma recorded significant variation in spikelet sterility percentage.

4.5.5 1000 grain weight

The mean data on 1000 grain weight is given in Table 11.

The variety Jyothi recorded (24.20 g) significantly higher 1000 grain weight than Uma (21.14 g).

Crop grown under three different levels of UV-B radiation caused significant differences in 1000 grain weight. The highest (23.76 g) 1000 grain weight was observed in T_2 followed by T_3 (22.32 g) and the lowest (21.92 g) was observed in T_1.

The interactive effect among varieties and treatments did not produce any significant variation in thousand grain weight.

4.5.6 Grain yield per pot

The mean data on grain yield per pot is given in Table 11.

Table 11: Mean 1000 grain weight (g), Grain yield (g), Straw yield (g) and Harvest index (%) of two rice varieties under different UV-B levels.

	1000 grain weight (g)	**Grain yield (g)**	**Straw yield (g)**	**Harvest index (%)**
V_1	24.20	57.94	99.54	34.36
V_2	21.14	54.92	104.37	34.48
Significance	**S**	**NS**	**NS**	**NS**
T_1	21.92	16.58	128.78	10.97
T_2	23.76	79.64	87.92	47.51
T_3	22.32	73.07	89.17	44.77
CD	**0.88**	**6.57**	**9.42**	**2.59**
V_1T_1	22.97	8.91	121.60	6.83
V_1T_2	25.43	84.19	89.22	48.61
V_1T_3	24.19	80.71	87.79	47.65
V_2T_1	20.87	24.24	135.95	15.12
V_2T_2	22.10	75.08	86.63	46.42
V_2T_3	20.45	65.43	90.55	41.89
CD	**NS**	**9.30**	**NS**	**3.67**

V_1- Jyothi

V_2- Uma

T_1- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation).

T_2- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero).

T_3- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

Comparatively more grain yield per pot was recorded in variety Jyothi and less in Uma but both varieties could not produce significant difference.

The crop under UV-B excluded condition (T_2) recorded the highest (79.64 g) grain yield per pot followed by T_3 (73.07 g) which was significantly different from T_1 (16.58 g). T_2 and T_3 yield levels were on par.

The interactive effect of varieties and treatments recorded significant variation in grain yield per pot. The highest (84.19 and 75.08 g respectively) grain yield per pot was recorded under T_2 condition for both varieties Jyothi and Uma respectively. The lowest yield of 8.91 and 24.24 g was recorded in T_1 condition in the respective varieties.

4.5.7 Straw yield per pot

The mean data on straw yield per pot is given in Table 11.

The straw yield per pot could not produce significant difference among the varieties.

The crop grown under different UV-B levels gave significantly higher straw yield per pot in T_1 condition (128.78 g) compared to T_2 (87.92 g) and T_3 (89.17 g), which were on par.

The interactive effect between varieties and treatment could not produce any significant difference for straw yield per pot.

4.5.8 Harvest index

The mean data on harvest index percentage is given in Table 11.

The harvest index percentage recorded non-significant difference between the varieties Jyothi and Uma.

Under different levels of UV-B radiation harvest index was recorded significant difference. T_2 recorded the highest (47.51 %) harvest index percentage

followed by T_3 (44.77 %) and the lowest (10.97 %) harvest index percentage recorded under T_1 condition.

The interactive effect in varieties and treatments was significantly different. The highest (48.61 and 46.42 %) harvest index percentage recorded under T_2 condition in both varieties Jyothi and Uma. Lowest (6.83 and 15.12 %) recorded under T_1 condition for above varieties, respectively.

Discussion

5. DISCUSSION

The present investigations were carried out to study the effect of UV-B radiation on morphological, phenological, physiological characters and yield parameters on two rice varieties Jyothi and Uma. The rice varieties were grown in pot culture under three different levels of UV-B radiation throughout the growing periods. The results obtained are discussed in this chapter.

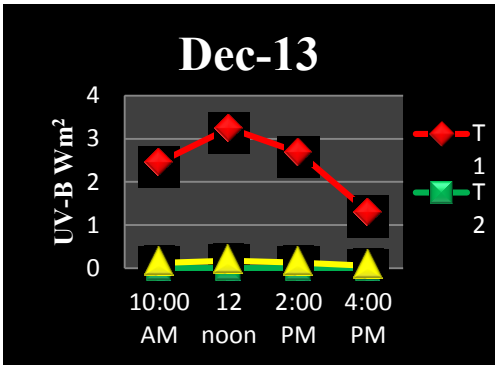
5.1 UV-B and PAR (Photosynthetically Active Radiation) measurements

The UV-B radiation and PAR were significantly higher in natural solar UV-B condition (T_1) when compared to T_3 where UV-B was supplemented with UV-B lamps in polyhouse. UV-B radiation and PAR were recorded higher values in the month of March 2014 and lower value during December 2013 under T_1 condition (Figure 1 and 2; Table 1). Highest values were observed during flowering stage and lowest value recorded during initial stage of the crop. Both the parameters showed gradual increase from 10 am to 12 noon and decreased from 12 noon to 4 pm in both open natural (T_1) and supplemented UV-B condition (T_3), and maximum values were observed at 12 noon in both conditions. All these indicated that the current level of natural solar UV-B radiation and light irradiance as PAR are beyond biologically active UV-B and PAR. Growth reduction in plants depends not only on the level of UV-B exposure but on the associated level of photosynthetically active radiation (Teramura, 1986).

5.2 Morphological character as influenced by UV-B radiation

Both rice varieties Jyothi and Uma grown without solar UV-B radiation (T_2) attained higher plant height and more tiller number than plant grown under natural solar UV-B radiation (T_1) (Table 3). There was up to 44.42 percent increase in shoot length under UV-B excluded condition (T_2) and 5 per cent under UV-B supplemented condition (T_3) at tillering stage whereas, these increments were 32.93 per cent and 18.61 per cent under T_2 and T_3 condition

(A)



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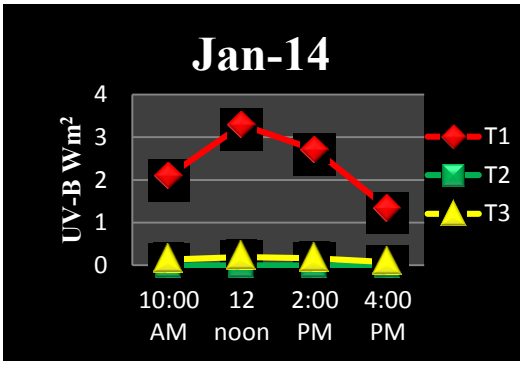
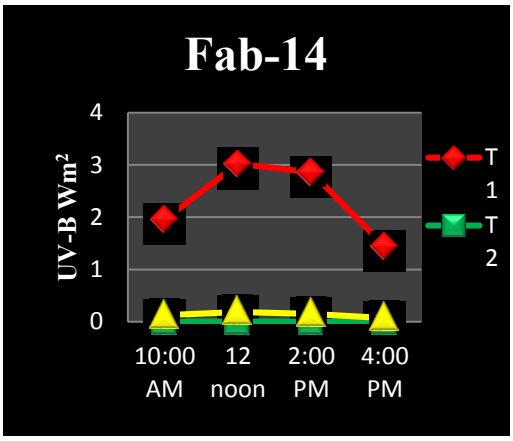


(C)



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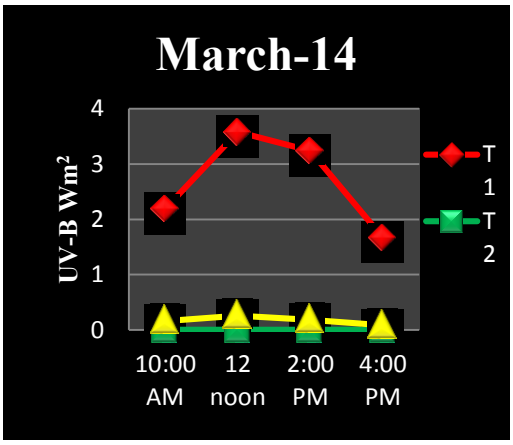

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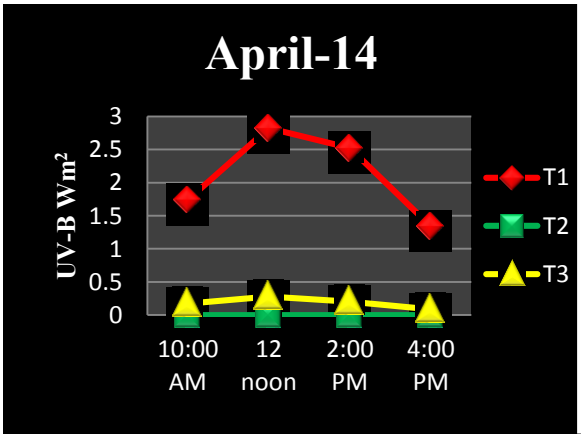


Fig.1.UV-B levels under different conditions during growing period of crop (Dec-13 to April-14); **T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation);**T_2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero);**T_3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

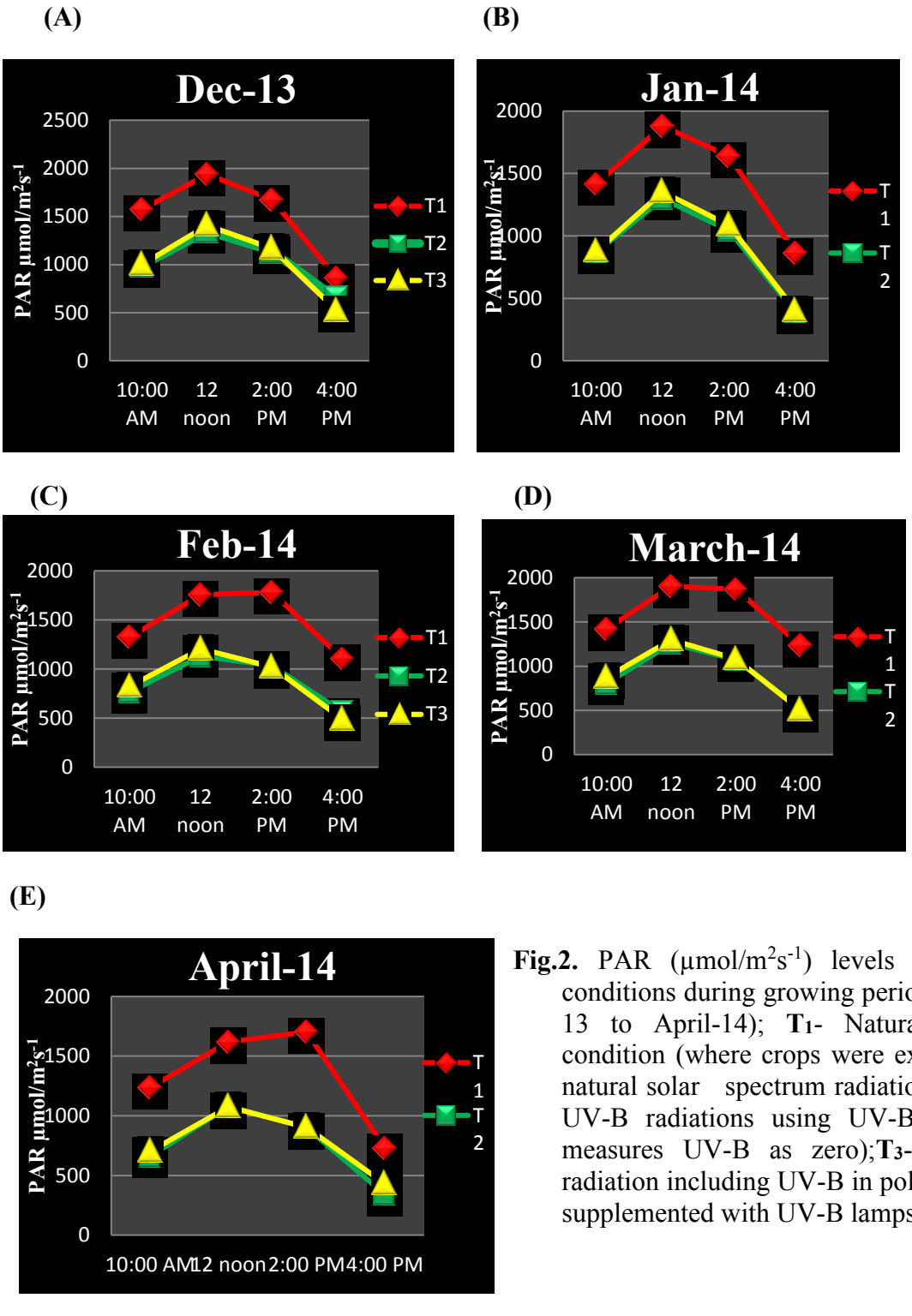


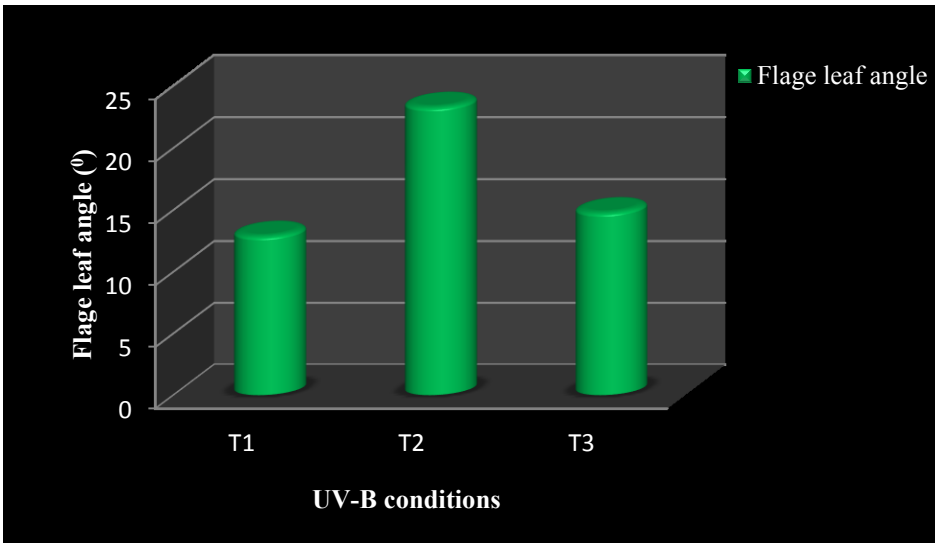
Fig.2. PAR (µmol/m^2s^{-1}) levels under different conditions during growing period of crop (Dec-13 to April-14); **T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation);**T_2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero);**T_3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps.

respectively at flowering stage. Tiller number was 33.9 per cent higher under UV-B excluded condition (T_2) at tillering stage. These suggest that the current level of UV-B radiation present in natural solar radiation can potentially inhibit the plant growth by reducing plant height and tiller number. Similar observations were reported in rice by Mohammed *et al.* (2007) that the ambient level of UV-B radiation reduced plant height by 5 per cent and tiller number by 25 per cent.

Leaf thickness measured as specific leaf weight was found to increase under open condition (T_1) than UV-B excluded condition (T_2) (Table 3). This leaf thickness was significantly more for variety Jyothi when compared to Uma at tillering stage, but this varietal difference was non-significant at flowering stage. However, increase in specific leaf weight cannot be assumed as a result of UV-B radiation stress as different species have different mechanism for tolerating UV-B stress (Rozema *et al.,* 1997a). The earlier reports also indicated that increase in leaf thickness was a typical UV-B induced response (Jansen *et al.,* 1998; Jansen, 2002; Krizek, 2004). Klem *et al.* (2012) have reported that leaf thickness was increased by enhanced level of UV-B and PAR. The present result also corroborated this inference that leaf thickness increased under open condition which received more UV-B radiation and PAR.

The results on number of productive tillers indicated significant variation between varieties and treatments. Among the varieties Jyothi recorded the highest number of productive tillers per hill and among treatments open condition (T_1) produced more number of productive tillers per hill than UV-B excluded condition (T_2) (Table 4). The UV-B and PAR data indicated that at initial stage of growth UV-B radiation and PAR were comparatively less when compared to later stages of growth. This may be optimum for turning maximum number of productive tillers at open condition compared to other conditions. Further the high photosynthetic rate at earlier stage of growth may enhance the number of productive tillers. In open condition (T_1) 66.54 per cent of total tillers turned to productive whereas, under UV-B supplemented condition (T_3) 63.37 per cent and under UV-B excluded condition (T_1) 60 percent turned into productive

(A)



(B)

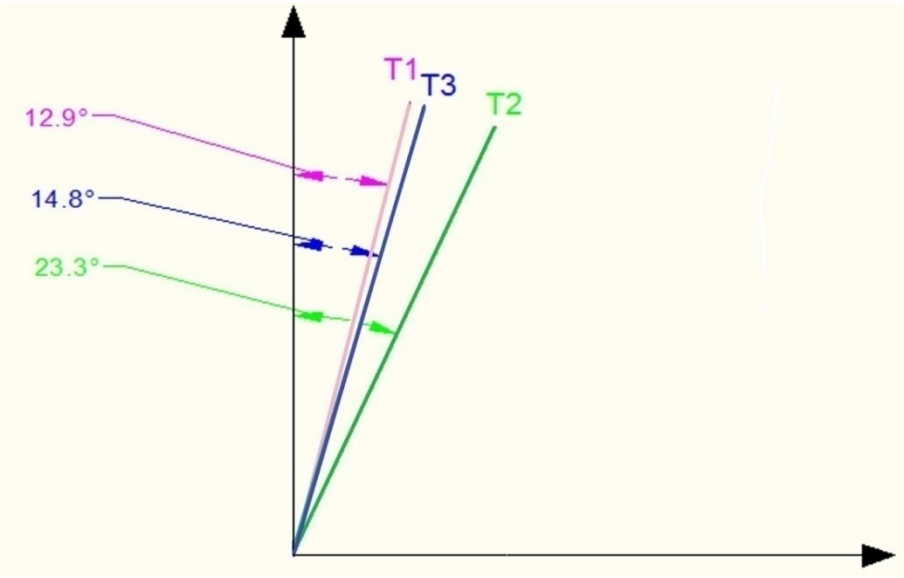


Fig.3. Effect of UV-B radiation on flag leaf angle (^{0}) under UV-B conditions (**T_1**- Natural solar UV-B conditions (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

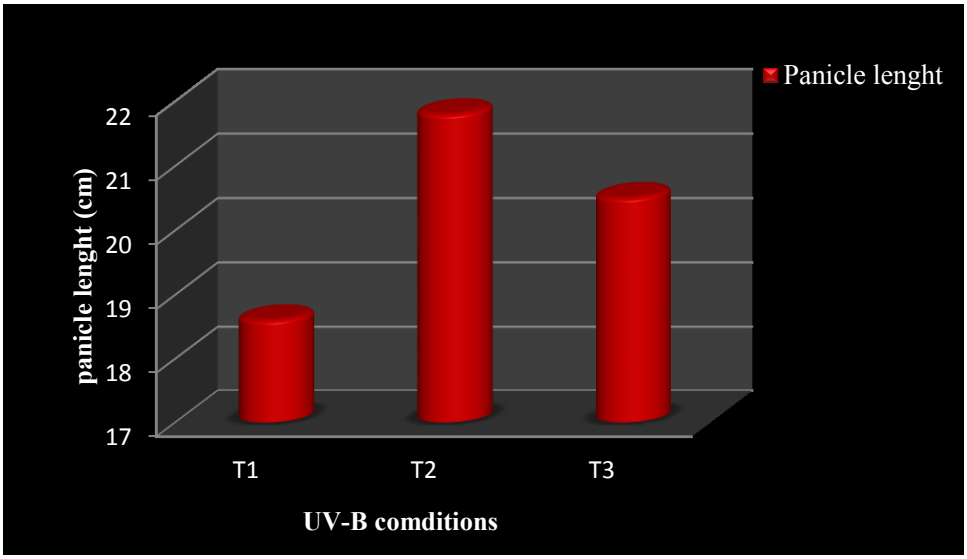


Fig.4. Effect of UV-B radiation on panicle length under UV-B conditions (**T_1**- Natural solar UV-B conditions (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

tillers. Similar finding that tiller number was decreased in rice under elevated UV-B radiation was reported by Hidema *et al.* (2005).

In rice, both flag leaf angle and panicle length had an important effect on rice yield. Modification of flag leaf angle has been emphasised as means of obtaining better light utilization with more upright leaf permitting penetration of solar energy into lower leaf. The result on flag leaf angle indicated that it is significantly influenced by UV-B radiation. At 50 per cent flowering stage the flag leaf angle was very erect under T_1 and T_3 condition and might have received low relative light intensity. But at T_2 condition at the same stage the flag leaf angle had a better horizontal inclination (Figure 3; Table 4). Both steeper leaf angle and increased wider angle i.e. self shading leaf angle may reduce potential carbon gain by decreasing total light penetration. The present result was further confirm with the observation of Dutta *et al.* (2002) that for enhancing grain yield in rice flag leaf angle must be wide and vertical.

The panicle length also reduced under natural solar condition (T_1) (Figure 4; Table 4). Earlier report of Mohammed and Tarpley (2009) also explained that enhanced UV-B radiation caused decrease in main stem panicle length and number of primary branches per panicle in rice crop. The results also indicated that increased panicle length under T_2 condition may be related with high free IAA content in leaves, which is consistent with the observation that panicle length increased in rice by exogenously applied IAA (Choi *et al.,* 2012).

5.3 Phenological characters affected by UV-B radiation

In the present study the duration from transplanting to appearance of first panicle (days to heading), 50% flowering and days to harvestable maturity varied under different levels of UV-B radiation (Table 5). The result indicated that the UV-B radiation alters the above phenophases and prolonged time to achieve the respective growth phases under natural solar condition (T_1) than UV-B excluded condition (T_2). Plant attained all the phenophases four to five days earlier under UV-B excluded condition (T_2) (Figure 5). The delay to achieve all the

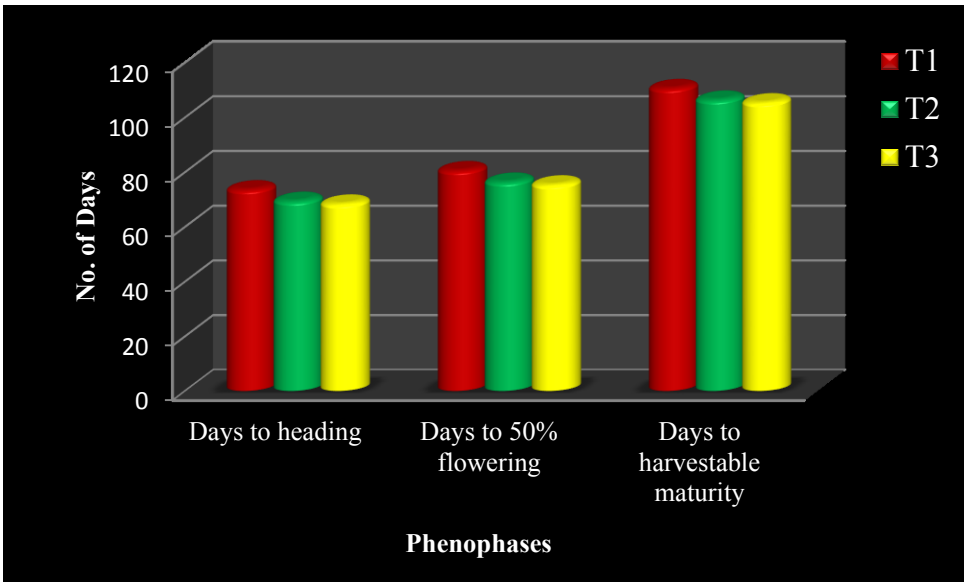


Fig.5. Effect of UV-B radiation on days to heading, days to 50% flowering and days to harvestable maturity under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

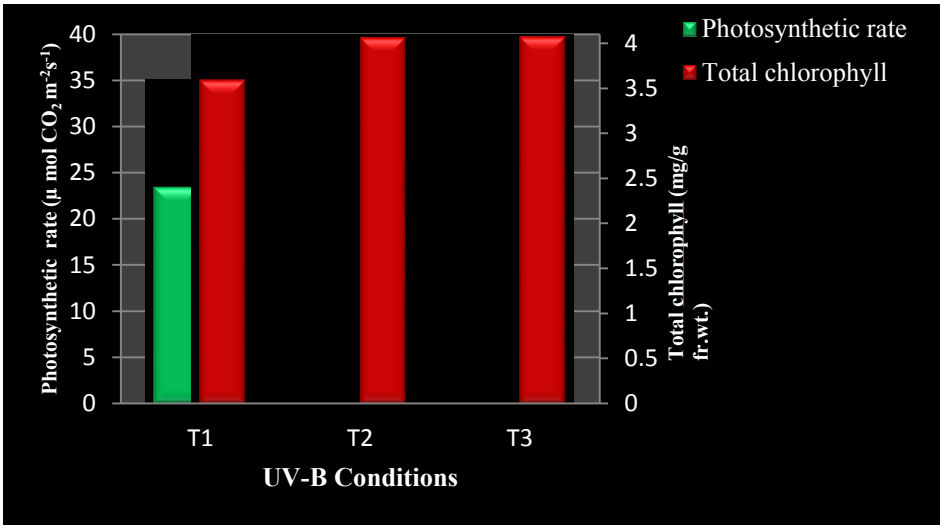
phenophases under natural solar UV-B condition (T_1) may be due to the low chlorophyll content which in turn reduced photosynthetic rate at tillering stage. Similar result, delay to achieve growth phases like flowering, was reported in crops like bush bean and green gram under high UV-B radiation (Saile and Tevini, 1997; Rajendiran and Ramanujam, 2004). Sikuku *et al.* (2010) also reported that environmental stresses took longer time to flower and to mature as compared to crop grown under optimum growth conditions.

At tillering stage the photosynthetic rate was more under T_2 condition when compared to flowering stage. Hence this high photosynthetic rate at vegetative stage could be attributed to difference in photoassimilates accumulated to attain sufficient physiological maturity for flowering and other phenophases of growth. Among the two varieties Jyothi and Uma, the results indicated that all phenophases delayed in Uma when compared to Jyothi.

5.4 Physiological characters affected by UV-B radiation

Photosynthesis is the most important metabolic process of plant essential for production of biomass. The gas exchange measurements indicated significant reduction in photosynthesis and transpiration rate under open condition (T_1) (Table 6). The reduction in rate of photosynthesis was accompanied by decrease in transpiration rate and stomatal conductance. This finding is consistent with result obtained by YunSheng *et al.* (2011) in barely and Basahi *et al.* (2014) in lettuce. The lowest photosynthetic rate expressed under open condition (T_1) was due to stomatal closure under enhanced level of UV-B radiation in open condition. The decrease in photosynthesis also have seen as a result of the corresponding decrease in chlorophyll content (chlorophyll ‘a’, chlorophyll ‘b’ and total chlorophyll) in plant exposed to T_1 condition (Figure 6). Petrulova *et al*. (2014) also observed similar results in *Matricaria chamomilla*. Stomatal closure by enhanced UV-B and increased leaf diffusive resistance has also been demonstrated with the action spectrum peaking below wavelength of 290 nm. (Tevini and Teramura, 1989). The photosynthetic rate inhibition is an

(A) At Tillering stage



(B) At Flowering stage

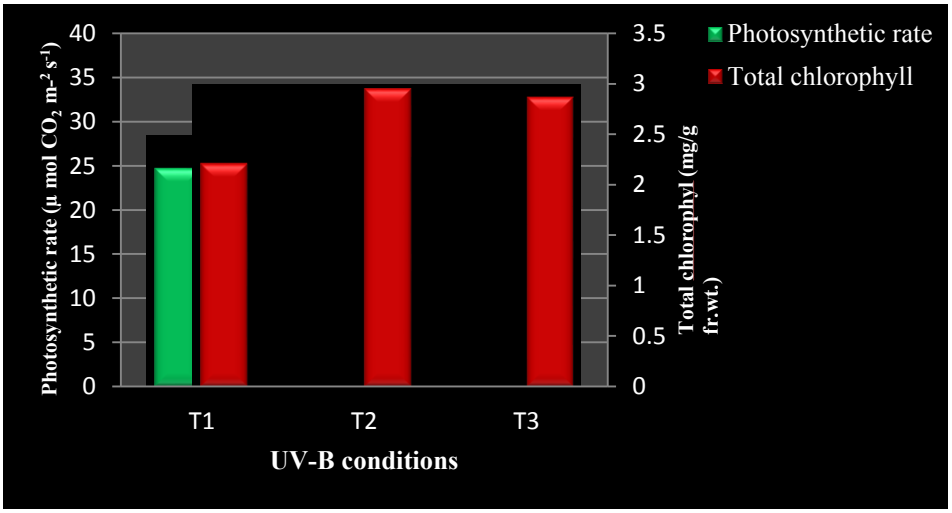
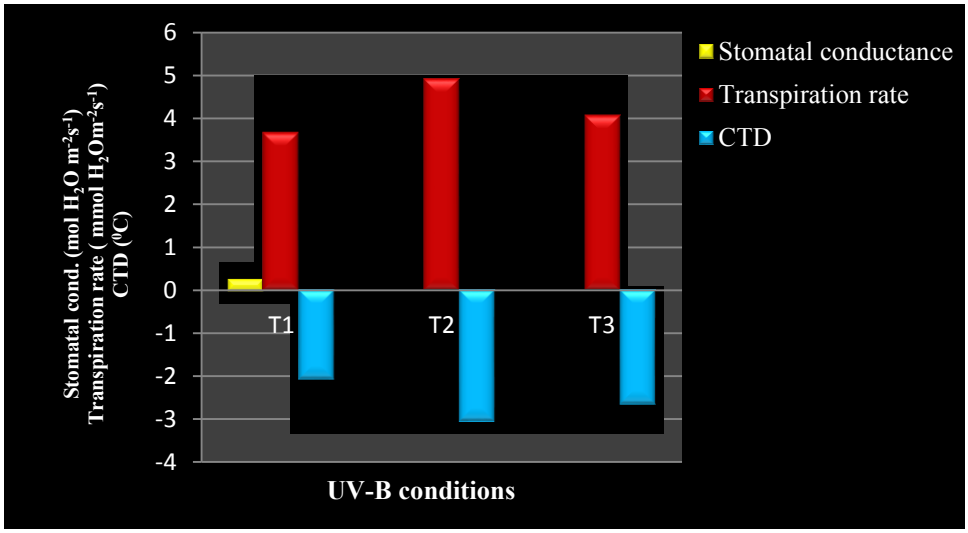


Fig.6. Effect of UV-B radiation on Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1}) and Total chlorophyll (mg g^{-1} fr. wt.) under UV-B condition (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

(A) At Tillering stage



(B) At Flowering Stage

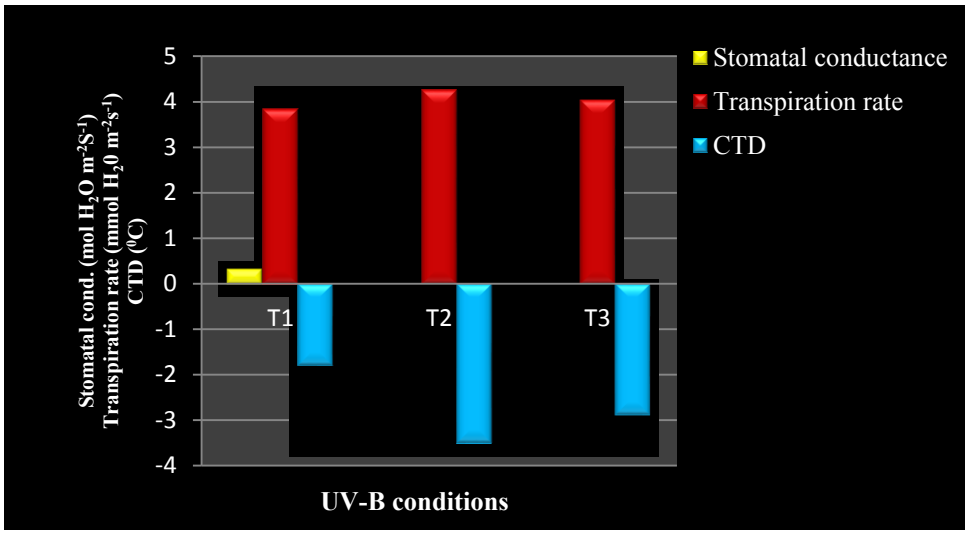


Fig.7. Effect of UV-B radiation on Transpiration rate (mmol H_2O m^{-2} s^{-1}), Stomatal conductance (mol H_2O m^{-2} s^{-1}) and CTD (^0C) under UV-B condition (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

accumulation effect of UV-B radiation at photosystem, thylakoid membrane and stromal compounds like RuBisCO (Nedunchezhian and Kulandaivelu, 1991; Kulandaivelu *et al.*, 1991). The increased plant growth and dry matter accumulation in UV-B excluded crop (T_2) may primarily be as a result of increased photosynthesis. Though the varieties could not express a significant difference in photosynthetic rate at tillering stage, Jyothi recorded high photosynthetic rate and stomatal conductance at flowering stage.

The result indicated more canopy cooling under UV-B excluded condition (T_2) and high leaf temperature in open natural condition (T_1) (Figure 7). This is related to high transpiration rate in T_2 which in turn cause high CTD (Canopy Temperature Depression) whereas, in open condition high UV-B radiation caused less transpiration rate there by maintained high leaf temperature. Guendous *et al.* (2012) also correlated CTD with transpiration rate and stomatal conductance and hence suggested that CTD could be used as selection criteria under any environmental stress condition. Munjal and Rena (2003) reported that adjustment of microclimate like cool canopy during grain filling period in wheat was an important physiological character for stress tolerance.

5.5 Biochemical characters affected by UV-B radiation

Decrease in chlorophyll pigment content (Chlorophyll 'a', chlorophyll 'b' and total chlorophyll) was evident during exposure of the crop to the open condition (T_1), where they received more UV-B radiation (Table 7; Figure 6). The content of chlorophyll 'a' was significantly reduced at both stages i.e. tillering and flowering stage under open condition (T_1) whereas, chlorophyll 'b' and total chlorophyll showed significant reduction at flowering stage only. From these results it is inferred that the UV-B radiation affected the degradation of chlorophyll 'a' rather than chlorophyll 'b' and total chlorophyll. Similar situation has been observed by Lidon and Ramalho (2011) in rice. Day *et al.* (1996) also reported that chlorophyll content decreased due to high UV-B radiation in pea owing to reduction in expression of chlorophyll a/b binding protein.

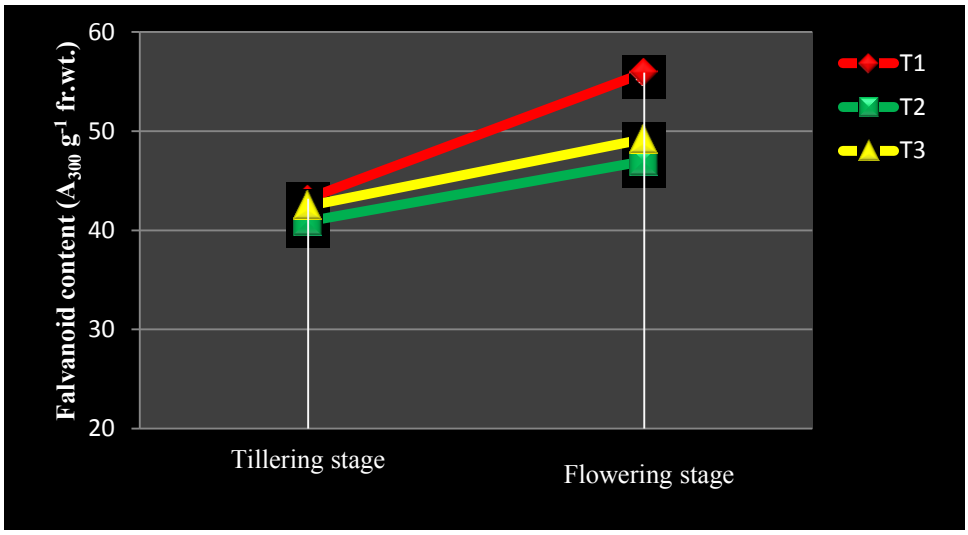


Fig.8. The content of Flavanoid (A300 g-1 fr. wt.) increase from tillering stage to flowering stage under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

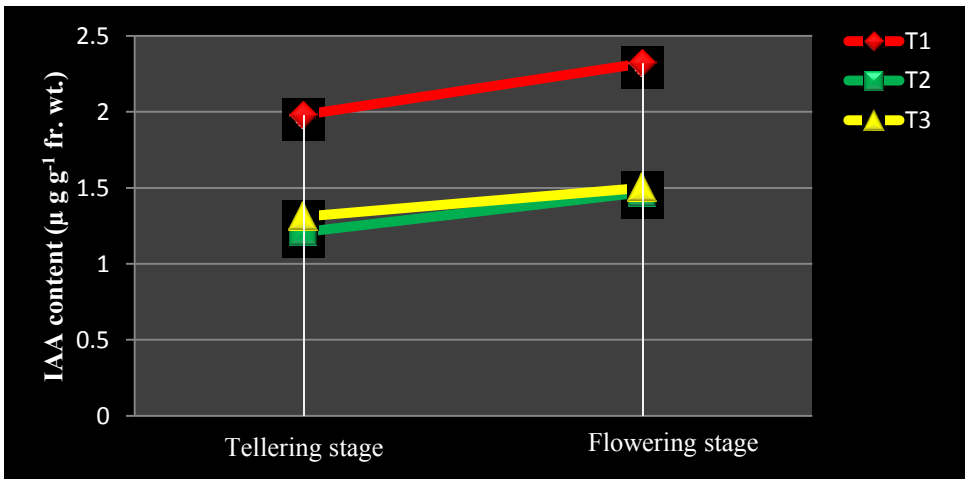


Fig.9. The content of IAA (µ g g^{-1} fr. wt.) content increase from tillering stage to flowering stage under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

The flavanoids, which are implicated as photo protecting pigment varied significantly between variety and treatment only at flowering stage (Table 8; Figure 8). The highest flavanoid content in leaves of rice was observed under T_1 condition. This may be due to the high UV-B radiation received at canopy level under T_1 condition in the month of March-2014 where crop was at flowering stage. UV-B radiation received at tillering stage may not be at a significant level to induce flavanoid content at that stage. The flavanoid concentration can reduce UV-B penetration and protects photosynthetic apparatus to some extent depending on the threshold level of UV-B radiation. The present observation is in agreement with the findings of Ziska and Teramura, 1992; Dai *et al*., 1992; Yuan *et al.,* 2010 in rice.

Catalase is the most efficient antioxidant enzyme which protects plants by scavenging free radicals and H_2O_2. Present study also indicated that the catalase activity was significantly high under T_1 condition at tillering and flowering stages (Table 8). The catalase activity was increased by 15.02 per cent under open condition (T_1) at tillering stage and 48.82 per cent at flowering stage. It shows that catalase activity was enhanced by increase in UV-B radiation under open condition (T_1). The finding correlated with the views expressed by Xu *et al.* (2008) in soybean and Fedina *et al.,* 2010 and Yongmei *et al.,* 2014 in rice. The varieties Jyothi and Uma differed in catalase activity at tillering and flowering stages. Among varieties Uma recorded the highest catalase activity at both stages.

The remarkable difference in endogenous IAA content was observed between varieties and also between treatments at tillering and flowering stages (Figure 9; Table 9). UV-B excluded condition (T_2) recorded high endogenous IAA content at both stages. The increase in IAA content at flowering stage reflected more yield under T_2 condition. Crop received high UV-B radiation under open natural condition (T_1) showed lower endogenous IAA content during active growth of the plant. This may be due to interference of UV-B radiation with auxin metabolism possibly through photo oxidation of IAA. Such a trend was observed by Ros and Tevini, (1995) in sunflower seedlings. This was further confirmed

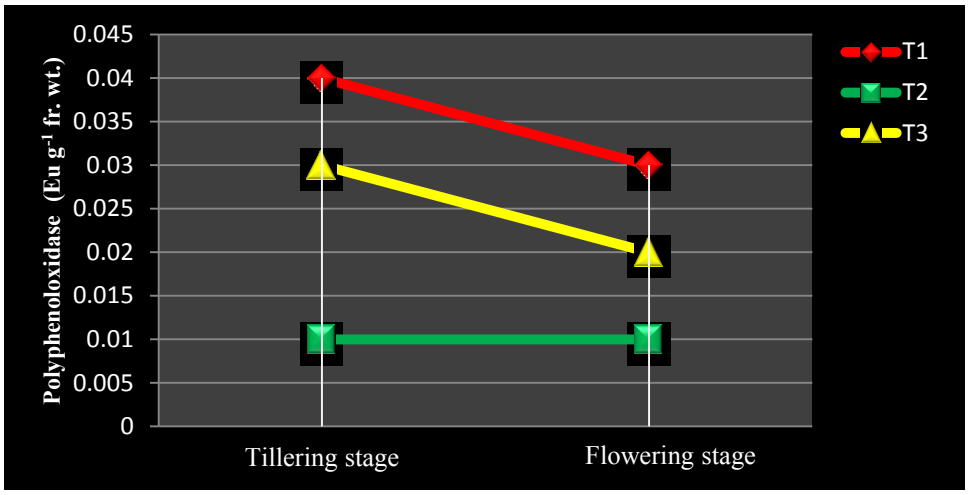


Fig.10. The content of Polyphenoloxidase activity (EU g^{-1} fr. wt.) increase from tillering stage to flowering stage under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

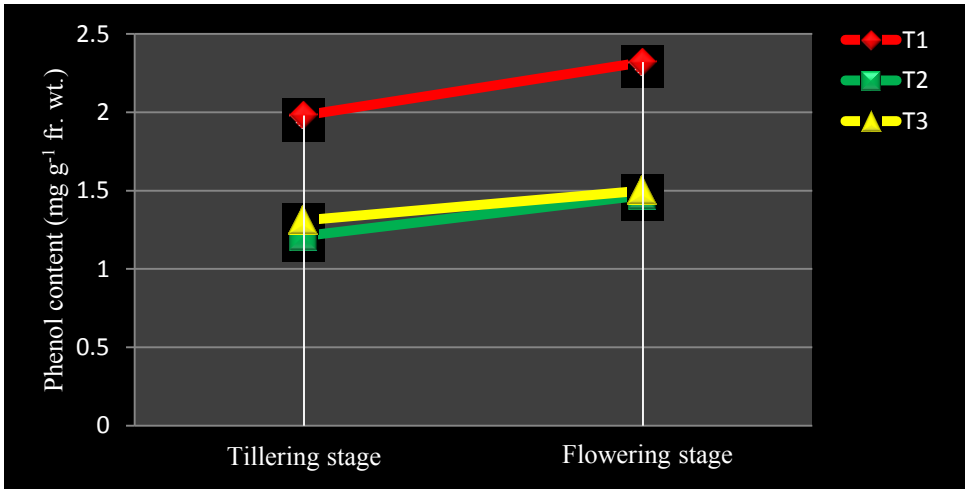
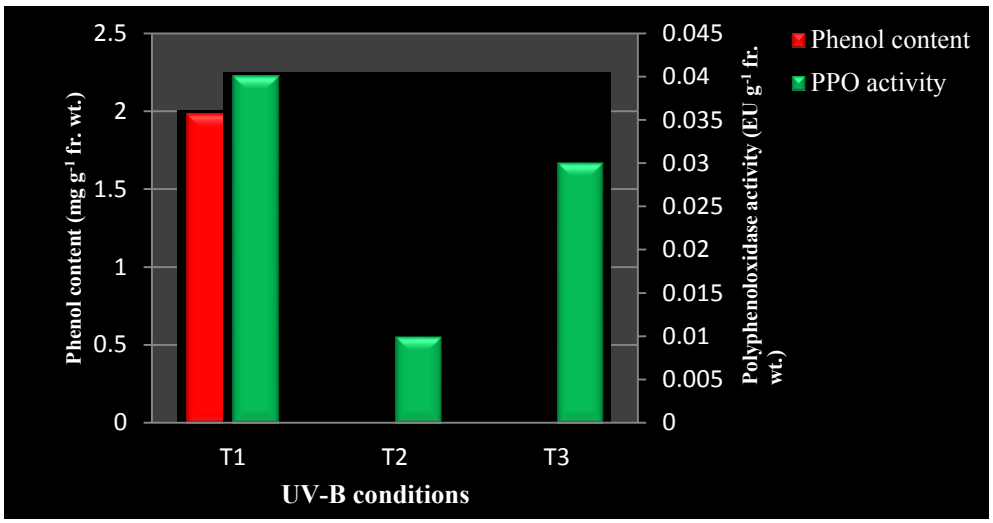


Fig.11. The content of Phenol content (mg g^{-1} fr. wt.) increase from tillering stage to flowering stage under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

(A) At tillering stage



(B) At Flowering stage

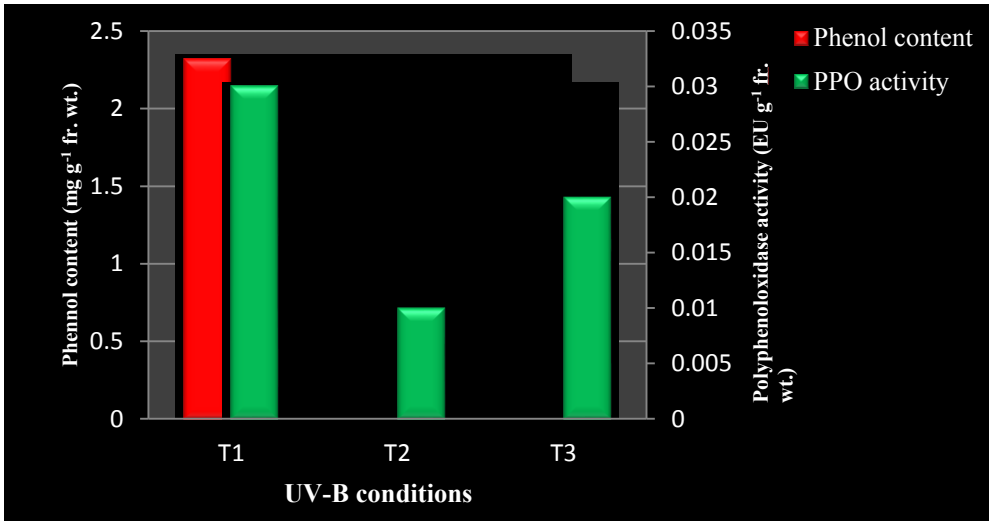


Fig.12. Effect of UV-B radiation on Phenol content (mg g^{-1} fr. wt.) and Polyphenoloxidase activity (EU g^{-1} fr. wt.) under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

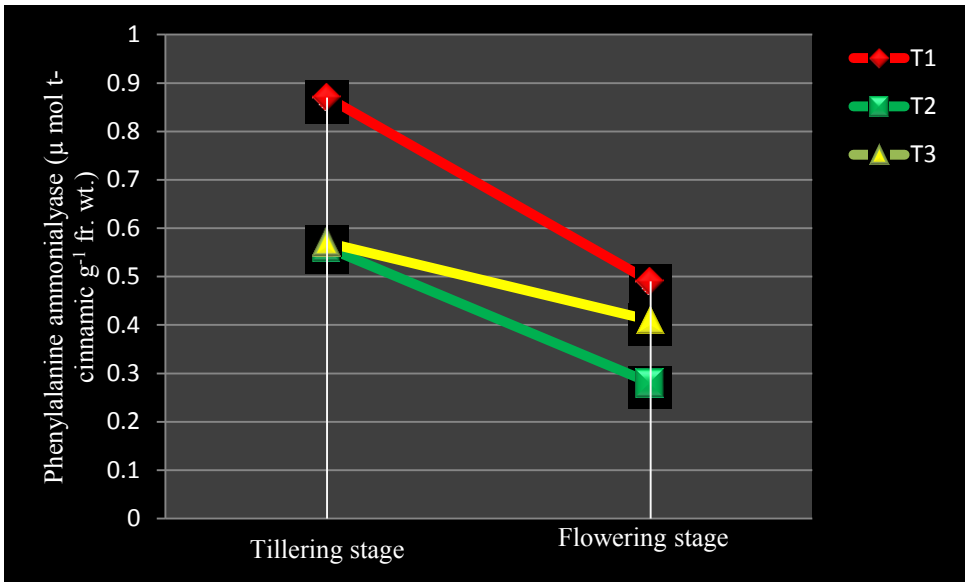
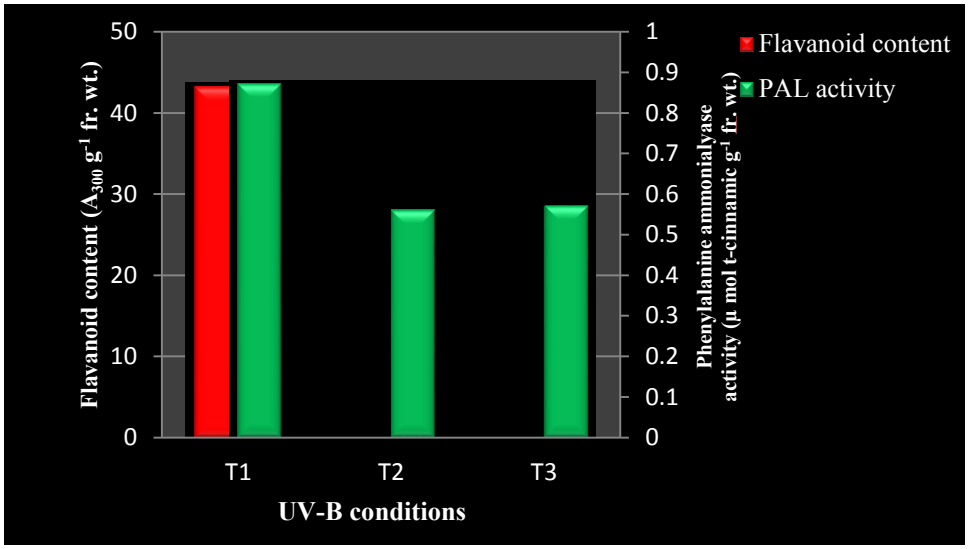


Fig.13. The content of Phenylalanine ammonialyase (µ mol t-cinnamic g^{-1} fr. wt.) increase from tillering stage to flowering stage under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

(A) At Tillering stage



(B) At Flowering stage

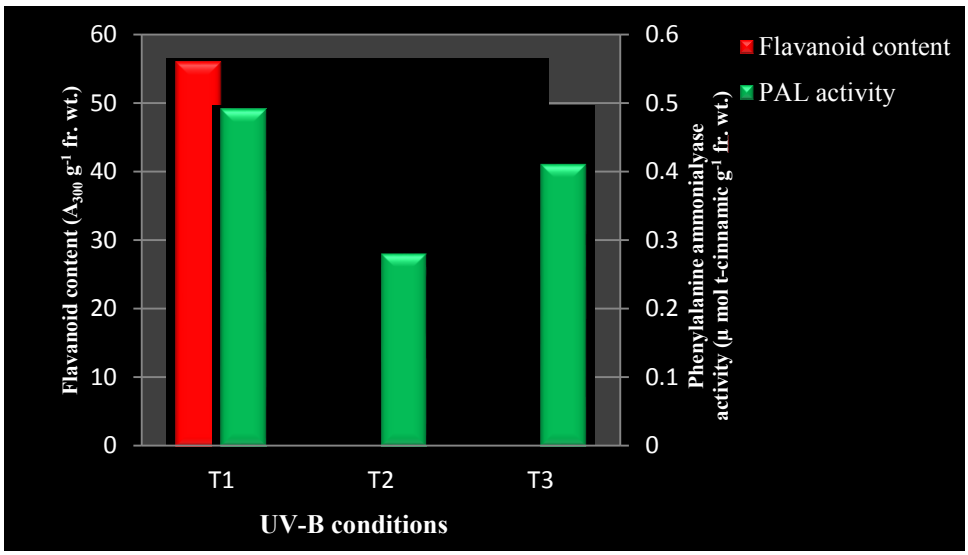


Fig.14. Effect of UV-B radiation on Flavanoid (A_{300} g^{-1} fr. wt.) and Phenylalanine ammonialyase activity (µ mol t-cinnamic g^{-1} fr. wt.) under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

with the finding of Jansen *et al.* (1998) who reported that UV-B also interferes with indoleacetic acid (IAA) metabolism, possibly via photooxidation of IAA, resulting in hormonal imbalances that would certainly induce morphogenic effects.

In the present investigation the PPO activity decreased from tillering to flowering stage where as phenol content increased from tillering to flowering stage (Figure 10 and 11; Table 9). This indicated that at tillering stage more oxidation of phenolic compounds occurred and hence PPO activity was more at all the conditions *viz;* natural solar UV-B (T_1), UV-B supplemented (T_3) and UV-B excluded (T_2) conditions. But at flowering stage where the crop experienced more UV-B under open condition (T_1) when compared to tillering stage, the total phenol increased to act as a defence compound while PPO activity was decreased (Figure 12). This result is in agreement with the results of earlier studies conducted by Balakumar *et al.* (1997) in tomato and Agarwal (2007) in *Cassia auriculata* L.

Similar to PPO, PAL activity also decreased from tillering to flowering stage (Figure 13; Table 9). Though significantly more activity was observed at initial stage in all treatments, maximum PAL activity was observed under open condition in both tillering and flowering stages. This may be due to the reason that UV-B in open condition enhances PAL activity where it produced more phenolic acids gets modified later through phenylpropanoid metabolism to form the precursor of secondary metabolites including flavanoids (Figure 14). This is also evident from the increase in flavanoid content at flowering stage in the present study under T_1 condition. Earlier reports of Khan *et al.* (2003) and Shaukat *et al*. (2013) also indicated similar trend.

5.6 Yield and yield parameters affected by the UV-B radiation

In the present study, yield parameters are significantly affected by higher levels of UV-B radiation under open condition (T_1). The results showed that UV-B excluded condition (T_2) increased the economic yield for both varieties

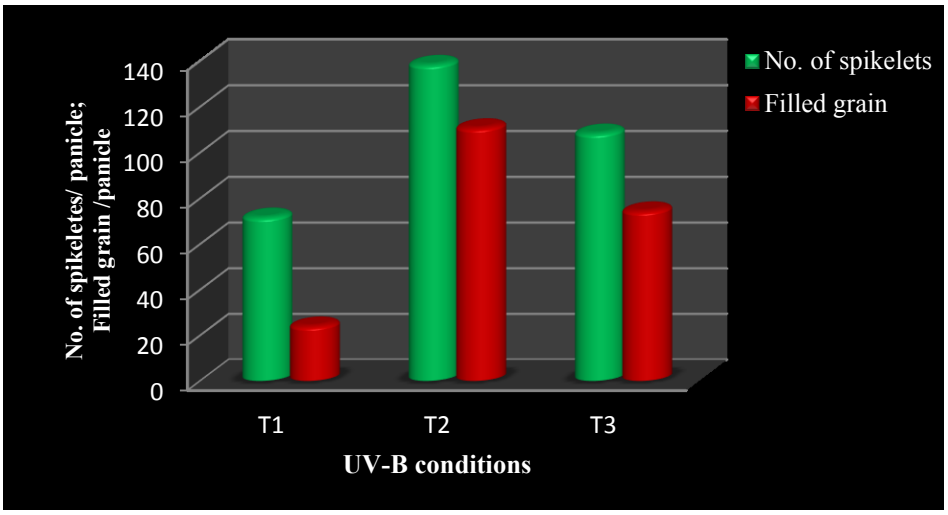


Fig.15. Effect of UV-B radiation on No. of spikelets per panicle and filled grain per panicle under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

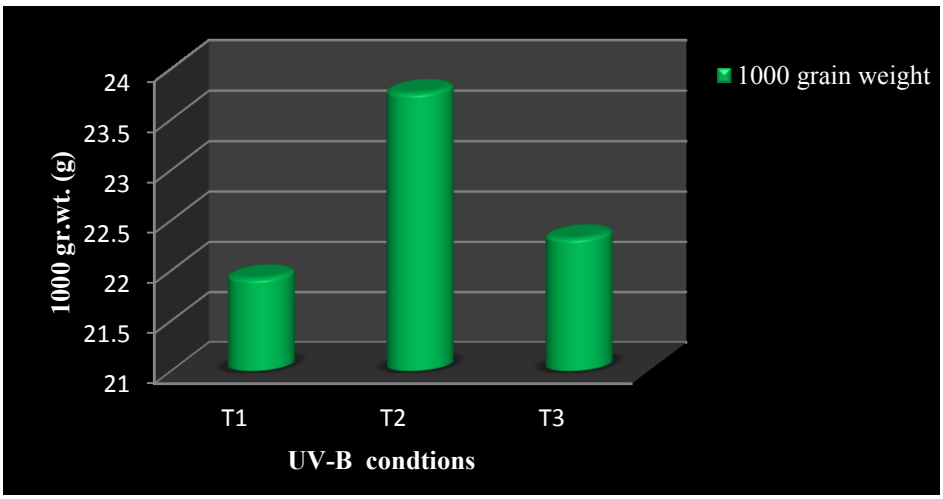


Fig.16. Effect of UV-B radiation on 1000 grain weight (g) under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

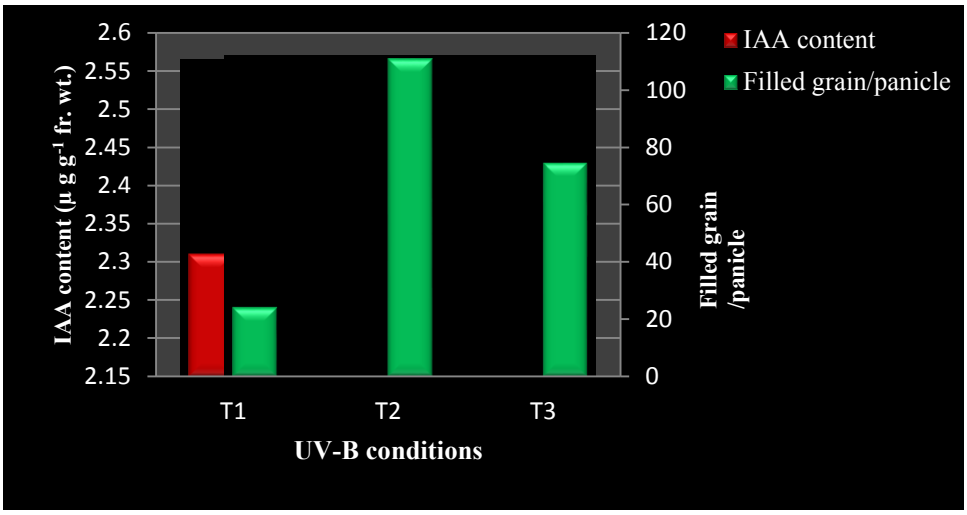


Fig.17. Effect of UV-B radiation on IAA (µg g^{-1} fr. wt.) and Filled grain per panicle at flowering stage under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

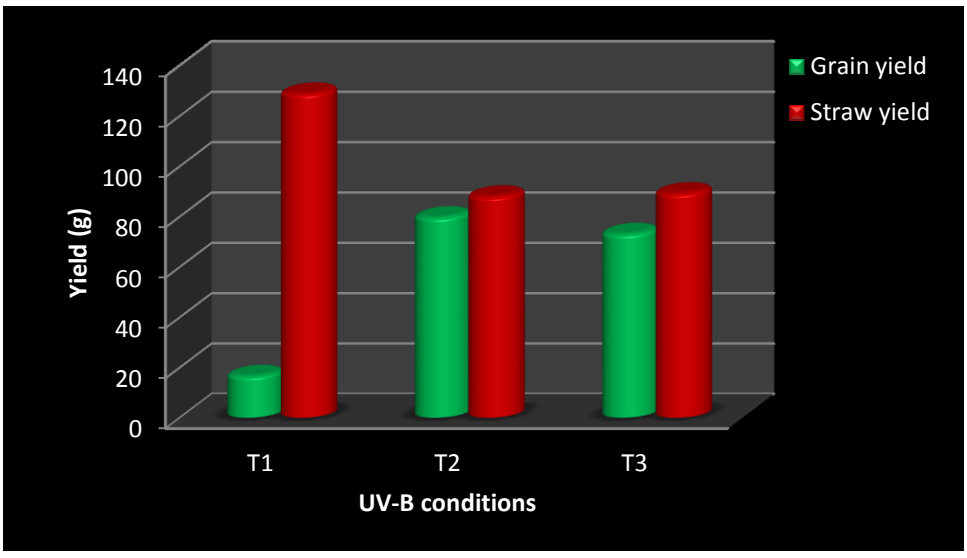
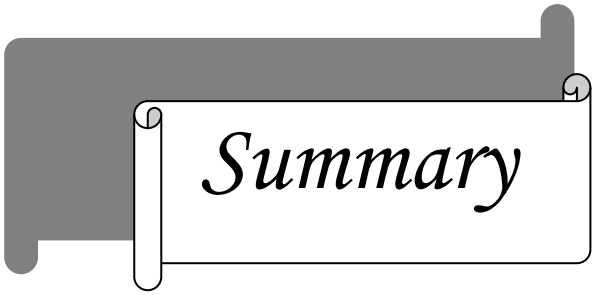


Fig.18. Effect of UV-B radiation on 1000 grain weight (g) under UV-B conditions (**T_1**- Natural solar UV-B condition (where crops were exposed to 100% natural solar spectrum radiation); **T2**- Reduced UV-B radiations using UV-B filters (which measures UV-B as zero); **T3**- 85% ambient radiation including UV-B in polyhouse + UV-B supplemented with UV-B lamps).

compared to ambient level of UV-B (T_1). Under open UV-B condition (T_1) number of panicle per hill was higher than UV-B excluded condition (T_2), but number of spikelet per panicle and number of filled grain per panicle was higher under UV-B excluded condition (T_2) (Figure 15 and 16; Table 10), thereby contributed to higher yield under UV-B excluded condition (T_2). This might be also due to more panicle length, higher photosynthetic rate, stomatal conductance, more chlorophyll and IAA content and low flavanoid content under UV-B excluded condition (T_2). Similar results were reported by Yuan *et al.* (1998) in wheat and Liu *et al.* (2013) in soybean. The increased IAA content at early stage of flowering may regulate grain filling probably through manipulating the cell division in endosperm and thereby creating the sink strength (Figure 17). This is in consistent with the earlier findings of Yuan *et al.* (2010), who suggested that IAA plays a key role in regulation of grain development and filling in rice. The more number of filled grains in T_2 condition may be associated with more IAA content at flowering stage. The increase in IAA content at flowering stage might have stimulated cell division in endosperm and this could have created an attraction for the translocation of photoassimilates to developing grain. The UV-B radiation under open condition restricted filling of grain and further grain development leading to lesser number of filled grains per panicle and thousand grain weight. Spikelet sterility was observed more under open solar condition. Mohammed and Tarpley (2009) reported in rice that enhanced UV-B radiation increase the spikelet sterility. The increase in spikelet sterility might be due to the direct effect of UV-B or might be due to decreased carbon supply to the spikelet as a result of enhanced UV-B radiation. More flavanoid and phenol content, PAL, PPO and catalase activity under T_1 condition might indicate that more photoassimilates are converted as secondary metabolites to overcome stress. The previous studies have also shown a decrease in carbon production at enhanced UV-B radiation (Zhao *et al.,* 2003).

Grain yield was more in crop grown under UV-B excluded condition (T_2) than crop grown under natural solar UV-B condition (T_1) whereas,

the straw yield was higher in T_1 (Figure 18; Table 11). This study suggested that increase in straw yield might be often accompanied by substantial modification in partitioning of biomass into component of plant organ under T_1 condition. A large proportion of biomass was allocated to the leaves and stem and less in to spikelets under T_1 condition. A similar conclusion in wheat has been reported by Teramura (1980) and Yuan *et al.* (1998). Under open solar UV-B condition (T_1) grain yield and straw yield are positively related to thousand grain weight and harvest index. The weight of thousand grains is less in T_1 condition as compared to UV-B excluded condition (T_2) and same trend have seen for harvest index also, where more harvest index were recorded under UV-B excluded condition (T_2). Decrease in harvest index due to enhanced UV-B radiation was also shown in the study of Yuan *et al.* (1998). Reproductive stage is the most important period to achieve high grain yield. Grain yield decreased due to high UV-B received in open condition (T_1) at flowering stage, which in turn decreased the harvest index. The crop grown in open condition received high solar UV-B radiation throughout the growth period of the crop, at reproductive and grain filling phase. Though the crop grown under natural solar radiation expressed more number of productive tillers per hill, it could not produce more number of spikelet and filled grain per panicle. Instead it produced more amount of flavanoid and phenol content by channelizing the photo assimilates at flowering stage.


Summary

6. SUMMARY

Chemical profile of atmosphere has been changed during few decades due to anthropogenic activity, which arose as serious threat to agriculture, reducing productivity of major crops. There has been considerable concern over the depletion of stratospheric ozone as a result of manmade ozone depleting pollutants. Solar electromagnetic radiation contains Ultraviolet-B (UV-B) in the range of 280-320 nm. Depletion of the stratospheric ozone layer has resulted an increase in UV-B radiation reaching the earth's surface with serious photo biological damage to all living organism. UV-B radiations have high energy and potential for causing reversible or irreversible biological damage. UV-B radiation is highest in tropical and sub tropical region where major foods crops such as rice is grown. But little is known about the response of this crop to ambient solar UV-B radiation in Kerala. Some of the studies conducted in Kerala indicated that decrease in ozone layer taking place in some areas where sun burns are reported in human beings. Failure of rice crop in puncha season has lead to abandoning of double cropping in productive rice ecosystem like the kole lands of Kerala. Hence, the present study was undertaken at College of Horticulture, Vellanikkara to understand the effect of UV-B radiation on rice. The experiment was conducted in pot culture during December 2013-April 2014, with two varieties Jyothi and Uma under three different levels of UV-B radiation i.e. natural solar UV-B condition where crops were exposed to 100% natural solar radiation (T_1), reduced UV-B radiations using UV-B Mylar film which measures UV-B as zero (T_2) and 85% ambient radiation including UV-B + UV-B supplemented with UV-B lamps in polyhouse (T_3).

The main objective of the study was:

- To understand the effect of Ultraviolet-B (UV-B) radiation on various morphological, phenological, physiological and biochemical changes in rice.

The study revealed that the current level of natural solar UV-B is high during third cropping season (puncha season) and has negative impact on morphological, phenological, physiological and biochemical parameters which, reduced the economic yield in rice.

The salient findings of the study are as follows:

1. Natural solar UV-B condition (T_1) recorded high levels of UV-B radiation 3.58 Wm^2 and PAR of 413.27 Wm^2 during month of March-2014 compared to other two conditions i.e. UV-B excluded (T_2) and UV-B supplemented (T_3) conditions during growing period of crop (Dec-2013 to April- 2014). UV-B and PAR level measured in T_2 and T_3 condition were lower than outside condition.

2. The main yield attributing characters such as number of spikelets per panicle, filled grain per panicle, panicle length and 1000 grain weight were produced more under UV-B excluded condition (T_2) compared to natural solar UV-B condition (T_1) and UV-B supplemented condition (T_3) hence it consequently contributed more yield under T_2 condition.

3. Crop grown under natural solar UV-B condition (T_1) recorded low photosynthetic rate, transpiration rate and canopy temperature depression (CTD) at both the tillering and flowering stages. This contributed to low values in yield attributing characters as well as to low yield under natural solar UV-B condition (T_1).

4. IAA content, which increased from vegetative to reproductive stage, recorded high value at both stages under UV-B excluded condition (T_2). The high IAA content at reproductive stage may regulate grain filling through manipulating the cell division in the endosperm and thereby creating the sink strength. It also helps better translocation of photoassimilates to developing sink.

5. Leaf thickness, phenol and flavanoid content, which are having protective function to high level of UV-B radiation, increased under natural solar UV-B condition (T_1).

6. The crop grown under natural solar UV-B condition (T_1) recorded more number of productive tillers and panicles per hill but it could not produce high yield when compared to crop grown under UV-B excluded condition (T_2). It is inferred that this happened due to channelization of the photoassimilates for enhancing leaf thickness, phenol and flavanoid content which was recorded high at flowering stage under T_1 condition.

7. The UV-B radiation altered the phenophases of rice crop like days to heading, days to 50% flowering and days to harvestable maturity. In the present study the phenophases of rice crop was delayed by 4-5 days under natural solar UV-B condition (T_1).

8. The flag leaf angle also has important effect on rice yield. Both steeper leaf angle and increased wide angle i.e. self shading leaf angle may reduce potential carbon gain by decreasing total light penetration. In this study high levels of solar UV-B radiation affected the flag leaf angle which resulted steeper flag leaf angle under natural solar UV-B condition (T_1) and UV-B supplemented condition (T_3) whereas, optimum erect flag leaf observed under UV-B excluded condition (T_2).

9. The present study revealed that the photosynthetic rate was lower under natural solar UV-B condition (T_1) along with reduced chlorophyll ‘a’ and total chlorophyll content. This might have also contributed lower yield under T_1 condition.

10. The activity of enzyme such as catalase, PPO and PAL seen to be high under open condition and UV-B supplemented condition than UV-B

excluded condition. Catalase is antioxidant enzyme which protects plant by scavenging free radicals and H_2O_2 whereas, PPO and PAL plays important role under phenylpropanoid pathway by synthesising phenolic compounds to protects plant from high level of UV-B radiation.

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Annexure

ANNEXURE I

Table: Data on Photosynthetically Active Radiation (PAR) (µmol/m^2s^{-1}) throughout the growing period under different UV-B levels

Dates	T1 (Natural solar condition)				T2 (UV-B excluded condition)				T3 (85% ambient + UV-B lamps)			
December-2013	**10:00 AM**	**12 noon**	**2:00 PM**	**4:00 PM**	**10:00 AM**	**12 noon**	**2:00 PM**	**4:00 PM**	**10:AM**	**12 noon**	**2:00 PM**	**4:00 PM**
23th Dec- 30th Dec	1573.33	1938.71	1676.83	864.17	990.83	1348.83	1138.67	646.17	1000	1408.17	1167	524.67
January-2014												
1st week 1 Jan- 4 Jan	1584.99	1935.75	1748.75	853.75	996.25	1334.5	1127.5	453.75	974.99	1355.25	1175	473.01
2nd week 6 Jan- 10 Jan	1170.25	1846.5	1583.25	813.49	800.99	1250.75	892.49	357	726.25	1352.75	905.75	356
3rd week 13 Jan- 18 Jan	1440.01	1894.83	1511.83	670.67	907.17	1284.17	888.50	285.67	975.17	1306.33	917.83	288.83
4th week 20 Jan- 25 Jan	1503.99	1761.4	1464	958.19	829.79	1360.2	1201	376.4	868.99	1433.8	1275.2	416
5th week 27 Jan- 31 Jan	1380	1965.6	1888	1034.4	818.8	1263	1109.8	483.59	848.79	1310.6	1148.4	483.40
February-2014												
1st week 1 Feb- 7th Feb	1387.60	1969.4	1859.8	1128.6	797.80	1276.8	1114	767.79	861.01	1380.8	1140.8	528.20
2nd week 10 Feb- 15 Feb	1155.02	1721	1353.33	955.67	670.83	1059.83	765.67	443.17	722.49	1129	781.17	453.33
3dr week 17 Feb- 22 Feb	1232.17	1708	1937.5	1078.33	723.17	1093.17	1065.17	523.67	776.83	1156.17	1114.83	517.33
4th week 24 Feb- 28 Feb	1526.75	1624.25	1979.25	1258.75	876.50	1091.25	1195.25	509.50	931.5	1163	1056.75	456.75
March-2014												
1st week 3rd Mar- 7 Mar	1437.40	1693	1918.8	1229.4	791.60	1098.2	1096.4	532.80	826.59	1185.8	1128	517.20
2nd week 10 Mar- 15	1437.17	1966	1902.67	1508.33	867.83	1320.33	1157.83	603.02	872.19	1352.67	1228.66	590.33
3rd week17 Mar- 22 Mar	1417.83	1964.33	1793.17	1011.17	827.67	1291	954.5	456.83	900.50	1268.33	991.17	429.17
4th week 24 Mar- 31	1393.83	1981	1854.5	1182.5	731.99	1316.33	1076.5	460.67	889.33	1382.17	978.83	463.83
April-2014												
1st week 1st Apr- 11 Apr	1236.99	1618.14	1702.71	729.86	660.28	1079.28	903.57	338.57	703.01	1075.14	901.86	428.14

ANNEXURE II

Table: Data on Maximum, Minimum Temperature (^{0}c), Relative Humidity (%) and Sunshine hours under natural solar condition (T_1).

December-2013		**Max. Temp.**	**Min. temp.**	**Relative Humidity (%)**	**Sunshine (hrs)**
1st week	23th Dec- 30th Dec	31.3	22.1	53	72.6
January-2014					
1st week	1 Jan- 4 Jan	32.6	22.4	54	64.9
2nd week	6 Jan- 10 Jan	32.8	23.1	53	56.7
3rd week	13 Jan- 18 Jan	33.2	23.7	50	61.4
4th week	20 Jan- 25 Jan	32.5	23.3	51	65.4
5th week	27 Jan- 31 Jan	33.7	22.3	47	69.2
February-2014					
1st week	1 Feb- 7th	35.1	21	37	68.9
2nd week	10 Feb- 15	33.6	22.6	70	51.9
3rd week	17 Feb- 22	35	24.3	54	52.8
4th week	24 Feb- 28	35.2	24.6	60	61
March-2014					
1st week	3rd Mar- 7	35.1	25.1	54	50.4
2nd week	10 Feb- 15	37.4	22.7	42	67.8
3rd week	17 Mar- 22	37.3	24.7	65	59.6
4th week	24 Mar- 31	38.1	24.3	50	8.9
April-2014					
1st week	1st Apr- 11	36.3	25.9	71	49.8

ANNEXURE III

Table: Data on Temperature (^{0}c) and Humidity (%) under two different levels (T_2 - UV-B excluded condition and T_3 – UV-B Supplemented condition) at 10 am.

Dates	**T_2- UV-B excluded condition**		**T_3- UV-B supplemented condition**	
December-2013	**Temperature**	**Humidity**	**Temperature.**	**Humidity**
23th Dec- 30th Dec	35.5	34.5	37.65	39.5
January-2014				
1st week 1 Jan- 4 Jan	32.8	46	34.2	45.25
2nd week 6 Jan- 10 Jan	32.77	46.5	33.9	46.25
3rd week 13 Jan- 18 Jan	33.91	38.68	35.75	37.66
4th week 20 Jan- 25 Jan	31.98	43.6	34.08	40.8
5th week 27 Jan- 31 Jan	31.18	41.33	34.2	39.16
February-2014				
1st week 1 Feb- 7th	31.26	39.28	34.3	38.8
2nd week 10 Feb- 15	32.4	50.16	35.96	46.66
3dr week 17 Feb- 22	32.53	46.5	36.98	43.5
4th week 24 Feb- 28	34.3	41.75	36.87	39.5
March-2014				
1st week 3rd Mar- 7	35.3	43.8	40.22	40
2nd week 10 Mar- 15	34	36.33	36.86	32.33
3rd week17 Mar- 22	35.55	37.83	38.28	37.16
4th week 24 Mar- 31	36.01	37.66	37.53	38.5
April-2014				
1st week 1st Apr- 11	34.54	47.42	36.74	45.85

ANNEXURE IV

Table: Data on Temperature (^{0}c) and Humidity under two different levels (T_2 - UV-B excluded condition and T_3 – UV-B Supplemented condition) at 2 pm.

Dates	**T_2- UV-B excluded condition**		**T_3- UV-B supplemented condition**	
December-2013	**Temperature**	**Humidity**	**Temperature**	**Humidity**
23th Dec- 30th Dec	36.25	33	39.95	27.5
January-2014				
1st week 1 Jan- 4 Jan	35.97	40	37.62	39.5
2nd week 6 Jan- 10 Jan	35.27	38.5	36.9	34.25
3rd week 13 Jan- 18 Jan	39.6	32	39.4	25
4th week 20 Jan- 25 Jan	35.24	39.8	37.1	34.4
5th week 27 Jan- 31 Jan	36.12	35	37.76	29.2
February-2014				
1st week 1 Feb- 7th Feb	35.34	30.6	37.96	29.4
2nd week 10 Feb- 15	34.38	46.5	37.11	46.16
3dr week 17 Feb- 22	35.15	41.66	39.2	39.5
4th week 24 Feb- 28	35.6	38.25	39.27	35.75
March-2014				
1st week 3rd Mar- 7	35.22	43.8	39.48	39.8
2nd week 10 Mar- 15	35.35	30	38.33	26.83
3rd week17 Mar- 22	36.91	32.66	39.2	34
4th week 24 Mar- 31	37.08	28.5	39.68	26.33
April-2014				
1st week 1st Apr- 11 Apr	36.18	42	38.21	39.71

Effect of UV-B radiation on physiological and phenological plasticity in rice (*Oryza sativa* L.)

By

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ABSTRACT OF THESIS

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Abstract

A global depletion of the stratospheric ozone layer, largely due to the release of pollutant such as chlorofluorocarbons (CFCs) caused by human activities, has resulted in an increase of solar Ultraviolet-B (UV-B) radiation in the range of 280-320 nm at the earth's surface. Elevated UV-B exposure causes temporary or irreversible damage to plant growth and development. Though UV-B is only a minor component of total solar radiation (less than 0.5%), due to its high energy, its potential for causing biological damage is very high.

UV-B radiation is highest in tropical region where rice is grown as the major food crop in these regions. Decline in rice yield during puncha season (Dec-March) gives an indication on the effect of UV-B radiation on rice yield. Failure of rice crop in puncha season has lead to abandoning of double cropping in productive rice ecosystem like kole lands of Kerala. This needs detailed investigations to come up with realistic recommendations to overcome such situations. Therefore, the present study was conducted to understand the effect of UV-B radiation on morphological, physiological, phenological and biochemical changes in rice (*Oryza sativa* L.).

The experiment was conducted in pot culture during December 2013-April 2014, with two varieties Jyothi and Uma under three different levels of UV-B radiation i.e. - natural solar UV-B condition where crops were exposed to 100% natural solar radiation (T_1), reduced UV-B radiations using UV-B Mylar film which measures UV-B as zero (T_2) and 85% ambient radiation including UV-B + UV-B supplemented with UV-B lamps in polyhouse (T_3).

The results indicated that UV-B radiation, in the range of 1.30 to 3.58 Wm^2, during the study period affected the productivity of the crop. There was significant variation in UV-B radiation from 10 am to 4 pm in all the months throughout the growing period and the maximum value was recorded during the month of March, 2014. The highest crop yield was recorded in UV-B excluded condition (T_2). This was due to more No. of spikelet per panicle, filled grain per panicle and 1000 grain weight. High photosynthetic rate, stomatal conductance and more canopy cooling at both vegetative and reproductive phases, along with more IAA content, total chlorophyll and chlorophyll 'a' have contributed the high yield in T_2 condition.

The increase in physiological parameters like photosynthetic rate, stomatal conductance and canopy cooling; morphological traits like flag leaf angle and panicle length and biochemical constituents like Chlorophyll 'a', total chlorophyll and IAA content observed under UV-B excluded condition (T_2) positively favoured the high yield and harvest index in the present study. Though the crop grown under natural solar radiation expressed more No. of productive tillers per hill, it could not produce more No. of spikelet and filled grain per panicle. Instead it produced more amount of flavanoid and phenol content by channelizing the photo assimilates at flowering stage.

The phenophases of the crop like days to heading, 50% flowering and days to harvestable maturity were delayed by 4-5 days under open condition (T_1).The varieties Jyothi and Uma could not produce significant difference in yield.

In the present study decrease in yield and yield attributes were observed due to the current level of natural solar UV-B radiation. The UV-B radiation under open condition restricted filling of grain and further grain development leading to lesser number of filled grains per panicle and thousand grain weight.