INTERACTIVE EFFECT OF UV RADIATION AND ELEVATED TEMPERATURE ON RICE GROWTH AND PHYSIOLOGY

By

Amjath. T

(2016-11-103)

THESIS

Submitted in partial fulfilment of the

Requirement for the degree of

Master of Science in Agriculture

(PLANT PHYSIOLOGY)

Faculty of Agriculture

Kerala Agricultural University, Thrissur

Department of Plant Physiology
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

2018

DECLARATION

I hereby declare that the thesis entitled **"Interactive effect of UV radiation and elevated temperature on rice growth and physiology"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title, of any other university or society.

Vellanikkara

Date: 16-10-2018

AMJATH. T

(2016-11-103)

CERTIFICATE

Certified that the thesis entitled **"Interactive effect of UV radiation and elevated temperature on rice growth and physiology"** is a record of research work done independently by **Mr. Amjath. T (2016-11-103)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellanikkara
Date: 16-10-2018

Dr. T. Girija
(Major Advisor)
Professor and Head
Department of Plant Physiology
College of Horticulture, Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of **Mr. Amjath. T (2016-11-103)**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Plant Physiology**, agree that the thesis entitled **"Interactive effect of UV radiation and elevated temperature on rice growth and physiology"** may be submitted by **Mr. Amjath. T** in partial fulfillment of the requirement for the degree.

Dr. T. Girija 9/10/18
Professor and Head
Department of Plant Physiology
College of Horticulture, Vellanikkara.

Dr. P. S. Abida 9/10/18
Professor and Head
Division of Plant Breeding
Regional Agricultural Research Station
Pattambi.

Dr. B. Ajithkumar 9/10/18
Assistant Professor and Head
Department of Agricultural Meteorology
College of Horticulture, Vellanikkara.

Dr. S. Krishnan 9/10/18
Professor and Head
Department of Agricultural Statistics
College of Horticulture, Vellanikkara.

EXTERNAL EXAMINER:

Dr. A. Senthil 9/10/18
Associate Professor
Department of Crop Physiology
Tamilnadu Agricultural University
Coimbatore.

Acknowledgement

First and foremost I bow my head before the ***Almighty God*** *for showers of blessing throughout my research work to complete the research successfully.*

I am immensely happy to express my profound and deep sense of whole hearted gratitude to my major advisor ***Dr. T. Girija*** *. Professor and Head, Department of Plant Physiology, College of Horticulture, Vellanikkara for her valuable guidance, suggestions, constructive criticisms, constant encouragement, monthly approach, affectionate advice and unfailing patience throughout the course of this research work and preparation of thesis and above all, for being a wonderful teacher.*

I consider it as my privilege to express my deep-felt gratitude to ***Dr. B. Ajithkumar****, Asst. Professor and Head, Dept. of Agricultural Meteorology, College of Hortiulture, Vellanikkara member of my advisory committee for his timely help and suggestion, valuable guidance, cooperation throughout the research programme and preparation of thesis.*

I am deeply oblique to ***Dr. S. Krishnan****, Professor and Head, Dept. of Agricultural statistics, College of Horticulture, Vellanikkara member of advisory committee for his expert advice and constructive criticisms during the statistical analysis of data which helped in successful completion of this work.*

I express my gratitude to ***Dr. P. S. Abida*** *, Professor and Head, Division of Plant Breeding, RARS, Pattambi, member of advisory committee for her unfailing support and timely help. I thank her for all the help and cooperation she has extended in performing the research work in the research station.*

I wish to express my sincere thanks to all the non- teaching staff members ***Sheena chechi, Amminichechi, Jinichechi*** *and laborers for their whole hearted cooperation and timely assistance.*

I avail this opportunity to thank my seniors ***Shafeeqa itha, Neethuchechi, Garggichechi, Vishnu. K, S,Sreepriyachechi*** *and* ***Parvathy chechi*** *for their support, help, care and encouragement.*

My heartfelt gratitude cannot be captured in words for the unflinching support and constant encouragement of my classmates, friends and juniors ***Ms. Athira. K, A, Ms. Sreealaja Kizhakkekkara, Ms. Shaniba. M, Ms. Linu, Mr. Amal Premachandran, Mr. Anil, Mr. Fazeedh, Mr Jazeel, Mr. Adersh, Mr. Abid V, MrAnto V, Mr. Rakesh P.S, Mr. Bennett Thomas K, Mr. Mohammed Murthala.***

I owe special thanks to ***Dr. A. T. Francis****, Librarian, College of Horticulture and all other staffs of library who helped for collection of literature for writing my thesis.*

I express my deep sense of gratitude to ***Kerala Agricultural University*** *for financial and technical support of my study and research work.*

I am in dearth of words to express my love towards my beloved ***Parents, Sister and Grandparents*** *for their boundless affection, moral support, eternal love, deep concern and prayer.*

It would be impossible to list out all those who have helped me in one way or other in the successful completion of this work. I once again express my heartful thanks to all those who helped me in completing this venture in time.

Amjath. T

DEDICATED TO

MY PARENTS

MY ADVISOR

TEACHERS

FRIENDS

FARMERS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ANNEXURES

SLno.	Title	Annexure no.
1	Data on UV-B radiation (Wm^{-2}) under four different conditions	1
2	Data on Temperature (^0C) under four different conditions	2

LIST OF ABBREVIATIONS

@	at the rate of
^0C	Degree Celsius
per cent	Per cent
m^{-2}	Per square meter
CD	Critical difference
Cm	Centimeter
et al.	Co-authors/Co-workers
CO_2	Carbon-dioxide
Fig.	Figure
Ml	Milli litre
M	Molar
g	Gram
i.e.	That is
µ	Micro
UV	Ultra violet
CRD	Completely randomized design
OD	Optical Density
A_{663}	Absorbance at 663 nm
A_{645}	Absorbance at 645 nm
IAA	Indole-acetic acid
GA	Gibberellic acid

Introduction

17

1. INTRODUCTION

Rice is the staple food for about half of the world's population and it also serves 20 per cent of the calories consumed worldwide. It is cultivated under various ecologies than any other food crop, ranging from deep water to low land irrigated conditions. Climatic factors are the major constraints which limits the productivity of rice. Among different climatic factors UV radiation and increase in temperature are unavoidable. As per IPCC the average global atmospheric temperature may increase from 1.4^0C to 5.8^0 C in future and it will be very significant with respect to global rice production. Ozone layer depletion during the last few decades has abruptly increased the incidence of solar UV-B radiation (280-320 nm) that reaches the earth surface.

The agrarian economy of Kerala is primarily dependent on rice cultivation. The increase in temperature and UV light and decrease in rainfall may adversely affect the rice productivity of the state. Studies conducted in Department of Plant Physiology, College of Horticulture, Vellanikkara has shown that ambient UV-B levels ranges from 2.18 Wm^{-2} to 3.58 Wm^{-2} during the month of March (Shafeeqa, 2016) which coincides with an additional crop of rice in the kole lands of Kerala. Nandini *et al.* (2010) reported that the poor yield of an additional crop of rice in the kole lands was due to high temperature from panicle initiation to grain filling stages.

Cereals are always under threat due to rising temperature since it has both direct as well as indirect effect on crop production. According to Krishnan *et al.* (2011) high temperature stress can be defined as rise in temperature beyond a critical threshold for a duration of time sufficient to cause inevitable damage to plant growth and development. Frequent episodes of elevated temperature above 35^0C can affect the yield attributes of rice. The impact of temperature stress on rice depends upon the different growth stages, such as vegetative and reproductive phases. (Zhang *et al.*, 2007).

Based on growth and photosynthetic response of rice in greenhouse and growth chamber studies, Van *et al.* (1976) proposed that rice was fairly sensitive to UV-B radiation when compared to other crops. Searles *et al.* (1995) suggested that growth and physiological processes of most of the plant species are negatively affected by supplemental UV radiation. Studies conducted by Wagh (2015) in College of Horticulture, Vellanikkara showed that rice variety, Uma yielded more when it was grown under UV excluded condition. This was due to more number of spikelets per panicle, higher photosynthetic rate, high stomatal conductance and more canopy cooling at vegetative and reproductive stages.

Like other environmental factors, temperature and UV radiation are complex and difficult to control. If the climate changes are not so significant, most of the crops will adapt to these changes. However in the present scenario the changes are prominent with frequent occurrence of extreme episodes (Peng *et al.,* 2004). Unpredictable shift in atmospheric temperature, challenges the farmer in the selection of crop varieties and time of sowing. Hence it is pertinent to identify the critical growth stages of crop that are most influenced by the changes in temperature and UV radiation. The solution to overcome these abiotic stresses is to identify the phenophases of the crop that are affected by these stresses and their ultimate effect on the performance and yield of the crop. With this background a study has been proposed with the following objective

1. To understand the interactive effect of UV radiation and elevated temperature during different phenophases of rice and its effect on growth physiology and productivity.

Review of Literature

2. REVIEW OF LITERATURE

The growth and productivity of rice crop is depends upon several climatic factors. Among these factors increasing atmospheric temperature and UV-B radiation are important. According to Cox *et al.* (2000) global mean temperature will rise by 0.3^0C per decade. Intensified rice production in rainfed low land and dryland agricultural system are prone to high temperature (Mackill *et al.*,1982). Depletion of stratospheric ozone layer by the emission of chloroflurocarbon and other gases has increased the incidence of UV-B radiation on earth surface. Among the cultivated crops rice is reported to be more sensitive to UV-B (Van *et al.*, 1976). The influence of UV-B radiation and elevated temperature on morphological, physiological, biochemical and yield attributes of the rice plant is reviewed under this chapter.

2.1 Effect of UV-B radiation and elevated temperature on morphological and phenological parameters of rice

2.1.1 Plant height

Rice plant elongates vigorously up to 30 days with rise in temperature within 30 to 35^0 C and ceases to elongate at the time of heading (Osada *et al.*, 1973). Oh-e *et al.* (2007) observed that rice cultivar grown under different temperature gradient chambers showed significant variation in height.

Wheat and soybean showed reduction in plant height under UV-B induced condition. This change in plant height may be associated with UV-B induced changes in cell division and elongation (Barnes *et al.*, 1988). Studies in two mustard variety (Pusa gold and varuna) showed that supplementary UV radiation significantly reduced the plant height by 17 per cent and 11per cent respectively after 30 days of planting (Pal *et al.*, 1998). Rice grown under high UV-B (10 KJ) condition showed

12 per cent decrease in plant height and 17 per cent reduction in the number of viable leaves than the low UV-B (5 KJ) condition (Mohammed and Tarpley, 2013).

2.1.2 Number of tillers

According to Chaudhary and Ghildyal (1970) the temperature above 33^0 C is not favorable for tillering in rice. Oh-e *et al.* (2007) observed that high temperature conditions reduced the number of tillers at maturity stages of rice. Wassmann *et al.* (2009) reported that high temperature above threshold level lead to reduction in plant height, tiller number and biomass in rice crop.

Hidema *et al.* (2005) observed a significant decrease in tiller number of Japanese rice cultivar under elevated UV-B conditions during 2002 and 2003. Study conducted by Farooq *et al.* (2007) in rice cultivars under two different conditions ie., sub ambient UV-B and ambient UV-B showed that significant decrease in vegetative tiller production under sub ambient UV-B radiation.

2.1.3 Number of days to heading

Generally low temperature delays and high temperature accelerates heading in rice (Ahn and Vergara, 1969). For example, studies conducted in IR 24 by Yoshida (1981) showed that number of days to heading was increased from 96 at 24^0 C to 134 at 21^0 C and decreased to 81 at 30^0 C. According to Zakira *et al.* (2002) high temperature stress in rice increased the grain filling rate but reduced the total number of filled grains. He also found that an average increase of 1^0 C with respect to ambient decreased the yield up to 10 per cent. Various phenological stages in rice such as panicle initiation, 50 per cent flowering and days to harvest are found to be shorter in temperature stress condition (2^0C and 4^0C) than ambient condition (Rani and Maragatham, 2012). These observations are in agreement with those of Das *et al.* (2014), who reported that temperature stress above 35^0 C significantly reduced the flowering period in rice.

Rajendiran and Ramanujan (2004) reported that green gram (*Vigna radiata* L.) plants grown under elevated UV condition showed delayed flowering when compared to normal condition.

2.2 Effect of UV radiation and elevated temperature on physiological parameters of rice

2.2.1 Photosynthetic rate

Among the biochemical and physiological processes that take place in plants, photosynthesis is most susceptible to heat stress. Taniyama *et al.*, (1988) reported that, the photosynthetic rate reduced to half when the temperature goes beyond 35^0C. Similarly Zhang *et al.* (2007) revealed that, the net photosynthetic rate, flowering duration and pollen viability of rice flag leaves get decreased with increasing air temperature (above 35°). Another study conducted by Yun-ying *et al.* (2009) in rice showed that temperature stress not only during panicle initiation but also vegetative and grain filling stages reduces the photosynthetic rate of flag leaves. Two rice genotypes (Jumaitun *et al.,* 2016) recorded a net photosynthetic reduction of 38 per cent and 20 per cent , when they were subjected to heat stress at a temperature 40^0 C during panicle initiation stage.

Plants exposed to UV-B radiation showed decreased photosynthesis due to changes in the activities of the enzyme Rubisco (Furbank and Taylor, 1995). Hidema *et al.* (1997) concluded that the supplementary UV-B radiation resulted in reduction of Rubisco, soluble protein, chlorophyll and leaf nitrogen content in fully expanded leaves of rice plant. UV-B excluded studies in maize and mung bean showed increased photosynthetic rate and stomatal conductance (Pal *et al.*, 1997). UV stress was not only inhibiting photosynthesis but also lead to photo oxidative destruction of photosynthetic apparatus (Solhaug and Gauslaa 2004). The D1 and D2 proteins of photosystem were severely affected by UV-B radiation, which in turn affected the productivity of plants (Kataria *et al.*, 2014).

2.2.2 Stomatal conductance

Stomatal conductance can play an important role in rice as adaptation to elevated temperature stress. Taiz and Zeiger (2002) found that, under high temperature conditions the stomatal conductance is increased which enables more CO_2 diffusion into leaves and thereby increasing the photosynthetic rate. Rane *et al.* (2003) reported that under ambient condition, stomatal conductance had poor relation with grain yield, but under elevated temperature this parameter appeared to be more important. According to Munjal and Dhanda (2004), stomatal conductance decreased in rice under high temperature stress due to closure of stomata. It is one of the mechanisms of plant to conserve water and retain its functional integrity under stress. Studies conducted in aromatic rice genotypes by Islam. (2011) revealed that with increasing temperature (34^0C) the leaf stomatal conductance and transpiration rate increased at both bolting and grain filling stages while photosynthetic rate decreased.

Tevini and Teramura (1989) reported that enhanced UV-B radiation resulted in closure of stomata which lead to increased leaf diffusive resistance. Similar studies in Pea plants showed that abaxial and adaxial stomatal conductance were decreased under enhanced UV-B radiation (Nouges *et al.*, 1998)

2.2.3 Transpiration rate

Studies conducted in Indonesian rice cultivars by Jumiatun *et al.* (2016) revealed that with increasing temperature transpiration rate also increased.

Liu *et al.* (2003) reported that enhanced UV-B exposure reduced the transpiration rate due to stomatal diffusion resistance in *Trichosanthes kirilowii.* Enhanced UV-B radiation negatively affected the photosynthetic rate, stomatal conductance and transpiration rate in lettuce under field condition (Basahi *et al.*, 2014).

2.2.4 Pollen viability

Pollen viability is one of the important criterion of pollen quality (Dafni and Firmage, 2000). Temperature stress during the flowering period in rice decreases the ability of pollen grains to swell which resulted in poor anther dehiscence (Matsui *et al*, 2000). Poor pollen shredding as well as inadequate pollen growth in temperature above 34^0C resulted in reduced yield of rice (Mackill *et al.*, 1982). Prasad *et al.* (2006) reported that elevated temperature just before or soon after anthesis resulted in poor anther dehiscence as well as poor pollen germination. All these factors contributed to reduced spikelet fertility. Matured rice pollen consists of different protein isoforms as well as proteins of cell wall metabolism. The disorganization of proteins and lipids at high temperature can influence the structure and integrity of pollen which can affect the viability (Shi *et al.*, 2013).

2.3 Effect of UV-B radiation and elevated temperature on biochemical parameters of rice

2.3.1 Chlorophyll content

High temperature stress enhances the activity of chlorophyllase enzyme and there by reduces the chlorophyll content of leaves. The ultimate reduction in chlorophyll may result in damage to electron transport and hence decrease photosynthetic ability of plants (Misra *et al.* 1986). Rice cultivars (N22 and Vandana) subjected to prolonged heat stress resulted in severe loss of chlorophyll content by 67 per cent and 39 per cent respectively (Sailaja *et al.*, 2014)

Under enhanced UV exposure Sato and Kumagai (1993) noted a general decrease in the leaf chlorophyll content and plant height among 198 cultivars of rice representing India and Japan. Huang *et al.* (1993) reported that, with increasing length and intensity of UV-B radiation, the membrane of grana and thylakoid get disintegrated. Lipid peroxidation in chloroplast due to increased UV radiation resulted in reduced chlorophyll content in many plant species (Marwood and

Greenberg, 1996). Components of chloroplast such as grana and thylakoid are sensitive to UV-B radiation. A general 10 per cent reduction in chlorophyll content was observed in many plants when they were exposed to UV-B radiation and the reduction was more among dicots than monocots (Pal *et al.*, 1998)

2.3.2 Amylose content

Ambient temperature has great influence on amylose content and gelatinization properties of grains. Studies conducted in rice by Asaoka (1985) revealed that amylose content reduce with rise in ambient temperature while the gelatinization temperature increases. Temperature stress during the grain development stage resulted in low amylose content of rice grains which in turn affects the structure of amylopectin. (Inouchi *et al.*, 2000). Variation in ambient temperature during grain filling stages affected the starch accumulation (Umemoto *et al.*, 1995) and changed the proportion of amylose to amylopectin in endosperm of rice (Ahmed *et al.*, 2008).

2.3.3 Proline content

Rice plants subjected to high temperature stress during heading and flowering stage resulted in more accumulation of proline in the flag leaves than the natural condition (Zhang *et al.*, 2007). In order to overcome heat stress conditions, plants stabilize the structure of membrane bilayer by producing osmoprotectants such as glycine betaine, proline and soluble sugars (Wahid *et al.*, 2007). Proline is an important amino acid which plays a highly beneficial role in plants exposed to different stress conditions. Tang *et al.* (2008) reported that a short period exposure of elevated temperature to rice resulted in high proline accumulation and decreased when conditions are prolonged. Biochemical and physiological characterization of three Colombian rice cultivars (F60, F733 and F473) revealed that the proline content increased by 200per cent when the temperature increased from 25 to 35^0 C. However further increase in temperature reduced the proline content by 45 per cent (Sanchez *et al.*, 2014).

Studies conducted by Mahdavian *et al.* (2008) showed that proline content of leaves of *Capsicum annum* is higher (8.2 m M/gFw) under UV-B condition compared to control (5.6 m M/gFw).

2.3.4 IAA content

IAA content was found to be more under high temperature during the early grain filling period and a decreasing trend was observed up to 35 days after anthesis. (Kabir *et al.*, 2017)

Study conducted by Huang *et al.* (1997) in IR 68 rice cultivar indicated that the activities of enzymes, IAA oxidase and peroxidase are up regulated by UV-B treatments. The increase in IAA oxidase activity was positively related with IAA destruction. The reduced concentration of IAA due to photolytic degradation and formation of 3- methylene oxindole inhibited the growth of sunflower seedlings under enhanced UV (Ros and Tevini, 1995). The enzyme peroxidase functions as IAA oxidase and inhibited seedling elongation in sunflower.

2.3.5 GA content

Larkindale *et al.* (2005) reported that plants grown under heat stress condition recorded minimum GA, auxin and cytokinin compared to other phytohormones ABA and ethylene. GA is considered as an important phytohormone which controls many physiological processes that take place in plants including seed germination, organ elongation and flower development (Yamaguchi, 2008). Study conducted by Kabir *et al.* (2017) revealed that low temperature stress enhanceed the GA content in the rice flag leaves and endosperm during the grain development stage, while the GA was comparatively lower in high temperature treatments.

2.4 Effect of UV-B radiation and elevated temperature on yield and yield parameters f rice

2.4.1 Number of panicle per plants

Hidema *et al.* (2005) reported that supplemental UV-B radiation in rice lead to reduction in panicle number, tiller number, dry mass and grain yield.

2.4.2 Number of spikelets per panicle

According to Matsushima and Tsunoda (1958) high temperature in the range 32 to 33^{0}C is favourable for spikelet differentiation. Ambient levels of solar radiation and temperature influenced the spikelet number per unit land area during the reproductive growth (Yoshida, 1981)

2.4.3 Grain yield

The length of ripening period and the capacity of grains to accept carbohydrate were affected by temperature, which determines the filled grain per centage in rice (Yoshida, 1983). High temperature condition after the heading stage in rice resulted in damaged as well as smaller kernals at maturity which ultimately lead to reduced yield. (Yoshida and Hara, 1977). A study in Philippines showed that rice yield decreased upto 27per cent due to 2^0 C rise in temperature at different locations. (Crisanto and Leandro, 1994). These findings were in corroboration with Rani and Maragatham (2012), according to them yield reduction in rice due to rise in temperature was 13.3per cent at 2^0 C and 23per cent at 4^0 C. Temperature stress induced changes in plant physiological processes such as respiration and photosynthesis and thus lead to shortened life cycle and diminished plant productivity (Barnabás *et al.*, 2008). According to Cladwell (1968) covering of plants with mylar sheet which filter UV-B radiation enhanced flowering, and ultimately yield.

Kataria *et al.* (2014) found that, exclusion of UV-B enhanced the yield parameters such as number of leaves in amaranthus and number of panicles, grain yield per plant in wheat and sorghum. Studies conducted at College of Horticulture,

Vellanikkara in 2015 showed that rice variety Uma recorded higher yield when it was grown under UV-B excluded condition. This was due to more no of spikelets per panicle, higher photosynthetic rate, higher stomatal conductance and more canopy cooling at vegetative and reproductive stages (Wagh, 2015).

2.4.4 Thousand grain weight

Even though high temperature during ripening affected the grain, the 1000 grain weight of a particular variety remains almost unchanged under different environments (Soga and Nozaki, 1957). However Murata (1976) observed that the thousand grain weight of same variety varied from 21g to 24g at different temperatures. Elevated temperature during grain developmental stages enhances the accumulation of dry matter in grain, but reduces the grain filling period. In rice, with every 1^0 C rise in temperature, grain filling period decreases, which reduces average weight of grains and fraction of mature grain.

The impact of temperature stress on plants depend up on the intensity, duration and stage of stress relative to plant development, but more adversely it affects the reproductive and grain filling stages. Vaghefi *et al.* (2010), imposed two rice varieties (sensitive and tolerant to heat) to temperature stress (35-40^{0}C) and observed a decrease in 1000 grain weight by 7-9 per cent in sensitive cultivar and 3-4per cent in tolerant cultivar. Jeng *et al,* (2003) reported that, the sink capacity (1000 grain weight) of rice was reduced under high temperature as a result of increased spikelet sterility and low activity of starch synthase.

2.4.5 Chaff per cent

According to Satake and Yoshida (1978) exposure of spikelets at a temperature above 35^0 C for about 5 days during flowering period resulted in formation of sterile spikelet and set no seed. Study conducted by Prasad *et al.* (2006) in rice cultivars showed that spikelet fertility was decreased up to 72 per cent under high temperature conditions. Flowering (anthesis and fertilization) and booting

(microsporogenesis) are considered as the most susceptible stages of development to temperature in rice (Farrel *et al.*, 2006). Short periods of high temperature (35 to 38^0C) during anthesis decreased spikelet fertility in rice, hence subsequent yield (Jagadish *et al.,* 2008). Yield losses under high temperature regimes were attributed to reduction in grain weight and spikelet sterility (Shi *et al.,* 2013).

Temperature stress (above 33^0C) coincides with heading stage of rice crop leads to significant reduction in anther dehiscence as well as spikelet sterility. Rice variety (IR-64, MTU-1010) subjected to temperature stress resulted in reduction of spikelet fertility up to 81 per cent and 72 per cent respectively. The decline in spikelet fertility was mainly due to decreased ability of pollen grains to swell and poor anther dehiscence (Mahantashivayogayya *et al.*, 2016).

Materials and Methods

3. MATERIALS AND METHODS

31

The study aims to understand interactive effect of UV radiation and elevated temperature on rice (*Oryza sativa*. L) growth and physiology. A pot culture experiment was carried out at Department of Plant Physiology, College of Horticulture, during February 2018. Details of materials used and methods adopted are presented in this chapter.

3.1 General details

3.1.1 Location

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

3.1.2 Season

Crop duration was from January to May 2018

3.2.1 Plant Material

Rice variety Uma (MO-16) developed by Rice Reasearch Station, Mancompu was used in this study. It is a non lodging medium duration variety (115-120 days) with a promising yield of more than 5t/ha.

3.2.2 Details of experiment

Design : Completely Randomized Design (CRD)

Treatments : 12 (4×3)

Replication : 3

No of pots per replication : 3

Growing conditions : The polyhouses used in the study had the following specifications.

1- Polyhouse with green net on all four sides of size 21.37 m^2 with polythene sheet roofing of 0.25 mm thickness which contains UV filter that transmits 80per cent full spectrum and excludes UV-B light, (T_1).
2- Polyhouse of size 21.37 m^2 cladded with 0.15 mm thick polyethylene sheet and with roofing of 0.25 mm thick poly filter, which transmits 80per cent of full spectrum radiation and excludes UV-B, (T_2).
3- Polyhouse of size 21.37 m^2 cladded with 0.15 mm thick polyethylene sheet and an extra 0.25 mm thick polythene sheet on all four sides for inducing high temperature with minimum UV-B, (T_3).
4- Open condition - where crop is exposed to 100per cent natural solar UV radiation and external temperature, (T_4).

14 day old seedlings were planted in pots. Nine pots each were transferred to the polyhouses and retained there for a period of 30 days and returned back to open condition. The next set of nine pots each were kept in polyhouse for next 30 days. This was repeated to coincide with the following growth phases of plant.

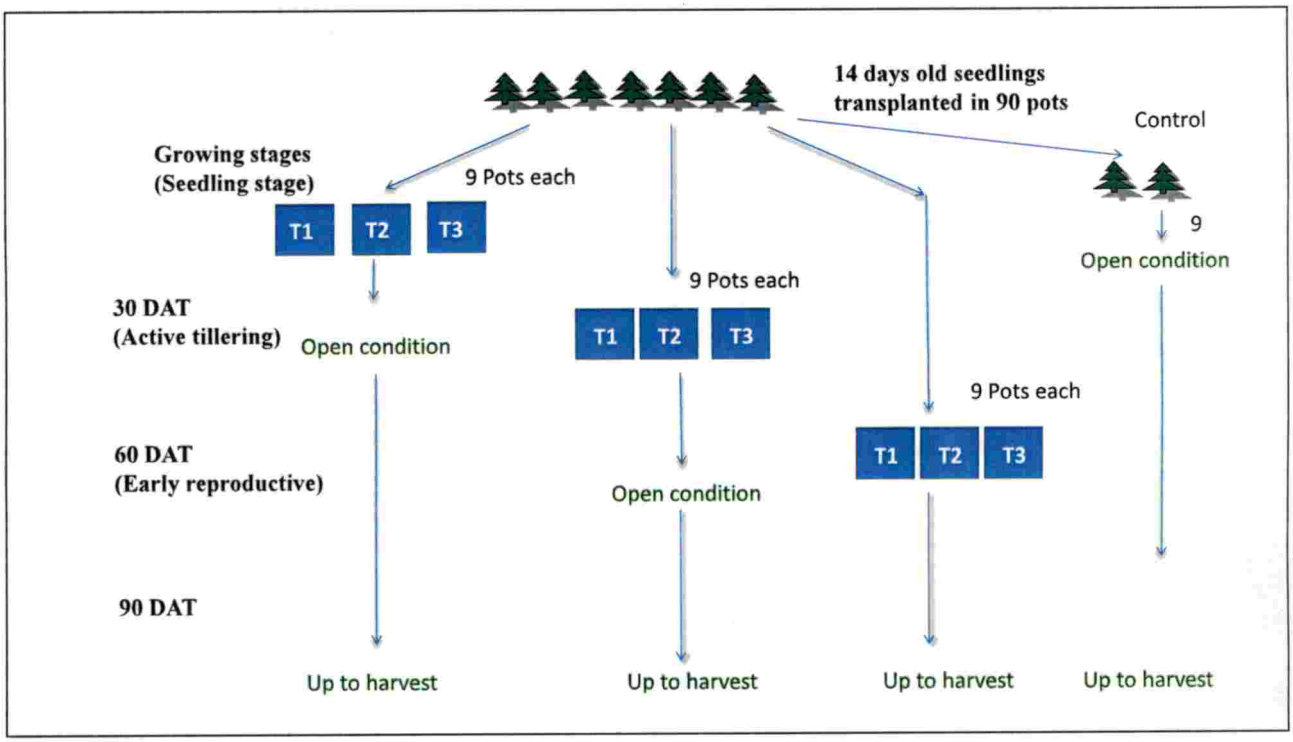
1. Seedling to active tillering phase (15-45 days, P_1)
2. Active tillering to early reproductive phase (45-75 days, P_2)
3. Early reproductive to harvest phase (75- 105 days, P_3)

3.2.3 Crop raising and management

Pot culture experiment was carried out in the College of Horticulture Vellanikkara. Three by fourth of the earthen pots were filled with soil collected from Kottepadam and FYM was applied in each pot at the time of pot filling @ 5t/ha. 15 day old seedlings were planted in pots (total 90) at the rate of two seedlings/hill and

two hills/pot. Initially nine pots each were placed in three polyhouses for a period of 30 days. After 30 days, these pots were removed from polyhouses and placed in open condition. Nine pots each with plants in the active tillering phase (45 DAS) were placed in three polyhouses for a period up to 60 days and then returned back to open condition. After 60 days, remaining nine pots each with plants in the early reproductive phase (75 DAS) were transferred to the polyhouses and maintained till harvest. A set of nine pots was retained in open condition as control. Fertilizers such as urea (46 per cent N) factomphos (20 per cent P) and muriate of potash (58 per cent K) were applied at the rate of 90:45:45 kg/ha respectively.

Fig.1 Diagrammatic representation of stress imposition



T_1 - Low temperature and low UV-B

T_2- High temperature (1^0C) and low UV-B

T_3- High temperature (2^0C) and low UV-B

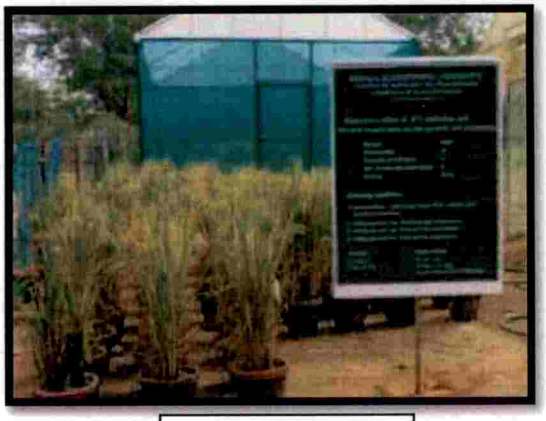
T_4-Control (Open condition)

Plate 1: View of different growing conditions

Seedling

Active tillering

Early reproductive



Harvest

Plate 2: Representative image of different growth stages

Plate 3: Gas exchange measurement using IRGA

3.2.4 UV-B and Temperature measurements

Ultraviolet B radiation was measured using UV-B meter (Model- 3414F, Field Scout, Spectrum technology, Icn.USA). Readings were taken at 11 am daily throughout the growing period. Radiation unit was expressed as Wm^{-2}.

Daily ambient temperature was taken using digital thermometer (MEXTECH Multi thermometer). Readings were taken at 11 am throughout the growing period. Temperature unit was expressed as ^0C.

3.3 Observations recorded

3.3.1 Morphological and phenological observations

a) Plant height

Plant height was measured using meter scale from the base of the plant to the tip of the longest leaf. Totally 18 plants were selected randomly from each treatment at 30^{th}, 60^{th} and 90^{th} day after transplanting.

b) Number of tillers per hill

Number of tillers were counted manually in each pot at 30^{th}, 60^{th} and 90^{th} day after transplanting. It was expressed as number of tillers per hill.

c) Days to heading

The number of days when 50 per cent panicle tip emerged from the flag leaf sheath in each pot was recorded as days to heading and it was counted from date of transplanting. The mean value was expressed in days.

d) Days to 50per cent flowering

Number of days to 50 per cent flowering was counted from transplanting in each treatment. The mean value was expressed in days.

e) Days to harvest

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

3.3.2 Physiological observations

Physiological parameters were taken at 30th, 60th and 90th days after transplanting

3.3.2.1 Leaf gas exchange parameters

Photosynthetic rate (μ mol m^{-2} s^{-1}), transpiration rate (m mol H_2O $m^{-2}s^{-1}$) and stomatal conductance (mol H_2O m^{-2} s^{-1}) were recorded using portable photosynthesis system (PPS- Model –LI-6400 of Licor Inc. Lincoln, Nebraska, USA) during 30th, 60th and 90th day after transplanting. Readings were made on physiologically active leaf (3rd leaf from top) and a total of three plants were selected from each treatment for measurement. Observations were recorded between 9.00 am to 10.30 am.

3.3.2.2 Pollen viability

For pollen viability, three anthers from different plants were selected for each treatment. Viability was determined using acetocarmine stain. Pollen grains stained uniformly were considered as viable. It was estimated as the ratio of number of stained pollen to total number of pollen grains.

3.3.3 Biochemical characters

Biochemical parameters were estimated at 30th, 60th and 90th day after transplanting in each treatment.

a) IAA content

IAA oxidase activity was estimated by the method suggested by Parthasaradhy *et al.* (1970) with slight modification, using Garden Weber reagent. Hundred milligram of sample was homogenized in a mortar and pestle using phosphate buffer and centrifuged. Extract was collected and volume made up to 25 ml. Ice-cold

phosphate buffer and auxin were added to 1ml sample extract taken from 25 ml. The absorbance was read at 520 nm and the enzyme activity was expressed as µg of unoxidised auxin g^{-1} h^{-1}.

b) GA content

The method for extraction, purification and estimation of endogenous plant hormone gibberellic acid (GA) was modified from that described by Sunderberg (1990) and Kojima (1995). Hundred gram of plant sample was homogenized in a mortar and pestle with methanol (ice-cold) and kept at 4^0 C in dark for four hours. The homogenate was centrifuged, filtered and solid residue was further extracted twice with the same solvent.

The methanolic extract was combined and concentrated to a water residue in vacuum at 50^0 C for one hour. The volume was adjusted to 10 ml with phosphate buffer and partitioned in a separating funnel with 10 ml of diethyl ether by stirring for 3 minutes. The ether phase was discarded and the aqueous phase was adjusted to pH 2.7 with 0.4 M HCl. The partitioned aqueous extract was collected twice with 0.4 M $NaHCO_3$. This was then partitioned with 10 ml ethyl acetate. The aqueous phase was decanted and stored at 4^0 C after adding 2 ml of methanol. This was used for gibberellin estimation by adding zinc acetate (2 ml) and potassium ferrocyanide (2 ml). It was then centrifuged and the supernatant collected was kept at 20^0 C for 75 minutes after adding 30 per cent HCl. The absorbance was read at 254 nm using a UV- VIS spectro photometer (Spectroquant, Pharo 300, MerckKGaA, Germany). GA content was calculated and expressed in µg g^{-1}.

c) Chlorophyll content

The total chlorophyll, chlorophyll a and chlorophyll b was estimated in physiologically active leaf by the method suggested by Hiscox and Israelstam (1979) using DMSO as extraction reagent. Readings were taken in UV-VIS

spectrophotometer (Spectroquant, Pharo 300, MerckKGaA, Germany) at two wavelengths 645 and 663 nm. The formulae used for chlorophyll calculation is given below and the results were expressed in mg g^{-1} fr.wt.

Chlorophyll a = $[(12.7\times A_{663}) - (2.69\times A_{645})] \times V/ 1000\times W$

Chlorophyll b = $[(22.9\times A_{645}) - (4.68\times A_{663})] \times V/ 1000\times W$

Total chlorophyll = $[(20.2\times A_{645}) + (8.02\times A_{663})] \times V/ 1000\times W$

Where A – Absorption at given wavelength

V – Volume of supernatant solution made

W- Weight of the sample

d) Amylose content

Hundred milligram sample was powdered using pestle and mortar. 1 ml of ethanol followed by 10 ml of 1N NaOH was added to the sample and left overnight. Then the volume was made up to 100 ml using distilled water. 2.5 ml of extract was pipetted out and 20 ml distilled water added to it followed by 2 drops of phenolphthalein. It was then titrated against 0.1 N HCl until the pink color just disappeared. Then 1 ml of iodine reagent was added to it and volume was made up to 50 ml. The absorbance was read at 590 nm using a UV- VIS spectro photometer (Spectroquant, Pharo 300, Merck KGaA, Germany). Amylose content was calculated and expressed in percentage (Jain *et al.*, 2012).

e) Proline content

Proline content was determined by the method of Bates *et al.* (1973) and expressed as μ moles g^{-1} tissue. Absorbance was taken at 520 nm.

3.3.4 Yield attributes

a) Number of panicle per plant

Number of panicle was counted from nine plants in each treatment after harvest and the mean was value noted and expressed as number of panicles per plant.

b) Number of spikelet per panicle

Nine panicle were selected randomly from each treatment for counting the number of spikelets. Mean value was expressed as number of spikelet per panicle.

c) 1000 grain weight

1000 grains were randomly selected from each replication and weighed using electronic balance. It was recorded as 1000 grain weight in gram.

d) Grain yield

Manual harvest was done in all pots. Grain yield was taken using electronic balance and recorded as grain yield per plant.

e) Chaff percentage

Samples were collected from randomly selected nine plants. Chaff percentage was calculated and expressed in percentage.

3.4 Statistical analysis

Statistical analysis was done using WASP 2.0, developed by ICAR, Goa. Pair wise comparisons of the treatments were done using critical difference.

Results

4. RESULTS

The pot culture experiment was conducted to understand the interactive effect of UV-B radiation and elevated temperature on rice growth and physiology at College of Horticulture, Vellanikkara.

The morphological, physiological, biochemical and yield attributes were calculated and analyzed statistically. The mean data of all observations are given in the tables.

4.1 UV-B and temperature analysis

The mean values of UV-B radiation recorded in each growing condition are given in the table 1. Readings were taken at 11 am throughout the growing period (Feb-2018 to May-2018).

Significantly higher UV-B radiation was recorded under open condition when compared to polyhouses. Maximum UV-B radiation (2.99 Wm^{-2}) was recorded in the month of February – 2018 and minimum values were recorded during May-2018 (1.57 Wm^{-2}). Negligibly lesser UV-B radiation (80 to 90 % lesser than ambient) was recorded in T_1 (0.17 Wm^{-2}), T_2 (0.15 Wm^{-2}) and T_3 (0.16 Wm^{-2}) conditions.

Table 1: Variation in UV-B radiation (Wm^{-2}) during the growth period

Month/Treatment	T_1	T_2	T_3	T_4	CD (0.05)
February	0.28	0.27	0.28	2.99	0.35
March	0.21	0.20	0.21	2.71	0.43
April	0.18	0.16	0.17	1.88	0.23
May	0.17	0.15	0.16	1.57	0.04

The mean value of monthly temperature is given in the Table 2. Readings were taken at 11 am throughout the growing period.

Significantly higher temperature was recorded during the month of February-2018 (35.97^0C) and minimum temperature during May- 2018 (32.90^0C) in open condition. Among different growing conditions, T_3 recorded higher temperature (37.97^0C) and minimum temperature was recorded in T_1 (31.58^0C).

Table 2: Variation in temperature (^{0}C) during the growth period

Month/Treatment	T_1	T_2	T_3	T_4	CD (0.05)
February	34.76	37.09	37.97	35.97	1.01
March	34.50	36.75	37.63	35.49	1.74
April	33.74	36.08	37.15	35.20	0.99
May	31.58	33.93	34.95	32.90	1.24

4.2 Morphological and phenological characters

4.2.1 Plant height

4.2.1.1 Plant height at 30 DAT (Seedling to active Tillering stage)

Plant height was taken 30 days after planting and the mean values showed significant variation between four treatments (Table 3). Plants grown under T_2P_1 recorded maximum height (58.44cm) followed by T_1P_1 (53.83cm) which was on par with T_3P_1 (52.72cm) and the lowest height was recorded under T_4 (45.55 cm) condition (absolute control).

Table 3: Effect of UV-B radiation and elevated temperature on plant height at 30 DAT

Treatments	Plant height (cm)
T_1P_1	53.83^b
T_2P_1	58.44^a
T_3P_1	52.72^b
T_4(Control)	45.55^c
CD (0.05)	4.12

4.2.1.2 Plant height at 60 DAT (Active tillering to early reproductive stage)

Plant height after 60 days of transplanting showed significant variation between treatments (Table 4). Among four treatments T_1P_2 recorded maximum height (97.27cm) which was on par with T_2P_2 with a height of 96.31 cm. T_3P_2 recorded a plant height of 93.99 cm which was on par with the lowest value T_4 (90.63 cm).

Table 4: Effect of UV radiation and elevated temperature on plant height at 60 DAT

Treatments	Plant height (cm)
T_1P_2	97.27^a
T_2P_2	96.31^a
T_3P_2	93.99^{ab}
T_4 (Control)	90.63^b
CD (0.05)	3.86

4.2.1.3 Plant height at 90 DAT (Early reproductive to harvest stage)

Comparative evaluation of plant height taken 90 DAT revealed significant variation (Table 5). Maximum plant height was recorded by T_2P_3 (102.22 cm) which was on par with T_3P_3 (101.07cm). Other two treatments such as T_1P_3 and T_4 recorded a plant height of 95.55 cm and 93.22 cm respectively.

Table 5: Effect of UV radiation and elevated temperature on plant height at 90 DAT

Treatments	Plant height (cm)
T_1P_3	95.55^b
T_2P_3	102.22^a
T_3P_3	101.07^a
T_4 (Control)	93.22^b
CD (0.05)	4.16

4.2.1.4 Comparison of plant height at 90 DAT of all treatments

Analysis of plant height at the time of harvest did not show any significant variation between treatments (Table 6). Most of the plants attained a plant height more than 95 cm except control ,T_4 (93.22 cm). Plants kept in T_3 during P_1 recorded maximum height (T_3P_1, 103 cm) and T_4 recorded minimum height.

Table 6: Influence of stress induction during different phenophases on plant height

Treatments	Plant height (cm)
T_1P_1	96.44
T_2P_1	98.88
T_3P_1	103.00
T_1P_2	97.66
T_2P_2	98.22
T_3P_2	97.55
T_1P_3	95.55
T_2P_3	102.22
T_3P_3	101.07
T_4	93.22
CD (0.05)	NS

4.2.2 Number of tillers per hill

4.2.2.1 Number of tillers per hill at 30 DAT (Seedling to active tillering stage)

Mean value of number of tillers per hill showed significant variation during the first phase of growth (Table 7). Highest no of tillers per hill was recorded in T_4 (11.27) and T_3P_1 (7.27) had the least number of tillers. T_3P_1 was on par with T_1P_1 (8.16) and T_2P_1 (8.99).

Table 7: Effect of UV-B radiation and elevated temperature on number of tillers per hill at 30 DAT

Treatments	No. of tillers per hill
T_1P_1	8.16^b
T_2P_1	8.99^b
T_3P_1	7.27^b
T_4 (Control)	11.27^a
CD (0.05)	2.08

4.2.2.2 Number of tillers per hill at 60 DAT (Active tillering to early reproductive stage)

The number of tillers per hill showed significant variation in the early reproductive stages of growth (Table 8). Highest no of tillers per hill was observed in T_4 (33.06) and lowest was in T_3P_2 (20.76). T_2P_2 and T_1P_2 recorded 25.46, 26.93 number of tillers respectively.

Table 8: Effect of UV-B radiation and elevated temperature on number of tillers per hill at 60 DAT

Treatments	No.of tillers per hill
T_1P_2	26.93^b
T_2P_2	25.46^b
T_3P_2	20.76^c
T_4 (Control)	33.06^a
CD (0.05)	3.92

4.2.2.3 Number of tillers per hill at 90 DAT (Early reproductive to harvest stage)

Significantly higher number of tillers per hill was recorded in T_4 (16.62). T_2P_3 recorded 14.79 number of tillers per hill and which was on par with T_1P_3 (14.56). Lowest number of tillers per hill was observed in very high temperature treatment T_3P_3 (12.45).

Table 9: Effect of UV-B radiation and elevated temperature on number of tillers per hill at 90 DAT

Treatments	No.of tillers per hill
T_1P_3	14.56^b
T_2P_3	14.79^b
T_3P_3	12.45^c
T_4 (Control)	16.62^a
CD (0.05)	0.92

4.2.2.4 Comparison of tiller number per hill at 90 DAT of all treatments

Mean data of number of tillers per hill showed significant variation (Table 10). Maximum number of tillers was recorded in T_4 (16.62) which was on par with T_1P_2 (15.66). Lowest number of tillers per hill was recorded in T_3P_3 (12.45) was on par with T_3P_1 (12.66).

Table 10: Influence of stress induction during different phenophases on tiller number

Treatments	No. of tillers per hill
T_1P_1	14.33^{cd}
T_2P_1	14.00^{cd}
T_3P_1	12.66^{e}
T_1P_2	15.66^{ab}
T_2P_2	13.66^{cde}
T_3P_2	13.33^{de}
T_1P_3	14.56^{bcd}
T_2P_3	14.79^{bc}
T_3P_3	12.45^{e}
T_4	16.62^{a}
CD (0.05)	1.27

4.3.3 Days to heading

When a comparison was made between the plants exposed to stress condition at different phases of growth, results showed significant variation in the days to heading (Table 11). More number of days to heading was recorded in T_4 (73 days) and it was on par with T_1P_1 (71.33 days). Early heading was observed in T_2P_2 (66 days) which was on par with T_3P_2 (66.66 days), T_2P_1 (67 days), T_3P_1 (68 days) and T_3P_3 (68 days). Among the different treatments, plants grown under T_2 and T_3 recorded less number of days to heading.

Table 11: Influence of stress induction during different phenophases on days to heading

Treatments	Days
T_1P_1	71.33^{ab}
T_2P_1	67.00^{de}
T_3P_1	68.00^{de}
T_1P_2	70.33^{bc}
T_2P_2	66.00^{e}
T_3P_2	66.66^{de}
T_1P_3	70.66^{bc}
T_2P_3	68.00^{de}
T_3P_3	68.66^{cd}
T_4	73.00^{a}
CD (0.05)	2.32

4.3.4 Days to 50% flowering

A comparative evaluation of plants subjected to stress at different phases indicated that there was a significant variation in the number of days required for 50% flowering (Table 12). Early completion of 50% flowering was observed in T_2P_2 (71 days) which was on par with T_2P_1 (71.33 days), T_3P_2 (71.66 days) and T_3P_1 (72 days). Late completion of 50% flowering was recorded in T_4 (77.33 days). Plants grown under T_1 condition at different stages (P_1, P_2 and P_3) recorded 75, 73.66 and 75.66 days, respectively for completion 50% flowering.

Table 12: Influence of stress induction during different phenophases on days to 50% flowering

Treatments	Days
T_1P_1	75.00^{bc}
T_2P_1	71.33^{f}
T_3P_1	72.00^{ef}
T_1P_2	73.66^{cd}
T_2P_2	71.00^{f}
T_3P_2	71.66^{f}
T_1P_3	75.66^{b}
T_2P_3	73.33^{de}
T_3P_3	73.66^{cd}
T_4	77.33^{a}
CD (0.05)	1.64

4.3.5 Days to harvest

Plants grown under elevated temperature condition attained early harvestable maturity than plants grown in the open condition (Table 13). T_2P_2 (110.66 days) recorded the lowest number of days to harvest which was on par with T_2P_1 (111.33 days) and T_3P_1 (112.00 days). Plants in open condition (T_4) took more number of days to harvest (116.33 days). It was on par with T_1P_2 (115.33 days) and T_1P_1 (115.00 days).

Table 13: Influence of stress induction during different phenophases on days to harvest

Treatments	Days
T_1P_1	115.00^{ab}
T_2P_1	111.33^{de}
T_3P_1	112.00^{de}
T_1P_2	115.33^{ab}
T_2P_2	110.66^{e}
T_3P_2	112.33^{d}
T_1P_3	114.66^{b}
T_2P_3	112.66^{cd}
T_3P_3	114.00^{bc}
T_4	116.33^{a}
CD (0.05)	1.35

4.3 Physiological characters

4.3.1 Photosynthetic rate

4.3.1.1Photosynthetic rate at 30 DAT (Seedling to active tillering stage)

After 30 days of transplanting, all treatments recorded significantly higher photosynthetic rate except T_4 ($20.81 \mu molm^{-2}s^{-1}$). The highest photosynthetic rate of 23.95 μ mol $m^{-2}s^{-1}$ was recorded by T_2P_1. The photosynthetic rate of in T_3P_1 ($21.01 \mu molm^{-2}s^{-1}$) and T_1P_1 ($21.05 \mu molm^{-2}s^{-1}$) were on par with each other.

Table 14: Effect of UV-B radiation and elevated temperature on photosynthetic rate 30 DAT

Treatments	Photosynthetic rate ($\mu molm^{-2}s^{-1}$)
T_1P_1	21.05^b
T_2P_1	23.95^a
T_3P_1	21.01^b
T_4 (Control)	20.81^b
CD (0.05)	1.58

4.3.1.2 Photosynthetic rate at 60 DAT (Active tillering to early reproductive stage)

Compared to 30 DAT, all the treatments recorded higher photosynthetic rate at 60 DAT (Table 15). Significantly higher photosynthetic rate was observed in T_2P_2 (26.17 $\mu molm^{-2}s^{-1}$) when compared to all other treatments. The photosynthetic rate recorded in T_1P_2 (23.82 $\mu molm^{-2}s^{-1}$) was on par with T_4 (23.39 $\mu molm^{-2}s^{-1}$). T_3P_2 (21.63 $\mu molm^{-2}s^{-1}$) recorded the lowest photosynthetic among all the treatments.

Table 15: Effect of UV-B and elevated temperature on photosynthetic rate at 60 DAT

Treatments	Photosynthetic rate ($\mu molm^{-2}s^{-1}$)
T_1P_2	23.82^b
T_2P_2	26.17^a
T_3P_2	21.63^c
T_4 (Control)	23.39^b
CD (0.05)	1.44

54

4.3.1.3 Photosynthetic rate at 90 DAT (Early reproductive to harvest)

Mean data of photosynthetic rate at 90 DAT is given in the Table 16.

T_2P_3 (13.18μmolm^{-2}s^{-}1) recorded the highest photosynthetic rate followed by T_1P_3 (11.67μmolm^{-2}s^{-1}). The lowest photosynthetic rate was recorded in T_3P_3 (9.83μmolm^{-2}s^{-1}) which was on par with T_4 (10.67μmolm^{-2}s^{-1}).

Table 16 : Effect of UV-B and elevated temperature on photosynthetic rate at 90 DAT

Treatments	Photosynthetic rate (μmolm^{-2}s^{-1})
T_1P_3	11.67^{b}
T_2P_3	13.18^{a}
T_3P_3	9.83^{c}
T_4 (Control)	10.67^{bc}
CD (0.05)	1.18

4.3.1.4 Comparison of photosynthetic at 90 DAT of all treatments

Comparison of photosynthetic rate showed significant variation within the treatments. T_2P_3 (13.18 μmolm^{-2}s^{-1}) recorded maximum photosynthetic rate followed by T_1P_3 (11.67 μmolm^{-2}s^{-1}) which was on par with T_4 (10.67μmolm^{-2}s^{-1}), T_1P_1 (10.68μmolm^{-2}s^{-1}), T_3P_1 (10.93 μmolm^{-2}s^{-1}), T_2P_1 (11.14μmolm^{-2}s^{-1}), T_2P_2 (10.63 μmolm^{-2}s^{-1}) and T_3P_2 (11.15 μmolm^{-2}s^{-1}). The lowest photosynthetic rate was recorded in T_3P_3 (9.85 μmolm^{-2}s^{-1}).

Table 17: Influence of stress induction during different phenophases on photosynthetic rate

Treatments	Photosynthetic rate ($\mu molm^{-2}s^{-1}$)
T_1P_1	10.68^{bc}
T_2P_1	11.14^{bc}
T_3P_1	10.93^{bc}
T_1P_2	10.04^{c}
T_2P_2	10.63^{bc}
T_3P_2	11.15^{bc}
T_1P_3	11.67^{ab}
T_2P_3	13.18^{a}
T_3P_3	9.85^{c}
T_4	10.67^{bc}
CD (0.05)	1.602

4.3.2 Transpiration rate

4.3.2.1 Transpiration rate at 30 DAT (Seedling to active tillering stage)

Transpiration rate at 30 DAT showed significant difference among treatments (Table 18). The transpiration rate was found higher in T_2P_1 (2.11m mol H_2O m^{-2} s^{-1}) compared to other treatments. The lowest transpiration rate was observed in T_3P_1 (1.37m mol H_2O m^{-2} s^{-1}) which was on par with absolute control T_4 (1.21m mol H_2O m^{-2} s^{-1}).

Table 18: Effect of UV-B and elevated temperature on transpiration rate at 30 DAT

Treatments	Transpiration rate (m mol H_2O m^{-2} s^{-1})
T_1P_1	1.35^b
T_2P_1	2.11^a
T_3P_1	1.37^b
T_4 (Control)	1.21^b
CD (0.05)	0.41

4.3.2.2 Transpiration rate at 60 DAT (Active tillering to early reproductive stage)

Mean data of transpiration rate 60 DAT is given in the Table 19. Among different treatments T_2P_2 (2.92 m mol H_2O m^{-2} s^{-1}) recorded the highest transpiration rate followed by T_1P_2 (2.07 m mol H_2O m^{-2} s^{-1}) which was on par with T_4 (1.89 m mol H_2O m^{-2} s^{-1}) as well as T_3P_2 (1.98 m mol H_2O m^{-2} s^{-1}).

Table 19: Effect of UV-B and elevated temperature on transpiration rate at 60 DAT

Treatments	Transpiration rate (m mol H_2O m^{-2} s^{-1})
T_1P_2	2.07^b
T_2P_2	2.92^a
T_3P_2	1.98^{bc}
T_4 (Control)	1.89^{bc}
CD (0.05)	0.53

4.3.2.3 Transpiration rate at 90 DAT (Early reproductive to harvest)

Transpiration rate at 90 DAT did not shown any significant variation within treatments (Table 20). Maximum transpiration rate was recorded in T_2P_3 (1.13 m mol H_2O m^{-2} s^{-1}) and T_4 recorded minimum (1.07 m mol H_2O m^{-2} s^{-1})

Table 20: Effect of UV-B and elevated temperature on transpiration rate at 90 DAT

Treatments	Transpiration rate (m mol H_2O m^{-2} s^{-1})
T_1P_3	1.07
T_2P_3	1.13
T_3P_3	1.03
T_4 (Control)	1.07
CD (0.05)	NS

4.3.2.4 Comparison of transpiration rate at 90 DAT of all treatments

Significant variation in transpiration rate was observed within the treatments (Table 21). Among different treatments T_2P_3 (1.13 m mol H_2O m^{-2} s^{-1}) recorded the highest transpiration rate. The Lowest transpiration rate was recorded in T_3P_3 (1.03 m mol H_2O m^{-2} s^{-1}) which was on par with T_3P_2 (1.03 m mol H_2O m^{-2} s^{-1}) and T_1P_1 (1.05 m mol H_2O m^{-2} s^{-1}).

Table 21: Influence of stress induction during different phenophases on transpiration rate

Treatments	Transpiration rate (m mol H_2O m^{-2} s^{-1})
T_1P_1	1.05^{bcd}
T_2P_1	1.06^{b}
T_3P_1	1.07^{b}
T_1P_2	1.06^{bc}
T_2P_2	1.06^{b}
T_3P_2	1.03^{cd}
T_1P_3	1.07^{b}
T_2P_3	1.13^{a}
T_3P_3	1.03^{d}
T_4	1.07^{b}
CD (0.05)	0.02

4.3.3 Stomatal conductance

4.3.3.1 Stomatal conductance at 30 DAT (Seedling to active tillering stage)

Significantly higher stomatal conductance was observed in T_2P_1 (0.15 mol H_2O m^{-2} s^{-1}) compared to all other treatments. T_1P_1 recorded a stomatal conductance of 0.11mol H_2O m^{-2} s^{-1} which was on par with T_3P_1 (0.11mol H_2O m^{-2} s^{-1}). Among the four treatments T_4 (0.10 mol H_2O m^{-2} s^{-1}) recorded the lowest stomatal conductance.

Table 22: Effect of UV-B and elevated temperature on stomatal conductance at 30 DAT

Treatments	Stomatal conductance (mol H_2O m^{-2} s^{-1})
T_1P_1	0.11^b
T_2P_1	0.15^a
T_3P_1	0.11^b
T_4 (Control)	0.10^b
CD (0.05)	0.02

4.3.3.2 Stomatal conductance at 60 DAT (Active tillering to early reproductive)

T_2P_2 (0.17 mol H_2O m^{-2} s^{-1}) recorded significantly higher stomatal conductance at 60 DAT compared to other treatments. T_1P_2 and T_4 (Control) were on par with 0.12 mol H_2O m^{-2} s^{-1} and 0.11 mol H_2O m^{-2} s^{-1} stomatal conductance respectively. Lowest stomatal conductance was recorded by T_3P_2 (0.10 mol H_2O m^{-2} s^{-1}).

Table 23: Effect of UV-B and elevated temperature on stomatal conductance at 60 DAT

Treatments	Stomatal conductance (mol H_2O m^{-2} s^{-1})
T_1P_2	0.12^b
T_2P_2	0.17^a
T_3P_2	0.10^c
T_4 (Control)	0.11^{bc}
CD (0.05)	0.01

4.3.3.3 Stomatal conductance at 90 DAT (Early reproductive to harvest)

Comparison of stomatal conductance of plants grown under different condition at 90 DAT did not show any significant variation. Maximum stomatal conductance was observed in T_2P_3 (0.10 mol H_2O m^{-2} s^{-1}) and minimum was recorded in T_3P_3 (0.07 mol H_2O m^{-2} s^{-1}).

Table 24: Effect of UV-B and elevated temperature on stomatal conductance at 90 DAT

Treatments	Stomatal conductance (mol H_2O m^{-2} s^{-1})
T_1P_3	0.08
T_2P_3	0.10
T_3P_3	0.07
T_4 (Control)	0.08
CD (0.05)	NS

4.3.3.4 Comparison of stomatal conductance at 90 DAT of all treatments

Analysis of stomatal conductance at harvest stage did not show any significant variation within treatment (Table 25). Maximum stomatal conductance was observed in T_2P_3 (0.10 mol H_2O m^{-2} s^{-1}) and minimum in T_3P_3 (0.07 mol H_2O m^{-2} s^{-1}).

Table 25: Influence of stress induction during different phenophases on stomatal conductance

Treatments	Stomatal conductance (mol H_2O m^{-2} s^{-1})
T_1P_1	0.07
T_2P_1	0.08
T_3P_1	0.08
T_1P_2	0.08
T_2P_2	0.07
T_3P_2	0.08
T_1P_3	0.08
T_2P_3	0.10
T_3P_3	0.07
T_4	0.08
CD (0.05)	NS

4.3.4 Pollen viability

Significant variation in pollen viability was observed between treatments (Table 26). Maximum pollen viability was recorded in T_1P_3 (86.54%) and it was on par with T_1P_2 (85.37%), T_1P_1 (85.01%), T_2P_1 (84.80%), T_4 (83.02%) and T_3P_1 (82.48%). Significantly lower pollen viability was recorded in T_3P_3 (43.30%).

Table 26 : Influence of stress induction during different phenophases on pollen viability

Treatments	Percentage
T_1P_1	85.01[a]
T_2P_1	84.80[a]
T_3P_1	82.48[ab]
T_1P_2	85.37[a]
T_2P_2	77.35[b]
T_3P_2	69.28[c]
T_1P_3	86.54[a]
T_2P_3	68.45[c]
T_3P_3	43.30[d]
T_4	83.02[ab]
CD (0.05)	7.29

4.4 Biochemical characters

4.4.1 IAA content

4.4.1.1 IAA Content at 30 DAT (Seedling to active tillering stage)

Mean values of IAA content at four different growing conditions are given in the Table 27. Significantly higher IAA content was observed in T_3P_1 (5.203 mg g^{-1}) which was on par with T_1P_1 (5.202 mg g^{-1}) followed by T_2P_1 (3.86 mg g^{-1}). The lowest IAA content of 1.67 mg $g^{-1}$was recorded in T_4.

Table 27: Effect of UV-B radiation and elevated temperature on IAA content at 30 DAT

Treatments	IAA content (mg of unoxidised auxin g^{-1} hr^{-1})
T_1P_1	5.20[a]
T_2P_1	3.86[b]
T_3P_1	5.20[a]
T_4 (Control)	1.67[c]
CD (0.05)	1.10

4.4.1.2 IAA Content at 60 DAT (Active tillering to early reproductive stage)

IAA content 60 DAT did not showed any significant variation between the treatments (Table 28). Maximum and minimum IAA content was observed in T_1P_2 (6.01) and T_4 (5.37) respectively.

Table 28: Effect of UV radiation and elevated temperature on IAA content at 60 DAT

Treatments	IAA content (mg of unoxidised auxin g^{-1} hr^{-1})
T_1P_2	6.01
T_2P_2	5.99
T_3P_2	5.52
T_4 (Control)	5.37
CD (0.05)	NS

4.4.1.3 IAA content at 90 DAT (Early reproductive to harvest stage)

IAA content in leaves were found to be non significant during 90 DAT (Table 29). Among four treatments T_3P_3 (4.25mg g^{-1}) recorded maximum IAA content followed by T_2P_3 (4.21mg g^{-1}). Minimum IAA was observed in T_4 (3.41 mg g^{-1}).

Table 29 : Effect of UV radiation and elevated temperature on IAA content at 90 DAT

Treatments	IAA content(mg of unoxidised auxin g^{-1} hr^{-1})
T_1P_3	4.01
T_2P_3	4.21
T_3P_3	4.25
T_4 (Control)	3.41
CD (0.05)	NS

4.4.1.4 Comparison of IAA content at 90 DAT of all treatments

Comparative evaluation of IAA content of all treatments did not show any significant variation within treatment (Table 30). The highest IAA content was recorded in T_2P_3 (4.21 mg g^{-1}) and minimum in T_3P_1 (3.18 mg g^{-1}).

Table 30: Influence of stress induction during different phenophases on IAA content

Treatments	IAA content (mg of unoxidised auxin g^{-1} hr^{-1})
T_1P_1	3.29
T_2P_1	3.38
T_3P_1	3.18
T_1P_2	3.29
T_2P_2	3.34
T_3P_2	3.24
T_1P_3	4.01
T_2P_3	4.21
T_3P_3	4.25
T_4	3.41
CD (0.05)	NS

4.4.2 GA content

65

4.4.2.1 GA content at 30 DAT

Significant variation in GA was found between treatment (Table 31). T_2P_1 (29.70 µg g^{-1}) recorded maximum GA and it was significantly superior to other treatments. The lowest GA was observed in T_4 (18.08 µg g^{-1}). T_3P_1 and T_1P_1 recorded 24.36 µg g^{-1} and 23.58 µg g^{-1} GA respectively.

Table 31: Effect of UV-B and elevated temperature on GA content at 30 DAT

Treatments	GA content (µg g^{-1})
T_1P_1	23.58^b
T_2P_1	29.70^a
T_3P_1	24.36^a
T_4(Control)	18.08^c
CD (0.05)	4.94

4.4.2.2 GA content at 60 DAT

Significant variation in GA content was not observed when plants of P_2 were kept in different polyhouses under different temperature regimes. Maximum GA content was recorded in T_3P_1 (21.42) and minimum recorded in T_4, control (16.60)

Table 32: Effect of UV-B and elevated temperature on GA content at 60 DAT

Treatments	GA content (µg g^{-1})
T_1P_1	20.45
T_2P_1	20.94
T_3P_1	21.42
T_4(Control)	16.60
CD (0.05)	NS

4.4.2.3 GA content at 90 DAT

Plants kept under different temperature regimes in the reproductive stage (90 DAT) did not shown any significant variation in GA content. Higher GA content was observed in T_2P_1 (16.62) and T_4 recorded minimum (14.00)

Table 33: Effect of UV-B and elevated temperature on GA content at 90 DAT

Treatments	GA content ($\mu g\ g^{-1}$)
T_1P_1	16.20
T_2P_1	16.62
T_3P_1	15.26
T_4(Control)	14.00
CD (0.05)	NS

4.4.2.4 Comparison of GA content at 90 DAT of all treatments

Comparative evaluation of GA content at harvest stage did not show any significant variation within treatments. Plants grown under polyhouse condition during the P_3 recorded more GA than plants grown in open condition. T_2P_1 recorded maximum GA (16.62) and T_3P_1 recorded (13.05) minimum.

Table 34: Influence of stress induction during different phenophases on GA content

Treatments	GA content ($\mu g\ g^{-1}$)
T_1P_1	14.00
T_2P_1	13.43
T_3P_1	13.05
T_1P_2	14.27
T_2P_2	13.87
T_3P_2	14.19
T_1P_3	16.20
T_2P_3	16.62
T_3P_3	15.26
T_4	14.00
CD (0.05)	NS

4.4.3.1 Chlorophyll content at 30 DAT (Seedling to active tillering stage)

Contents of Chlorophyll a, chlorophyll b and total chlorophyll were found significantly different at 30 DAT within treatments. T_3P_1 recorded maximum chlorophyll b (1.67 mg g^{-1} fr.wt) and total chlorophyll (4.25 mg g^{-1} fr.wt). The highest chlorophyll a was recorded in T_1P_1 (2.86 mg g^{-1} fr.wt). T_4 recorded the lowest chlorophyll content (chl a- 1.76, chl b- 0.84, total chl- 2.60 mg g^{-1} fr.wt)

Table 35: Effect of UV-B and elevated temperature on chlorophyll content at 30 DAT

Treatments	30 DAT (Active tillering stage)		
	Chlorophyll a (mg g^{-1} fr.wt)	Chlorophyll b (mg g^{-1} fr.wt)	Total Chlorophyll (mg g^{-1} fr.wt)
T_1P_1	2.86	0.84	3.70^a
T_2P_1	2.49	1.23	3.73^a
T_3P_1	2.58	1.67	4.25^a
T_4 (Control)	1.76	0.84	2.60^b
CD (0.05)	0.52	0.48	0.76

4.4.3.2 Chlorophyll content at 60 DAT (Active tillering to early reproductive stage)

Significant variation in chlorophyll content was not observed when the plants of phase 2 were kept under different temperature regimes and lower UV-B condition (Table 36). Maximum total chlorophyll was recorded in T_2P_2 (2.94 mg g^{-1} fr.wt) and minimum in T_1P_2 (2.32 mg g^{-1} fr.wt).

Table 36: Effect of UV-B and elevated temperature on chlorophyll content at 60 DAT

Treatments	60 DAT (Early reproductive stage)		
	Chlorophyll a (mg g^{-1} fr.wt)	Chlorophyll b (mg g^{-1} fr.wt)	Total Chlorophyll (mg g^{-1} fr.wt)
T_1P_2	1.91	0.40	2.32
T_2P_2	2.08	0.79	2.94
T_3P_2	1.85	0.55	2.40
T_4 (Control)	1.75	0.69	2.44
CD (0.05)	NS	NS	NS

4.4.3.3 Chlorophyllcontent at 90 DAT (Early reproductive to harvest)

The total chlorophyll and Chlorophyll a were non-significant during the harvest stage while Chlorophyll b was significant. The highest total chlorophyll content was observed in T_3P_3 (2.14 mg g^{-1} fr.wt) and lowest was recorded in T_4 (1.53 mg g^{-1} fr.wt).

Table 37: Effect of UV-B and elevated temperature on chlorophyll content at 90 DAT

Treatments	90 DAT (Harvest stage)		
	Chlorophyll a (mg g^{-1} fr.wt)	Chlorophyll b (mg g^{-1} fr.wt)	Total Chlorophyll (mg g^{-1} fr.wt)
T_1P_3	1.38	0.36	1.74
T_2P_3	1.47	0.38	1.85
T_3P_3	1.32	0.81	2.14
T_4 (Control)	1.30	0.23	1.53
CD (0.05)	NS	0.26	NS

4.4.4.1Amylose content

Amylose content of grains showed significant variation within the treatments (Table 38). T_1P_1 had higher amylose content (25.03%) which was on par with T_4 with 24.35% amylose. Least amylose content was observed in T_3P_3 (16.05%). T_3P_2 had 17.17% amylose content which was on par with T_3P_3. Remaining treatments such as T_1P_2, T_1P_3, T_2P_1, T_3P_1, T_2P_2 and T_2P_3 recorded 23.44%, 23.32%, 22.07%, 22.06%, 19.02% and 17.65% of amylase content respectively.

Table 38: Effect of UV-B and elevated temperature on amylose content

Treatments	Percentage
T_1P_1	25.03^{a}
T_2P_1	22.07^{c}
T_3P_1	22.06^{c}
T_1P_2	23.44^{bc}
T_2P_2	19.02^{d}
T_3P_2	17.17^{ef}
T_1P_3	23.32^{bc}
T_2P_3	17.65^{de}
T_3P_3	16.05^{f}
T_4	24.35^{ab}
CD (0.05)	1.41

4.4.4.2 Proline content

Synthesis of proline in the rice flag leaves were significantly influenced by the UV and temperature treatments (Table 39). Plants subjected to stress during the phase 2 and phase 3 synthesised more proline than other stages. Among treatments T_3P_3 (338.51 μ mol g^{-1}) recorded more proline content which was on par with T_3P_2 having 329.08 μmol g^{-1} proline. Six out of ten treatment including control recorded a proline

content less than 100 µmol g^{-1}. Minimum proline content was observed in T_1P_1 (65.81 µmol g^{-1}) followed by T_2P_1 (76.27µmol g^{-1}).

Table 39: Effect of UV-B and elevated temperature on proline content

Treatments	Proline (µmol g^{-1})
T_1P_1	65.81^c
T_2P_1	76.27^c
T_3P_1	87.68^c
T_1P_2	91.21^c
T_2P_2	155.88^b
T_3P_2	329.08^a
T_1P_3	92.78^c
T_2P_3	163.90^b
T_3P_3	338.51^a
T_4	90.85^c
CD (0.05)	35.14

4.5 Yield characters

4.5.1 Number of panicles per plant

Analysis of number of panicles per plant at harvest stage showed significant variation within treatments (Table 40). Among different treatments, T_4 (8.26) recorded maximum number of panicles per plant. Significantly lower number of panicles per plant was recorded in T_3P_3 (6.10). All other treatments recorded a panicle number in between 5 and 7.

Table 40: Influence of stress induction during different phenophases on panicle number

Treatments	Panicle (number)
T_1P_1	7.06^{cd}
T_2P_1	6.96^{d}
T_3P_1	6.36^{e}
T_1P_2	7.60^{b}
T_2P_2	6.66^{e}
T_3P_2	6.63^{e}
T_1P_3	7.23^{cd}
T_2P_3	7.31^{C}
T_3P_3	6.10^{f}
T_4	8.26^{a}
CD (0.05)	0.27

4.5.2 Number of spikelets per panicle

Mean data of number of spikelets per panicle were given in the Table 41.

Number of spikelets per panicle were significantly influenced by the UV-B and temperature treatments at different phenophases of growth. Among various treatments T_2P_1 (189.85) recorded the maximum number of spikelets per panicle followed by T_3P_1 (169.55) and it was on par with T_2P_1. Least number of spikelets per panicle was observed in T_4 (135.88) was on par with T_3P_3 (140.11), T_3P_2 (140.55), T_2P_3 (149.00), T_1P_3 (149.77) and T_1P_1 (150.88).

Table 41: Influence of stress induction during different phenophases on spikelets per panicle

Treatments	Spikelets per panicle (No.)
T_1P_1	150.88^{bcd}
T_2P_1	189.85^{a}
T_3P_1	169.55^{ab}
T_1P_2	157.77^{bc}
T_2P_2	163.66^{b}
T_3P_2	140.55^{cd}
T_1P_3	149.77^{bcd}
T_2P_3	149^{bcd}
T_3P_3	140.11^{cd}
T_4	135.88^{d}
CD (0.05)	23.78

4.5.3 Thousand Grain weight

Mean data of thousand grain weight of different treatments are in the Table 42.

Maximum thousand grain weight was observed in T_1P_1 with 24.07g. It was on par with T_4 (23.91g) and T_2P_1 (23.72g). Minimum thousand grain weight was recorded in T_3P_3 (21.30g). T_3P_1 recorded 22.40g of thousand grain weight which was on par with T_3P_3. All other treatments recorded a thousand grain weight in between 22.40g and 23.72g.

Table 42: Influence of stress induction during different phenophases on thousand grain weight

Treatments	Weight (gm)
T_1P_1	24.07^{a}
T_2P_1	23.72^{abc}
T_3P_1	22.40^{d}
T_1P_2	22.79^{cd}
T_2P_2	22.86^{bcd}
T_3P_2	22.19^{de}
T_1P_3	22.90^{bcd}
T_2P_3	22.56^{d}
T_3P_3	21.30^{e}
T_4	23.91^{ab}
CD (0.05)	1.07

4.5.4 Yield

Mean data of grain yield per plant grown under different conditions were given in the Table 43.

Significant difference was found between the treatments for yield. T_2P_1 recorded the maximum yield of 32.08g per plant and which was on par with T_1P_3 (30.16g), T_1P_2 (31.34g), T_3P_1 (30.58g) and T_1P_1 (29.04g). Plants imposed stress after 60 days of transplanting with intensity T_3 (T_3P_3) resulted in the lowest yield of 13.83g and which was significantly different from T_4 (24.02g).

75

Table 43: Influence of stress induction during different phenophases on yield

Treatments	Yield (g)
T_1P_1	29.04^{ab}
T_2P_1	32.08^{a}
T_3P_1	30.58^{ab}
T_1P_2	31.34^{ab}
T_2P_2	28.00^{b}
T_3P_2	23.50^{c}
T_1P_3	30.16^{ab}
T_2P_3	24.00^{c}
T_3P_3	13.83^{d}
T_4	24.02^{c}
CD (0.05)	3.64

4.5.5 Chaff percentage

Mean value of chaff percentage of different treatments are given in the Table 44.

T_3P_3 (50.71%) recorded higher chaff percent than any other treatments followed by T_3P_2 (33.37%) and it was 17 % lesser than T_3P_3. Among the treatments T_1P_3 recorded the lowest chaff percentage of 23.84 which was on par with T_4, control (25.00) and T_1P_1 (24.67) and T_1P_2 (25.69). All other treatments recorded a chaff percent between 25 and 30.

Table 44: Influence of stress induction during different phenophases on chaff percentage

Treatments	Percentage
T_1P_1	24.67^{d}
T_2P_1	26.26^{cd}
T_3P_1	26.70^{bcd}
T_1P_2	25.69^{d}
T_2P_2	29.15^{bcd}
T_3P_2	33.37^{b}
T_1P_3	23.84^{d}
T_2P_3	32.72^{bc}
T_3P_3	50.71^{a}
T_4	25.00^{d}
CD (0.05)	6.91

Discussion

5. DISCUSSION

The incidence of UV-B radiation has been reported to be high during the summer months in Kerala. The atmospheric temperature is also maximum during this period. Both of these factors have been identified to have negative impact on rice growth and productivity. An attempt is made from the results to discuss the interactive effect of UV-B radiation and elevated temperature on the growth and physiology of rice variety Uma and also identify the phenophases which are most sensitive to environmental changes.

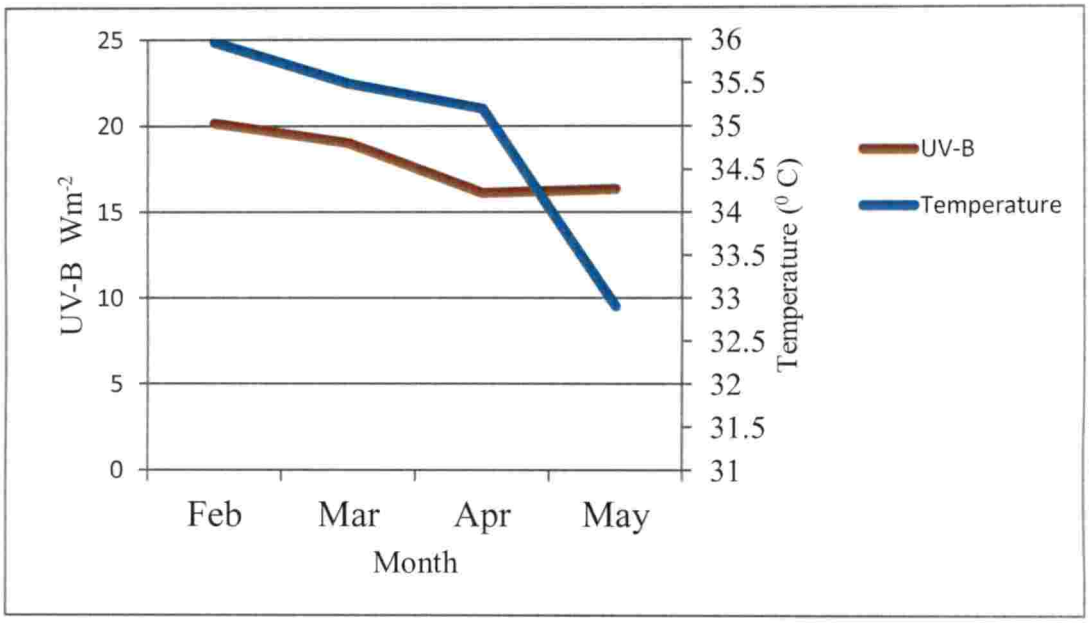
5.1 UV-B and temperature measurements

The incidence of UV-B radiation is found to be in the range of 1.56 to 2.99 Wm^{-2} during the summer months from February-2018 to May-2018. The high values of UV-B is reported to have deleterious effects on growth and productivity of rice (Shafeeqa, 2016). During this period increase in atmospheric temperature is also a major problem for the crop.

The increase in UV-B and atmospheric temperature coincides with the second cropping season of paddy cultivation in the kole lands of Thrissur. In the current study, UV-B radiation has been excluded in the polyhouses (T_1, T_2 and T_3), so as to bring out the effects of high temperature on the crop and also the interactive effect of UV-B and temperature on rice (T_4).

Statistical analysis of UV-B and temperature throughout the growing period showed that both parameters recorded maximum values during the month of February-2018. This indicates that with increasing UV-B in atmosphere temperature also increases.

Fig. 2: Interaction of UV-B and temperature during February-2018 to May-2018 in open condition



5.2 Morphological characters as influenced by UV-B radiation and elevated temperature

The results showed that plants kept in the polyhouses recorded higher plant height as compared to those kept in the open condition (Fig 2). This might be due to decreased IAA content in plants which were grown under open condition (Table 27). The UV-B radiation was more in open condition compared to polyhouses.

According to Ros and Tevini (1995), UV-B radiation causes photo-oxidative destruction of auxin, which will negatively influence the extensibility of cell wall there by reducing the plant height. Observations of Grimstad and Frimanslund (1993) on cucumber revealed that increasing temperature contributes to increase in inter nodal length. Hence in the present study, both high temperature and lower UV-B conditions inside polyhouses might have contributed to the enhancement in plant height.

Plants in polyhouses duringP_1 (Seedling to active tillering) were taller than those subjected to the same condition in the P_2 (Active tillering to Early reproductive) phase (Fig 3). In the P_2 phase the assimilate partitioning is more towards tiller formation than in improving height. This might be the reason for the lower plant height for plants kept in polyhouse during P_2 phase. More over P_2 phase is related to qualitative developmental changes in the plant rather than quantitative growth improvement. Earlier heading observed in these plants, substantiates the above observation (Table 11)

Considering the number of tillers per hill, plants grown under open condition recorded more tillers than that in the polyhouses with high temperature and low UV-B in all the three stages of growth (Fig 4). According to Sato (1972), high temperature impairs tillering in rice. More over reduced UV-B condition enhances IAA production in the plant. These reports substantiate the reduction in the number of tillers observed in the plants grown in polyhouse.

These results can be compared with the theory of Leopold and Plummer (1961) state that indole-acetic acid (IAA) produced in the apical meristem and young leaves directly inhibits the auxiliary bud growth. This might have contributed to higher number of tillers in plants grown under open condition. Even though number of tillers was maximum in plants grown under open condition, 50 per cent tiller decline was noticed at the time of harvest indicating that excess tillering did not contribute to yield.

Fig 3: Comparison of stress induction during different phenophases on plant height

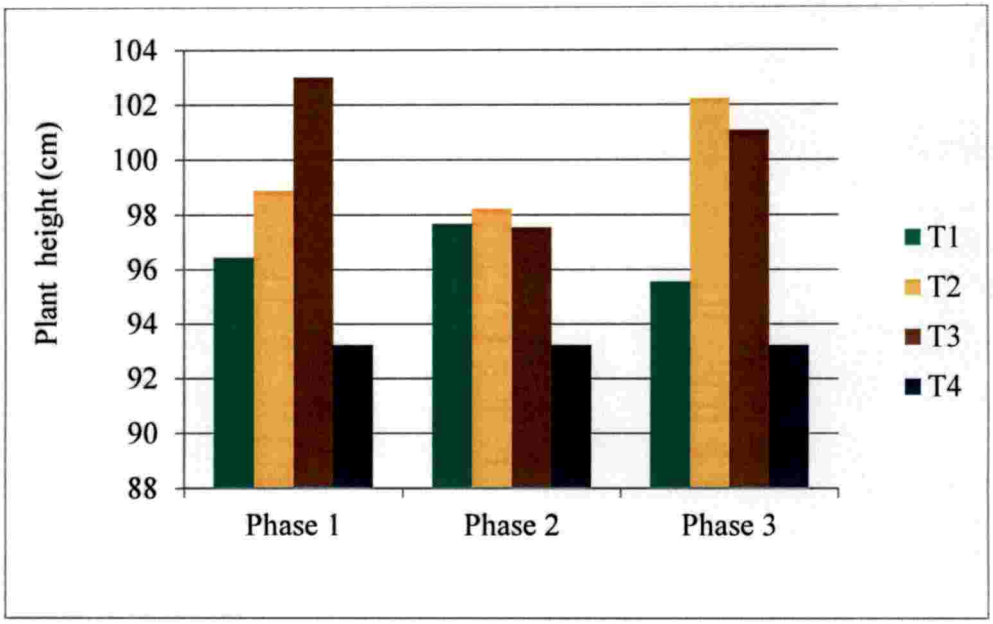
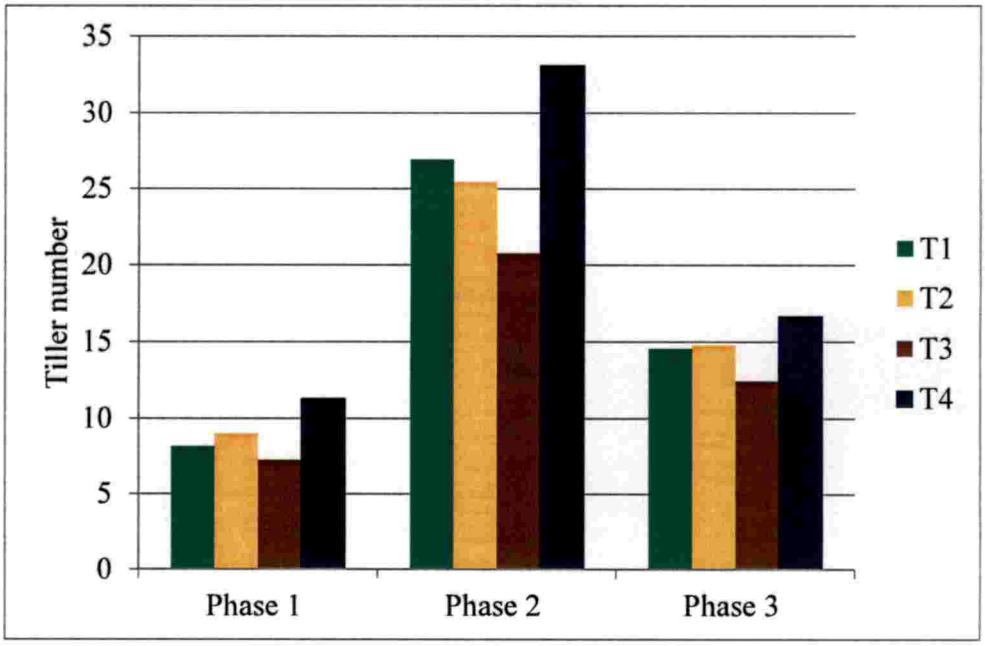


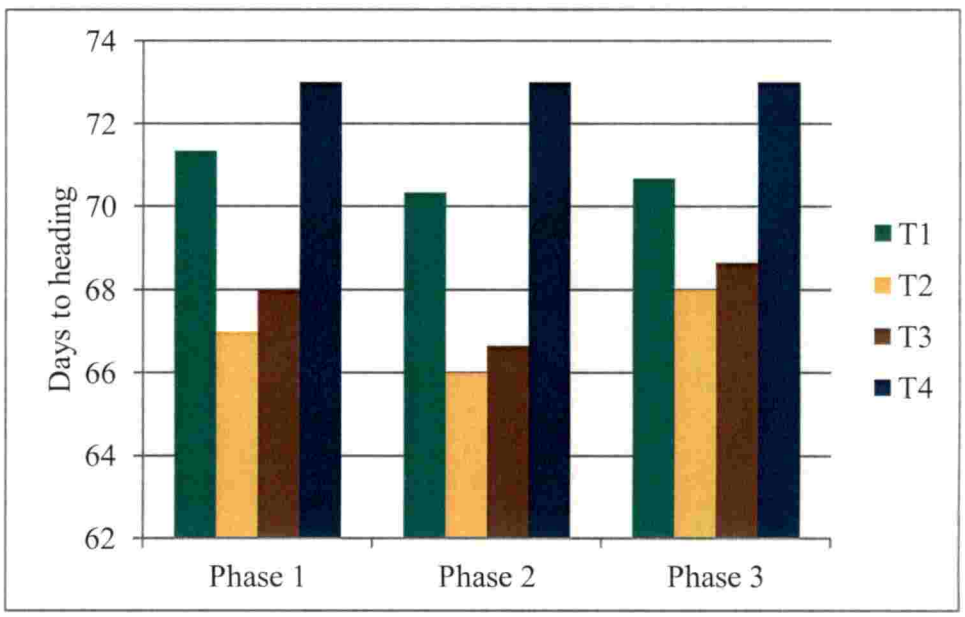
Fig 4: Comparison of stress induction during different phenophases on tiller number



5.3 Phenological characters influenced by UV-B radiation and elevated temperature

Plants grown under high temperature condition in polyhouses showed earlier flowering and was more prominent for those plants exposed to this condition during the P_2 phase of growth. The increasedchlorophyll content and higher photosynthetic rate under polyhouse condition might have enhanced the growth processes contributing to earlier flowering. A similar study conducted by Rani and Margatham (2013) reported that various phenological stages in rice such as panicle initiation, 50 percent flowering and days to harvest decreased with high temperature stress.

Fig 5: Comparison of stress induction during different phenophases on days to heading



T_1- Low temperature and low UV-B **P_1- Phase 1**

T_2- High temperature (1^0C) and low UV-B **P_2- Phase 2**

T_3- High temperature (2^0C) and low UV-B **P_3- Phase 3**

T_4- Control (Open condition)

5.4 Physiological characters influenced by UV-B and elevated temperature

Among different physiological processes, photosynthesis is the most important parameter that influence the growth and development of a crop. The present study reveals that plants grown under polyhouse condition with an average temperature of 36^0 C (1^0 C higher than ambient, T_2) recorded higher photosynthetic rate in all the three stages of growth. Even though T_2 recorded higher photosynthetic rate at all the stages of growth, it was more prominent during P_2 phase (Fig 6).The higher content of chlorophyll and stomatal conductance recorded in T_2 substantiate these results (Fig 7,9). Lower photosynthetic rate observed in open condition can be attributed to higher UV-B irradiance (Wagh,2015).

Plants grown in polyhouse with an average temperature 37^0 C (T_3) also recorded low photosynthetic rate as a result of decreased stomatal conductance. These results are in conformity with Zhang *et al.*(2007) who proposed that the photosynthetic rate and flowering duration in rice get decreased with increasing air temperature above 35^0C.

Plants grown in the T_3 as well as T_2 condition during the P_3 (Early reproductive to harvest) phase recorded minimum pollen viability compared to plants in the T_1 and T_4 (Fig8). The percentage reduction was 50 in T_3P_3 and 20 in T_2P_3. These results can be compared with the findings of Mastui *et al.* (2000), who reported that temperature stress during the flowering period decreases the pollen viability and anther dehiscence. The changes in pollen viability was reflected in the final yield of plant. The lowest grain yield was recorded in T_3P_3 (13.83 g) which had only 50 percent viable pollen.

Fig 6: Comparison of stress induction during different phenophases on photosynthetic rate

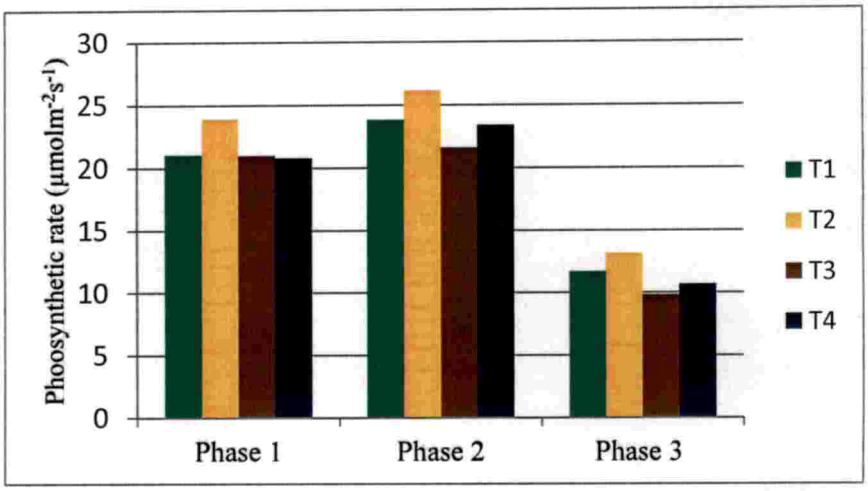
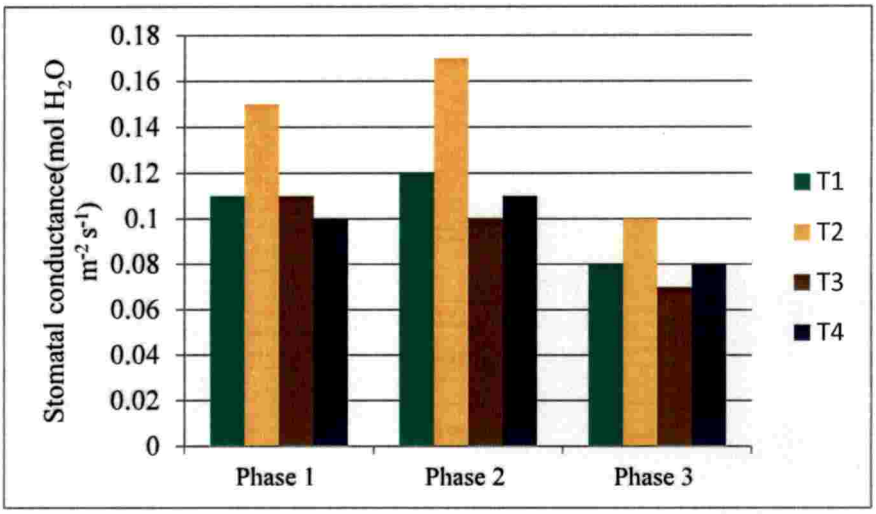


Fig 7: Comparison of stress induction during different phenophases on stomatal conductance



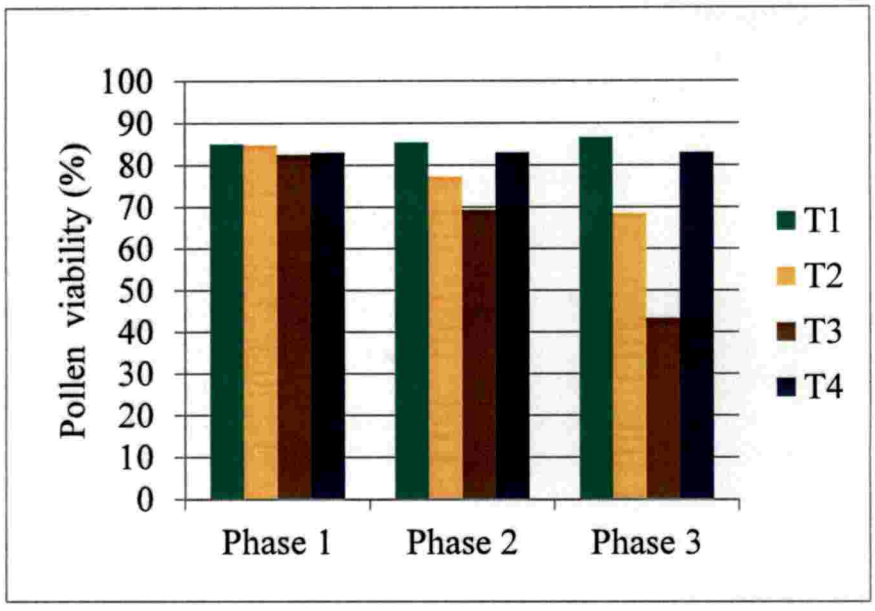
T_1- Low temperature and low UV-B **P_1- Phase 1**

T_2- High temperature (1^0C) and low UV-B **P_2- Phase 2**

T_3- High temperature (2^0C) and low UV-B **P_3- Phase 3**

T_4- Control (Open condition)

Fig 8: Comparison of stress induction during different phenophases on pollen viability



T_1- Low temperature and low UV-B **P_1- Phase 1**

T_2- High temperature (1^0C) and low UV-B **P_2- Phase 2**

T_3- High temperature (2^0C) and low UV-B **P_3- Phase 3**

T_4- Control (Open condition)

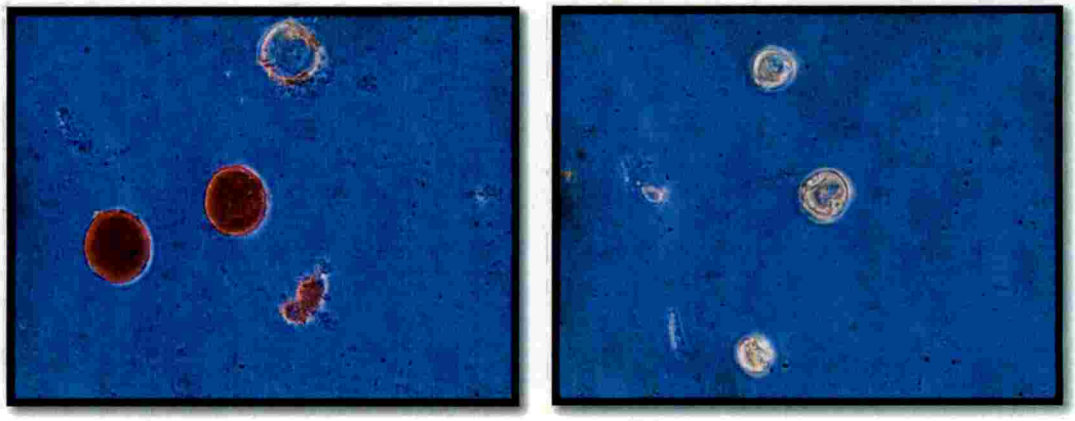


Plate 4: Representative microscopic view of fertile (left; T_1P_3) and sterile (right; T_3P_3) pollen grains observed in pollen viability test

5.5 Biochemical characters affected by UV-B radiation and elevated temperature

Plants grown in the open condition recorded 67 per cent reduction in IAA when compared with plants grown inside polyhouses (Table 27). The percentage reduction was maximum during the P_1 phase. The incidence of UV-B was the highest during the month of February-2018, which coincides with P_1 phase. Ros and Tevini (1995) reported that enhanced UV-B leads to photolytic degradation of IAA in sunflower seedlings. The difference in IAA concentration of plants grown under open and polyhouse condition were not significant during P_2 and P_3 phases. This might be due to the decreased UV-B irradiance in open condition during the April and May months, coinciding with P_2 and P_3 phases.

The present study revealed that GA content was lesser in plants grown under open condition compared to plants in the polyhouses. The reduction was more prominent during the P_1 (Table 31). The variation in plant height during the P_1 substantiates the results. Higher UV-B negatively affects the GA content on leaves in plants grown under open condition. This can be confirmed with the findings of Tevini and Teramura (1989) reported that UV-B treated spinach leaves showed lower endogenous gibberellins activities at the period of active growth.

Chlorophyll pigments (Chlorophyll a, Chlorophyll b and total chlorophyll) were higher in plants grown under polyhouse condition in all the three phases. Enhanced UV-B irradiance decreased the chlorophyll content of plants in the open condition. This may be due to disintegration of components of chloroplast, such as grana and thylakoid which are sensitive to UV-B radiation (Huang *et al.*,1993). Present study showed that among different phases of growth, stress during P_1 phase may have more impact on cholorophyll. Since the difference in chlorophyll content within plants grown under different condition was more prominent in P_1 phase.

Results indicate that the amylose contents of grain decreased significantly with increasing temperature (35^0C) during the early reproductive to harvest stage. A similar decrease was also observed in P_2 phase (Fig 10). The amylose contents was decreased up to 35 percent in grains of plants grown under high temperature stress with respect to plants in the low temperature treatments. The findings of Ahmed *et al.*(2008) revealed that high temperature during grain filling stage decreases amylose contents of grains. Plants grown under high temperature (T_3) during the P_1 phase recorded more amylose in grains than those subjected to stress in P_2 and P_3 phases. This indicates that the grain filling stage is more sensitive to high temperature. Plants grown in the open (High UV-B) condition recorded marginally higher amylose than in the T_2 and T_3. This shows that UV-B does not necessarily have an impact on amylose contents of grains.

Proline content was increased by 372 and 172 percent in plants subjected to high temperature stress of 1^0C and 2^0C than ambient respectively. However, the proline content remained similiar in plants grown under low temperature treatment with respect to control (Fig 11).These findings can be compared with results of Zhang *et al.* (2007) reported that proline content in flag leaf of rice during heading and flowering was higher under elevated temperature stress than ambient condition.

Fig 9: Comparison of stress induction during different phenophases on chlorophyll content

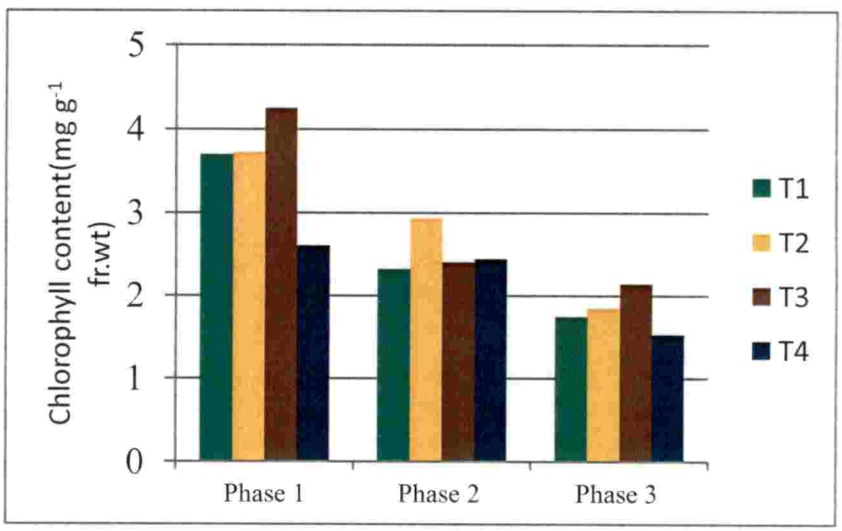


Fig 10: Comparison of stress induction during different phenophases on amylose content

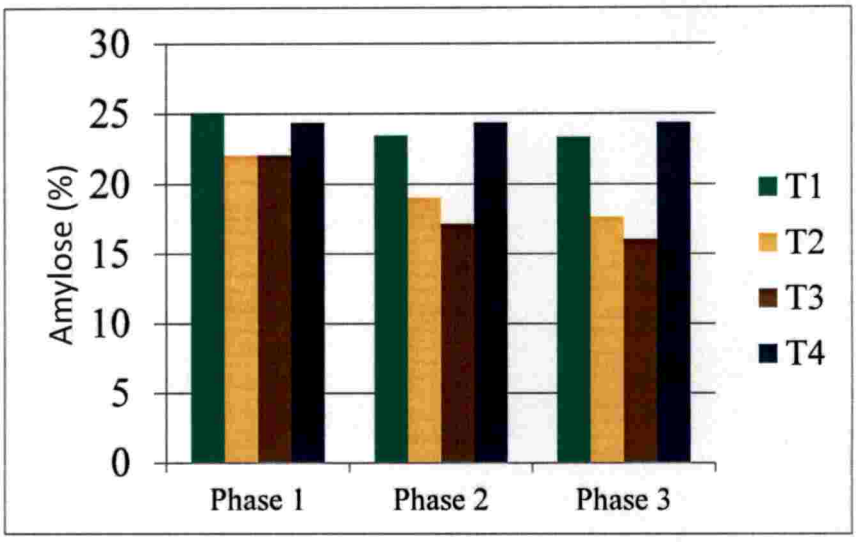
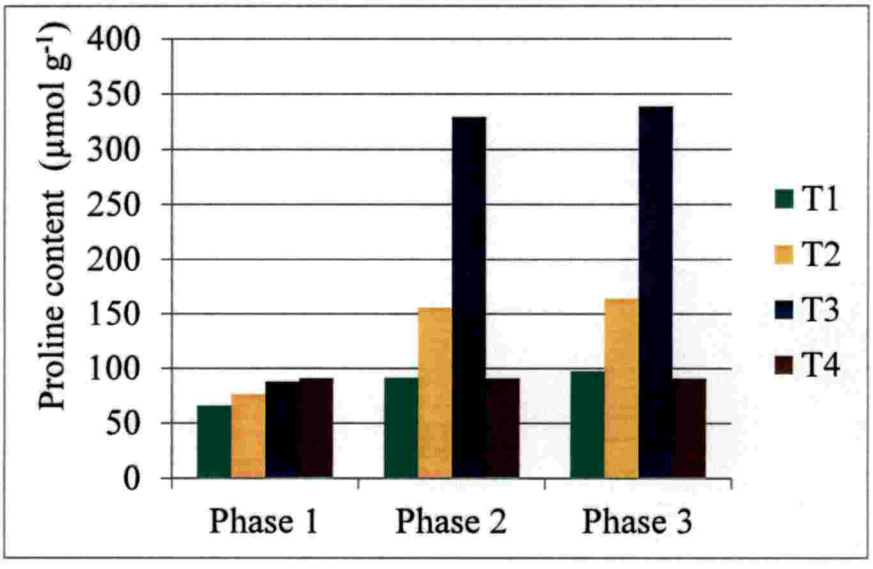


Fig 11: Comparison of stress induction during different phenophases on proline content



T_1- Low temperature and low UV-B **P_1- Phase 1**

T_2- High temperature (1^0C) and low UV-B **P_2- Phase 2**

T_3- High temperature (2^0C) and low UV-B **P_3- Phase 3**

T_4- Control (Open condition)

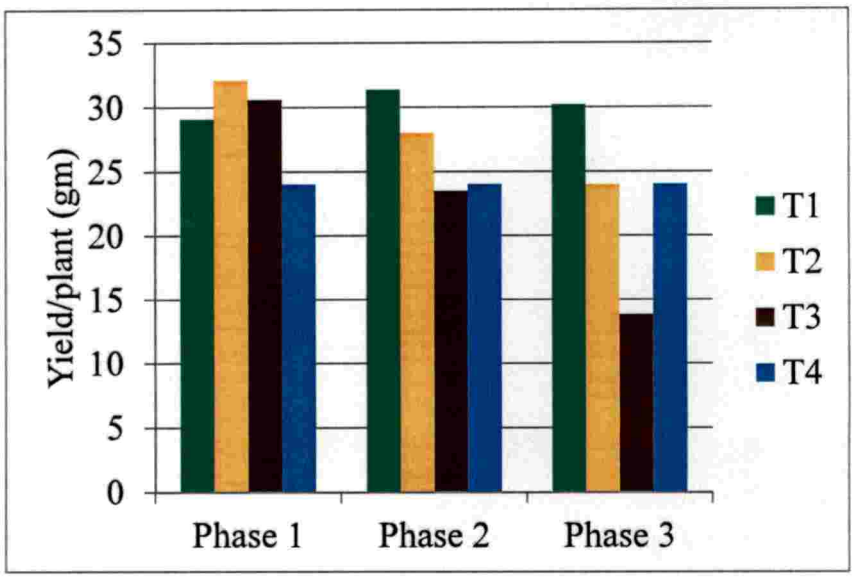
5.6 Yield and yield attributes influenced by UV-B and elevated temperature

When the plants were subjected to high temperature stress (T_3) during P_2 and P_3 phase there was a yield decline of 13.3 per cent to 56.6 per cent respectively as compared to plants grown under low temperature (T_1) condition (Fig 12).Under open condition where plants exposed to high UV-B and ambient temperature the yield decline was 20 per cent as compared to plants in T_1, where the temperature was 1^0C lower than ambient and UV-B was excluded. This indicates that rice is affected by both high temperature and UV-B radiation. A 1^0 C rise in temperature above ambient has caused a 13 per cent decline in yield while both UV-B and temperature stress has contributed to 20 per cent yield loss.

Increased chaff percentage (50 percent, Table 44) and reduction in number of spikelets per panicle (26 per cent) might be the two reasons for decreased yield of plants grown under T_3 condition. Similarly, 29 per cent reduction in spikelets per panicle was observed in open condition (Table 41), which also leads to decreased yield.

Plants subjected to stress during the first phase of growth (Seedling to active tillering) recorded marginally higher yield as compared to stress during the second (Active tillering to early reproductive) and third phases (Early reproductive to harvest). This indicates that stress after active tillering stage is more harmful to crop growth and productivity.

Fig 12: Comparison of stress induction during different phenophases on yield



T_1- Low temperature and low UV-B **P_1- Phase 1**

T_2- High temperature (1^0C) and low UV-B **P_2- Phase 2**

T_3- High temperature (2^0C) and low UV-B **P_3- Phase 3**

T_4- Control (Open condition)

Summary

6. SUMMARY

91

Rice is an important cereal crop and occupies second position in global agriculture. The growth and productivity of the crop is intimately associated with different climatic regimes. The increase in temperature along with global warming may have direct impact on crop production especially cereals. Ozone layer depletion during the last few decades has abruptly increased the incidence of solar UV-B radiation (280-320 nm). The increase in temperature and incidence of UV-B radiation during the summer months adversely affect the additional crop of rice in kole lands of Kerala. Hence the present study was undertaken at College of Horticulture, Vellanikkara to understand the interactive effects of UV-B radiation and elevated temperature during different phenophases of rice and its effect on growth physiology and productivity.

The experiment was conducted in pot culture during Feb-May 2018, with Uma rice variety under four different growing condition i.e., T_1-Low temperature (1^0 lesser than ambient) and low UV-B, T_2- High temperature (1^0C Higher than ambient) and low UV-B, T_3- High temperature (2^0C higher than ambient) and low UV-Band T_4- open condition.

The salient findings of the study are as follows

1. Maximum UV-B radiation (2.99 Wm^{-2}) and temperature (37.97^0C) was recorded during the month of February- 2018 in open condition.

2. UV-B radiation and elevated temperature altered the phenological characters rice crop like days to heading, 50 per cent flowering and harvestable maturity. High temperature stress in T_2 and T_3 condition reduced the phenophaes of the crop by 4-6 days.

3. Plants grown under open condition (T_4) recorded more number of tillers per hill compared to plants in the other conditions (T_1, T_2 and T_3). The decreased IAA content in T_4 condition enhanced the auxiliary bud growth, which resulted in increased number of tillers in T_4.

4. Plants grown under open as well as T_3 condition recorded lower photosynthetic rate during the three stages of growth. The decreased chlorophyll content in T_4 and reduced stomatal conductance in T_3 were the major reasons for reduced photosynthetic rate.

5. The plant hormones IAA and GA were higher under lesser UV-B conditions

6. Among the phenophases, stress imposed during P_1 (seedling to active tillering) improved the productivity of the crop.

7. Stress imposed after active tillering (P_2 and P_3) stages affected the yield components and reduced the productivity of the crop.

8. Elevated temperature coinciding with early reproductive stage affected the pollen viability resulted in higher chaff percentage.

9. The amylose content of grains was found to be lower in high temperature growing conditions.

Conclusion

UV-B and high temperature are major weather parameters that influences the productivity of rice during the third crop season. The influence of these parameters on the phenology, biochemistry and physiology of rice plants indicate that early stress during the period up to active tillering is comparatively less harmful. While stress experienced during reproductive stage drastically reduced the yield. Among the weather parameters UV-B radiation influences the biochemical components of plants such as IAA, GA and chlorophyll contents while high temperature affects mostly on yield components.

Future line of work

- Seed hardening can be examined as a mechanism to impart stress tolerance.
- The effects of imposing stress during seedling stage on growth and productivity of rice can be studied.
- Epigenetic mechanisms regulating stress memory responses is worth exploring.

References

REFERENCES

Ahmed, J., Ramaswamy, H.S., Ayad, A., and Alli, I. 2008. Thermal and dynamic rheology of insoluble starch from basmati rice.*Food Hydrocoll.*22(2): 278-287.

Ahn, S. B., and Vergara, B. S. (1969). Studies on responses of the rice plant to photoperiod. III. Responses of Korean varieties. *J. Korean Soc.Crop Sci.* 5: 45–49.

Asaoka, M., Okuno, K., and Fuwa, H. 1985. Effect of environmental temperature at the milky stage on amylose content and fine structure of amylopectin of waxy and nonwaxy endosperm starches of rice (*Oryza sativa* L.). *Agric. Biol. Chem.* 49(2): 373-379.

Barnabas, B., Jager, K., and Feher, A. 2008. The effect of drought and heat stress on reproductive processes in cereals. *Plant cell environ.*31(1): 11-38.

Barnes, P.W., Jordan, P.W., Gold. W.G, Flint, S.D., and Caldwell, M.M. 1988. Competition, morphology, and canopy structure in wheat (*Triticum aestivum* L.) and wild oat (*Avena fatua* L.) exposed to enhanced ultraviolet-B radiation. *Funct. Ecol.* 2: 319-330.

Basahi, J.M., Ismail, I.M., and Hassan, I.A., 2014. Effects of enhanced UV-B radiation and drought stress on photosynthetic performance of lettuce (*Lactuca sativa* L. Romaine) plants. *Annu. Res. Rev. Biol.* 4(11):1739-1756.

Bates, L., Waldren, R. P., and Teare, I. D. 1973. Rapid determination of free proline for water stress studies. *Plant and Soil.* 39: 205-207.

Caldwell, M. M. 1968. Solar ultraviolet radiation as an ecological factor for alpine plants. *Ecological Monogr.*38(3): 243-268.

Chaudhary, T. N. and Ghildyal, B. P. (1970). Influence of submerged soil temperature regimes on growth, yield, and nutrient composition of rice plant. *J. Agron.* 62, 281–285.

Cox, P.M., Betts, R.A., Jones, C.D., Spall, S.A., and Totterdell, I.J., 2000. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature.* 408(6809): 184.

Crisanto, R. E. and Leando, V. B. 1994. 'Climate Impact Assessment for Agriculture in the Philippines: Simulation of Rice Yield under Climate Change Scenarios', *Implications of ClimateChange for International Agriculture: Crop Modelling Study*, U.S. Climate Change Division Report, EPA 230-B-94-003, 2–14.

Dafni, A. and Firmage, D. 2000. Pollen viability and longevity: practical, ecological and evolutionary implications. *Pollen and pollination.* 113-132. Springer, Vienna.

Das, S., Krishnan, P., Nayak, M. and Ramakrishnan, B., 2014. High temperature stress effects on pollens of rice (Oryza sativa L.) genotypes. *Environ. and Exp. Bot.* 101: 36-46.

97

Farooq, M.,Shahzad, M. A., Basra., and Khan, B. M.2007.Seed priming improves growth of nursery seedlings and yield of transplanted rice.*Arch. of Agron. and Soil Sci.*53:315-326.

Farrel, T. C., Fox, K. M., Williams, R. L., and Fukai, S. 2006. Genotypic variation for cold tolerance during reproductive development in rice: screening with cold air and cold water. *Field Crops Res.* 98: 178-194.

Furbank, R.T. and Taylor, W. C. 1995. Regulation of photosynthesis in C3 and C4 plants: a molecular approach. *The Plant Cell.*7(7): 797.

Grimstad, S. O. and Frimanslund, E. 1993. Effect of different day and night temperature regimes on greenhouse cucumber young plant production, flower bud formation and early yield. *Sci. hortic.* 53(3): 191-204.

Hidema, J., Kumagai, T., Sutherland, J.C., and Sutherland, B. M. 1997. Ultraviolet B-sensitive rice cultivar deficient in cyclobutyl pyrimidine dimer repair. *Plant Physiol.*113(1): 39-44.

Hidema, J., Zhang, W., Yamamoto, M., Sato, T., and Kumagai, T. 2005. Changes in grain size and grain storage protein of rice (Oryza sativa L.) in response to elevated UV-B radiation under outdoor conditions. *J. radiat.Res.*46(2): 143-149.

Hiscox, J. D. and Israelstam, G. F. 1979. A method for fextraction of chlorophylls from leaf tissue without maceration. *Can. J. Bot.* 57: 1332-1334.

98

Huang, L.K., He, J., Chow, W.S., Whitecross, M.I., and Anderson, J.M. 1993. Responses of detached rice leaves (*Oryza sativa* L.) to moderate supplementary ultraviolet-B radiation allow early screening for relative sensitivity to ultraviolet B irradiation.*Funct. Plant Biol.* 20(3):285–297.

Huang, S., Dai, Q., Peng, S., Chavez, A. Q., Miranda, M. L. L., Visperas, R. M., and Vergara, B. S. 1997.Influence of supplemental ultraviolet-B on indoleacetic acid and calmodulin in the leaves of rice (*Oryza sativa* L.).*Plant Growth Reg.*21(1): 59–64.

Inouchi, N., Ando, H., Asaoka, M., Okuno, K., and Fuwa, H. 2000. The effect of environmental temperature on distribution of unit chains of rice amylopectin. *Starchstarke*. 52 (1): 8-12.

Islam, M. T. 2011. Effect of temperature on photosynthesis, yield attributes and yield of aromatic rice genotypes. *Int. J. Sustain. Crop Prod.* 6(1): 14-16.

Jain, A., Rao, S. M., Sethi, S., Ramesh, A., Tiwari, S., Mandal, S. K., Singh, N. K., Modi, N., Bansal, V., and Kalaichelvani, C. 2012. Effect of cooking on amylose content of rice. *Eur. J. Exp. Biol*, 2(2): 385-388.

Jeng, T. L., Tseng, T. H., Wang, C. S., Chen, C. L., and Sung, J. M. (2003). Starch biosynthesizing enzymes in developing grains of rice cultivar Tainung 67 and its sodium azide-induced rice mutant. *Field Crop Res*. 84(3): 261–269.

Jumiatun, A.J., Lubis, I., Chozin, M.A., and Miyazaki, A. 2016. Morphological, physiological and yield responses of some rice varieties (*Oryza sativa* L.) as exposed under high temperature in Indonesia. *Am. J. Plant Physiol.*11: 33-41.

Kabir, M.H., Liu, Q., Su, Y., Huang, Z., and Xiao, L. 2017. Dynamics of phytohormones and their relationship with chalkiness of early indica rice under different post-anthesis temperature regimes. *Bangladesh J. Agric. Res.*42(1): 53-65.

Kataria, S. and Guruprasad, K. N. 2014. Exclusion of solar UV components improves growth and performance of Amaranthus tricolor varieties. *Sci. Hortic.*174: 36-45.

Kataria, S., Jajoo, A., and Guruprasad, K. N. 2014. Impact of increasing Ultraviolet-B (UV-B) radiation on photosynthetic processes. *J. Photochem and Photobiol. B: Biol.*137:55-66.

Kojima, K. 1995. Simultaneous measurement of ABA, IAA and GA's in citrus- role of GA in relation to sink ability. *J. Agrl. Res.* 29: 179-185.

Krishnan, P., Ramakrishnan, B., Reddy, K. R., and Reddy, V. R. 2011. High-temperature effects on rice growth, yield, and grain quality. *Adv. Agron.* 111: 87-206.

Larkindale, J., Hall, J.D., Knight, M. R., and Vierling, E. 2005. Heat stress phenotypes of Arabidopsis mutants implicate multiple signaling pathways in the acquisition of thermotolerance. *Plant Physiol.*138(2): 882-897.

Leopold, A.C. and Plummer, T.H. 1961. Auxin-phenol complexes. *Plant Physiol.* 36(5): 589.

100

Liu, Y., Luo, N. S., Zhong, Z. C., Zhou, Y. H., and Zhang, P. Y. 2003. Effects of enhanced ultraviolet-B (UV-B) radiation on diurnal variations of photosynthesis and water use efficiency in trichosanthes korilowii maxim. *J. Southwest Agric. Univ.*5: 377-381.

Mackill, D.J., Coffman, W.R., and Rutger, J.N. 1982. Pollen shedding and combining ability for high temperature tolerance in rice 1. *Crop. Sci.* 22(4): 730-733.

Mahantashivayogayya, K., Lakkundi, B.S., Diwan, J.R., Ramesha, M.S., Ibrahim, M., Reddy, B.M., Guruprasad, G.S. and Pramesh, D., 2016. Original Research Article Open Access. *J. Rice Res.* 9(2): 167-178.

Mahdavian, K., Ghorbanli, M., and Kalantari, K.M. 2008. The effects of ultraviolet radiation on the contents of chlorophyll, flavonoid, anthocyanin and proline in Capsicum annuum L. *Turkish J.Bot.*32(1): 25-33.

Marwood, C.A.and Greenberg, B.M. (1996). Effect of supplementary UV-B radiation on chlorophyll synthesis and accumulation of photosystems during chloroplast development in *Spirodela oligorrhiza*. *Photochem. and Photobiol.*64(4):664–670.

Matsui, T., Omassa, K., and Horie, T. 2000. High temperature at flowering inhibits swelling of pollen grains, a driving force for thecae dehiscence in rice (*Oryza sativa* L.). *Plant Prod. Sci.* 3(4): 430-434.

Matsushima, S. and Tsunoda, K. 1958. Analysis of developmental factors determining yield and its application to yield prediction and culture improvement of lowland rice.: XLV. Effects of temperature and its daily range in different growth-stages upon the growth, grain yield and its constitutional factors in rice plants. *Jpn. J. Crop Sci.*26(4): 243-244.

101

Misra, A. N. 1986. Effect of temperature on senescing rice leaves. Photoelectron transport activity of chloroplast. *Plant Sci.* 46: 1-4.

Mohammed, A. R. and Tarpley, L. 2013. Effects of Enhanced Ultraviolet-B (UV-B) Radiation and Antioxidative-type Plant Growth Regulators on Rice (*Oryza sativa* L.) Leaf Photosynthetic Rate, Photochemistry and Physiology. *J. Agric. Sci.* 5: 115-128.

Munjal, R. and Dhanda, S. S. 2004. Physiological and morphological traits associated in bread wheat under heat stress. In: *Proceedings of 91st Indian Science Congress part III (advance abstracts)*, 1-3 January 2004, Chandigarh.

Murata, Y. 1976. Productivity of rice in different climatic regions of Japan. "Climate and Rice", pp. 449–470. International Rice Research Institute, Los Banos, Philippines.

Nandini, K., Jaikumar, U., and Girija, T. 2010. Physiological analysis on yield decline in rice (*Oryza sativa* L.) with high temperature in kole wet lands of Kerala. Proceedings of National conference of Plant physiology on Physiological and Molecularapproaches for crop improvement under Changing Environment, 25-27, November, 2010, BHU, Varanasi.138p.

Nogués, S., Allen, D.J., Morison, J.I., and Baker, N.R. 1998. Ultraviolet-B radiation effects on water relations, leaf development, and photosynthesis in droughted pea plants. *Plant Physiol.*117(1):173-181.

Oh-e, I., Saitoh, K., and Kuroda, T. 2007. Effects of high temperature on growth, yield and dry-matter production of rice grown in the paddy field. *Plant Prod. Sci.* 10(4): 412–422.

102

Osada, A., Takahashi, H., Dhammanuvong, S., Sasiprapa, V., and Gunthararom, S. 1973. Seasonal changes in growth pattern of tropical rice: I. Environmental factors affecting plant height, tillering, weight and leaf area. *Jpn. J.Crop Sci.* 42(3): 343-350.

Pal, M., Jain, V., and Sengupta, U. K. 1998. Influence of enhanced UV-B radiation on mustard: cultivar response. *Indian J. Plant Physiol.*Vol. 3(1): 188-193.

Pal, M., Sharma, A., Abrol, Y. P., and Sengupta, U. K. 1997. Exclusion of solar UV-B radiation from normal spectrum on growth of mungbean and maize. *Agri. Eco.and Environ.* 60: 29-34.

Parthasarathy, K., Balu, D.R.C.,and Rao P.S. 1970. Studies on Sandal Spur. VIII. Polyphenol oxidase activity and metabolism of sandal in healthy and diseased. *Proc. Indian Acad. Sci.* 72: 277-284.

Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S., and Cassman, K. G. 2004. Rice yields decline with higher night temperature from global warming. In: *Proceedings of the National Academy of Sciences*, 6 July. 2004, USA. 9971-9975.

Prasad, P.V.V., Boote, K.J., Allen Jr, L.H., Sheehy, J.E., and Thomas, J.M.G. 2006. Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. *Field crops res.* 95(2-3): 398-411.

Rajendiran, K. and Ramanujam, M. P. 2004. Improvement of biomass partitioning, flowering and yield by triadimefon in UV-B stressed *Vigna radiata* (L.).*Wilczek.Biologia plant.*48(1): 145-148.

103

Rane, M.J., Pan, Y., Singh, S., Powell, D.W., Wu, R., Cummins, T., Chen, Q., McLeish, K.R., and Klein, J. B. 2003. Heat shock protein 27 controls apoptosis by regulating Akt activation. *J. Biol. Chem.* 23: 145-156.

Rani, B. A. and Maragathom, N. 2012. Effect of elevated temperature on rice phenology and yield. *Indian J. Sci.Technol.* 6(8): 133-142.

Ros, J. and Tevini, M. 1995. Interaction of UV-radiation and IAA during growth of seedlings and hypocotyl segments of sunflower. *J. Plant. Physiol.*146(3): 295-302.

Sailaja, B., Anjum, N., Prasanth, V.V., Sarla, N., Subrahmanyam, D., Voleti, S.R., Viraktamath, B.C. and Mangrauthia, S. K. 2014. Comparative study of susceptible and tolerant genotype reveals efficient recovery and root system contributes to heat stress tolerance in rice. *Plant. mol. Biol. rep*, 32(6): 1228-1240.

Sanchez-Reinoso, A.D., Garces-Varon, G., and Restrepo-Diaz, H. 2014. Biochemical and physiological characterization of three rice cultivars under different daytime temperature conditions. *Chilean J. of agric. Res.*74(4): 373-379.

Satake, T. and Yoshida, S. 1978. High temperature-induced sterility in indica rices at flowering. *Jpn. J. Crop Sci.*47(1): 6-17.

Sato, K. 1972. Growth Responses of Rice Plant to Environmental Conditions: I. The effects of air-temperatures on the growth at vegetative stage. *Jpn. J. Crop Sci.* 41(4): 388-393.

Sato, T. and Kumugai, T. 1993. Cultivar differences in resistance to the inhibitory effects of near UV radiation among Asian ecotype and Japanese lowland and upland cultivars of rice (*Oryza sativa* L.). *Jpn. J. Breed.* 43: 61-68.

Searles, P.S., Caldwell, M.M., and Winter, K. 1995. The response of five tropical dicotyledon species to solar ultraviolet-B radiation. *Am. J. Bot.* 82(4): 445-453.

Shafeeqa, T. 2016. Mitigation of solar ultraviolet-B radiation induced photoinhibition in photochemistry and photosynthesis of rice (*Oryza sativa* L.). MSc (Ag) thesis, Kerala Agriculrural University, Thrissur. 84p.

Shi, W., Muthurajan, R., Rahman, H., Selvam, J., Peng, S., Zou, Y., and Jagadish, K. S. 2013. Source–sink dynamics and proteomic reprogramming under elevated night temperature and their impact on rice yield and grain quality. *New Phytol.* 197(3): 825-837.

Soga, Y. and M. Nozaki. 1957. Studies on the relation between seasonal changes of carbohydrates accumulated and the ripening at the stage of generative growth in rice plant. *Proc. Crop sci.Soc. Jpn.* 26: 105-108.

Solhaug, K.A. and Gauslaa, Y. 2004. Photosynthates stimulate the UV-B induced fungal anthraquinone synthesis in the foliose lichen Xanthoria parietina. *Plant, Cell & Environ.*27(2):167-176.

Sunderberg, B. 1990. Influence of extraction solvent (buffer, methanol, acetase) and time on the quantification of Indole-3- acetic acid in plants. *Plant Physiol.* 78:293-297.

105

Taiz, L. and Zeiger, E. 2002. *Plant physiology*. Sinuaer associates incorporation publishers, Saunderland.

Tang, R. S., Zheng, J. C., Jin, Z. Q., Zhan., D.D., Hunag, Y. H., and Chen, L. H. 2008. Possible correlation between high temperature induced floret sterility and endogenous levels of IAA, GA and ABA in rice (Oryza sativa L.). *Plant growth regulators*. 54: 37-43.

Taniyama, T., S.V. Subbaiah, M.L. N. Rao., and K. Ikeda. 1988. Cultivation and ecophysiology of rice plants in the tropics: III. Photosynthesis of rice cultivars of India, measured by the Tsuno's simple method. *Jpn. J. Crop Sci.* 57(1):184-190.

Tevini, M. and Teramura, A. H. 1989. UV-B effects on terrestrial plants. *Photochem. and Photobiol.*50(4): 479-487.

Umemoto, T., Nakamura, Y., and Ishikura, N. 1995. Activity of starch synthase and the amylose content in rice endosperm. *Phytochem.*40(6): 1613-1616.

Van, T.K., Garrard, L.A., and West, S. H. 1976. Effects of UV-B Radiation on Net Photosynthesis of Some Crop Plants 1. *Crop Sci.* 16(5): 715-718.

Vaghefi, N., Shamsudin, M.N., Makmom, A., and Bagheri, M. 2011. The economic impacts of climate change on the rice production in Malaysia. *International J. Agric. Res.* 6(1): 67-74.

Wagh, Y.S. 2015. Effect of UV-B radiation on physiological and phenological plasticity in rice (*Oryza sativa L.).* MSc (Ag) thesis, Kerala Agricultural University, Thrissur.80p.

106

Wahid, A., Gelani, S., Ashraf, M., and Foolad, M. R. 2007. Heat tolerance in plants: An overview. *Environ. Exp. Bot.* 61(3): 199-223.

Wassmann, R., Jagadish, S.V.K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R.K. and Heuer, S. 2009. Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. *Adv. in Agron.*102: 91-133.

Yamaguchi, S. 2008. Gibberellin metabolism and its regulation. *Annu. Rev. Plant Biol.*59: 225-251.

Yoshida, S. 1981. Fundamentals of Rice Crop Science. International Rice Research Institute, Los Banos, Philippines.

Yoshida, S. 1983. Rice In "Potential Productivity of Field Crops Under Different Environments" (W. H. Smith and S. J. Banta, Eds.). 103-127. International Rice Research Institute, Los Banos, Philippines.

Yoshida, S. and Hara, T. 1977. Effects of air temperature and light on grain filling of an indica and a japonica rice (*Oryza sativa* L.) under controlled environmental conditions. *Soil Sci. Plant Nutr.*23(1): 93-107.

Yun-Ying, C., Hua, D.U.A.N., Li-Nian, Y.A.N.G., Zhi-Qing, W.A.N.G., Li-Jun, L.I.U., and Jian-Chang, Y.A.N. G. 2009. Effect of high temperature during heading and early filling on grain yield and physiological characteristics in indica rice. *Acta Agron. Sinica.*35(3): 512-521.

107

Zakaria, S., Matsuda, T., Tajima, S. and Nitta, Y. 2002. Effect of high temperature at ripening stage on the reserve accumulation in seed in some rice cultivars. *Plant Prod. Sci.* 5(2):160-168.

Zhang, G. L., Chen, L. Y., Zhang, S. T., Liu, G. H., Tang, W. B., He, Z. Z., and Wang, M. 2007. Effects of high temperature on physiological and biochemical characteristics in flag leaf of rice during heading and flowering period. *Scientia Agricultura Sinica*. 40: 1345-1352.

108

INTERACTIVE EFFECT OF UV RADIATION AND ELEVATED TEMPERATURE ON RICE GROWTH AND PHYSIOLOGY

By

Amjath. T

(2016-11-103)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the

Requirement for the degree of

Master of Science in Agriculture

(PLANT PHYSIOLOGY)

Faculty of Agriculture

Kerala Agricultural University, Thrissur

Department of Plant Physiology
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

2018

KERALA AGRICULTURAL UNIVERSITY

COLLEGE OF HORTICULTURE, VELLANIKKARA

Department of Plant Physiology

Master's Defence Seminar

Interactive effect of UV radiation and elevated temperature on rice growth and physiology

Abstract

Name : Amjath T

Admission No. : 2016-11- 103

Major Advisor : Dr. T. Girija

Venue : Seminar Hall

Date : 14/08/2018

Time : 11 AM

Rice is a staple food for more than half the world's population. The growth and productivity of the crop is intimately associated with climatic variants. Among different climatic factors, temperature and incidence of UV-B radiation are important. The incidence of stress (Temperature and UV) at different stages of growth determines the productivity of the crop. Hence the present study was undertaken with the prime objective of evaluating the interactive effect of UV-B radiation and elevated temperature at different phenophases of Uma rice variety and its effect on growth and productivity.

The study was carried out at College of Horticulture, Vellanikkara during Jan to May-2018. The UV-B radiation and atmospheric temperature were maximum during this season. 14 days old Uma seedlings were used as plantingmaterial. It was grown under four different conditions, namely T_1(1^0C lesser than ambient+ low UV-B), T_2 (1^0 C higher than ambient+ low UV-B), T_3 (2^0 C higher than ambient+ low UV-B), T_4 (Open condition). The plants were kept in the polyhouses for 30 days during three phenophases of the crop *viz*, seedling to active tillering (P_1), active tillering to early reproductive (P_2) and early reproductive to harvest (P_2) and returned to ambient condition to complete their life cycle. Morphological, biochemical, physiological and yield parameters were analyzed during the growth period.

Exposure of plants to T_1 (1^0 C below ambient) had least negative influence on growth, physiology and yield of the crop across different developmental stages. A 1^0C increase in temperature above ambient (T_2) in phase 1 improved the yield and yield parameter. However the impact was negative under same condition during phase 2 (P_2) and phase 3 (P_3). Maximum deleterious effects were observed in T_3 during phase 2 and 3.

Plants grown in open condition had lower plant height and higher number of tillers as compared to plants grown in polyhouse condition (T_1, T_2 and T_3). Number of days to heading was less in plants grown under high temperature conditions (T_2 and T_3). The photosynthetic rate, stomatal conductance and transpiration rate were maximum in T_2 condition in all the three phases of growth.

Analysis of biochemical parameters showed that the IAA content was 67 percent lesser in plants grown under open condition as compared to ployhouses during P_1. Similar decrease was also found in the case of gibberellic acid and chlorophyll. Amylose content of the grain were significantly reduced in the plants grown under T_2 and T_3 conditions during P_2 and P_3.

Plants exposed to temperature above ambient level (T_2 and T_3) during P_2 and P_3 stages recorded a reduction in yield. Maximum yield reduction was observed in T_3 condition which was 13 percent in P_2 and 56 percent in P_3. Reduction in spikelets number and pollen viability were the main reasons. The study indicates that plants were most sensitive to high temperature stress during the P_2 and P_3 stages, which can contribute to drastic yield decline while, the early stress can have a positive influence on yield.

Annexure

ANNEXURE I

Table: Average weekly mid-day UV-B (Wm^{-2}) radiation under different growing conditions during the cropping period.

Dates/Treatment	T_1	T_2	T_3	T_4
Feb 1-7	0.32	0.33	0.34	3.25
Feb 8-15	0.32	0.32	0.33	3.42
Feb 16-23	0.21	0.21	0.22	2.86
Feb 24-31	0.24	0.22	0.21	2.46
Mar 1-7	0.21	0.23	0.24	3.25
Mar 8-15	0.23	0.21	0.22	3.14
Mar 16-23	0.20	0.18	0.20	2.12
Mar 24-28	0.22	0.20	0.21	2.35
Apr 1-7	0.18	0.15	0.16	1.61
Apr 8-15	0.19	0.19	0.19	2.30
Apr 16-23	0.17	0.16	0.17	1.73
Apr 24-30	0.20	0.17	0.18	1.89
May 1-7	0.17	0.16	0.16	1.63
May 8-15	0.17	0.14	0.15	1.49
May16-23	0.18	0.17	0.17	1.60
May24-31	0.17	0.16	0.16	1.56

T_1- Low temperature and low UV-B

T_2- High temperature (1^0C) and low UV-B

T_3- High temperature (2^0C) and low UV-B

T_4- Control (Open condition

ANNEXURE II

Table: Average weekly mid-day Temperature (^{0} C) under different growing conditions during the cropping period.

Dates/Treatment	T_1	T_2	T_3	T_4
Feb 1-7	34.12	36.26	37.36	35.21
Feb 8-15	34.61	36.59	37.54	35.72
Feb 16-23	35.14	37.89	38.26	36.73
Feb 24-31	35.18	37.65	38.75	36.25
Mar 1-7	36.19	38.41	39.12	37.01
Mar 8-15	34.18	36.21	37.47	35.51
Mar 16-23	34.19	36.41	37.48	35.20
Mar 24-28	33.46	35.98	36.47	34.27
Apr 1-7	32.96	35.62	36.65	34.56
Apr 8-15	33.56	35.48	36.47	34.89
Apr 16-23	33.95	36.74	37.85	35.41
Apr 24-30	34.52	36.48	37.65	35.94
May 1-7	31.92	34.59	35.24	33.64
May 8-15	32.46	34.65	35.41	33.41
May16-23	31.47	33.57	35.12	32.98
May24-31	30.48	32.94	34.03	31.60

T_1- Low temperature and low UV-B

T_2- High temperature (1^0C) and low UV-B

T_3- High temperature (2^0C) and low UV-B

T_4- Control (Open condition