INFLUENCE OF HIGH TEMPERATURE STRESS ON MORPHO -PHYSIOLOGICAL CHARACTERISTICS IN RICE GENOTYPES (*Oryza sativa* L.)

Thesis

Submitted to the

G.B. Pant University of Agriculture & Technology, Pantnagar-263145, Uttarakhand, INDIA

By

Maneesh Lingwan
B.Sc.

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Science

(PLANT PHYSIOLOGY)

JUNE, 2016

ACKNOWLEDGEMENT

I shall ever, remain thankfully indebted to all those learned souls, my present and former teachers, known and unknown hands who directly or indirectly motivated me to achieve my goal and enlightened me with the touch of their knowledge and constant encouragement. I feel this is an extremely significant and joyous opportunity bestowed upon me by the goddess of learning, to think about and thank all those persons. I thank almighty for carrying me when I could not walk and helping me safe under his company of love, care and endless blessings without which this tedious and wearisome task could not be accompanied.

Words in my lexicon fail to elucidate my profound sense of veneration & indebtness to Dr. Atul Kumar, Professor & former Head, Department of Plant Physiology and chairman of my Advisory Committee for his inspiring guidance and encouragement, constructive criticism, congenial discussion, valuable suggestions and keen interest during the course of investigation & all the assistance provided throughout the tenure of study. I am immensely rejoiced to owe my deep sense of gratitude to Dr. Alok Shukla, Professor, Department of Plant Physiology for the many invaluable pointers that were beneficial to my progress during the project.

I deem it to be my privilege to acknowledge the indelible inspiration and constructive help received from the members of my Advisory Committee namely Dr. Alok shukla, Professor, Department of Plant Physiology, Dr. Deepti Shankhdhar, Assistant Professor , Department of Plant Physiology and Dr. Vandana A Kumar, Professor, Department of Biochemistry .I extend my sincere thanks to Head of department, Dean College of Agriculture, Dean Post-Graduate Studies, Director and staff members of University Library.

I am also thankful to all the teaching staff members of Department of Plant Physiology, for their time to time help and encouragement during course of study. I must express my special regards to all non teaching stuff Ramnaval uncle, Jogender uncle (Late), Manoj Joshi sir, Geeta mam, Kamlesh sir, Umesh bhaiya, Guddu bhaiya, Pantnagar for their valuable help and support I received during the course of my research work.

I acknowledge my heartfelt thanks to my seniors Nitin Sir, Narendra sir and Vinai Sir for their cooperation and help and without whom the completion of my research would have been a distant reach.I would also like to owe thanks to my seniors Deepika mam, Veena mam, Geeta mam, Prinsa mam, Babita mam, Rukkaiya mam, Deepti mam and my Ritu di for their continuous help, support, and thoughtfulness for being perennial source of inspiration & cooperation throughout my degree programme.

I fall short of words to express my sincere thanks to my dear batch mates Rakesh, Sudesna , Ritika and Jyoti .I highly acknowledge them for providing the warm company, love & care, encouragement, active help during the degree programme. Blissful moments shared with them will remain cherish able. I also thank to my loving juniors Neeraj, Pragya, Priyanka,

Pratibha, Tnavi, Sadaf, Bushra for their valuable help and respect. It is difficult to express the gratitude I owe to all my friends especially Sawan, Himanshu, Hement, B. Kamal, Devesh, Suresh, Pankaj, P.Kamal Himanil, Ankita.

I pay my sublime obeisance to my esteemed my papa Ravindar Singh Lingwan and Maa, Smt. Beena Devi who sacrificed their today for my better tomorrow. Their source of ever-replenishing strength, persistent inspiration, blessing and silent prayers has put this tireless venture to a fruitful result. I express my sincere thanks and special sentiments to my Dadi, Smt. Indumati Devi and Tae ji (Late) Rami Devi for their ceaseless inspiration, moral and spiritual support, profound love and unending encouragement, guiding me to achieve success at every step in life.

I apologize for the faux pass of the persons who have extended the help in a way or other and deserved such thanks.

At last but not the least, I am greatly thankful to all those peoples, who helped me during my degree programme.

Pantnagar
June, 2016

(Maneesh Lingwan)
Author

CONTENTS

S. No.	CHAPTER	Page No.

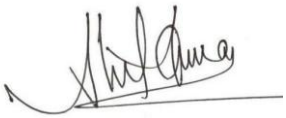
LIST OF TABLES

LIST OF FIGURES

C E R T I F I C A T E

This is to certify that the thesis entitled **"Influence of high temperature stress on morpho-physiological characteristics in rice genotypes (*Oryza sativa* L.)"** submitted in partial fulfillment of the requirements for the degree of **Master of Science,** with major in **Plant Physiology** of the College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. Maneesh Lingwan, Id. No.47013**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

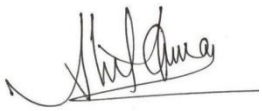


Pantnagar
June, 2016

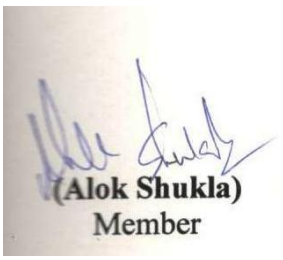
(Atul Kumar)
Chairman
Advisory committee

C E R T I F I C A T E

We, the undersigned, members of the Advisory Committee of **Mr. Maneesh Lingwan, Id. No.47013,** a candidate for the degree of **Master of Science,** with major in **Plant Physiology,** agree that the thesis entitled **"Influence of high temperature stress on morpho-physiological characteristics in rice genotypes (*Oryza sativa* L).**" may be submitted in partial fulfillment of the requirements for the degree.



(Atul Kumar)
Chairman
Advisory committee



(Alok Shukla)
Member

(Vandana A. Kumar)
Member

(Deepti Shankhdhar)
Member

C O N T E N T S

LIST OF TABLES

LIST OF FIGURES

List of Abbreviations

T	Treatment
cm	Centimeter
m	meter
g	Gram
kg	Kilogram
mg	Miligram
et.al	Etalia, (Co-worker)
Fig.	Figure
C. D.	Critical Difference
C. V.	Co-efficient of Variance
SEm.±	Standard Error of mean
viz.	Videlicet (Namely)
%	Per cent
µg	Microgram
µl	Microliter
conc.	Concentration
HCl	Hydrochloric acid
SOD	Super oxide dismutase
CAT	Catalase
TDM	Total dry matter
m^2	Meter square
cm^2	Centimeter square
m	Meter
ppm	Parts per millions
nm	Nanometer
CCB-G	Coomassie brilliant blue G-250 dye
BSA	Bovine serum albumin
Gn	Genotype
Wt.	Weight
Fr.	Fresh
DAF	Day after flowering
SLA	Specific leaf area
SLW	Specific leaf weight

Introduction

Rice (*Oryza sativa* L.) is the most broadly devoured staple food by over half of the world's populace and it provides 27 % of dietary energy supply around the world. The expanding world populace and shrinkage of agricultural area are the two fundamental reasons of an estimated food shortage and nourishment deficiency in the coming days. Rice production must enhance at least 25% by 2030 in order to feed the estimated world populace. The situation is more aggravated due to the enormous loss of crop yield as a consequence of various abiotic stresses **(Zeigler *et al* ., 2014).**

Rice has been developed under an extensive variety of climatic conditions. Almost 90% of the world's rice is grown and devoured in Asia where half of the populace relies on rice for food. However, rice crop is currently exposed to temperatures higher than the critical threshold temperature of 33 ºC during the sensitive stages at flowering and early grain-filling in South Asia (India ,Bangladesh) and Southeast Asia (Thailand, Myanmar) **(Wassmann *et al* ., 2009).**

Among always changing components of the environment, constantly rising temperature is considered as one of the most critical stress. The worldwide air temperature is anticipated to ascend by 0.2 °C every decade, which will lead to 1.8-4.0 °C higher temperatures than the present level by 2100. Emission of Green House Gases (GHG) such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) from agricultural farming is one of the major sources contributing to this worldwide increment of temperature **(Maraseni *et al* ., 2009; Smith and Olesen, 2010).**

Studies have demonstrated that the annual mean maximum and minimum temperatures have expanded by 0·35 and 1·13 °C, respectively, for the period during 1979–2003 at the International Rice Research Institute, Manila, Philippines. Temperature and rainfall are the two critical components of worldwide atmosphere that vary from year to year and vacillate widely over a period of time. Besides, the atmospheric CO_2 concentration is expected to rise from 400 µmol mol^{-1} as of now to somewhere around 485 and 1000 µmol mol^{-1} by 2100 **(IPCC, 2014).**

As a consequence of greenhouse impacts on numerous other atmospheric trace gases including CO_2, the warming of Earth may further escalate. In previous 150 years,

worldwide average surface air temperature has expanded significantly by 0.15-0.5^{0}C every decade. Plant response to high temperature differs with the degree of temperature, duration and plant type. At compelling high temperature, cell death or cellular damage may occur within minutes which may prompt to a catastrophic collapse of cellular organization. Heat stress influences the steadiness of different proteins, RNA species, membranes and cytoskeleton structures and alters the efficiency of enzymatic responses in the cell, which ultimately leads to metabolic imbalance **(Pagamas *et al.*, 2008; Ruelland *et al.*, 2010; Suzuki *et al.*, 2012).**

All plant tissues are susceptible to high temperature stress at the growth and developmental stages but reproductive structures are the most sensitive and an increment of a few degrees in temperature, at the time of flowering, can cause a considerable loss in grain yield **(Lobell *et al.*, 2011).** Rapidly warming atmosphere may truly influence crop yields in the tropics and subtropics by the end of this century (**Battisti, 2009).** Flowering period is a standout amongst the most sensitive periods to heat stress in rice. Heat stress, right now, could bring about great decrease in grain yield because of pollen sterility, low grain weight, empty or unfilled grains, and poor seed setting. Various physiological parameters likewise are also influenced by heat stress, such as chlorophyll content, net photosynthetic rate, and RuBP carboxylase activity **(Ou *et al.*, 2005).**

The harmful impacts of high temperature during reproductive growth period of rice have turned into a difficult issue to handle. In recent years, high temperature has caused serious yield losses and the most sensitive development phase of rice to heat stress is the flowering time. Heat stress, particularly during this stage, results in low seed setting rate and loss of grain yield **(Peng *et al.*, 2004; Morita *et al.*, 2005).**

The expansion in temperature has been striking and can cause irreversible harm to plant growth and development **(Wahid *et al.*, 2007).** It has been demonstrated that there is 7-8% reduction in rice yield for every 1°C increment in daytime temperature from 28°C to 34°C. It was predicted that rice development is influenced by high temperature practically at all development stages. However, high temperature is more damaging if it happens just before or during anthesis **(Satake and Yoshida, 1978).**

The two most sensitive stages are booting (microsporogenesis) and flowering (anthesis and fertilization). High temperature influences anther dehiscence, pollination

and pollen germination which then lead to spikelet sterility and yield loss **(Yoshida *et al.*, 1981).**

Exposure to heat stress at anthesis that is unable to withstand for 60 minutes at 33.7°C, may bring about spikelet sterility **(Jagadish *et al.*, 2007)**. Studies on both high day temperatures and high night temperatures have exhibited negative impacts on rice spikelet fertility and yields. High day temperatures beyond the critical threshold during sensitive growth stages like gametogenesis and flowering lead to low seed-set **(Prasad *et al.*, 2006; Jagadish *et al.*, 2011).** Grain quality is one of the major factors for any new cultivar to be accepted by consumers and thereby embraced by farmers and agriculturists. The fundamental qualities that characterize market cost are the proportion of chalk and broken grains in the sample **(Cooper *et al.*, 2008).** At high temperature during grain filling stage, chalkiness causes grains to break. Concentration of amylose and gelatinization temperature contributes to texture and cooking time. With high temperature, amylose concentration decreases in numerous rice varieties and gelatinization temperature increases **(Cuevas *et al.*, 2010).**

Temperatures higher than the ideal, impelled floret sterility and thus decreased rice yield **(Nakagawa *et al.*, 2003)**. Spikelet sterility increased greatly at temperatures higher than 35 °C. A key mechanism of high-temperature incited floret sterility in rice is the decreased capacity of the pollen grains to swell, resulting in poor anther dehiscence **(Matsui *et al.*, 2000).** This swelling of pollen grains in the locules is the driving thrust for anther dehiscence **(Matsui *et al.*, 1999).**

Altogether, rice provides 20% of global human per capita energy and 15% of per capita protein, although rice's protein content is modest, ranging around 4–18%. The atmospheric CO_2 level is projected to increase in the future, which will have significant effects on various plants. As a C_3 plant, rice will certainly benefit from this increase in CO_2, mainly through reduced photorespiration. A positive role of CO_2 enrichment has also been shown for biomass accumulation, tillering, panicles per plant and grain yield of rice **(Baker *et al.*, 1990, 1992; Ziska & Teramura, 1992)**.

The effects of high temperature on fertilization and grain filling fluctuated among various genotypes and developmental stages of plant when exposed to the stress. The negative impacts were more prominent if heat stress occurred at early heading stage than at early filling stage. Under high-temperature stress, the heat-tolerant genotypes show stronger root activity, more dynamic antioxidative barrier

framework in leaves, and higher ATPase activity in grains, and lower leaf temperature than the heat-sensitive rice genotypes **(Yun-Ying *et al*., 2009)**

Heat stress has turned into a noteworthy concern for crop production world-wide since it significantly influences the growth, development and productivity of plants. However, the extent to which this happens in particular climatic zones relies on the probability and periods of high temperature and on the diurnal timing of high temperature. Temperature changes from season to season and fluctuates day by day, which confounds the unambiguous meaning of the stress including role of temperature, since the response to various temperatures is determined by a plant's capacity to adjust to different climatic conditions. Plant responses to high temperature change within species as well as at different developmental stages **(Hasanuzzaman *et al.*, 2013).** Gentle expansion in night temperature during the reproductive growth stage lessened the yield which was credited to diminishing biomass, crop growth rate, grain weight, and harvest index **(Zhang *et al.*, 2013).** High leaf temperature can lessen plant development and limit crop yields, with estimates of up to 17% decline in yield per 10^{o} C increase in average growing season temperature **(Lobell and Asner, 2003).**

During vegetative stage, rice can endure moderately high temperatures (35^{0}C/25^{0}C; expressing day/night temperature regime). Temperatures beyond this critical level could diminish plant height, tiller number and total dry weight **(Yoshida, 1981).** The flowering stage in rice is more delicate to heat stress than the vegetative stage. In addition, increased temperature causes genuine reduction in grain size and amylose content (**Zhu *et al.*, 2005; Ying *et al.*, 2009).** Higher rates of sterility were seen in warm humid than hot arid environment due to humidity impacts on transpirational cooling **(Julia *et al.*, 2012, 2013). Xie *et al.*, (2012)** reported that high air temperature during heading stage negatively influenced SPAD value (relative content of chlorophyll) in rice flag leaves, significant reduction occurring with the continuous increment of air temperature. As the most important source organs, rice flag leaves play a dominant role in providing assimilates for the development of sink organs (grains). Nevertheless, limited reports regarding physiological responses of rice flag leaves to high air temperature are available now **(Zhang *et al*., 2007; Xie *et al*., 2012).**

Rice noodle structure relies upon gelatinization and retrogradation properties of starch. Higher amylose content in rice is believed to be a critical variable contributing to noodle quality. The proportion of amylose to amylopectin, and the branching properties of the amylopectin molecules of rice starch, can affect its physical, textural and sticking properties during cooking. The eating and cooking quality of rice is normally assessed by three factor physical and chemical characteristics of starch as indirect indices: amylose content (AC), gel consistency, and gelatinization temperature. The amylose content (AC) of rice, recognized as one of the most important determinants of eating and cooking quality, has been reported to be mainly controlled by the *Wx* gene of chromosome 6 **(Lou *et al.*, 2009).**

In cereals, high temperature after anthesis may affect cell formation and development of the endosperm tissue. Endosperm cell number does give off an impression of being adjusted by high temperature in the chronic range (<30°C), but the cells that develop under these conditions are either smaller or fail to fill out due to lessened starch deposition. Heat-shock conditions, especially early in development may results in deformed grains with the sort of damage depending on the precise timing and severity of stress **(Wardlaw and Wrigley, 1994).** The grains ripened during high temperature at day and night showed poor rice quality. These two conditions could bring about decrease of the grain maturity weight, milled rice rate, brown rice rate, amylose content and gel consistency, while chalkiness degree was increased. High day temperature had more impact on rice yield rate, chalkiness and gel consistency than the high night temperature **(Li *et al.*, 2011).** Considering the seriousness of heat stress, the present work will be carried out with the following objectives.

Objectives:

- To evaluate the different rice genotypes under heat stress on morphological basis.
- To evaluate the phenological characteristics of different rice genotypes under elevated temperature.
- To study the physiological and biochemical basis of heat stress tolerance in different rice genotypes.

Review of Literature

Rice is central to the food security and nutrition of more than half of the world's populace. As a "strategic" commodity in numerous Asian countries, it is liable to an extensive variety of government controls and interventions. Furthermore, rice production is highly sensitive to climate. Higher than ideal least and most extreme temperatures have been shown to push down rice yields in both the research center and the field, making this crop highly vulnerable to the increased temperatures anticipated to happen as a consequence of environmental change **(Welch *et al.*, 2010).**

World rice production is spread across more than 114 nations and rice is grown on 144 million homesteads around the world, more than for any other crop. In Asia, it gives occupations not only for the millions of small-scale farmers and their families but also for the many landless workers who derive salary from working on these farms. **(FAO 2013)** Rice additionally dominates overall crop production (as measured by the share of crop area harvested of rice) and overall food consumption (as measured by the share of rice altogether caloric intake) to a much greater extent in rice-producing Asia than somewhere else on the world More than 50% of all calories consumed by humans are provided by rice, wheat, and maize. Human consumption accounts for about 76% of total production for rice compared with 63% for wheat and 14% for maize ,Rice is the world's most important food crop for the poor **(Dawe *et al.*, 2010).**

Higher CO_2 levels will influence stomatal behavior beneficially by reducing water loss through transpiration, thus increasing water use efficiency **(Wassmann *et al.*, 2009**). So the projected rise in CO_2 concentration will be advantageous in some ways for rice growth and development. However, the overall effect is negative when increases in both CO_2 and temperature are taken into account simultaneously **(Moya *et al.*, 1998; Wassmann *et al.*, 2009).** The rising CO_2 level may exacerbate future scenarios for rice production in the long run, as it will further increase the global temperature. Furthermore, research on the interactive effect of these two climatic

components has revealed that the canopy temperature increases with an increase in CO_2 level due to closure of stomata,

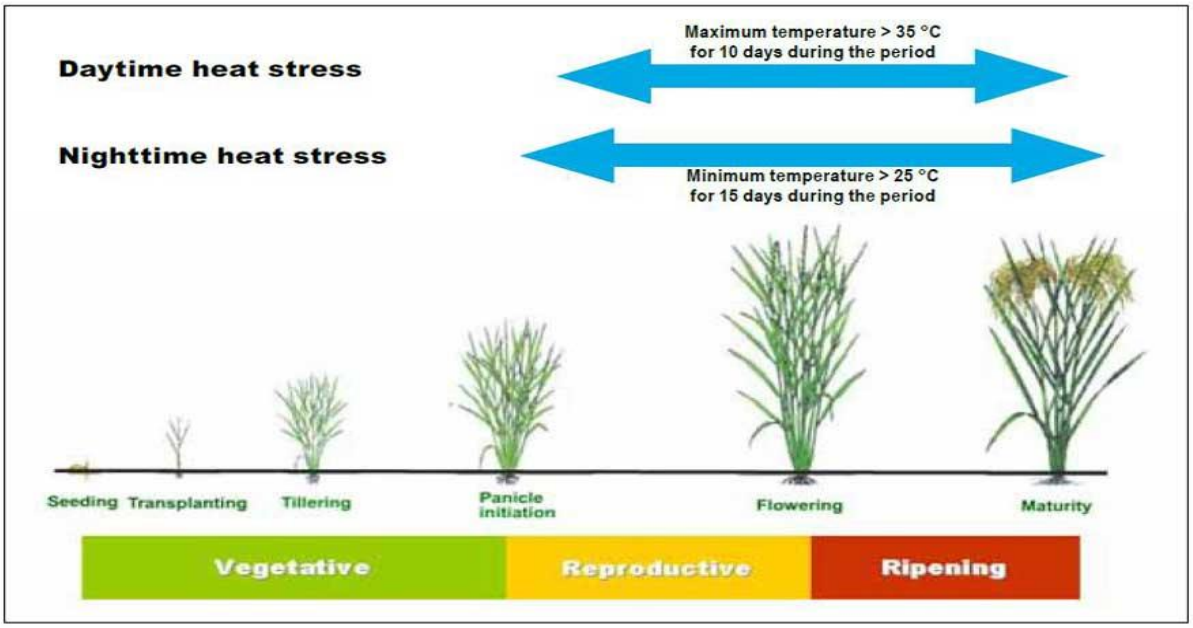


Figure: 2.1. Temperature thresholds at critical growth stages of rice. **(IRRI 2012)**

which in turn, may also reduce the critical air temperature for spikelet sterility **(Matsui *et al.*, 1997).** Rice is one of the major cereal crops consumed by more than half of world population and as it originated in tropical and subtropical areas, it has more or less ability to endure high temperatures. However, the growth and development stages of normal rice can be impaired in temperatures above a certain threshold **(Welch *et al.*, 2010).**

Response of the rice plant to varying temperature at different growth stages

Temperature alongside photoperiod is the fundamental main driving force for crop development**.** The ideal temperature for the normal development of rice extents from 27to 32°C**.** High temperature influences almost all the developmental stages of rice from emergence to ripening and harvesting. The formative stage at which the plant is exposed to heat stress determines the seriousness of the conceivable damage to the crop **(Wahid *et al.*, 2007).** However, flowering (anthesis and fertilization) and to a lesser degree the first stage booting (microsporogenesis) are considered to be the most susceptible stages to high temperature in rice **(Satake & Yoshida 1978)**. Rice is unfavorably influenced by high temperature in the lower elevations of the tropics and

by lower temperature in the temperate regions. At various times amid the life cycle of rice plant is differentially sensitive to temperature stress. Consequently, the fundamentally low and high temperatures, regularly beneath 20ºC and above 30º C, vary from one developmental stage to another. Critical temperatures contrast according to cultivars, diurnal changes, duration of critical temperature, and physiological status of the plant. **(Farrell *et al.*, 2006)**

Heat treatment at different growth stage causes major effect

Growth and developmental reactions of plants are emphatically affected by temperature and its interaction with other elements such as relative humidity (RH) and light under natural environments. For instance, the threshold temperature impelling floret sterility in rice is documented to be 35 ºC **(Jagadish *et al.*, 2008),** while rice paddies can sustain temperatures up to or above 40 ºC when accompanied by sufficient water supply and low RH, which permits the plant canopy microclimate to drop well underneath the critical threshold (~33ºC) by utilizing transpiration cooling effectively (**Weerakoon *et al.*, 2008)**

Effect of heat stress on seedling growth

Rice plants are most firmly connected to the soil water environment from sowing to the establishment of completely useful photosynthetic and water transport systems. Seed germination influences survival and intensity crosswise over diverse environments. Temperature has a profound impact on germination. Major impacts created by heat stress on rice plant to changing temperature at various developmental and growth stages includes reduced germination percentage, abnormal seedlings, plant emergence, poor seedling vigor, reduced radicle and plumule growth of germinated seedlings **(Yoshida, 1978).** High temperatures may change the aggregate phenological duration by lessening the life period. Increases in temperatures 1–2 °C than the optimum results in shorter grain filling periods and adversely influences yield components of cereal. **(Hasanuzzaman *et al.*, 2013)**.

Table 2.1: Effect of high temperature stress in rice at different growth stages

Heat treatment	Growth stage	Major effect	References
25-42.5^{0} C	Vegetative stage	Decrease CO2 assimilation rate	**(Djanaguiraman *et al.*, 2011)**
>33^{0} C, 10 days	Heading stage	Reduced pollen and	**(Hurkman *et al., 2009)***
32^{0} C (night temp.)	Reproductive stage	Decreased yield,	**(Suwa *et al.*, 2010)**

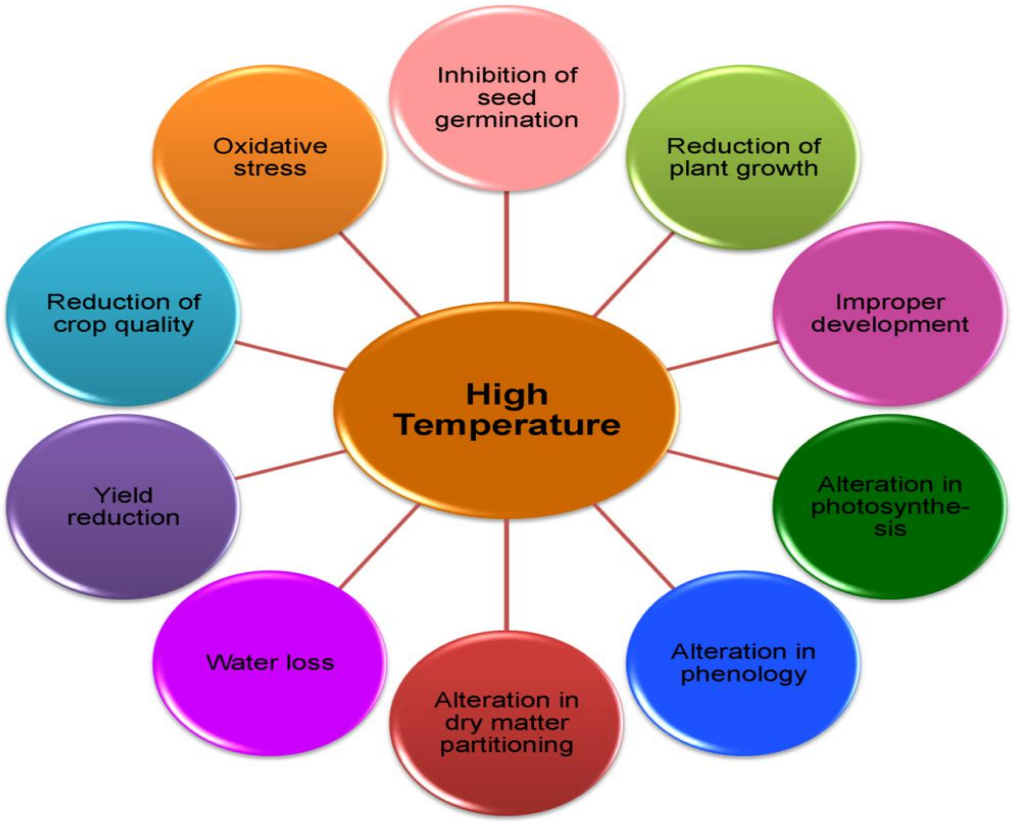


Figure: 2 Major effects of high temperature on plants. **(Hasanuzzaman *et al.*, 2013)**

Seedling emergence and development occurs when the first principal internode called the mesocotyl has elongated and pushed the tip of the rice coleoptile (epiblast or first sheathing leaf) through the soil surface. The length of the mesocotyl shifts with cultivars. Some semi-dwarf varieties may have a short mesocotyl and generally will not emerge if covered by more than 1/2 to 3/4 inch of soil. A moderate

increase in temperature speeds up leaf emergence which is a principal ecological determinant of leaf appearance in rice **(Gao *et al.*, 1992; Ritchie, 1993).**

Effect of heat stress on growth parameter

Physiologically, heading time (days from sowing to heading) can be partitioned into two formative stages: vegetative growth time and reproductive growth time. The vegetative growth time can be further partitioned into the basic vegetative phase and the photoperiod-sensitive phase. As temperature increases, growth of plant generally accelerates as a linear function of daily average temperature. When the temperature was increased above 24ºC heading time decreased to 91 days at 27 ºC and to 86 days at 30 ºC. These impacts propose the existence of a ceiling temperature. Generally high temperature accelerates and low temperature delays heading **(Ahn and Vergara, 1969; Hosoi and Tamagata, 1973).**

Effect of high temperature on roots

The genome-wide expression investigation demonstrated that HsfA2a and HsfA2d were induced over thousand-fold upon heat shock in rice root and shoot, and displayed high expression level at all growth phases of panicle development, and that the three HsfB2 family members, a, b and c, were significantly affected under heat shock in roots, shoot and panicle. It was likewise demonstrated that HsfA2f and HsfA3 were induced upon heat shock in rice panicle **(Chauhan *et al.*, 2011).** Latest studies have recommended that temperature is one of the main considerations to regulate aquaporin phosphorylation. The role of root temperature in managing the water uptake capability of rice roots and the conceivable association with aquaporins were investigated. The root hydraulic conductivity decreased with decreasing root temperature in a deliberate temperature range between 10° C and 35° C **(Murai-Hatano *et al.*, 2008).**

Effects of elevated air temperature on physiological characteristics of flag leaves

Leaf is a principal plant organ that undergoes photosynthesis. The photosynthate from leaves is the main source of grain-filling materials in rice. In rice, 90% of grain yield originates from the photosynthetic production of leaves after heading, especially from flag leaf. So flag leaf area is important factor for grain yield

in rice. High temperature stress seriously limits photosynthetic production capability of rice, which mainly originates from the higher reducing rate of leaf photosynthetic velocity under high temperature stress. This is an important factor for reduction of grain yield **(Xie *et al.*, 2011).**

It has been reported that rice pollen fertility, flowering duration and net photosynthetic rate of flag leaves decreased rapidly when air temperature was over 35°, Rice grain filling rate increased while grain-filling duration was shortened obviously due to insufficient assimilation and the nutrition competition among grains under high air temperature conditions **(Nagato *et al.*, 1966; Kobata and Uemuki, 2004**). A moderate increase in temperature speeds up leaf emergence, and temperature is a key environmental determinant of leaf appearance in rice **(Gao *et al.*, 1992; Ritchie, 1993).** The decrease in the ratio of panicle weight to green leaf area proposes that the source/sink proportion may have been influenced. The accumulation of carbohydrate in leaf and increase in specific leaf weight indicate feedback inhibition. Decrease in the number of filled grain per panicle declines grain yield largely. High temperature actuated infertility can make grain yield almost zero **(Ziska *et al.*, 1996).**

Leaf is a most vital and principal plant organ that undergoes photosynthesis. The photosynthate from leaves is the primary source of grain-filling materials in rice. In rice, 90% of grain yield starts from the photosynthetic production of leaves after heading, particularly from flag leaf. So flag leaf area is important variable for grain yield in rice. High temperature stress seriously constrains photosynthetic production capability of rice, which chiefly originates from the higher reducing rate of leaf photosynthetic velocity under high temperature stress. This is an imperative component for reduction of grain yield **(Xie *et al.*, 2011).**

Effect of high temperature on culm of rice

Remobilization of carbohydrate from the leaf sheath and culm of rice plant to grain adds to yield as much as 38% and the contribution varied extensively among rice varieties **(Yoshida and Ahn, 1968).** The phosphorylase activity reached a most extreme, trailed by a steady decrease at high temperature. In addition, the succinic-dehydrogenase activity at rachilla vanished, and soon yellowing started. A large amount of assimilate can occur in leaves and culms because of the event of sterile spikelets and subsequently photosynthetic rate may be depressed due to the

accumulation of starch in the chloroplasts in plants grown under high temperature **(Oh-e *et al.*, 2007).**

Effect of heat stress in number of productive tillers

Tillers are branches that develop from the leaf axils at each unelongated node of the fundamental shoot or from different tillers during vegetative growth growing autonomously by means of its own adventitious roots. Tillering is a two-stage process: the arrangement of axillary buds at each leaf axil and its subsequent growth (**Yoshida, 1973)** reported that higher temperatures stress increased tiller numbers in rice plant. At 3–5 weeks after sowing, temperature just somewhat influenced the tillering rate and the relative growth rate, except at the lowest temperature (22ºC) tested. Tiller number per plant decides panicle number which is a key component of grain yield **(Yoshida, 1981).**

The number of productive tillers (per unit ground area), spikelet sterility and grain weight are important components of yield **(Sheehy *et al.*, 2001)** and that are affected by the cultivation system and by environmental factors among which temperature is considered to be agronomically important **(Singla *et al.*, 1997)**. Production of tillers is sensitive to temperature **(Mitchell, 1953)** and tiller production in rice is an important agronomical trait **(Li *et al.*, 2003).** Furthermore, tiller number in the small grains is positively correlated with panicle dry weight per area **(Paulsen, 1987)**. Spikelet sterility in rice is also sensitive to temperature, where the degree of sensitivity depends upon the developmental stage of the spikelet **(Zakaria *et al.*, 2002).** Moreover, HNT (>29 ◦C) increases spikelet sterility of rice with a subsequent reduction in seed-set and grain yield **(Satake and Yoshida, 1978; Ziska *et al.*, 1996).** In addition, there is a strong negative linear relationship between fertile spikelets per square meter and increase in night temperatures **(Peng *et al.*, 2004).**

Effect of heat stress on yield components of rice

The yield capacity of rice is basically reliant on both vegetative (number of panicles per unit area) and reproductive (number of spikelets per panicle) stages. The actual yield is acknowledged at flowering and during grain filling (filled spikelet percentage and weight per grain) phases. Temperature impacts rice yield by specifically influencing the physiological processes involved in grain production, the

length of ripening is conversely connected with daily mean temperature, high temperature can seriously impair ripening. Both grain weight and percentage of filled spikelets are influenced by high temperatures **(Krishnan *et al.*, 2011).**

Grain yield is by all account the only consideration in the cultivation of rice, and grain dimensions, the appearance in terms of color, texture, and surface abnormalities and milling attributes are likewise essential variables regulating the popularity and marketability. Inferable from high temperatures during the ripening period, abnormal morphology and coloration happen in rice, likely because of reduced enzymatic activity related to grain filling, respiratory consumption of assimilation products and decreased sink activity **(Inaba and Sato, 1976; Tsukaguchi and Iida, 2008).** The chalkiness is one of the key elements in deciding rice quality and price. In Japan, chalky grains are conventionally classified into various categories such as milky white rice, white-belly rice, white-core rice, white-based rice and white-back rice **(Yoshioka *et al.*, 2007).** In general, the temperature reasonable for ripening is considered to be 24ºC at which temperature the maximum grain weight is observed **(Kobata *et al.*, 2004).**

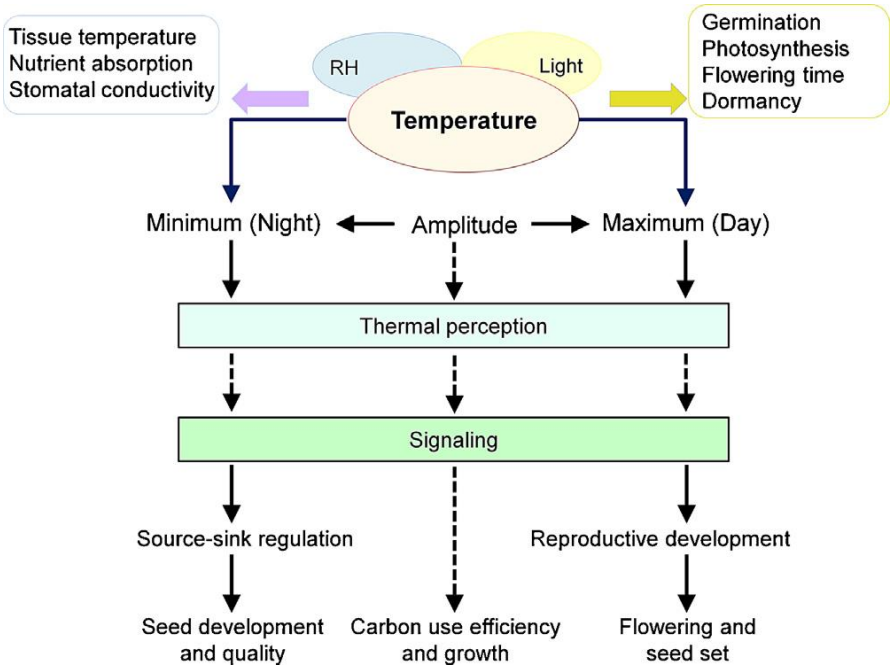


Figure: 3. Overview of temperature and associated physical factors (relative humidity (RH), light) affecting key physiological processes in plants. Figure shows differential plant responses with absolute values and amplitude of diurnal temperature variation. Broken arrows indicate unknown/insufficient information on the mechanism regulating respective physiological response **(Bahuguna *et al.*, 2015).**

Effect of heat stress on phenological parameter

Seed set under high ambient air temperature basically relies on upon effective pollination and fertilization. As it was appeared in reciprocal studies with pollen from control plants on heat-stressed pistils and vice versa, the male gametophyte and not the pistil, is responsible for spikelet sterility under high stress temperature in rice plant **(Yoshida *et al.*, 1981).** Morphologically, large anthers **(Hashimoto, 1961; Suzuki, 1981)** and longer stigmas **(Suzuki, 1982)** contribute to increased resilience to cold stress during the booting stage and the same might be true for high temperature resistance at flowering **(Matsui and Omasa, 2002)**. Among physiological procedures happening at anthesis, anther dehiscence is seen to be the most critical stage affected by high temperature **(Matsui *et al.*, 2001).** Spikelet opening triggers pollen swelling which leading to anther dehiscence and pollen shedding from the anthers' apical and basal pores **(Matsui *et al.*, 1999).**

Expanded basal pore length in a dehisced anther was found to contribute essentially to successful pollination **(Matsui and Kagata, 2003),** most likely as a result of its proximity to the stigmatic surface. Longer stigmas may likewise be important for the same reason. After pollination, it takes about 30 min for the pollen tube to reach the embryo sac **(Cho, 1956).** Genotypic contrasts in pollen number and germinating pollen on the stigma **(Matsui *et al.*, 1997)** and spikelet fertility **(Matsui and Omasa, 2002; Prasad *et al.*, 2006)** under high temperatures in rice have been all around depicted. Similarly, in few different crops, pollen germination and pollen tube growth are appeared to be sensitive to high temperatures **(Kakani et al., 2005; Salem *et al.*, 2007).**

Exposure to 41 °C for 4 h at flowering caused irreversible damage and plants became completely sterile (IRRI 1976), whereas this high temperature(41 °C) had no effect on spikelet fertility at 1 day before or after flowering **(Yoshida *et al.*, 1981).** A key mechanism of high-temperature induced floret sterility in rice is the decreased ability of the pollen grains to swell, resulting in poor thecae dehiscence **(Matsui *et al.*, 2000).** This swelling of pollen grains in the locules is the driving force for anther dehiscence **(Matsui *et al.*, 1999). Endo *et al.*, (2009)** found that although high-temperature-treated pollen showed a normal round shape, some of the tapetum functions such as pollen adhesion to the stigma and its subsequent germination were negatively affected. **Endo *et al.*, (2009**) also identified some temperature responsive

genes in the anther by clustering of microarray data. Some other possible reasons discussed by researchers for decreasing spikelet fertility at high temperature are altered hormonal balance in the floret **(Michael and Beringer, 1980),** disturbance in the availability and transport of photosynthates to the kernel **(Afuakwa *et al.*, 1984),** lack of ability of the floral buds to mobilize carbohydrates under heat stress **(Dinar and Rudich, 1985)** and changes in the activities of starch and sugar biosynthesis enzymes **(Keeling *et al.*, 1994; Singletary *et al.*, 1994)**. Similarly, high temperatures at anthesis or soon after can cause poor pollen germination and retarded pollen tube growth, along with poor anther dehiscence. Different reasons have been discussed for variation of these traits among tolerant and susceptible cultivars. For example**, Matsui *et al.*, (2001)** stated that the occurrence of well-developed cavities in anthers, and thick locules walls which enable easy rupture of the septa in response to swelling of pollen resulted in better anther dehiscence and pollen shed in tolerant cultivars. Exposure of pollen grains to high temperature resulted in a loss of pollen viability within 10 min **(Song *et al.*, 2001)** and it was essential that more than 10 pollen grains germinated on the stigmata to ensure Successful fertilization of a rice floret **(Satake and Yoshida, 1978).** Given that 50% of the pollen grains on a stigma germinate, there must be over 20 pollen grains on a stigma to ensure fertilization (**Matsui and Kagata, 2003**). Along with this, exposure to high temperature for a few hours can reduce pollen viability greatly and therefore causes yield loss **(Wassmann and Dobermann, 2007)**. The stigma is less sensitive to heat than the anther and pollination of the stigma with unstressed pollen generally restores the spikelet fertility **(Yoshida *et al.*, 1981**). The decrease in spikelet fertility can be termed a phenotypic character of rice plant under high temperature, while the decrease in pollen germination and activity can be considered as the physiological factors responsible for this decrease (**Tang *et al.*, 2008).**

Effects of heat stress on panicle differentiation

Panicle differentiation happens commonly at temperatures between 18º and 30ºC. During tillering stage, the number of panicles will increase if the air temperature is less than 20ºC **(Yamamoto *et al.*, 1985).** After the active tillering stage, high temperatures decrease the number of panicles, particularly at maturity stage. In addition to the impacts of air temperature, the floodwater temperature

influences the number of panicles per plant and spikelets per panicle. The ideal temperature for ripening is lower than that for tillering and anthesis. The temperature optimum shifts to generally lower temperatures as rice grows. The panicle weight is known to decrease under high temperature in rice plant **(Newman *et al.*, 2001; Oh-e *et al.*, 2007; Ziska *et al.*, 1996). Kim *et al*., (1996)** reported that the rate of increase in dry matter in the panicle after the heading decreased under high temperature. This could be somewhat because of the increase in the number of sterile spikelets. The number of panicles is nearly connected with grain yield, but there is often a negative relationship between the number of panicles per unit land area and spikelets per panicle and also between the spikelets per unit land area and filled grain percentage or 1000-grain weight **(Yoshida, 1983)**.

Spikelets Sterility induction by high temperature

Sterility induction by high temperature is most sensitive at flowering stage and next at meiotic phase of spikelet that falls on 12 days before flowering **(Satake and Yoshida, 1978)**. During microsporogenesis the processes close to the meiotic stage are most delicate to high temperature **(Yoshida, 1981).** A noteworthy decrease in pollen production was found at 5◦C above ambient temperature **(Prasad *et al.*, 2006)** that was attributed to disabled cell division of pollen mother cell **(Takeoka *et al.*, 1992).** In rice, the reproductive processes that happen inside one hour after anthesis–dehiscence of anther, shedding of pollen, germination of pollen grains on stigma and elongation of pollen tubes are most sensitive to high temperatures and are disrupted at day temperatures above 33.8 ◦C prompting to spikelet sterility **(Satake and Yoshida, 1978).** Therefore, an 60 min. exposure of high temperature during flowering is sufficient to induce spikelet sterility and spikelet opened beyond ±1 h of the high temperature exposure are not influenced **(Satake and Yoshida, 1978; Wassmann *et al.*, 2009).** Among these reproductive processes happening inside one hour after anthesis, anther dehiscence is one of most susceptible process under high temperature **(Matsui *et al.*, 1999).** High temperatures at flowering repress swelling of the pollen grains , which is the main impetus for anther dehiscence in rice, Sterility is brought on by poor anther dehiscence and low pollen production and hence low numbers of germinating pollen grains on the stigma **(Matsui *et al.*, 2000, 2001; Prasad *et al.*, 2006).**

Weerakoon *et al.*, (2008) reported that grain sterility increased with increased humidity under high temperature over the critical value that actuates spikelet sterility in rice. Thermal stresses influence rice spikelet sterility during two critical periods, first at microspore phase during which meiosis is obstructed **(Satake, 1976),** and about fourteen days later during anthesis when pollination happens **(Satake *et al.*, 1978; Farrell *et al.*, 2006; Jagadish *et al.*, 2007)**. For instance, high night temperature prompted decrease in overall biomass, nitrogen, and nonstructural carbohydrate partitioning decreases rice yield and grain quality **(Shi *et al.*, 2013),** contrasted with increased spikelet sterility induced by high day temperature **(Jagadish *et al.*, 2010).**

Pollination in relation to spikelet fertility at high temperature

Pollination contributing elements (pollen production, viability and reception) assume a prevailing part in productivity of the crop. Generally, male reproductive development in rice is known to be more sensitive to high temperature stress **(Wassmann *et al.*, 2009). Prasad et al., (2006**) reported that high-temperature stress during rice flowering stage led to decreased pollen production and pollen shed. The main reasons were the inhibition of swelling of pollen grains, indehiscence of anthers and poor release of pollen grains **(Matsui *et al.*, 2000, 2005),** and thus lesser numbers of pollen grains were available to be intercepted by the stigma. **Mackill *et al.*, (1982)** reported that the corresponding fertility was positively correlated with the number of pollen grains shed on the stigma under both high and ambient temperatures production of pollens at elevated temperatures might be attributable to the impaired cell division of the microspore mother cells **(Takeoka *et al.*, 1992).** Likewise,high temperatures at anthesis or soon after can bring about poor pollen germination and retarded pollen tube growth, along with poor anther dehiscence. Various reasons have been discussed for difference in these traits among tolerant and susceptible cultivars. For example, (**Matsui *et al.*, 2001)** reported that the occurrence of well-developed cavities in anthers, and thick locule walls which empower easy rupture of the septa in response to swelling of pollen resulted in better anther dehiscence and pollen shed in tolerant cultivars. Real reasons for high temperature-induced spikelet sterility were attributed to decreased pollen shedding and decreased viability of pollen grains, resulting in a lesser number of germinated pollen grains on the **stigma (Matsui *et al.*,**

2000, 2001; Prasad *et al.*, 2006; Satake and Yoshida, 1978). Thus, high temperature at booting stage mainly decreases the fertility of pollen grains, while at flowering stage it fundamentally diminishes the number of pollens shedding on the stigma and the germination of the pollen grains.

High temperature causing anther dehiscence

Anther dehiscence is the most susceptible procedure during anthesis under high temperature **(Matsui *et al.*, 1999).** High temperature causes increase in vapor pressure deficit, enhancing evaporation from the anthers, in this way depriving the crucial moisture required for pollen grain swelling which is unavoidable for anther dehiscence. Artificial spikelet opening activated fast pollen swelling, resulting in anther dehiscence and subsequent pollen shedding from apical and basal pores **(Matsui *et al.*, 1999**). The anther basal pore length is considered to have a huge commitment toward pollination under high temperature as a result of its close proximity to the stigmatic surface (**Matsui and Kagata, 2003).** The significance of the apical pore under high temperature is not clearly understood. Then again, in some water stressed anthers of IR64, the basal pore failed to open while in the alternate anthers with open pores the pollen failed to shed from the opened apical pore, which was ascribed to increased pollen stickiness **(Liu *et al.*, 2005)** Dehiscence of the anther prompting to pollen deposition on the stigma is called as pollination. After pollination if takes about half an hour for the pollen tube to reach the embryo sac and fertilization will be completed in 1.5–4 hour (**Cho, 1956**). Rice pollen is highly sensitive to temperature and relative humidity **(Matsui *et al.*, 1997**) and loses its viability within 10 min of shedding **(Song *et al.*, 2001).** Spikelets having >20 germinating pollen on the stigma showed great concurrence with fertility at high temperature of 38º C **(Matsui *et al.*, 1997).**

Role of humidity in spikelet sterility at high temperature

Humidity also plays an imperative role in rice yield, as higher relative humidity (RH) at the flowering stage under elevated temperature affects spikelet fertility adversely (**Yan *et al.*, 2010). Nishiyama and Satake, (1981)** also reported that the dehiscence of the anther, which assumes an important role in the fertility of the spikelet, was promoted by dry air. The temperature inside the spikelet diminishes with a decrease in RH, possibly because of the enhancement of transpiration at low

RH **(Weerakoon *et al.*, 2008).** This reduction in temperature inside the spikelet builds the viability of pollen grains. Viable pollen grains assimilate moisture and swell at moderate to high RH levels and makes the required pressure for the rupture of the septum, which helps in the deposition of pollen on stigma and in this way delivers a fertilized spikelet **(Weerakoon *et al.*, 2008).**

Weerakoon et al., (2008) also reported that spikelet fertility was not generally inhibited by high humidity, They also observed that with increases in RH, pollen shedding on stigma was reduced at high temperature, while no such decrease with increased in RH was noted at lower air temperatures. These perceptions suggest that the shedding of pollen on the stigma and the ensuing spikelet sterility are affected by RH along with temperature.

Effect of high night temperature on grain weight

The high night temperatures (22/34ºC, day/night) were more harmful to grain weight in rice than high day temperatures (34/22ºC) and control conditions (22/22ºC) at ideal temperature (**Morita *et al.*, 2005).** The final grain weight which is the result of the rate and duration of grain growth is influenced by high temperatures which enhances growth rate in the early ripening period but lowered the duration of grain growth and at last result in abatements in final grain weight. The duration of grain filling characterized as the number of days required to achieve maximum weight, was found to be 13 days at a mean temperature of 28ºC and 33 days at 16ºC for cultivar IR20, an indica rice But in case of the cultivar Fujisaka 5, a japonica rice took a little longer days to ripen: 18 days at a mean temperature of 28ºC and 43 days at 16ºC **(Oh-e *et al.*, 2007).**Attributable to high temperatures during the ripening period, abnormal morphology and coloration occur in rice, most likely because of reduced enzymatic activity identified with grain filling, respiratory consumption of assimilation products and diminished sink activity **(Inaba and Sato, 1976; Tsukaguchi and Iida, 2008).** The chalkiness is one of the key element in deciding rice quality and price. In Japan, chalky grains traditionally ordered into different categories such as milky white rice, white-core rice, white-belly rice, white-based rice, and white-back rice **(Yoshioka *et al.*, 2007).**

Wakamatsu *et al.*, (2007) reported that the occurrences of white-back kernel and white-based kernel were high when an average temperature during the 20-day

period after heading was 27ºC or higher. High temperature and long sunshine hours during ripening period increased the grain fissuring of all cultivars tested in spite of the fact that the cultivars are known to differ in their susceptibility to fissuring. They also observed that the average daily maximum temperature during 10 days after heading showed the most elevated correlation with the percentages of fissured grains. High-temperature treatments when given at 6–10 days after flowering, during where the dry weight of spikelets was 14–40% of that at maturity, brought on the greatest grain fissuring. **Nagata *et al.,* (2004)** reasoned that high temperatures during the early stage of grain filling increased the rice grain fissuring at maturity. The grain weights for a rice cultivar are verging on steady in a stress-free environment **(Yoshida, 1981)**. However, under high temperature stress conditions, the grains at the tip of the panicle are the largest and heaviest because of the fact that they are normally filled first, while large numbers of blanks occur at the base of the panicle **(Stansel, 1975**). Hence, under stress conditions there is perhaps a competition among the grains inside the panicle, situated at various positions. The decrease in individual grain weight under HNT is not associated with a shortfall of carbohydrates in the leaves **(Morita *et al.,* 2005)**, however is associated with decreased grain dimension (**Counce *et al.,* 2005**). Past studies reported increased vegetative respiration rates **(Frantz *et al.,* 2004)** and leaf membrane injury **(Reynolds *et al.,* 1994)** as aftereffect of heat stress, which might decrease assimilate supply to the spikelet **(Hirai *et al.,* 2003**). The increase temperature in leaf causes leaf membrane injury can disrupt water, ion, and organic-solute movement across the plant membranes and thus affecting carbon production, consumption, transport and accumulation **(Christiansen, 1978).**

Effect of Heat Stress on Physiological Parameter

A few physiological mechanism of rice plants for heat tolerance had been recognized, including the specifically upregulated of Rubisco activase large isoform, the increase of different enzymes of the Calvin Cycle, a fall in Ferredoxin- NADP(H) oxidoreductase (FNR) and a consistent increase in expression of a thiamine biosynthesis protein (THI1).Rice plants can remodel their proteomes in response to high temperature stress. (**Lee *et al.,* 2001)** found that HSPs and energy- and metabolism-associated proteins were the major proteins influenced by a high temperature of 42°C in leaves but also lignification-related proteins were regulated by

high temperature, and various proteins related to protection were up-regulated at different high temperatures, indicating that diverse systems were embraced at various levels of high temperature: the higher the temperature, the greater the involvement of the protection machineries.

Symptoms of High-Temperature Injury in Rice

High-temperature stress influences different morphological, biochemical and physiological processes. Stress can bring about variable impacts at all functional levels of plants. When plants are exposed to stress, there are reductions in activities and energy for growth and development. Photosynthesis is delicate to high-temperature stress, and maintenance of high photosynthetic capacity is critical for tolerance and it is standout amongst the most heat sensitive physiological processes in plants. In rice, there is little temperature effect on leaf photosynthesis from 20 to 40ºC **(Egeh *et al.*, 1992).** In rice plant 1–2ºC increase in average temperature is not prone to have a substantial affect on leaf photosynthetic rates. However, variability in leaf photosynthetic rates inside rice plants and high photosynthetic rates at high temperatures do not necessarily support high rates of dry matter accumulation. Although global warming is liable to influence photosynthetic rates per unit leaf area of a closed canopy over the throughout the following century, very high temperatures can repress photosynthesis. The light-saturated photosynthetic rates of leaves are exceedingly correlated with atmospheric [CO_2], and temperature dependence of photosynthesis fluctuates with the growing temperature, even within a genotype **(Oh-e *et al.*, 2007).** With changes in developing temperature, rice may show significant phenotypic plasticity in its photosynthetic characteristics and temperature dependence of photosynthesis is sensitive to the [CO_2] and the optimal temperature increases with [CO_2]. **Lin *et al.*, (1997)** reported a cooperative improvement of photosynthetic rate with temperature under elevated [CO_2] during tillering stage relative to the elevated [CO_2] condition alone.

Chlorophyll content

In plants, chlorophyll content is a critical marker of photosynthetic activity, stress and nutritional status. Generally, healthy plants are required to have higher chlorophyll content than unhealthy plants developing in the same growth period.

Hence, studies on leaf chlorophyll content and its relationships with plant stress and nutrition are vital for agricultural field management and for improving rural practices and also for optimizing agricultural practices **(Liu *et al.*, 2010)**.Chlorophyll is a noteworthy photosynthetic pigment which functions as changing over light to energy to drive an electron uphill from then onto the next inside the reaction center. This energy is used by the plant to synthesize glucose molecule from carbon dioxide and water. Contrasts in leaf chlorophyll content can be a marker of plant vigor and its capacity for photosynthesis, emphatically dependent on chlorophyll content **(Carter and Spiering., 2002)** Therefore, chlorophyll content is a vital element in deciding plants performance in heat stress. Photosynthesis is standout amongst the most heat sensitive processes and can be totally inhibited by high temperature before different symptoms of the stress are detected. Decrease in photosynthesis could come from structural and functional disruptions of chloroplasts and reduction of chlorophyll accumulation under high temperature stress **(Dekov *et al.*, 2000; Camejo *et al.*, 2005).**

The dry matter of rice grain for the most part begins from the photosynthetic outcome of leaves after the heading stage **(Cao and Yang, 2001).** High temperature stress seriously restricts photosynthetic capability of rice plant, which for the most part begins from the higher reducing rate of leaf photosynthetic velocity under high temperature stress. This is an essential factor for reduction of grain yield **(Yao *et al.*, 2007).** There is a nearby correlation between photosynthetic capability and chlorophyll content. Chlorophyll is the material vehicle of photosynthesis in plants. In this manner, advancement of its content can accelerate the photosynthetic rate and at last increase the yield of rice. Chlorophyll biosynthesis and degradation is a dynamic process during growth and development in rice plant. In general, biosynthesis of chlorophyll is prevalent before heading and degradation of chlorophyll is predominant at later stage when the rice plant leaves turn yellow **(Kun *et al.*, 2010).**

Chlorophyll a and b contained in leaves of higher plants are the fundamental pigments of photosynthesis in the chloroplasts and have essential functions in the absorption and exploitation of the light energy, in this manner affecting photosynthetic efficiency. The total contents of chlorophyll and chlorophyll a (Chl a) changed somewhat when the seedlings were transferred from low light (LL) to high light (HL) during growth condition. However, the content of chlorophyll b (Chl b)

decreased significantly at 24 h of HL treatment compared to that of the LL control. The proportion of chlorophyll a to b (Chl a/b) increased since the 8 h time point of HL treatment **(Wei *et al.*, 2010).** The chlorophyll content of flag leaves reduced particularly under high temperature stress, which influenced the photosynthetic efficiency of the crop **(Xie *et al.*, 2011).**

Heat stress changed total chlorophyll content (Chl) and leaf photochemical efficiency in the stressed plants. The total chlorophyll content decreases in the heat stressed cultivars in relation to the control plants. An increase in the chlorophyll a/b proportion occurred in the high temperature treated plants, caused basically by a higher decrease in chlorophyll b content than chlorophyll a content. Consequently, these characteristics could be used as indicators of heat tolerance and the physiological status of cultivars under high temperature stress conditions, An increase in chlorophyll a/b proportion, coming about because of faster degradation of chlorophyll b, indicated a preferential decrease in light-harvesting chlorophyll a/b-binding proteins (LHC) associated with PSII (LHCII) to exchange excitation energy to the PS II core complex **(Xu *et al.*, 1995).** It is generally accepted that chlorophyll plays a crucial role in regulating photosynthesis, including the capture of sunlight and the change of luminous energy **(Oh *et al.*, 1997).** In general, chlorophyll content is positively associated with photosynthetic rate in rice leaves (**Liu, 1980).** SPAD instrument value represents the relative content of chlorophyll, which is convenient and successful tool for the research of chlorophyll level without damaging rice plant leafs. A strong correlation between chlorophyll content and SPAD value products of photosynthesis in leaves, being an critical parameter for evaluating photosynthetic function. In general, approximately 60% of assimilates demanded by rice grain-filling are derived from post-anthesis photosynthetic production delivered by flag leaves, which prominently contributes to grain filling. In this way, the photosynthetic ability of flag leaves is pivotal role for the determination of grain yield.

Effect of heat stress on photosynthesis

High temperatures lowered the chlorophyll fluroscence (Fv) in attached leaves, protoplasts, chloroplasts, and thylakoids of rice. Damage to PSII in photosynthetic organelles and thylakoids and the match between these profiles and Fv, an indicator of injury to PSII and the kinetics of injury over time suggest that the

photosystem is vulnerable to high-temperature damage in rice **(Al-Khatib and Paulsen, 1999)**. The Fv/Fm proportion decreased significantly under high temperature stress, when rice seedlings were dealt with at 26^0C, 35^0C, 40^0C and 45^0C for 48 h, respectively **(Han *et al.*, 2009)**.

Chlorophyll content is a very imperative component in deciding plants performance in heat stress. Photosynthesis is standout amongst the most heat sensitive processes, and can be completely restrained by high temperature before other symptoms of the stress are identified. Decrease in photosynthesis could come about because of structural and functional disruptions of chloroplasts and reduction of chlorophyll accumulation under high temperature stress **(Dekov *et al.*, 2000; Camejo *et al.*, 2005).**The chlorophyll content of flag leaves lowered particularly under high temperature stress, which affected the photosynthetic efficiency of the crop **(Xie *et al.*, 2011).** High temperature decreased chlorophyll content and the reduction was more in thermo-sensitive genotypes. In this test it was shown that high air temperature triggered a significant decrease in SPAD values, in soluble protein and sugar contents of flag leaves, inferring that photosynthetic mechanism was severely impaired alongside the reduction of photosynthesis under high air temperature **(Liu *et al.*, 2013)**

Chlorophyll Fluorescence

Chlorophyll fluorescence is an viable and non destructive tool for illustrating various aspects of the photosynthetic apparatus in intact leaves of higher plants. It can be utilized to estimate the rate of photosynthetic electron transport and photosynthetic quantum yield and capacity of thermal energy dissemination under high light stress **(Demming *et al.*, 1995; Sayad, 2004)**. Therefore, chlorophyll fluorescence method has allowed an increased comprehension of photochemical and nonphotochemical processes occurring in thylakoid membranes of chloroplast. Photosynthesis relies on the function of the light harvesting and electron transport system within chloroplast which is demonstrated by the photochemical efficiency, measured as the chlorophyll fluorescence variable yield (Fv/Fm proportion). This can be variably associated with the photochemical yield of the PS II. For the most part Fv/Fm ratio can be distinguished around 0.8 for healthy and normal plants on the bases of fluorescence induction kinetics. In case, plant experiences from any disease or abiotic stress it may reflect lower level of Fv/Fm **(Spano *et al.*, 2003).**

The PSII photochemical efficiency

(Fv/Fm) was appeared to reduce in rice seedlings in high temperature **(Han *et al.,* 2009**). No noteworthy reduction in Fv/Fm was seen in NH219 due to heat stress demonstrating no damage to photosystem II complex (PSII) or primary photochemical efficiency which was influenced maximum in the susceptible line IR64 and least in the mutant NH219. Ribulose bisphosphate carboxylase oxygenase (Rubisco) is a heat-labile protein in numerous plant species, limiting photosynthetic capacity during heat stress **(Kurek *et al.,* 2007).** However, its increased plenitude after heat treatment has been reported in heat tolerant rice species like *O.meridionalis* from Australia and its activity is associated with thermotolerance **(Scafaro *et al.,* 2010; Scafaro *et al.,* 2012).** Additionally transgenic rice over-expressing Rubisco activase I indicated greater photosynthetic activity (**Wu *et al.,* 2007).** Regeneration of RuBP was adjusted in high temperature due to disturbance of electron transport and inactivation of the oxygen evolving enzymes of PSII (**Parry *et al.,* 2013**). The stability of chlorophyll thylakoid complexes under water stress condition and reduced accumulation of reactive oxygen species under heat stress treatment has been reported in NH219 **(Panigrahy *et al.,* 2011).**

Effect of Heat Stress on Biochemical Parameter

Effect on Amylose Content

Temperature medications during grain filling had a considerable impacted on the total starch accumulation and apparent amylose content in rice endosperms, with high temperature treatment showing lower accumulation of total starch in rice endosperms than low temperature treatment, irrespective of rice genotypes **(Wei *et al.,* 2012).** High temperature lower starch accumulation in developing seeds by restricting sucrose transport **(Phan *et al.,* 2013)** and starch metabolism **(Yamakawa *et al.,* 2007; Yamakawa and Hakata, 2010; Phan *et al.,* 2013)** by suppressing genes involved in sucrose synthesis (SuSy2), sucrose breakdown (invertase, INV3), sucrose transport (SUT1), and starch synthesis (ADP-glucose pyrophosphorylase, AGPS2b; granule bound starch synthase, GBSSI; branching enzyme, BEIIb) in growing seeds. On the other hand, high temperature/heat stress impels genes for a-amylase (Amy1A,

Amy1C, Amy3A, Amy3D, Amy3E), which breakdown starch in endosperm **(Yamakawa *et al.*, 2007; Hakata *et al.*, 2012).** Hence,, starch breakdown, , evidently required to aid HSPs synthesis during stress, could be a key factor in falling apart grain quality under high temperature in major cereals such as rice, wheat, and maize **(Yamakawa *et al.*, 2007; Hurkman and Wood, 2011; Hakata *et al.*, 2012; Phan *et al.*, 2013).**

Rice starch is around 90 % of dry grain weight and is made out of two major classes of molecule; amylose which is essentially linear chains of α(1–4) linked glucose, and amylopectin which has α(1–6) branches in addition to the α(1–4) links. The physicochemical properties responsible for rice eating and handling quality are essentially dependant on the structure of these two molecules and relative abundance of these two molecules **(Patindol and Wang, 2002).** There are two main forms of amylopectin in rice, L-type and S-type, which contrast by the degree of polymerization (DP) in the DP ≤24 range. L-type amylopectin, which is generally characteristic of indica cultivars, have more chains in the DP 12–24 range relative to S-type amylopectin which is found in japonica cultivars **(Nakamura *et al.*, 2002).** The distinction in chain length distribution shows itself in gelatinsation temperature, L-type amylopectin starch has a higher gelatinisation temperature than S-type Amylopectin structure assumes a basic part in determining the physicochemical properties of rice starch and the texture of cooked rice **(Nakamura *et al.*, 2002; Reddy *et al.*, 1993).**

Rice Grains Ripened under High Temperature Showed Chalky Appearance and Low Amylose Content

It has been accounted for that high temperature at the milky stage of grain filling has the greatest impact on rice grain chalkiness **(Tashiro and Wardlaw, 1991)**, and the panicle is the most sensitive tissue to high temperature **(Sato and Inaba, 1973; Morita *et al.*, 2004).** high chalk occurrence in rice grains is predominantly attributable to adverse climatic conditions, particularly daily mean temperature or scenes of high temperature at filling stage **(Prasad *et al.*, 2006; Chakrabarti *et al.*, 2010).** Another conspicuous damage of high temperature stress during reproductive period is the decrease of pollen fertility, grain weight and plant harvests, in addition to the deteriorating palatability (**Jiang *et al.*, 2003; Yamakawa *et al.*, 2007; Li *et al.*,**

2011). Microscopic observation of the chalky part of high temperature-ripened grains uncovered that approximately stuffed starch granules create air spaces between themselves to reflect light randomly **(Tashiro and Wardlaw, 1991; Zakaria *et al.*, 2002).**

High temperature at filling stage could lowered amylose content (AC) in endosperm starches of nonwaxy rice plants, as a consequence of decreased activity of GBSS (Granule bound starch synthase), where Wx gene expression in rice grains is directed by temperature at the transcriptional and post-transcriptional level **(Asaoka *et al.*, 1985; Hirano and Sano, 1998; Larkin and Park, 1999).** Meanwhile, high temperature at filling stage could likewise increase the amount of long B chains of amylopectin and lessening short B chains **(Asaoka *et al.*, 1985),** which is more predominantly owing to the changing activities of soluble starch synthase (SSS), starch branchingenzyme (SBE) and starch debranching enzyme (DBE) in filling endosperms, rather than the limitation in sucrose supply from photosynthesis tissues and its cleavage metabolism in non-photosynthesis tissues. Starch debranching enzyme (DBE) is a key enzyme which is involved in starch the metabolism in rice endosperm **(James *et al.*, 2003; Jeon *et al.*, 2010).**

Effect of heat stress on protein content

The rice grain ripening period can be separated into two periods as indicated by the ripening of the embryo and endosperm. During the first half of the ripening period, rice embryos and endosperm undergo cell division and differentiation until the embryo reaches maturity, whereas the accumulation and transformation of starches and proteins take place in the second half of the ripening period **(Hong *et al.*, 1995).**

Identifying the useful proteins required in the reaction of rice to high temperature stress may provide the premise to improving heat tolerance in rice. In the experiment, a near proteomic analysis of paired, genetically similar heat tolerant and heat-sensitive rice lines was conducted. Two-dimensional electrophoresis (2-DE) revealed a total of 27 differentially expressed proteins in rice grains, transcendently from the heat-tolerant lines. The protein profiles obviously indicated variations in protein expression between the heat-tolerant and heat sensitive rice lines. Matrix-assisted laser desorption/ionization time-of-flight/time-of-flight mass spectrometry

(MALDI-TOF/TOF MS) analysis revealed that 25 of the 27 differentially showed proteins were homologous to known useful proteins. These homologous proteins were involved in biosynthesis, energy metabolism, oxidation, heat shock metabolism, and the regulation of transcription **(Liao *et al.*, 2013).**

Antioxidant Defense in Response to Heat-Induced Oxidative Stress

The reaction centers of PSI and PSII in chloroplasts are the significant sites of ROS generation. Despite the fact that ROS are also produced in different organelles viz. peroxisomes and mitochondria. A straight relationship exists between maximal efficiency of PSII and the accumulated ROS. It has been reported that because of the thermal damage to photosystems under HTs less absorbtion of photon occurs . In such stress conditions, if photon intensity is absorbed by PSI and PSII, the excess of which is required for CO_2 assimilation are considered as surplus electrons, those serve as the main source of ROS **(Fujimori *et al.*, 2011).** The HT increased leaf temperature which decrease the antioxidant enzyme activities that expanded malondialdehyde (MDA) content in leaves of rice plant . Heat stress (33 °C)) incited oxidative stress was observed to damage membrane properties, protein degradation and enzyme deactivation in wheat that lessened the cell viability remarkably. Heat stress induced oxidative stress also significantly increased the membrane peroxidation and decreased the membrane thermostability by 28% and 54% which shockingly increased electrolyte leakage in rice**(Hurkman *et al*., 2009).**

Antioxidant Defence Response to High Temperature Stress Generated Oxidative Stress

A key versatile mechanism in numerous plants grown under abiotic stresses, including saltiness, water deficit and extreme temperatures, is accumulation of certain organic compounds of low molecular mass, generally known to as compatible osmolytes **(Hare *et al.*, 1998; Sakamoto and Murata, 2002)**. Accumulation of stress related compounds are well archived under various types of stresses. In different plants free proline accumulates in response to a wide range of biotic and abiotic stresses such as salinity, water deficit stress and extreme high temperatures. Proline is a noteworthy organic molecule that accumulates in many plants exposed to

environmental stresses such as drought, salinity and high temperature **(Werner and Finkelstein, 1995; Kuznetsova and Shevyakova, 1997)**.

The function of proline is still not clear but it is recommended that proline acts as a compatible solute and its accumulation is involved in cytosolic osmotic adjustment during stress conditions, and scavenge the hydroxyl free radicals, and protect protein structure and enzyme activity under stress and it is an indicator of stress (stress related signal) **(Nanzo *et al.*,1999: Hasegava *et al.*, 2000)**. Despite numerous studies in plants, the roles of proline in osmotolerance in plants remain controversial **(Fedina *et al.*, 2002)**. The connection between the proline level and heat stress (role of proline in protecting pollen from heat stress), showed that injury by heat stress during floral development of sensitive genotypes might be because of the decline in proline concentration during the early floral bud development stage and its transportation is restrained from anther walls to pollen **(Talwar *et al.*, 2002)**. The accumulation of compatible solutes is one of the versatile strategies of plants in response to abiotic environmental stresses. Accumulation of these compatible solutes like proline, glycine betaine and sucrose contribute to osmotic adjustment, denaturation, prevention of protein, preservation of enzyme structure and activity and protection of membranes from injury by reactive oxygen species (ROS). Numerous osmolytes stabilize protein in vivo and in vitro **(Hare *et al.*, 1999; Sharma and Dubey, 2004)**.

The accumulation of compatible solutes like proline and other soluble sugars under drought stress was reliant on leaf age. Higher content of proline and soluble sugars were found in young leaves than older. These findings suggest that younger leaves have higher capability to adapt to the change in soil water moisture than old leaves **(Watanabe *et al.*, 2000; Cechin *et al.*, 2006)**. The increase of proline and soluble sugar content in leaves of rice plants was higher under drought stress, i.e. free proline content and soluble sugars can be utilized as drought tolerance indicators for selecting drought resistant genotypes **(Mostajeran and Rahimi-Eichi, 2009)**. Proline accumulation during stress may serve as a means of osmotic adjustment and storing carbon and nitrogen when stress leads to slower growth rate. The rice cultivars which accumulate higher proline content has higher grain yield under drought stress **(Pirdashti *et al.*, 2009).**

Plant Heat Shock Responses

Heat stress is responsible for the up-regulation of several heat inducible genes, commonly alluded as "heat shock genes" (HSGs) which encode HSPs and these dynamic products are especially vital for plant's survival under fatal high temperature. High temperature prompted constitutive expression of majority of the HSPs and protect intracellular proteins from being denaturation and preserve their stability by protein folding in this manner acts as chaperones. In plants, well-characterized HSPs can be grouped into five different families: HSP100 (or ClpB), HSP90, HSP70 (or DnaK), HSP60 (or GroE) and HSP 20 (or small HSP, sHSP) **(Hasanuzzaman *et al.*, 2013).** It was reported that heat shock treatments effectively incited HSPs in some varieties, and furthermore influenced the constituted fractions in other. Profiles of the control plants of all the varieties in general indicated higher concentration of low molecular weight proteins in basmati rice **(Morimoto 1997; Cellier *et al.*, 1998; Iqbal *et al.*, 2010).** Plants reacts to heat stress by upgrading the expression of genes encoding heat shock protein (HSPs) genes through initiation of heat shock factors (HSFs) which communicate with heat shock elements present in the promoter of HSP genes. In the callus of cell derived from rice seed embryos, heat shock depresses normal protein synthesis, but enhances the synthesis of specific proteins **(Fourre and Lhoest, 1989).** Contingent on whether the temperature increase is rapid or gradual, contrasts are observed in the production of Hsps.

Role of HSPs in inducing thermo-tolerance

HSPs can help in adapting with heat stress by enhancing photosynthesis, partitioning of assimilate, nutrient and water use efficiency also in membrane thermal stability (**Wahid *et al.*, 2007).** A positive relationship has been archived in numerous plant species between HSPs and heat tolerance of the entire plant **(Huang & Xu 2008).** Additionally, a relationship between HSPs and reactive oxygen species (ROS) has been proposed which proves the hypothesis that during the span of evolution plants were able to suppress ROS and now plants are utilizing these ROS as signalling molecules to instigate HSPs **(Timperio *et al.*, 2008)**. Better acclimation was accounted when the high temperature stress occurs gradually instead of through a sudden change in temperature **(Larkindale & Vierling 2008)**. Interruption of some plant growth hormones for example ethylene, salicylic acid, abscisic acid, calcium

and hydrogen peroxide through mutation influenced the thermo-tolerance capability of the plants, in spite of the fact that the levels of accumulated HSPs did not vary from their wild types in these mutated plants **(Larkindale *et al.*, 2005).** At the point when applied exogenously, these chemicals can increases thermotolerance without an accompanying accumulation of HSPs (**Larkindale and Knight, 2002),** mainly through enhances antioxidant capacity and membrane thermal stability which can decrease the extent of injury caused by ROS **(Mohammed and Tarpley, 2009).**

Biotechnological Strategies for Development of Heat Stress Tolerance in Plants

It is additionally assessed that food quality will be influenced. For instance, elevated CO2 emissions representing likely levels in 2050 are associated with significant declines in the zinc, iron, and protein content of wheat, rice and soybeans **(Myers *et al.*, 2014).** Likewise, food safety may be compromised by a changing climate. High temperatures and compelling weather events make a more favorable environment for food-borne pathogens for example, campylobacter and salmonella **(Tirado *et al.*, 2010).** which lessen sufferers' ability to absorb nutrients. Sustainable growth in rice production worldwide is expected to ensure food security, maintain human health, and manage the livelihoods of millions of small farmers. Demand for rice has been relentlessly expanding over the years due to populace and income growth in major rice consuming countries, and worldwide demand for rice may increase by about 90 Mt (paddy equivalent) by 2020 **(Mohanty 2009).** A standout amongst the most serious long-term challenges to achieve sustainable growth in rice production is climate change **(Vaghefi *et al*,. 2011, Wassmann and Dobermann 2007, Adams *et al.*, 1998, IFPRI 2010).**

High night time temperature

Environmental temperature, particularly night time temperature during grain development, assumes an integral role in grain quality **(Cooper *et al.*, 2008).** High night time temperatures are identified with decreased panicle mass and increased numbers of chalky kernels **(Yoshida and Hara, 1977).** The head rice yield is impacted by the thickness appropriation pattern of a population of rice kernels and, by changing the thickness distribution of kernels, an increase in nighttime temperature could possibly lessen head rice yield **(Sun and Siebenmorgen, 1993; Siebenmorgen**

and Cooper, 2006). In general, as nighttime temperature increases, head rice yield decreases and High nighttime temperatures during grain development can bring about an increase in amylose content **(Resurreccion *et al.*, 1977),** and the extent of long chains of amylopectin can decrease **(Counce *et al.*, 2005).**

Recent studies in controlled-temperature and field-scale environments have set up that elevated nighttime air temperatures (NTATs) happening during critical grain-filling stages influence rice kernel development, bringing about decreased yield, increased kernel chalkiness, and reduced milling quality **(Peng *et al* ., 2004; Cooper *et al.*, 2006).** Different studies have shown that the chemical makeup of starch is affected by raised NTAT, as confirm by decreased amylose content (AC) and changes in ratios of long- to shortchain amylopectin **(Counce *et al* 2005; Cooper *et al.*, 2008).** Several hypotheses have been exhibited to clarify the impacts of NTAT stress, including reduced substrate supply to the endosperm, starting moderate starch granule growth and irregular granular organization **(Fitzgerald and Resurreccion 2009)** and interruption of enzymatic activity responsible for starch formation**(Counce *et al.*, 2005**). In spite of the fact that the underlying mechanisms that tie the effects of NTAT to the structural and functional changes of starch are not obviously established, these findings are critical to rice end-use applications, in light of the fact that functional properties of milled rice, which specifically impact cooking and sensory quality, are primarily controlled by starch physicochemical properties.

Effect of temperature on harmone

The mechanisms of anther dehiscence are well understood **(Matsui *et al.*, 2000**) however the physiological and biochemical reasons for reduced pollen activity and germination are not yet clear. Likewise, endogenous hormones are known to play an vital role in determining male fertility. **Tang *et al*., (2008)** measured the growth hormones in the anthers and found a reduction in indole acetic acid (IAA), gibberellic acid (GA3), free proline and soluble proteins however a huge significant increase in absisic acid (ABA) content. They presumed that low levels of IAA and GA and higher levels of ABA lead to pollen abortion, a major explanation behind male sterility. Concurrent decline in free proline and soluble proteins in the susceptible cultivar improved stress resulting in floret sterility. Moreover, accumulation of compatible osmolytes like sugars, sugar alcohols **(Sairam and Tyagi, 2004)**, glycine

betaine **(Sakamoto and Murata, 2002)** plays an versatile part under extreme temperatures by buffering cellular redox potential **(Wahid and Close, 2007).**

Mechanism of Signal Transduction and Development of Heat Tolerance

Plant hormones for example ABA, ethylene, GA, auxin, cytokinin, and brassinosteroids role in direct seed initiation and development of plant. A synergistic activity of auxin and GA in seed development initiation whereas role of cytokinin in cell division and differentiation in the endosperm during early seed development, brassinosteroids in cell elongation and a regulatory action of ethylene and ABA on sugar metabolism and seed maturation are obvious **(Sun *et al.*, 2010; Zhu *et al.*, 2011;Liu *et al.*, 2013; Sreenivasulu and Wobus, 2013).**Likewise, how these hormones respond with temperature signs is still a challenging aspect of research. For a case , high temperature reduces ABA and GA (GA7, GA19) accumulation in developing seeds of rice **(Hakata *et al.*, 2012).**

Socioeconomic vulnerability to climate change

Sustainable growth in rice production globally is expected to ensure food security, maintain human health, and sustain the livelihoods of millions of smallworkers and maintain the occupations of a huge number of little ranchers. Demand for rice has been relentlessly increasing over the years because of populace and income growth in major rice consuming countries, and global demand for rice may increase by about 90 Mt (paddy equivalent) by 2020 **(Mohanty 2009)**. One of the most serious long-term difficulties to accomplish reasonable development in rice production is climate change (**Vaghefi *et al.*, 2011, Wassmann and Dobermann 2007, Adams *et al.*, 1998, IFPRI 2010).** Rice productivity and sustainability are already threatened by biotic and abiotic stresses, and the effects of these stresses may be further aggravated by changes in climate in numerous places.

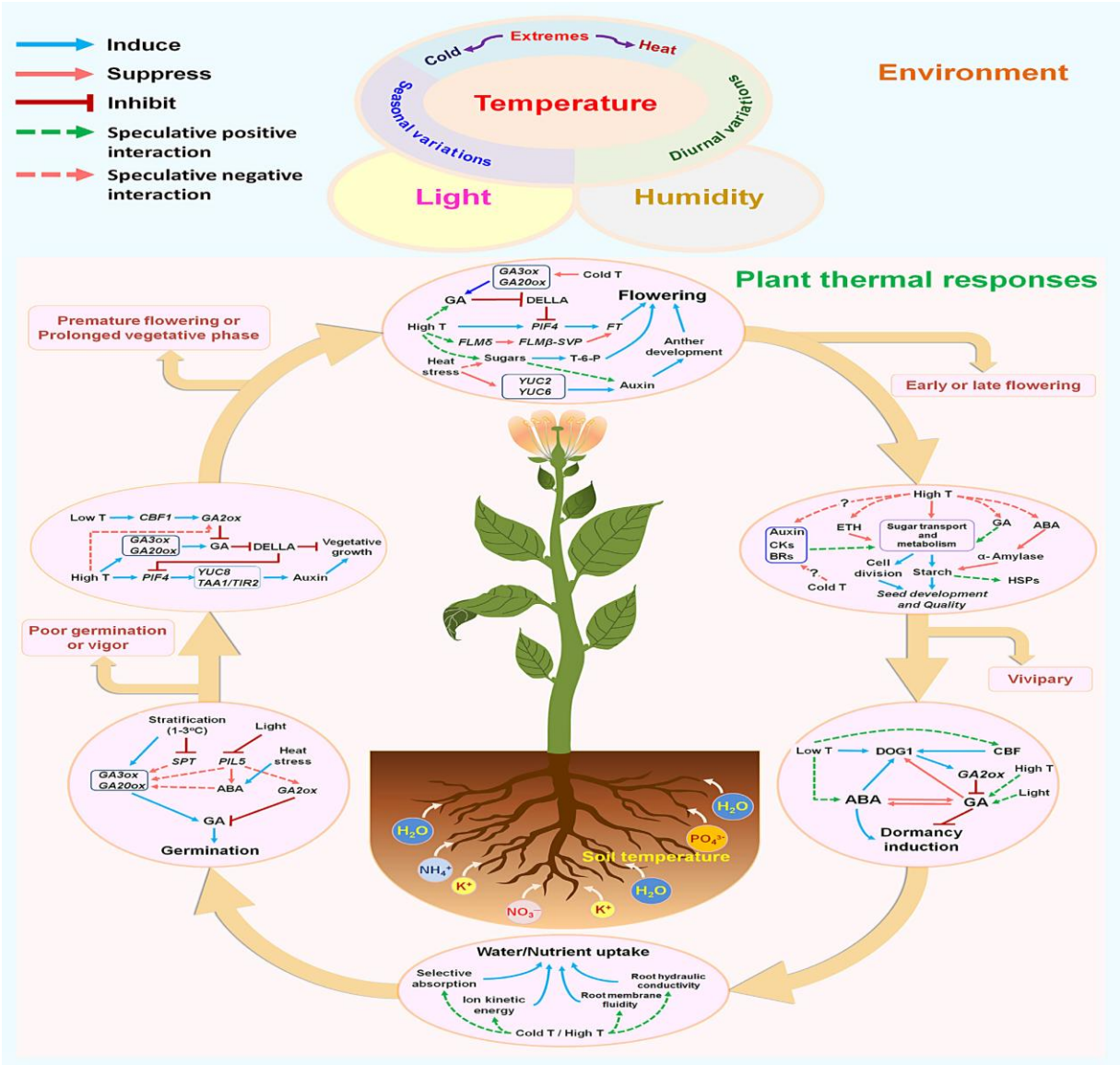


Figure:4..Plant responses to temperature cues: phenological development, transition, and retraction.Abbreviations: ABA, abscisic acid; BRs, brassinosteroids; CBF, C-repeat binding factor; CKs, cytokinins; DELLA, a negative regulator of GA response; DOG1, delay of germination 1; ETH, ethylene; FLM, FLOWERING LOCUS M; FT, Flowering Locus T; GA,gibberellic acid; GA2ox, GA 2-oxidase gene encode a GA degrading enzyme; GA3ox, GA3-oxidase, GA. **(Bahuguna *et al.*, 2015)**

Considering that the change in the worldwide atmosphere will result in more extreme events such as floods, droughts, and cyclones, significant economic benefits can be accomplished from the development of improved rice varieties that are more resilient to climate change. This type of innovation would allow rice producers to adapt to a intensifying worldwide climate and make them better able to mitigate the adverse effects of climate change in the future. In the long run, the returns to the

speculation of developing ‘climate change tolerant’ variety are high. Otherwise, resource- poor rice farmers in South Asia will remain highly vulnerable and food safety in the region may be at stake if new multiple stress-tolerant varieties of rice are not accessible in the near future.

Materials and Methods

A field experiment was conducted at Norman E. Bourlog Crop Research Centre of the G. B. Pant University of Agriculture and Technology, Pantnagar, U. S. Nagar, (Uttarakhand), during kharif period of 2015 to study the impact of heat stress on growth, development, improvement and yield of rice (*Oryza sativa* L.) genotypes.

General Description of Experimental Area

3.1 Experimental site

The field experiment was conducted during kharif season 2015 in rice physiology B1 block of Norman E. Bourlog Crop Research Centre of the G. B. Pant University of Agriculture and Technology Pantnagar, U. S. Nagar (Uttarakhand). Geographically Pantnagar lies in Tarai belt about 30 km. southwards of foot hills of Shivalik range of Himalayas at 29^{o} N latitude, 79^{o} 29' E longitude and at an altitude of 243.8 meter above from the sea level.

3.2 Experimental Material

The seeds of 24 rice genotypes, namely **IET 23339, IET 23354, IET 23356 ,IET 23392, IET 23947, IET 23949, IET 23951, IET 23957, IET 23976 IET 23979, IET 23996, IET 24075, IET 24082, DRRH-106 ,DRRH-107 ,DRRH-108 ,GOVIND, NDR-97 ,PA-6129, PHY-1,PHY-2 ,SABAGIDHAN, TULASI, N22** were obtained from the Directorate of Rice Research, Rajendranagar, Hyderabad.

3.3 Chemicals

Chemicals used in this study were of analytical trade and obtained from E. Merck (India) Ltd., Hi-media Pvt. Ltd. (India) and Spectrochem (India) Ltd.

3.4 Glass wares

Glass wares used in this study were obtained from Borosil.

3.5 Instruments used for the experiments

Centrifuge	:	Eppendorf Centrifuge-5424R
Digital Balance	:	Citizen Balance, Solan, India

Digital pH meter	:	GENEI, Bangalore
Hot Air Oven	:	Macro Scientific Works, Delhi, India
Micropipette	:	Nichipet, Japan, Tarson, India
Spectrophotometer	:	Genesys ,India
Refrigerator	:	LG, Godrej, India.
-20^{o} C deep freezer	:	Vestfrost
Water Distillation unit	:	Millipore, USA

3.6 Main Treatments

Nursery beds will be prepared in the field with sufficient water supply, and seeds will be sown by opening furrows, water were fully filled after the sowing and 21 days old seedlings will be transplanted via transplanting.

The nursery bed will be irrigated before uprooting in order to make soil soft so that on pulling the seedling one by one, there should be minimum root damage. The seedlings will be transplanted in two strips one for control and one for imposing heat stress. The straight-row method follows a uniform spacing between plants. The seedlings are transplanted in straight rows. Uniform spacing in planting are made of rope and wood. . Each entry will be sown in 3 rows of 1.5 meter length maintaining 20 cm spacing between rows and recommended plant to plant distance.

About a week after transplanting, missing plants were re-transplanted by gap filling. The heat stress treatment will be given during flowering by covering the stripe with polythene sheet supported by bamboo sticks like a tunnel before anthesis till maturity Both minimum and maximum temperature will be recorded every day with the help of minimum- maximum thermometer installed inside the tunnel.

3.7 Layout

The field experiment was carried out in two separate independent plot.

Experimental details

Date of sowing	13/06/2015
Date of transplanting	04/07/2015
Experimental design	Randomized block design

No. of treatment	Control vs. Heat
No. of replication	Three
Basal Dose	Phosphorus 45 kg ha-1 Potassium 60 kg ha-1
Dose of Nitrogen	1st 50% of Nitrogen (100 kg ha-1) at 10-15 days after transplanting and 2nd 25% at maximum tillering and rest 25% at panicle initiation.
Total plot area	120 m^2
Total Spacing with each	20 cm. × 10 cm.
No. of rows of each entries	3
No. of plants in each row	15
Length of each row	1.5 meter

3.8 Uprooting, Transplanting and Water Management

The nursery bed was irrigated before uprooting in order to make the soil soft so that on pulling the seedling one by one, there should be minimum root damage. Then the roots of the uprooted seedlings were washed to remove the mud. The seedlings were transplanted to the prepared field. Thin film of standing water was maintained in the field during transplanting up to the establishment of seedling. About a week after transplanting, missing plants were re-transplanted by gap filling

3.9 Weeding, Harvesting and Thrashing

Manual weeding was done regularly during crop growth. When crop attained the phase of maturity i.e. 90% of the panicle were yellow ripened, the crop was harvested manually. Thrashing of individual genotype was done by the help of thrasher after sun drying.

3.10 Morphological Characters

3.10.1 Number of tillers per plant

The number of tillers and plant height in centimeters of three randomly selected plants were recorded from each plot at flowering stages.

3.10.2 Plant Height- Plant height was measured in centimeters. By taking average height of three randomly selected plants from soil base up to the base of top most fully expanded leaf. It was measured with the help of meter scale at flowering and maturity stage.

3.10.3 Leaf length and width- Leaf length and width were measured in centimeter at the time of flowering.

3.10.4 Leaf area per hill- For computing leaf area, number of tiller per hill was counted; the length and maximum width of each leaf on the middle tiller was measured and leaf area of each leaf will be computed as follow

$$\text{Leaf Area} = K \times L \times W$$

Where, K= Constant factor

L= length of leaf (cm)

W= Width of leaf (cm)

3.10.5 Specific leaf weight- Specific leaf weight was calculated through leaf dry weight by dividing it with leaf area.

3.10.6 Specific leaf Area- Specific leaf area was calculated by leaf area divided by leaf dry weight.

3.10.7 Panicle weight- Panicle weight (g) was measured at flowering stage, after 7-8 days of flowering and maturity stage.

3.10.8 Stem Weight- Stem weight (g) without leaves was measured at flowering and at harvest stages by selecting three plants (hills)

3.10.8 No. of filled and unfilled grains per panicle- No. of filled and unfilled grains per panicle was measured at maturity stage.

3.10.10 Total dry matter-The total plant dry matter was calculated at flowering stage

and at maturity by uprooting the complete above ground plant part and then separating it into culm and leaves followed by placing them in an oven at 60^{o} C for three days, culm dry matter, leaf dry matter and total dry matter were taken out.

3.10.11 1000-grain weight-From control and heat treated plot, from each replication of each entry 1000-grain were selected randomly and weight was taken in gram (g).

3.10.12 Grain yield-Grain yield (economic yield) from three replication was recorded and then finally expressed in g/m^2 after harvesting.

3.11 Biochemical analysis

3.11.1 Chlorophyll content

Chlorophyll content was determined in fresh leaves at flowering stage by using a method described by **Hiscox, *et al.* (1979).**

Reagent:

Dimethyl sulfoxide (DMSO)

Estimation of chlorophyll content:

Chlorophyll content was estimated in freshly harvested leaves at flowering stage by DMSO method. To estimate chlorophyll content 50 mg of finely chopped leaves were taken in test tube in duplicate. Then 10 ml of dimethyl sulfoxide (DMSO) was added in each test tube and incubated at 65^{o} C for 3 hrs. in an oven. After incubation of 3 hrs., absorbance of DMSO containing chlorophyll was determined at 663 and 645 nm using a spectrophotometer against pure DMSO as a blank. The chlorophyll content was then calculated by using following formula

$$\text{Chl 'a'} = \frac{(12.7 \times \text{A663} - 2.63 \times \text{A645}) \times \text{V}}{\text{Weight (g)} \times 1000}$$

$$\text{Chl 'b'} = \frac{(22.9 \times \text{A645} - 4.48 \times \text{A663}) \times \text{V}}{\text{Weight (g)} \times 1000}$$

$$\text{Total Chl} = \frac{[(20.2 \times \text{A645}) + (8.02 \times \text{A663}) \times \text{V}]}{\text{Weight (g)} \times 1000}$$

A= Absorbance of chlorophyll extract at specific indicated wavelength

V=Final volume of the sample, and

W=Weight of tissue extracted on fresh weight basis

3.11.2 Amylose estimation

Amylose content was estimated in rice grain by using the method described by **Mc Cready *et al.* (1950).**

Reagents

1. **Distilled ethanol**
2. **Sodium hydroxide (1N NaOH):** 40 g NaOH dissolved in 1000 ml distilled water.
3. **Phenolphthalein (0.1%):** 0.1 g phenolphthalein in 100 ml distilled water.
4. **Iodine reagent:** 1 g iodine and 10 g KI were dissolved in water and the volume was made to 500 ml.
5. **Amylose standard:** 100 mg amylose in 10 ml 1N NaOH was dissolved and made final volume up to 100 ml with distilled water.

Standard curve

Amylose standard solution ranging from 2-18 mg was taken into different clean and dry test tubes and 20 ml distilled water was added along with three drops of phenolphthalein. After these, 0.1 N HCl was added drop by drop until the pink color just disappeared. Then 1 ml of iodine reagent was added and the volume was made up to 50 ml and absorbance was recorded at 590 nm using dilute iodine reagent (dilute 1 ml of iodine reagent to 50 ml with distilled water) as a blank. The standard curve was prepared and used for amylose estimation.

Amylose extraction

Rice grains were de-husked and ground with the help of pestle and mortar. Then 100 mg of powdered sample was taken, thereafter1 ml of distilled ethanol was added into it followed by 10 ml of 1 N NaOH and was kept overnight. Next day the volume was made up to 100 ml. Out of this extract 2.5 ml was taken out and 20 ml distilled water was added followed by three drops of phenolphthalein. After this 0.1 N HCl was added drop wise until the pink colour disappeared. Then 1 ml of iodine reagent was added and volume make up was done up to 50 ml. Absorbance was

recorded at 590 nm using dilute iodine reagent as a blank. The standard curve was prepared from amylose using which the estimation of amylose was done.

3.11.3 Protein estimation

Protein content was estimated in rice grain by using the method described by **Bradford (1976).**

Reagents

1. **Bradford dye:** 100 mg CBB-250 was dissolved in 50 ml ethanol and 100 ml of orthophosphoric acid (85% w/v) was added. The volume was made up to 1 litre with double distilled water. The solution was filtered and store at 4^{o} C in dark coloured bottle.

2. **BSA standard ppm:** 20 mg BSA was dissolved in 20 ml protein extraction buffer.

3. Protein extraction buffer (EB) (pH 7.2):

EDTA	5 mM
NaCl	50 mM
Na Phosphate	25 mM

4. PMSF (0.1M in alcohol)

Standard curve

Standard BSA solution ranging from 10-100 µg was taken into different clean and dry test tubes and made the final volume 300 µl with extraction buffer/double distilled water, than 3 ml of Bradford dye was added in each test tube and absorbance was recorded at 595 nm. 300 µl extraction buffer/double distilled water was mixed with 3 ml Bradford dye as a blank. The standard curve was prepared and used for protein estimation.

Protein extraction

Rice grains were de-husked and ground with the help of pestle and mortar. Then 500 mg of powdered sample was extracted in 2.5 ml of protein extraction buffer. Each sample solution was centrifuged at 4^{o} C and 10,000 rpm for 15 minute,

thereafter 20 µl supernatant was taken out from each sample separately in test tube and then made up with extraction buffer up to 300 µl and thereafter 3 ml of Bradford dye was added along with 2-3 drops of PMSF in each test tube. Absorbance was recorded at 595 nm. The standard curve was prepared from BSA and used for the estimation of protein.

Chlorophyll Fluorescence

Chlorophyll fluorescence was measured with a portable fluorimeter (Handy, PEA, Hansatch, UK). Measurements were taken by choosing various leaf positions, in the forenoon hours around 10.00 AM to avoid photo inhibition. The initial fluorescence (F0) was recorded on leaves adapted to darkness for more than 10 minutes by using leaf clips supplied by Hansatech instruments Ltd, UK. It was taken care that the fiber optics of the fluorimeter does not shade the leaf surface. A single saturating pulse of actinic light was applied to obtain the maximum fluorescence (Fm) when all PSII reaction centers are in reduced form. The maximum efficiency of PSII photochemistry in dark adapted state (Fv/Fm) was calculated. The maximum fluorescence level (Fm) of closed PS-II centre was determined by providing 1.5 sec. saturating pulse at 300 µ mol m^{-2} S^{-1} on dark adopted leaves by using following protocol:

1. Leaf clips were attached to mid portion of each leaf
2. Leaves were dark adapted for 10 min
3. The fluorometer probe connected to leaf clip holder
4. Chlorophyll fluorescence measurement using red light (1.5 sec, 3000 µ mol m^{-2} s^{-1})
5. Fv/Fmax ratio recorded from handy PEA [Fv/Fm = (Fm−F0) / Fm]

3.12 Statistical Analysis

The Statistical data were analyzed by Analysis of Variance (ANOVA) for Control and Treatment in Randomized Block Design. Three replicates from treatment were used to check for significant changes in expression compared with control.

Table.1. Date wise maximum and minimum temperature recorded by maximum and minimum temperature thermometer inside the poly sheet tunnel.

Date	Max. temp. (˚C)	Min. temp. (˚C)	Date	Max. temp. (˚C)	Min. temp. (˚C)
9/4/2015	43	22	**9/29/2015**	42	16
9/5/2015	42	22	**9/30/2015**	43	20
9/6/2015	42	22	**10/1/2015**	42	21
9/7/2015	39	22	**10/2/2015**	44	18
9/8/2015	39	23	**10/3/2015**	39	19
9/9/2015	42	22	**10/4/2015**	40	19
9/10/2015	44	23	**10/5/2015**	38	18
9/11/2015	44	23	**10/6/2015**	44	19
9/12/2015	43	24	**10/7/2015**	42	18
9/13/2015	46	26	**10/8/2015**	42	17
9/14/2015	42	23	**10/9/2015**	43	18
9/15/2015	44	21	**10/10/2015**	42	19
9/16/2015	47	22	**10/11/2015**	40	17
9/17/2015	44	23	**10/12/2015**	43	19
9/18/2015	47	26	**10/13/2015**	41	19
9/19/2015	47	25	**10/14/2015**	41	20
9/20/2015	43	23	**10/15/2015**	42	19
9/21/2015	43	23	**10/16/2015**	40	18
9/22/2015	42	23	**10/17/2015**	39	17
9/23/2015	41	22	**10/18/2015**	40	18
9/24/2015	45	21	**10/19/2015**	40	19
9/25/2015	35	21	**10/20/2015**	39	19
9/26/2015	38	19	**10/21/2015**	39	18
9/27/2015	39	19	**10/22/2015**	39	18

Figure 1: Crop transplanting

Figure 2: Crop after transplanting

Figure 3: Experiment site

Figure 4:Full view of heat stress block B1

Figure 5: Author during a visit to field

Figure 6: maximum and minimum thermometer

Figure 7: Hon'ble Vice chancellor visiting rice fields

Figure 8: Crop at maturity stage

Results and Discussion

Chapter 4 RESULTS AND DISCUSSION

This field experiment was performed to evaluate the influence of high temperature stress on different morphological, phenological, biochemical parameter and different physiological attributes in 24 genotypes of rice namely IET 23339, IET 23354, IET 23356 ,IET 23392, IET 23947, IET 23949, IET 23951, IET 23957, IET 23976 IET 23979, IET 23996, IET 24075, IET 24082, DRRH-106 ,DRRH-107 ,DRRH-108 ,GOVIND, NDR-97 ,PA-6129, PHY-1,PHY-2 ,SABAGIDHAN, TULASI, and N22.The morphological and phenological parameter included leaf length, leaf width, leaf area(cm^2), leaf dry weight(mg), specific leaf weight, specific leaf area, number of tillers per plant at flowering, stem dry weight per plant at flowering, panicle dry weights at flowering, 7-8 days after flowering and at maturity, stem dry weight at harvest, grain yield per plant at harvest, stem weight per plant at flowering, TDM per m^2 (leaf+stem), TDM (g/m^2) at harvest ,stem weight per m^2 at harvest, grain yield per m^2 at harvest, 1000 grains weight, number of filled and unfilled grains per panicle at harvest, while the biochemical parameter included total chlorophyll content at flowering, chlorophyll content one week after flowering and at maturity ,amylose content, and protein content etc.

4.1 Morphological parameters

4.1.1 Effect of high temperature stress on leaf length (cm), leaf width (cm) and leaf area (cm^2), at flowering stage in rice genotypes

The leaf length (cm) and leaf width (cm) was recorded from first flag leaf, second and third leaf from the top leaf of the plant at flowering stage of the rice genotypes. The effect was observed by three randomly selected leaves of control and treatment at flowering stages. Under control condition leaf length (cm) at flowering was highest in rice genotype namely PHY-1(56.32 cm) and the minimum in rice genotype namely Govind (36.67 cm). Similarly, in heat stress treatment PHY-1(54.41 cm) showed the maximum and Govind (35.80 cm) attained minimum plant leaf length and rice genotype DRRH-108(1.53cm) attained highest leaf width in both control and heat treatment while Govind have minimum width (0.97cm).

Heat stress in rice plant causes reduction in leaf area (cm^2) which is the ultimate result of reduced leaf length and leaf breadth at flowering **(Ubaidullah *et al.*, 2006).** And **(Ahamed *et al.*, 2010)** reported that under high temperature stress the leaf length and width of flag leaf of wheat varieties reduced significantly. The leaf area of different genotype was calculated by multiplying length and width of leaf at flowering and under high temperature leaf area (cm^2) and it was decreased in 11 genotype IET 23356, IET 23392, IET 23347, IET 23949, IET 23951, DRRH-108, Govind, PHY-1, PHY-2, Tulasi and N-22 while very slight increase was recorded in rest of rice genotypes. Under control condition leaf area (cm^2) at flowering was highest in rice genotype namely DRRH-107 (50.12cm^2) and the minimum in rice genotype namely Govind (27.75 cm^2). Similarly, under heat stress treatment rice genotype namely DRRH-107(55.51cm^2) showed the maximum and rice genotype namely Govind (26.09cm^2) attained minimum plant leaf area (cm^2). The leaf length, leaf width and leaf area for treatment (T) and Genotypes (G) was statistically significant and T×G interaction was also significant.

Heat stress treatment reduced the viable leaf area and photosynthetic activity per unit leaf area of rice plant and at higher temperature leaf senescence enhances and causes reduction in green leaf area and leaf number during reproductive development. The leaf area also known for the photosynthetic area has great influences on the rate and amount of photosynthesis **(Wardlaw *et al.*, 1995).** The amount of photosynthate obtained from leaves is the principal source of grain-filling materials in rice. So, the varieties with larger leaf area in high temperature will be benefited for proper grain-filling (**Altenbach *et al.*, 2003**).

During post-anthesis period high temperature stress in wheat is a major cause for reducing yield due to the loss of viable leaf area and a decrease in the duration of green leaves, ultimately causing yield loss, similar to our present findings. They also found that increased duration of green leaves have positive correlation with grain yield under high temperature. Leaf area of wheat largely depends on the diversity of the genotype, plant growth stage and air temperature. **(Vijayalakshmi *et al.*, 2007)**

4.1.2 The effect of heat stress on leaf dry weight (mg) at flowering stage in rice genotypes

The leaf dry weight (mg) was recorded from first, second and third leaf from the top of the plant at flowering stage of the rice genotypes. The leaves dry weight was recorded after

Table 4.1: Effect of heat stress on leaf length (cm) and leaf width (cm) at flowering of different rice genotypes

Genotypes	Leaf length (cm)		Leaf width (cm)	
	Control	Treatment	Control	Treatment
IET 23339	39.97±0.07	39.90±0.51	1.06±0.012	1.07±0.029
IET 23354	37.22±0.86	38.29±0.42	1.18±0.010	1.23±0.046
IET 23356	39.21±0.46	38.44±0.42	1.31±0.040	1.18±0.020
IET 23392	39.13±0.29	39.17±0.36	1.24±0.026	1.08±0.034
IET 23947	39.12±0.26	40.77±0.56	1.25±0.043	1.16±0.043
IET 23949	39.94±0.54	38.19±0.09	1.11±0.026	1.12±0.014
IET 23951	38.83±0.36	41.56±0.17	1.16±0.025	1.20±0.016
IET 23957	38.32±0.91	37.75±0.36	1.05±0.015	1.07±0.026
IET 23976	40.00±0.61	40.19±0.51	1.14±0.043	1.07±0.024
IET 23979	45.37±0.06	45.15±0.17	1.12±0.047	1.15±0.011
IET 23996	45.89±0.42	46.83±0.43	1.06±0.027	1.04±0.021
IET 24075	40.65±0.74	40.70±0.37	1.21±0.046	1.27±0.016
IET 24082	40.51±0.63	39.40±0.24	1.18±0.041	1.22±0.032
DRRH-106	41.35±0.59	40.69±0.88	1.16±0.015	1.24±0.043
DRRH-107	43.37±1.19	48.51±0.77	1.54±0.034	1.53±0.036
DRRH-108	44.09±0.33	43.68±0.01	1.50±0.034	1.45±0.005
Govind	36.67±0.26	35.80±0.64	1.01±0.014	0.97±0.010
NDR-97	40.14±0.15	41.00±0.39	1.19±0.015	1.21±0.007
PA-6129	41.70±0.66	41.35±1.04	1.10±0.045	1.17±0.009
PHY-1	56.32±0.35	54.41±0.41	1.29±0.034	1.30±0.059
PHY-2	42.01±0.78	41.88±0.12	1.11±0.082	1.09±0.032
Sabagidhan	40.27±0.34	41.72±0.61	1.38±0.017	1.35±0.042
Tulasi	40.02±0.65	39.70±0.74	1.28±0.041	1.28±0.039
N-22	47.48±0.62	46.39±0.21	1.33±0.010	1.24±0.008
	S. Em±	**CD at 5 %**	**S. Em±**	**CD at 5 %**
Treatment (T)	0.106	0.298	0.006	0.018
Genotypes (G)	0.367	1.03	0.022	0.063
T×G	0.520	1.46	0.032	0.089

Table 2: Effect of heat stress on Leaf area (cm^2) at flowering of different rice genotypes

Genotypes	Leaf area (cm^2)	Leaf area (cm^2)
	Control	Treatment
IET 23339	31.84±0.70	32.16±0.83
IET 23354	33.08±0.54	35.24±1.89
IET 23356	38.54±1.49	33.90±0.98
IET 23392	36.53±0.95	31.71±1.10
IET 23947	36.75±1.13	35.54±1.17
IET 23949	33.13±0.79	32.11±0.70
IET 23951	33.80±0.76	37.51±0.32
IET 23957	30.23±0.32	30.31±1.26
IET 23976	34.14±1.25	32.30±1.01
IET 23979	38.01±1.56	38.86±0.34
IET 23996	36.41±0.84	36.47±0.93
IET 24075	36.97±1.55	38.85±0.62
IET 24082	35.79±1.32	36.06±0.88
DRRH-106	36.01±0.53	37.81±1.64
DRRH-107	50.12±0.65	55.51±1.82
DRRH-108	49.72±1.11	47.64±0.43
Govind	27.75±0.84	26.09±0.46
NDR-97	35.78±0.36	37.24±0.16
PA-6129	34.50±2.20	36.22±0.79
PHY-1	54.49±1.42	53.08±2.21
PHY-2	34.98±2.69	34.15±1.02
Sabagidhan	41.71±0.29	42.14±1.32
Tulasi	38.47±1.88	38.26±1.69
N-22	47.420±.37	43.26±0.58
	S. Em±	**CD at 5%**
Treatment (T)	0.232	0.651
Genotypes (G)	0.803	2.257
T×G	1.136	3.192

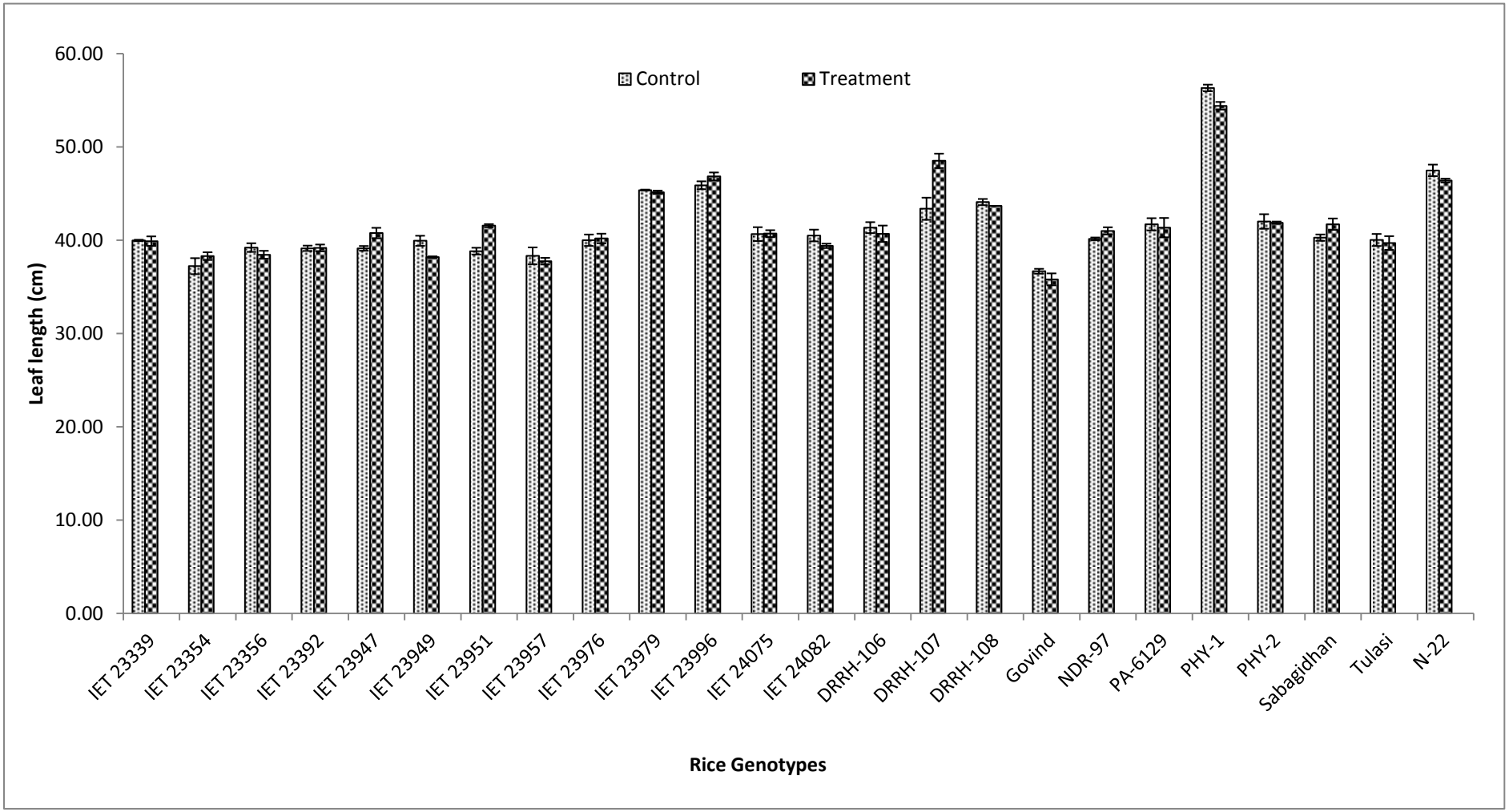


Fig.4. 1 (a): Effect of heat stress on leaf length (cm) at flowering stage of different rice genotypes

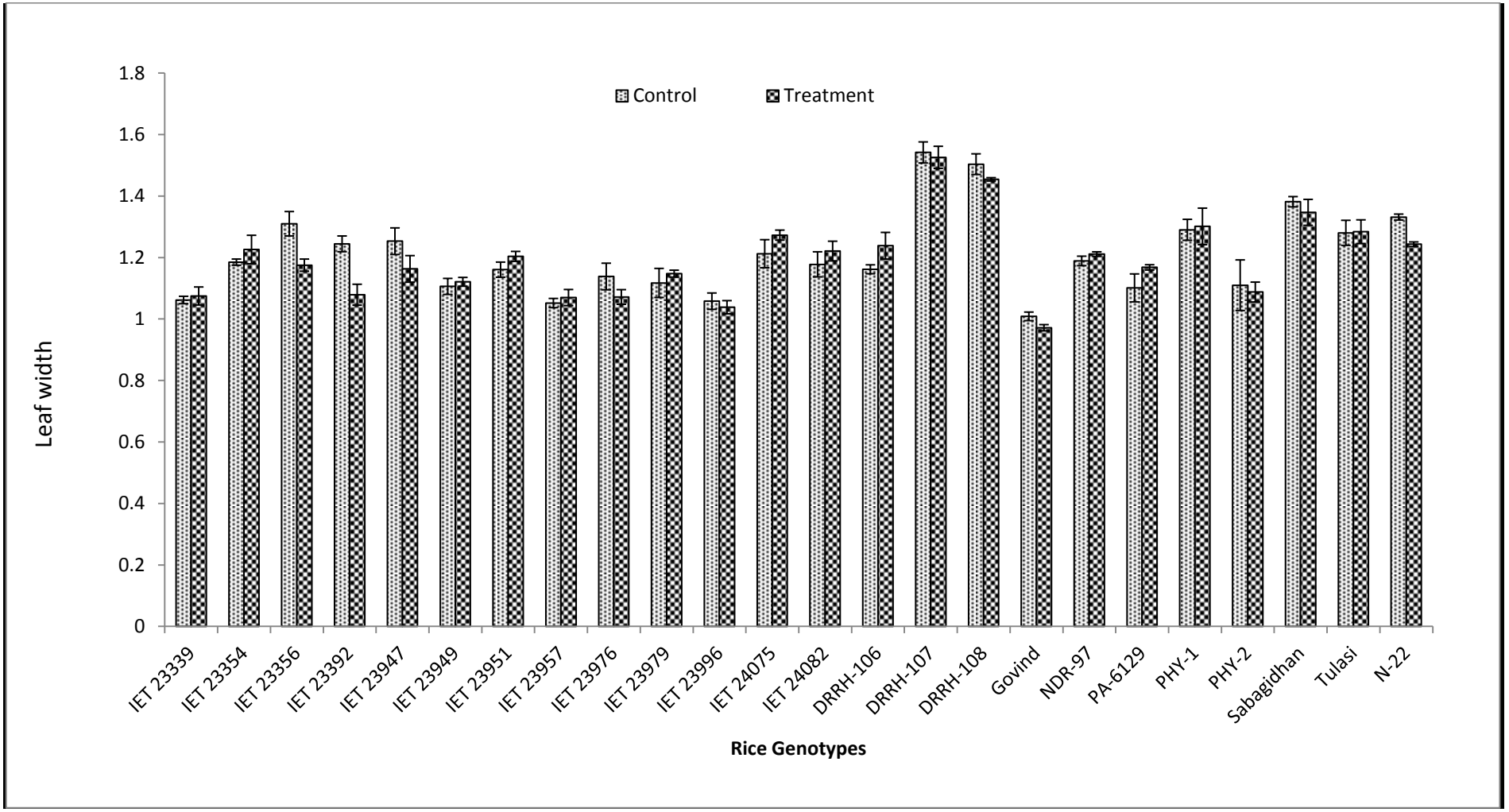


Fig. 1 (b): Effect of heat stress on leaf width (cm) at flowering of different rice genotypes

sun drying and oven drying. Under heat stress treatment, the leaf dry weight (mg) increased in 9 rice genotypes IET 23339, IET 23354, IET 23392, IET 23949, IET 23957, IET 23976, IET 23979, IET 23996 and N-22 while reduction in the leaf dry weight was observed in rest 15 rice genotypes. The maximum leaf dry weight (mg) was observed in rice genotype namely PHY-1 (276.87mg) and minimum in rice genotype namely Govind (158.89 mg) under heat treatment, but in control IET 23976 attained lowest (153.96 mg) leaf dry weight. The leaf dry weight for treatment (T) and Genotypes (G) was statistically significant and T×G interaction was also significant. **Fisher *et al.*, (1998)** reported that Genotypic difference in duration of green leaves and leaf area in response to decrease in leaf dry weight during heat stress and also supported by **Guttieri *et al.*, (2001) and** reported that dry matter accumulation decreased because of decrease in leaf number, leaf area index (LAI) and accelerated leaf senescence in rice plant and during the vegetative growth, high temperature stress can damage leaf gas exchange properties of plant.

4.1.3 The effect of heat stress on number of tillers per plant at flowering stage in rice genotypes

Under heat treatment the number of tillers per plant at flowering increased in 14 rice genotypes- IET 23339, IET 23354, IET 23949, IET 23957, IET 23979, IET 23996, IET 24075, IET 24082, DRRH-106, DRRH-108 ,Govind, NDR-97 ,PA-6129, PHY-2 and Sabagidhan while it decreased in rest of the genotypes. The maximum tillers per plant were observed in rice genotype namely PA-6129 (7.33) and it was also highest in control condition and minimum in rice genotype namely Tulasi (3.50) under heat treatment. IET 23947 have almost equal number of tiller (4.83) in control and heat treatment. It was significant for treatment (T), and also significant for genotypes (G) and T×G interactions.

Production of tillers is significantly sensitive to high temperature stress and tiller production in rice plant is an important agronomical trait **(Li *et al.*, 2003).**

Furthermore, tiller number is positively correlated with panicle dry weight per area where as heat stress causes in reduction of number of tillers, number of panicles and panicle length **(Poli *et al.*, 2013).**

Tiller number enhances with rising temperature in the range of 15–33ºC **(Chaudhary and Ghildyal., 1970)** and also found that temperatures above 33ºC was unfavorable for tillering in rice plant. The number of tillers per square meter during the early growth period

was generally larger under high temperature and the maximum tillering stage was earlier than under normal temperature conditions. At maturity, the number of tillers was found to be lower in high-temperature conditions than in ambient conditions inside a temperature gradient chamber **(Oh-e *et al.*, 2007).**The number of productive tillers (per unit ground area), spikelet sterility and grain weight are important components of yield that are affected by the cultivation system and by environmental factors among which high and low temperature is considered to be agronomically important **(Singla *et al*., 1997).**

4.1.4: the effects of heat stress on stem dry weight per plant at flowering stage and harvest stage in rice genotypes

The stem dry weight (g) per plant recorded by removing all leaves and panicle from the rice plant at flowering stage. Under heat treatment the stem dry weight (g) per plant were increased in 9 rice genotypes but decreased in IET 23947, IET 23949, IET 23951, IET 23957, IET 23976, IET 23996, DRRH-106, DRRH-107, DRRH-108, GOVIND, NDR-97, PHY-1, PHY-2, TULASI and N22 rice genotype. The maximum stem dry weight (g) per plant was observed in rice genotype namely PHY-1(20.93g) and the minimum stem dry weight per plant was found in rice genotype namely Govind (6.08g) under heat treatment. It was non-significant for treatment (T) and significant for genotypes (G) and T×G interaction.

Under heat treatment the stem dry weight (g) per plant at harvest was reduced in 13 rice genotypes and increased in other IET 23339, IET 23354, IET 23356, IET 23949, IET 23979, IET 24075, DRRH-106, DRRH-107, DRRH-108, GOVIND, and in NDR-97.The maximum stem dry weight during harvest was observed in rice genotype namely PHY-1(16.53g) and minimum was in rice genotype namely Govind (5.88g) under heat treatment. The stem dry weight per plant at harvest was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions.

The stem dry weight (g/m^2) was recorded by removing leaves and panicle from the plant of rice genotypes at the time of flowering stage. Under heat treatment the stem dry weight (g/m^2) decreased in 20 rice genotypes IET 23339, IET 23354, IET 23356 ,IET 23392, IET 23947, IET 23949, IET 23951, IET 23957, IET 23976, IET 23996, IET 24075, IET 24082, DRRH-106 ,DRRH-107 ,DRRH-108, NDR-97, PHY-1, PHY-2 , Tulasi, N22 while it increased in rest of the genotypes. The maximum stem dry weight (g/m^2) was

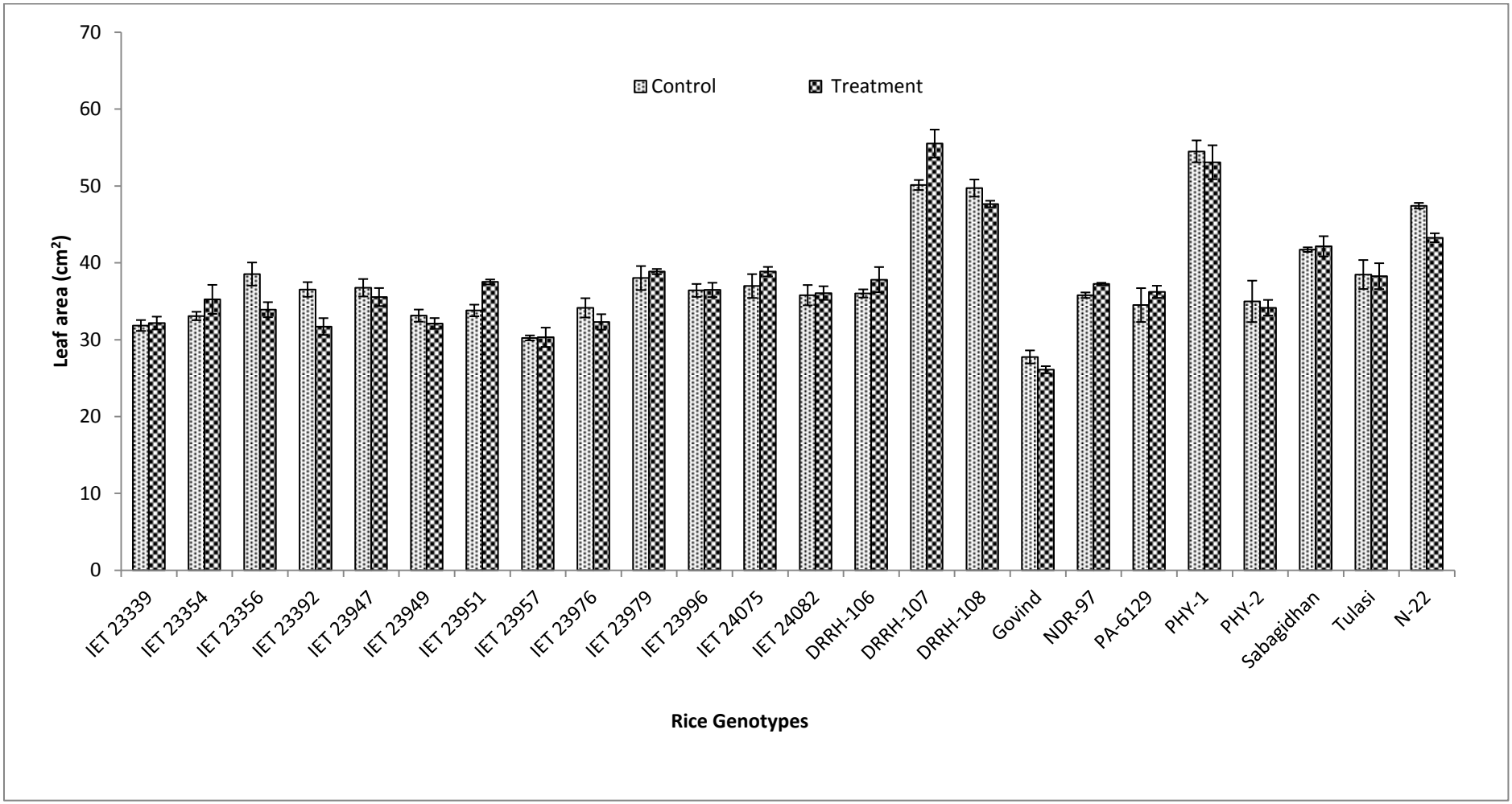


Fig. 2: Effect of heat stress on leaf area (cm^2) at flowering of different rice genotypes

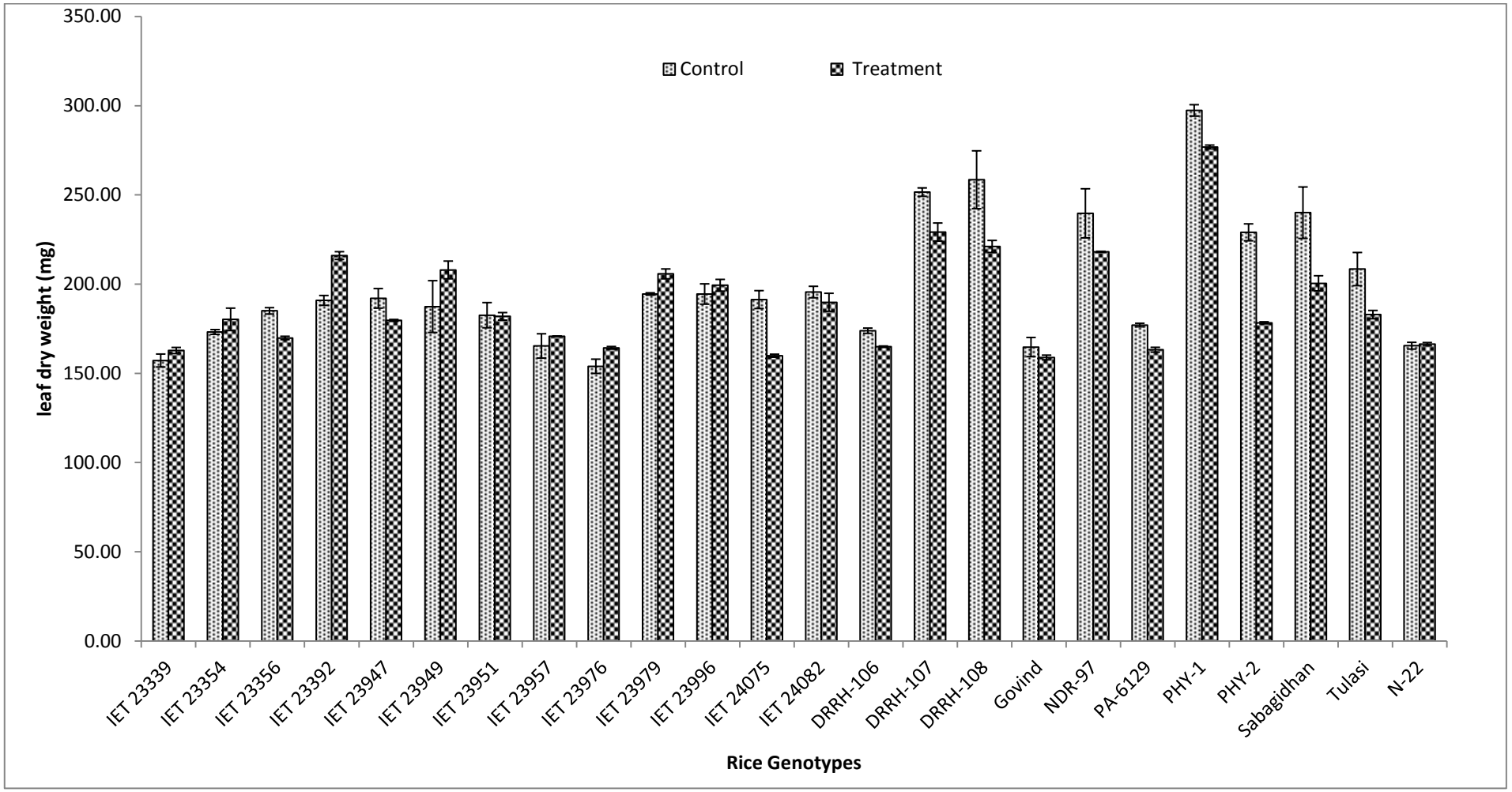


Fig. 3: Effect of heat stress on leaf dry weight (mg) at flowering of different rice genotypes

Table 3: Effect of heat stress on leaf dry weight (mg) at flowering of different rice genotypes

Genotypes	Leaf dry weight (mg)	Leaf dry weight (mg)
	Control	Treatment
IET 23339	157.19±3.62	162.81±1.71
IET 23354	173.19±1.33	180.26±6.28
IET 23356	185.03±1.79	169.83±0.95
IET 23392	190.88±2.75	216.00±2.19
IET 23947	192.03±5.48	179.68±0.53
IET 23949	187.42±14.52	207.96±4.97
IET 23951	182.60±7.06	181.94±2.12
IET 23957	165.37±6.81	170.80±0.13
IET 23976	153.96±3.99	164.29±0.75
IET 23979	194.50±0.64	205.75±2.76
IET 23996	194.47±5.70	199.36±3.29
IET 24075	191.34±5.02	159.87±0.86
IET 24082	195.57±3.22	189.81±5.05
DRRH-106	173.89±1.48	164.92±0.40
DRRH-107	251.58±2.35	229.19±5.07
DRRH-108	258.50±16.22	221.11±3.38
Govind	164.74±5.38	158.89±1.31
NDR-97	239.68±13.77	218.11±0.29
PA-6129	177.08±1.00	163.22±1.36
PHY-1	297.38±3.19	276.87±1.07
PHY-2	229.04±4.74	178.31±0.58
Sabagidhan	240.04±14.42	200.48±4.23
Tulasi	208.44±9.30	182.94±2.32
N-22	165.49±1.90	166.37±0.89
	S. Em±	**CD at 5%**
Treatment (T)	1.130	03.175
Genotypes (G)	3.917	10.999
T×G	5.539	15.555

Table 4: Effect of heat stress on number of tillers per plant at flowering of different rice genotypes

Genotypes	Number of tillers per plant at flowering	
	Control	Treatment
IET 23339	4.33±0.17	5.33±0.16
IET 23354	3.83±0.17	4.66±0.16
IET 23356	4.17±0.17	3.66±0.16
IET 23392	4.83±0.17	4.66±0.44
IET 23947	4.83±0.44	4.83±0.16
IET 23949	4.83±0.17	5.83±0.16
IET 23951	5.17±0.17	5.16±0.44
IET 23957	6.00±0.29	5.16±0.33
IET 23976	5.17±0.44	4.66±0.44
IET 23979	5.17±0.60	6.83±0.33
IET 23996	5.50±0.29	5.66±0.66
IET 24075	4.17±0.17	5.33±0.60
IET 24082	4.50±0.29	4.83±0.60
DRRH-106	4.33±0.44	4.66±0.16
DRRH-107	6.00±0.76	5.66±0.44
DRRH-108	4.17±0.44	4.50±0.00
Govind	5.50±0.58	6.50±0.28
NDR-97	5.17±0.33	6.33±0.33
PA-6129	6.50±0.58	7.33±0.60
PHY-1	4.67±0.17	4.50±0.50
PHY-2	5.00±0.29	5.16±0.33
Sabagidhan	3.83±0.33	4.00±0.28
Tulasi	4.67±0.44	3.50±0.00
N-22	5.33±0.17	5.00±0.28
	SEM±	**CD at 5%**
Treatment (T)	0.076	0.214
Genotypes (G)	0.265	0.744
T×G	0.375	1.053

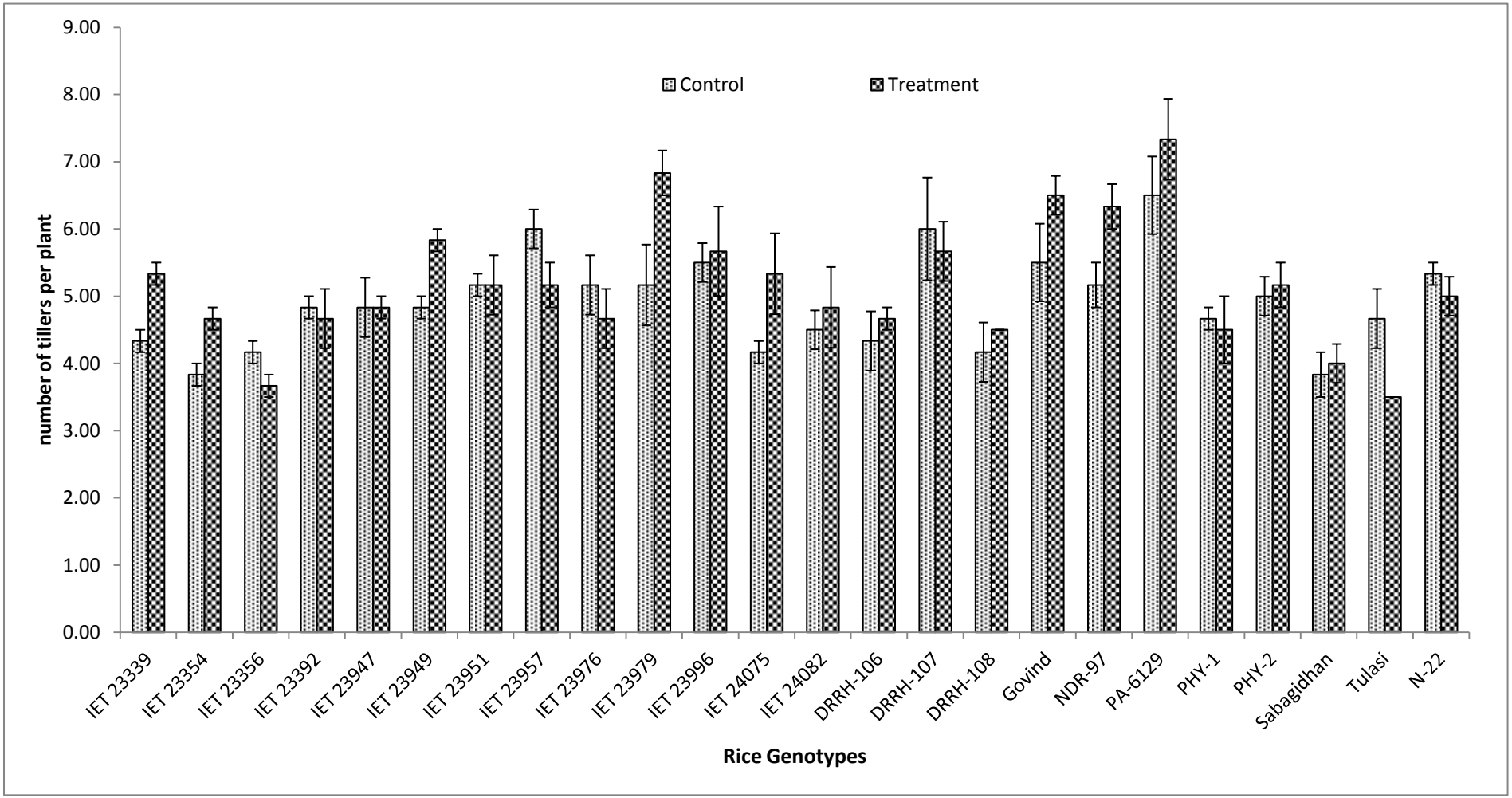


Fig. 4: Effect of heat stress on number of tillers per plant at flowering of different rice genotypes

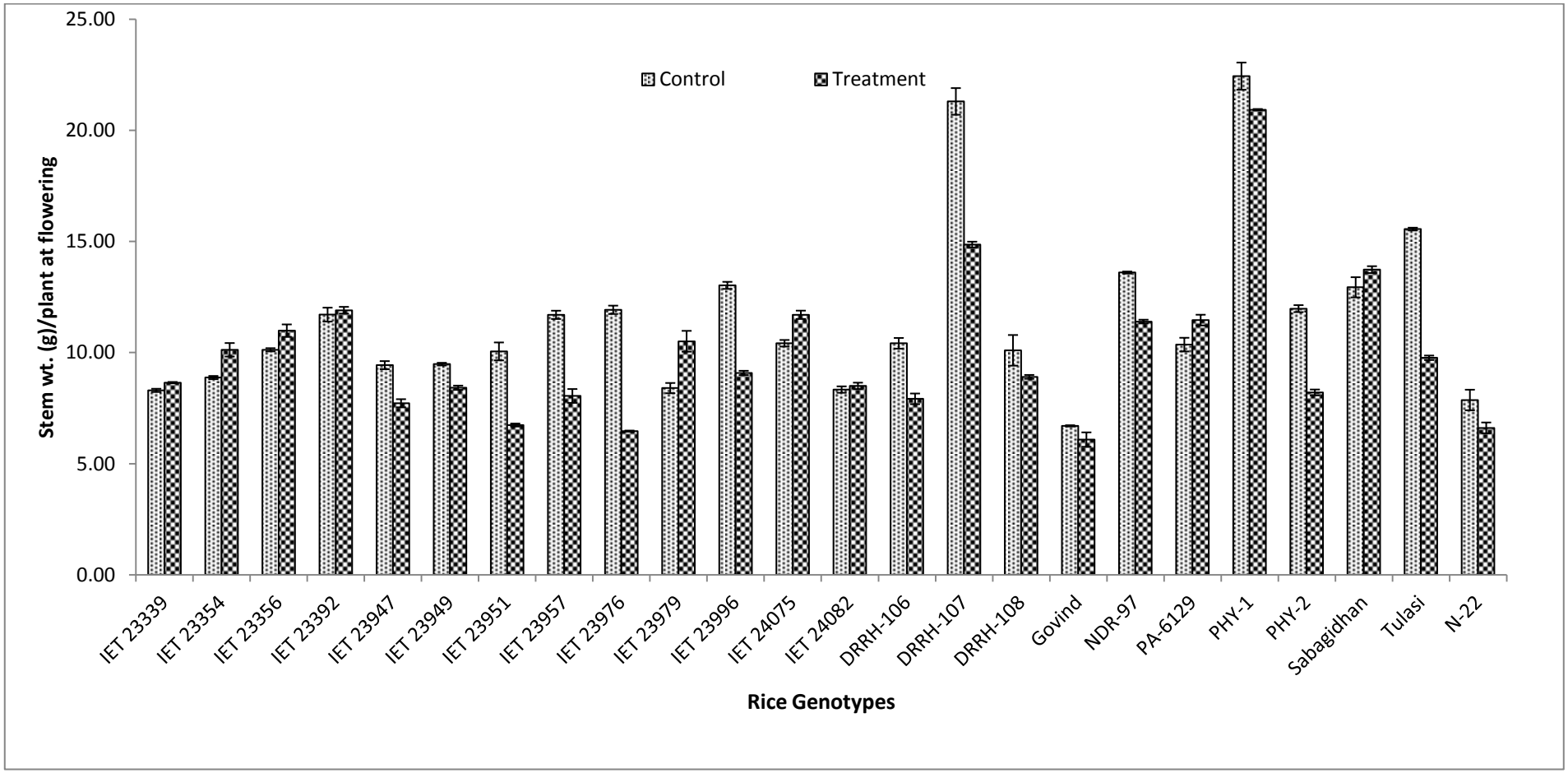


Fig. 5 (a): Effect of heat stress on stem dry weight per plant at flowering of different rice genotypes

Table 5(a): Effect of heat stress on stem wt. (g)/plant at flowering and stem wt. (g)/plant at harvest of different rice genotypes

Genotypes	Stem wt. (g)/plant at flowering		Stem wt. (g)/plant at harvest	
	Control	Treatment	Control	Treatment
IET 23339	8.30±0.07	8.65±0.03	6.38±0.22	7.08±0.24
IET 23354	8.88±0.07	10.13±0.30	7.67±0.58	8.63±0.22
IET 23356	10.13±0.07	10.99±0.28	7.00±0.19	9.33±0.00
IET 23392	11.71±0.31	11.91±0.15	10.42±0.24	9.63±0.79
IET 23947	9.43±0.18	7.72±0.18	10.54±0.26	7.50±0.10
IET 23949	9.48±0.06	8.42±0.10	6.67±0.48	6.75±0.14
IET 23951	10.05±0.40	6.74±0.07	6.67±0.00	6.33±0.00
IET 23957	11.70±0.19	8.05±0.31	11.00±0.53	7.79±0.79
IET 23976	11.93±0.19	6.46±0.03	9.50±0.29	6.24±0.10
IET 23979	8.40±0.23	10.51±0.47	8.50±0.29	10.29±0.31
IET 23996	13.03±0.16	9.08±0.10	12.00±0.00	7.92±0.24
IET 24075	10.42±0.15	11.70±0.19	7.50±0.00	9.21±0.31
IET 24082	8.34±0.14	8.50±0.14	7.88±0.22	7.50±0.00
DRRH-106	10.42±0.24	7.92±0.24	6.90±0.70	7.58±0.05
DRRH-107	21.30±0.60	14.86±0.13	11.58±0.19	12.46±0.31
DRRH-108	10.10±0.69	8.91±0.09	8.33±0.19	8.25±0.43
Govind	6.70±0.03	6.08±0.32	5.25±0.00	5.88±0.22
NDR-97	13.60±0.05	11.40±0.08	7.79±0.79	8.75±0.34
PA-6129	10.36±0.31	11.46±0.24	9.17±0.00	10.50±0.00
PHY-1	22.44±0.61	20.93±0.03	22.88±0.22	16.53±1.08
PHY-2	11.98±0.16	8.20±0.13	8.25±0.00	6.21±0.12
Sabagidhan	12.94±0.45	13.73±0.15	11.25±0.00	7.33±0.38
Tulasi	15.56±0.06	9.77±0.10	7.67±0.19	5.54±0.17
N-22	**7.87±0.46**	**6.61±0.24**	6.25±0.24	5.25±0.00
	SEM±	**CD at 5%**	**SEM±**	**CD at 5%**
Treatment(T)	0.053	0.150	0.072	0.204
Genotypes(G)	0.185	0.521	0.252	0.709
T×G	0.262	0.737	0.357	1.003

Table 5(b): Effect of heat stress on stem wt. (g)/ m^2 at flowering and stem wt. (g)/plant at harvest of different rice genotypes

Genotypes	Stem wt. (g)/m^2 at flowering		Stem wt. (g)/ m^2 at harvest	
	Control	Treatment	Control	Treatment
IET 23339	446.40±20.09	427.05±36.63	325.69±26.69	361.81±3.87
IET 23354	467.08±35.87	445.57±68.01	353.47±38.50	413.89±10.91
IET 23356	533.57±18.74	421.61±58.14	370.14±12.75	358.33±67.87
IET 23392	575.68±6.38	486.27±33.55	477.08±25.88	431.94±28.27
IET 23947	487.48±49.91	442.87±57.85	438.19±51.12	389.58±24.56
IET 23949	514.90±31.87	459.64±15.97	329.86±27.12	372.22±31.65
IET 23951	501.25±9.38	367.93±28.86	357.64±19.33	322.22±7.73
IET 23957	591.49±14.22	394.65±10.45	516.67±29.27	379.86±22.19
IET 23976	505.50±45.75	319.63±38.76	436.11±30.93	303.25±19.13
IET 23979	484.28±72.34	572.01±47.11	405.56±37.37	535.42±14.18
IET 23996	556.18±48.25	495.97±57.08	533.79±35.36	482.36±79.75
IET 24075	459.94±30.98	473.61±7.62	358.33±20.97	384.72±41.18
IET 24082	429.17±42.54	427.43±5.93	382.64±35.32	366.67±8.33
DRRH-106	443.75±41.37	400.69±14.92	331.52±16.35	361.70±14.55
DRRH-107	1009.47±35.87	727.76±35.98	648.61±72.59	550.69±41.50
DRRH-108	547.20±49.21	474.11±25.42	427.22±35.75	402.08±13.66
Govind	353.32±9.47	321.78±63.66	309.72±24.69	306.25±22.53
NDR-97	658.66±11.15	535.76±45.46	362.50±16.97	387.50±26.02
PA-6129	609.27±46.44	656.51±21.80	550.69±48.95	559.03±39.35
PHY-1	1063.60±32.58	1014.37±13.40	1111.81±16.68	893.61±33.67
PHY-2	515.93±44.71	422.40±27.17	400.69±5.93	318.06±13.19
Sabagidhan	604.36±59.11	679.66±28.42	488.89±40.47	373.61±10.23
Tulasi	842.12±34.50	512.14±22.55	433.33±36.40	277.08±8.42
N-22	437.62±32.41	370.94±36.63	325.69±9.34	277.08±10.69
	SEM±	**CD at 5%**	**SEM±**	**CD at 5%**
Treatment(T)	07.710	021.651	10.231	028.729
Genotypes(G)	26.710	075.004	35.442	099.521
T×G	37.774	106.071	50.122	140.744

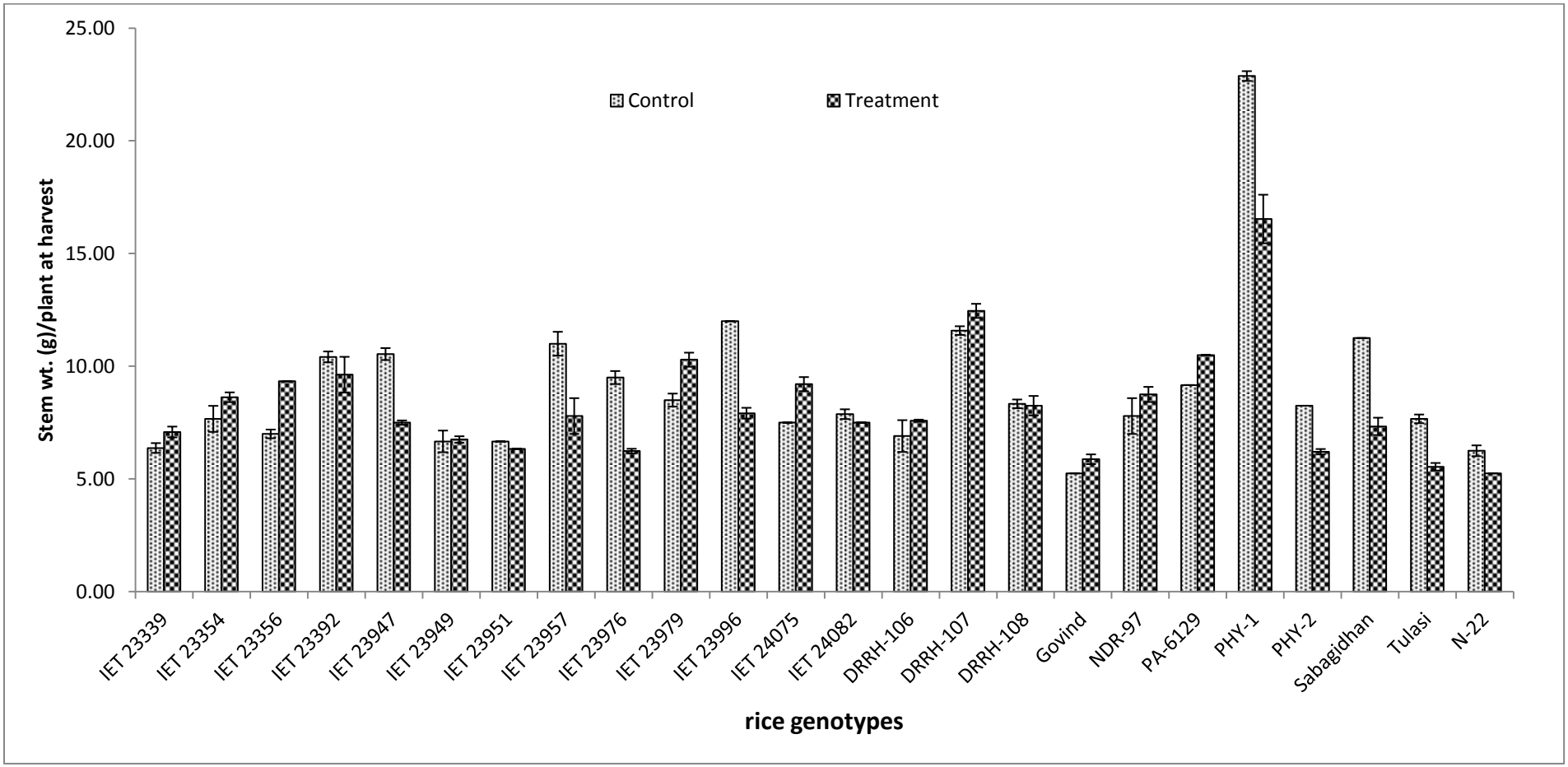


Fig. 5 (b): Effect of heat stress on stem dry weight (g) per plant at harvest of different rice genotypes

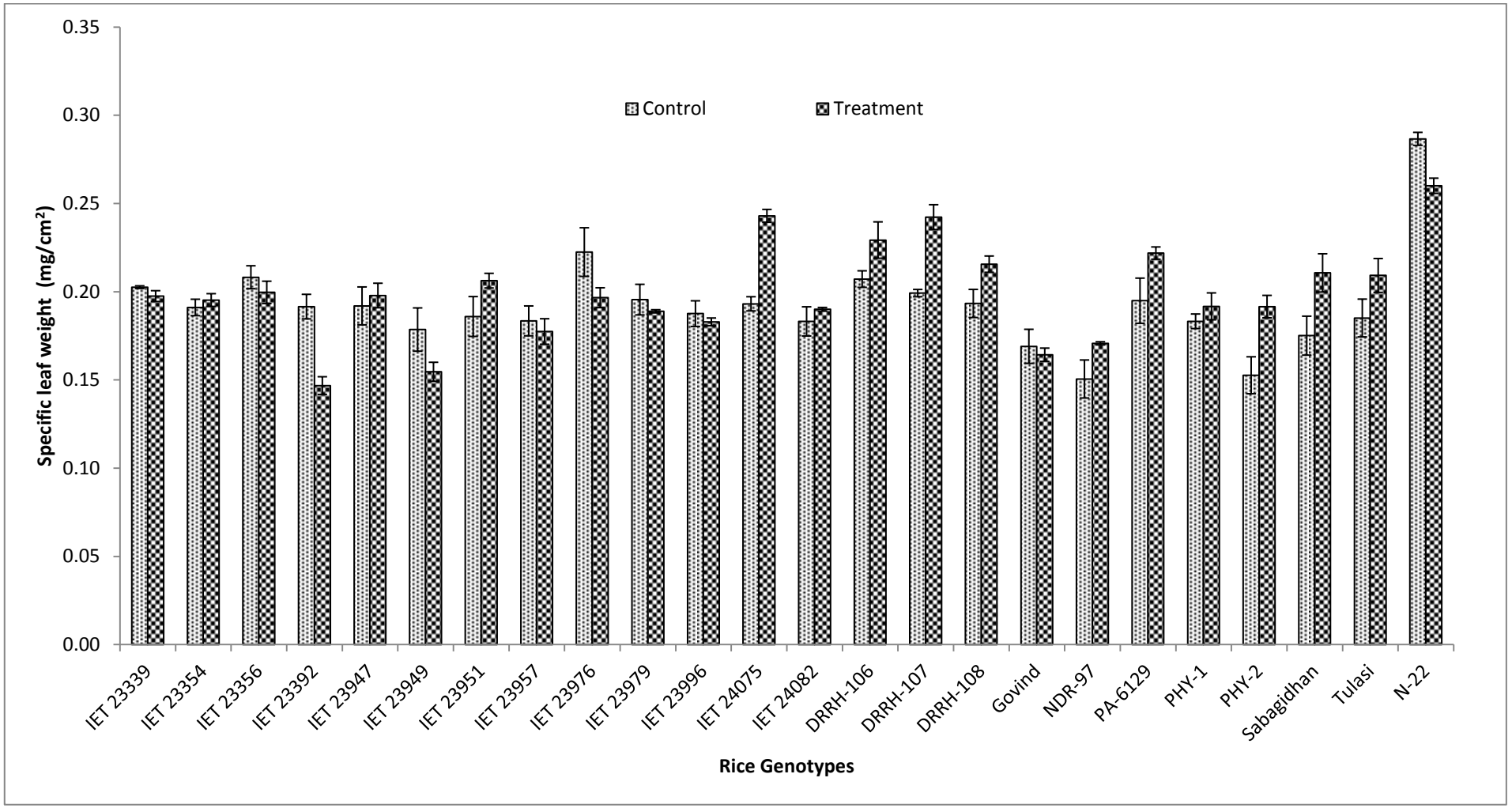


Fig. 6 (a): Effect of heat stress on specific leaf weight (mg/cm^2) at flowering of different rice genotypes

observed in rice genotype namely PHY-1(1014.37g) and the minimum stem weight (g/m^2) in rice genotype namely IET 23976 (319.63g) under heat treatment. It was statistically non significant for treatment (T) but significant for genotypes (G) and T×G interaction.

Under heat treatment the stem dry weight (g/m^2) at harvest stage was decreased in 16 rice genotypes IET 23356 ,IET 23392, IET 23947, IET 23951, IET 23957, IET 23976, IET 23996, , IET 24082, DRRH-106 ,DRRH-107 ,DRRH-108 ,GOVIND, PHY-1, PHY-2 ,SABAGIDHAN, TULASI, N22 while it increased in rest of the genotypes. The maximum stem dry weight (g/m^2) at harvest was observed in PHY-1 ($1111.81g/m^2$) in control and ($893.61g/m^2$) in treatment and the minimum stem weight (g/m^2) in rice genotype namely Tulasi ($277.08g/m^2$) was around same. It was statistically non- significant for treatment (T), whereas significant for genotypes (G) and T×G interaction. During grain-filling stage, high temperature stress for longer duration can accelerated the grain filling speed, and it led to the period of grain filling shorten, which causes reduced in single-grain weight and much more nutrients accumulated at culm of plant. Therefore, episode of high temperature stress during the rice growing stage would resulted in the increase in straw, especially at flowering stage. It meant that more straw would return to the field, which would have great effects on nutrients and carbon cycling **(Guo-hua *et al.*, 2013).**

4.1.5 The effect of heat stress on specific leaf weight and specific leaf area at flowering stage in rice genotype

Specific leaf area (SLA) is the total area of a leaf area divided by its dry leaf mass. Under heat treatment the specific leaf area (cm^2/mg) increased in 10 rice genotypes IET 23339, IET 23356, IET 23392, IET 23949, IET 23957, IET 23976, IET 23979, IET 23996, Govind and N22 while it decreased in rest of the genotypes. The maximum specific leaf area was observed in rice genotype namely IET 23392 (6.83 cm^2/mg) and minimum was in rice genotype namely N22 (3.85 cm^2/mg) under heat treatment. It was statistically non significant for treatment (T) but significant for genotypes (G) and T×G interaction.

Under heat treatment the specific leaf weight (mg/cm^2) was increased in 14 rice genotypes IET 23354, IET 23947, IET 23951, IET 23957, IET 24075, IET 24082, DRRH-106, DRRH-107, DRRH-108, NDR-97, PA-6129, PHY-1, PHY-2, Sabagidhan and Tulasi, while it decreased in rest of the genotypes. The maximum specific leaf weight was found in rice genotype namely N22 (0.26 mg/cm^2) and minimum in rice genotype namely IET

23392, IET 23349 (0.15 mg/cm^2) under heat treatment. The specific leaf weight was statistically non significant for treatment (T) but significant for genotypes (G) and T×G interactions.

4.1.6 The effect of heat stress on panicle dry weight (g) at flowering stage, one week after flowering and at maturity in rice genotypes

Under heat treatment the panicle dry weight (g) at flowering decreased for 15 rice genotypes IET 23339, IET 23356, IET 23392, IET 23976, IET 23996, IET 24075, IET 24082, DRRH-107, DRRH-108, NDR-97, PA-6129, PHY-1, Sabagidhan, Tulasi, N22.The maximum panicle dry weight was observed in rice genotypes namely IET 23354, (1.17g) and minimum in rice genotype namely IET 23392 (0.62g) under heat treatment. It was statistically not significant for genotypes (G), but significant for treatment (T) and T×G interaction.

Under heat treatment the panicle dry weight (g) after one week of flowering decreased in almost all 21 rice genotypes but slight increase was recorded in 3 rice genotype IET 23354, IET 23949, PHY-1. The maximum panicle dry weight (g) was observed in rice genotype namely IET 23354 (1.57g) and minimum panicle weight was found in rice genotype namely IET 23996 (0.97g) under heat treatment. It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interaction. The rate of increase in dry matter accumulation in the panicle after heading stage was small in the high temperature plots because of increase in number of sterile spikelet and the assimilation products accumulated in the leaf and culms (**Kim *et al*., 1996).**

Under heat treatment the panicle dry weight (g) at maturity was decreased in all the rice genotypes. The maximum panicle weight was observed in rice genotype namely DRRH-107 (4.44 g) in control and (3.33 g) in heat treatment and minimum in rice genotype namely Govind (1.80 g) under heat treatment. It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interaction. The optimal temperature for ripening of rice grain is lower than that for maximum tillering and at anthesis stages. The ambient temperature shifts to relatively lower temperatures as rice

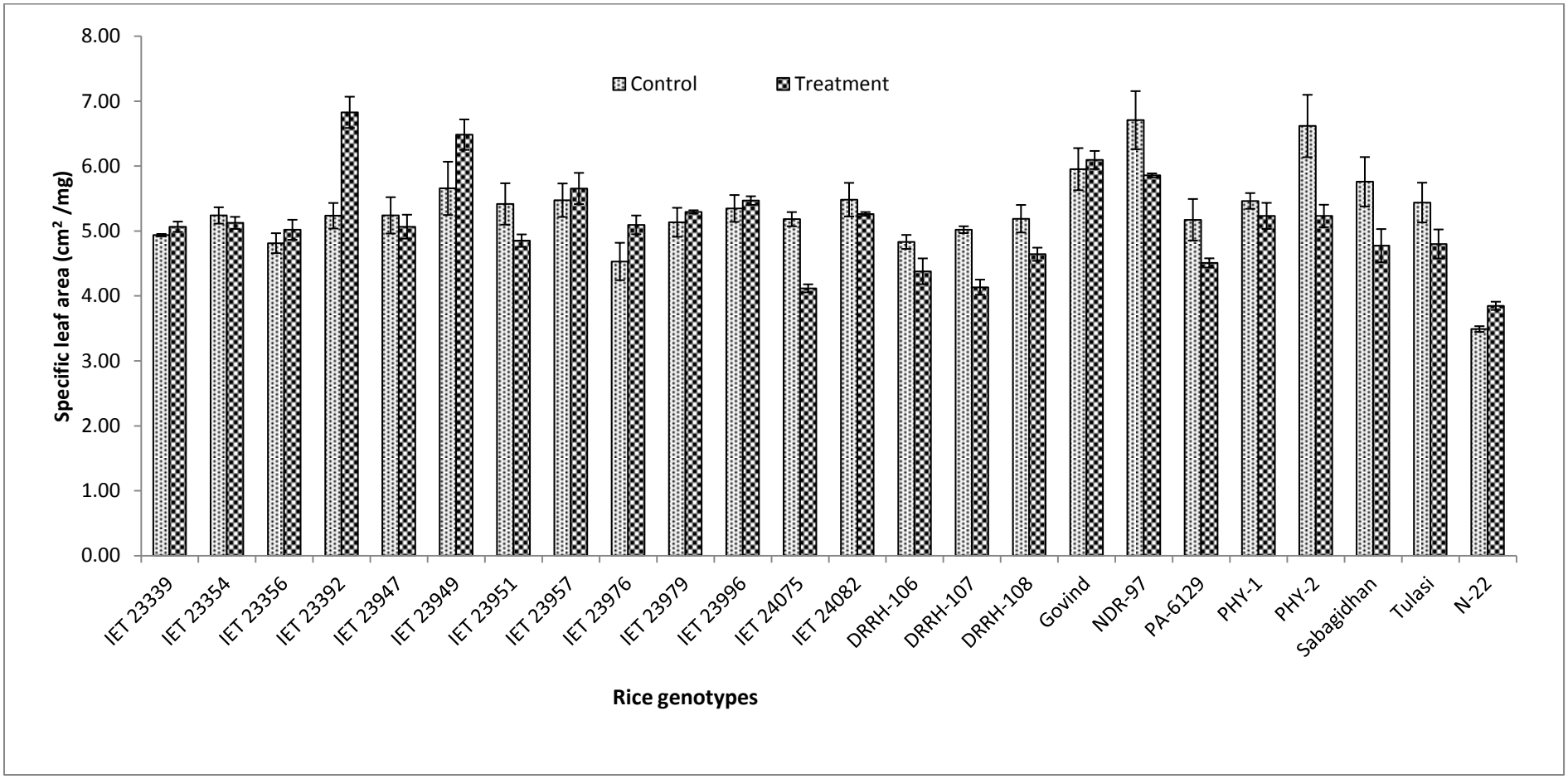


Fig. 6 (b): Effect of heat stress on specific leaf area (cm^2/mg) at flowering of different rice genotypes

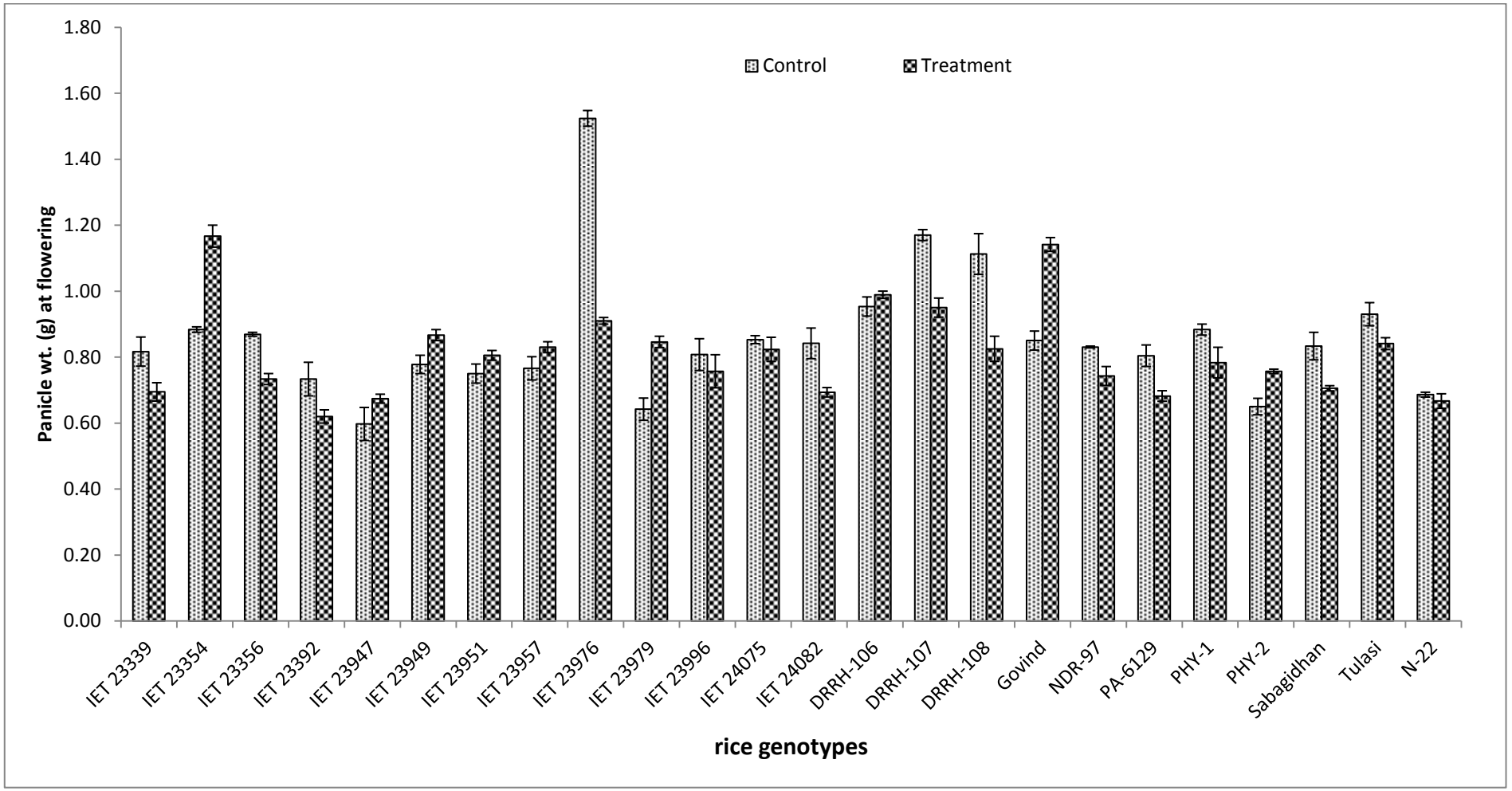


Fig. 7 (a): Effect of heat stress on panicle dry weight at flowering of different rice genotypes

Table 6: Effect of heat stress on specific leaf area and specific leaf weight at flowering of different rice genotypes

Genotypes	Specific leaf weight (mg/cm^2)		Specific leaf area (cm^2/mg)	
	Control	Treatment	Control	Treatment
IET 23339	0.20±0.001	0.20±0.003	4.94±0.02	5.07±0.080
IET 23354	0.19±0.005	0.20±0.004	5.24±0.13	5.12±0.094
IET 23356	0.21±0.006	0.20±0.006	4.81±0.15	5.02±0.154
IET 23392	0.19±0.007	0.15±0.005	5.23±0.20	6.83±0.241
IET 23947	0.19±0.011	0.20±0.007	5.24±0.28	5.07±0.184
IET 23949	0.18±0.012	0.15±0.005	5.66±0.41	6.48±0.235
IET 23951	0.19±0.011	0.21±0.004	5.42±0.32	4.85±0.096
IET 23957	0.18±0.008	0.18±0.007	5.47±0.26	5.66±0.241
IET 23976	0.22±0.014	0.20±0.006	4.53±0.29	5.09±0.145
IET 23979	0.20±0.009	0.19±0.001	5.13±0.22	5.29±0.025
IET 23996	0.19±0.007	0.18±0.002	5.35±0.21	5.47±0.066
IET 24075	0.19±0.004	0.24±0.004	5.18±0.11	4.12±0.062
IET 24082	0.18±0.008	0.19±0.001	5.48±0.26	5.26±0.029
DRRH-106	0.21±0.005	0.23±0.010	4.83±0.11	4.38±0.199
DRRH-107	0.20±0.002	0.24±0.007	5.02±0.05	4.13±0.117
DRRH-108	0.19±0.008	0.22±0.005	5.19±0.21	4.64±0.102
Govind	0.17±0.010	0.16±0.004	5.95±0.32	6.09±0.140
NDR-97	0.15±0.011	0.17±0.001	6.71±0.45	5.86±0.030
PA-6129	0.19±0.013	0.22±±0.003	5.17±0.32	4.51±0.071
PHY-1	0.18±0.004	0.19±0.008	5.46±0.12	5.23±0.201
PHY-2	0.15±0.010	0.19±0.006	6.62±0.48	5.23±0.173
Sabagidhan	0.18±0.011	0.21±0.011	5.76±0.38	4.77±0.257
Tulasi	0.19±0.011	0.21±0.010	5.44±0.31	4.80±0.224
N-22	0.29±0.004	0.26±0.004	3.49±0.04	3.85± 0.063
	SEM±	CD at 5 %	SEM±	CD at 5 %
Treatment(T)	0.001	0.004	0.043	0.122
Genotypes(G)	0.005	0.015	0.151	0.424
T×G	0.007	0.021	0.213	0.599

Table 7: Effect of heat stress on panicle dry wt. at flowering and one week after flowering of different rice genotypes

Genotypes	Panicle wt. (g) at flowering		Pan. Wt. (g) One week after fl.	
	Control	Treatment	Control	Treatment
IET 23339	0.82±0.044	0.69±0.028	1.58±0.08	1.15±0.05
IET 23354	0.88±0.008	1.17±0.033	1.39±0.11	1.57±0.07
IET 23356	0.87±0.006	0.73±0.017	1.16±0.02	1.08±0.08
IET 23392	0.73±0.051	0.62±0.020	1.34±0.13	1.07±0.07
IET 23947	0.60±0.050	0.67±0.013	1.51±0.06	1.15±0.08
IET 23949	0.78±0.028	0.87±0.017	1.00±0.00	1.33±0.07
IET 23951	0.75±0.029	0.81±0.015	1.20±0.03	1.15±0.08
IET 23957	0.77±0.035	0.83±0.017	1.39±0.11	1.00±0.00
IET 23976	1.52±0.024	0.91±0.010	1.91±0.05	1.30±0.05
IET 23979	0.64±0.034	0.85±0.017	1.50±0.05	1.07±0.07
IET 23996	0.81±0.048	0.76±0.050	1.14±0.03	0.97±0.03
IET 24075	0.85±0.012	0.82±0.037	1.22±0.03	1.21±0.00
IET 24082	0.84±0.046	0.69±0.014	1.37±0.07	1.21±0.06
DRRH-106	0.95±0.029	0.99±0.011	1.78±0.05	1.53±0.03
DRRH-107	1.17±0.017	0.95±0.029	1.70±0.12	1.38±0.02
DRRH-108	1.11±0.062	0.83±0.038	1.97±0.13	1.17±0.04
Govind	0.85±0.029	1.14±0.021	1.53±0.06	1.38±0.10
NDR-97	0.83±0.003	0.74±0.029	1.27±0.07	1.12±0.01
PA-6129	0.80±0.033	0.68±0.016	1.51±0.06	1.17±0.07
PHY-1	0.88±0.017	0.78±0.046	1.25±0.06	1.20±0.03
PHY-2	0.65±0.025	0.76±0.007	0.97±0.03	1.24±0.04
Sabagidhan	0.83±0.042	0.71±0.008	1.62±0.08	1.14±0.01
Tulasi	0.93±0.035	0.84±0.018	1.50±0.06	1.23±0.05
N-22	**0.69±0.007**	**0.67±0.022**	1.28±0.06	1.23±0.02
	SEM±	**CD at 5 %**	**SEM±**	**CD at 5%**
Treatment(T)	0.006	0.017	0.012	0.036
Genotypes(G)	0.021	0.059	0.044	0.126
T×G	0.029	0.083	0.063	0.178

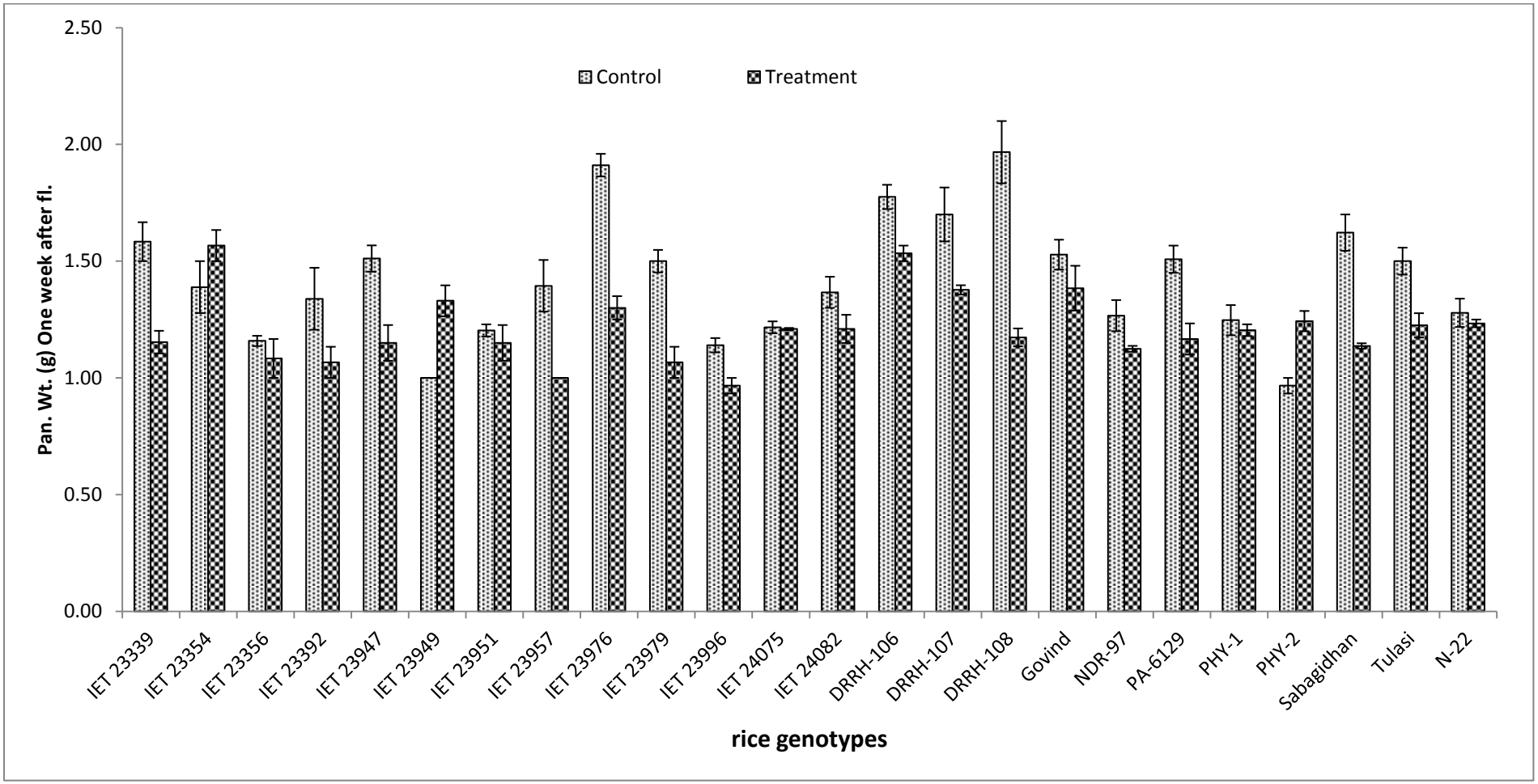


Fig. 7 (b): Effect of heat stress on panicle dry weight one week after flowering of different rice genotypes

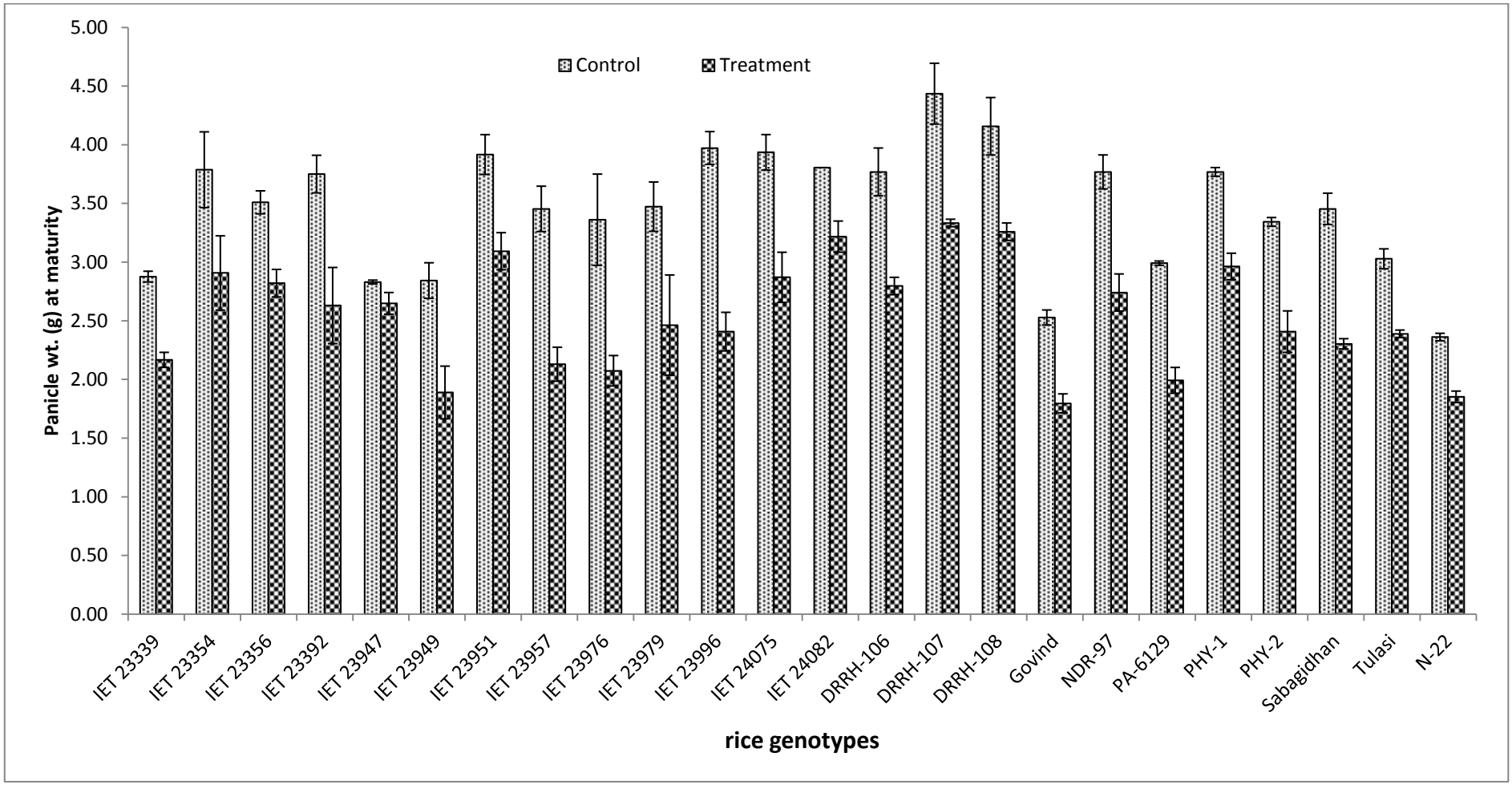


Fig. 8: Effect of heat stress on panicle dry weight (g) at maturity of different rice genotypes

plant grows but the panicle weight is known to decrease under high temperature **(Newman *et al*., 2001).**

4.1.7 The effect of heat stress on TDM (leaf+stem) g/m^2 at flowering in rice genotypes

Under heat treatment the total dry matter (leaf+stem) at flowering increased in two rice genotypes namely IET23979 and PA-6129 and decreased in rest of genotype. The maximum TDM (leaf+stem) was recorded in rice genotype namely PHY-1(1232.59g/m^2) and minimum was in rice genotype namely IET 23976 (415.54g/m^2) under heat treatment. It was non-significant for genotypes (G), but significant for treatment (T) and T×G interactions. The dry matter allocation in leaf blade, leaf sheath, culm and panicle were influenced greatly by high temperature stress. The weight increase in culm plus leaf sheath meant the enhanced partitioning in straw carbon. At flowering stage, dry weight of panicle decreased induced by pollen sterility, which lead to the nutrient transport impeded at culm and resulted in the dry matter increase in culm plus leaf sheath **(Guo-hua *et al*., 2013).**

4.1.8 Effect of heat stress on 1000-grain weight (g) at harvest in rice genotypes

Under heat treatment the 1000-grain weight (g) was decreased in all the rice genotypes. The maximum 1000-grain weight was found in rice genotype namely IET 23354 (28.19 g) under heat treatment and the minimum was in rice genotype namely DRRH-108 (17.64 g). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interaction.

Occurrence of high temperature stress at grain filling stage showed serious influence on 1000-grain weight then at flowering stage **(Guo-hua *et al*., 2013).** The grains ripened under day high temperature and night high temperature showed reduction of the grain maturity weight **.**High temperature during the early grain filling stage have a severe effect on grain development and final grain weights because heat stress affects endosperm cell division and starch biosynthesis and can reduce subsequent dry matter accumulation within the kernels **(Cairns *et al*., 2012)**.

It was shown that high night temperature decreased yield (90%) by affecting spikelet sterility (61%), and grain length (2%), width (2%), and weight **(Mohammed *et al*., 2010).**

4.1.9 Effect of heat stress on filled grains and unfilled grains per panicle at harvest and spikelet fertility (%) in rice genotypes

Under heat treatment the number of filled grains per panicle at harvest was decreased for all the rice genotypes. The maximum number of filled grains was found in rice genotype namely DRRH-108 (177.33) under heat treatment and minimum was in rice genotype namely IET 23979(44.00). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interaction. Under heat treatment the number of unfilled grains per panicle at harvest increased in all the rice genotypes.

The maximum number of unfilled grains was found in rice genotype namely IET 23949 (90.67) under heat treatment and minimum was in rice genotype namely N 22 (16.00). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interaction.

Temperatures higher than the optimum induced floret sterility and thus decreased rice yield **(Nakagawa *et al*., 2003).** In greenhouse experiments with both *indica* and *japonica* genotypes **(Jagadish *et al*., 2007).** It was found that less than 1 hour of exposure to temperatures above 33·7 °C was sufficient to induce sterility. **Weerakoon *et al*., 2008,** reported that grain sterility increased with increased humidity under high temperature above the critical value that induces spikelet sterility in rice.The temperature inside the spikelet decreases with a reduction in RH, possibly due to the enhancement of transpiration at low RH **(Weerakoon *et al*., 2008).**

This reduction in temperature inside the spikelet increases the viability of pollen grains. Viable pollen grains absorb moisture and swell at moderate to high RH levels and create the required pressure for the rupture of the septum, which helps in the deposition of pollen on stigma and thus produces a fertilized spikelet **(Weerakoon *et al*., 2008).** A key mechanism of high-temperature induced floret sterility in rice is the decreased ability of the pollen grains to swell, resulting in poor thecae dehiscence **(Matsui *et al*., 2000).** This swelling of pollen grains in the locules is the driving force for anther dehiscence.

(Matsui *et al*., 1999a; Endo *et al*., 2009) found that although high-temperature-treated pollen showed a normal round shape, some of the tapetum functions such as pollen

Table 8: Effect of heat stress on panicle wt. (g) at maturity of different rice genotypes

Genotypes	Panicle wt. (g) at maturity	
	Control	Treatment
IET 23339	2.88±0.05	2.17±0.06
IET 23354	3.79±0.32	2.91±0.32
IET 23356	3.51±0.10	2.82±0.12
IET 23392	3.75±0.16	2.63±0.32
IET 23947	2.83±0.02	2.65±0.09
IET 23949	2.84±0.15	1.89±0.22
IET 23951	3.92±0.17	3.09±0.16
IET 23957	3.45±0.19	2.13±0.14
IET 23976	3.36±0.39	2.07±0.13
IET 23979	3.47±0.21	2.46±0.43
IET 23996	3.97±0.14	2.41±0.16
IET 24075	3.94±0.15	2.87±0.21
IET 24082	3.81±0.00	3.22±0.13
DRRH-106	3.77±0.20	2.80±0.07
DRRH-107	4.44±0.26	3.33±0.03
DRRH-108	4.16±0.24	3.26±0.07
Govind	2.53±0.06	1.80±0.08
NDR-97	3.77±0.14	2.74±0.16
PA-6129	2.99±0.02	1.99±0.11
PHY-1	3.77±0.04	2.96±0.11
PHY-2	3.34±0.04	2.41±0.18
Sabagidhan	3.45±0.13	2.30±0.04
Tulasi	3.03±0.08	2.39±0.03
N-22	2.36±0.03	1.85±0.05
	SEM±	**CD at 5%**
Treatment (T)	0.032	0.091
Genotypes (G)	0.112	0.317
T×G	0.159	0.448

Table 9: Effect of heat stress on TDM (Leaf+Stem) g/m^2 at flowering of different rice genotypes

Genotypes	TDM (Leaf+Stem) g/m^2	TDM (Leaf+Stem) g/m^2
	Control	Treatment
IET 23339	497.62±21.48	579.62±29.04
IET 23354	671.67±31.98	596.74±41.14
IET 23356	732.02±32.38	603.70±64.46
IET 23392	829.68±56.32	655.91±72.59
IET 23947	718.19±66.88	615.99±42.98
IET 23949	693.98±18.66	646.85±81.54
IET 23951	691.04±15.88	557.63±61.06
IET 23957	824.59±48.05	570.43±29.51
IET 23976	638.19±24.54	415.54±7.44
IET 23979	758.80±52.46	787.81±32.80
IET 23996	750.58±52.24	685.37±58.67
IET 24075	611.97±78.63	600.36±66.29
IET 24082	641.32±94.46	610.71±31.06
DRRH-106	736.34±94.25	523.49±20.78
DRRH-107	1187.83±16.38	1051.89±30.68
DRRH-108	766.27±64.65	684.58±47.87
Govind	461.50±6.97	469.27±42.29
NDR-97	811.25±21.15	788.96±60.70
PA-6129	858.14±65.60	950.09±27.06
PHY-1	1580.63±41.38	1232.59±65.24
PHY-2	708.70±71.68	602.72±25.44
Sabagidhan	794.26±65.37	793.58±33.26
Tulasi	1030.78±56.73	622.50±34.29
N-22	544.75±36.78	502.96±33.29
	SEM±	**CD at 5%**
Treatment(T)	10.231	028.729
Genotypes(G)	35.442	099.521
T×G	50.122	140.744

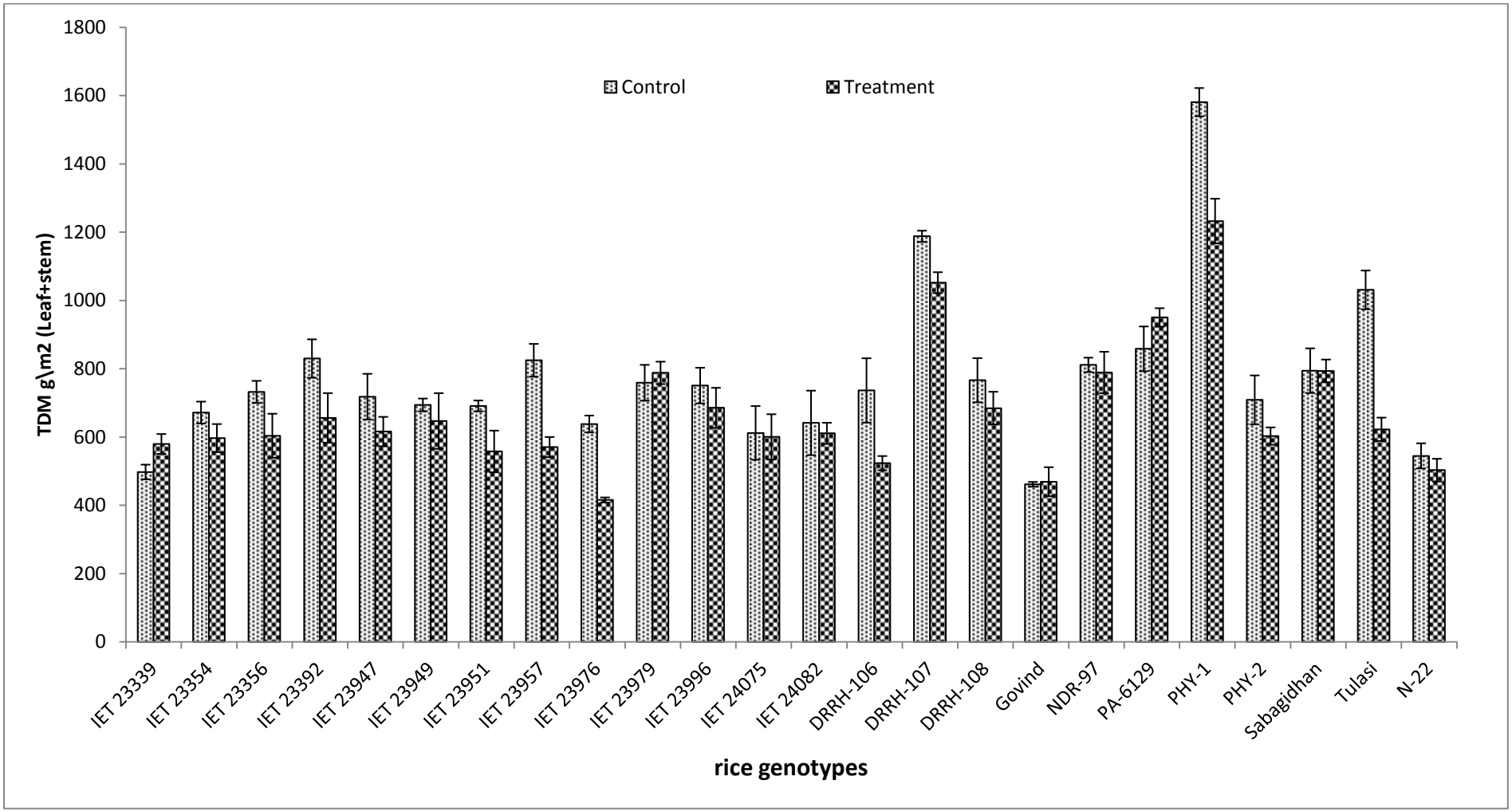


Fig. 9: Effect of heat stress on TDM (leaf+stem) g/ m^2 at flowering of different rice genotypes

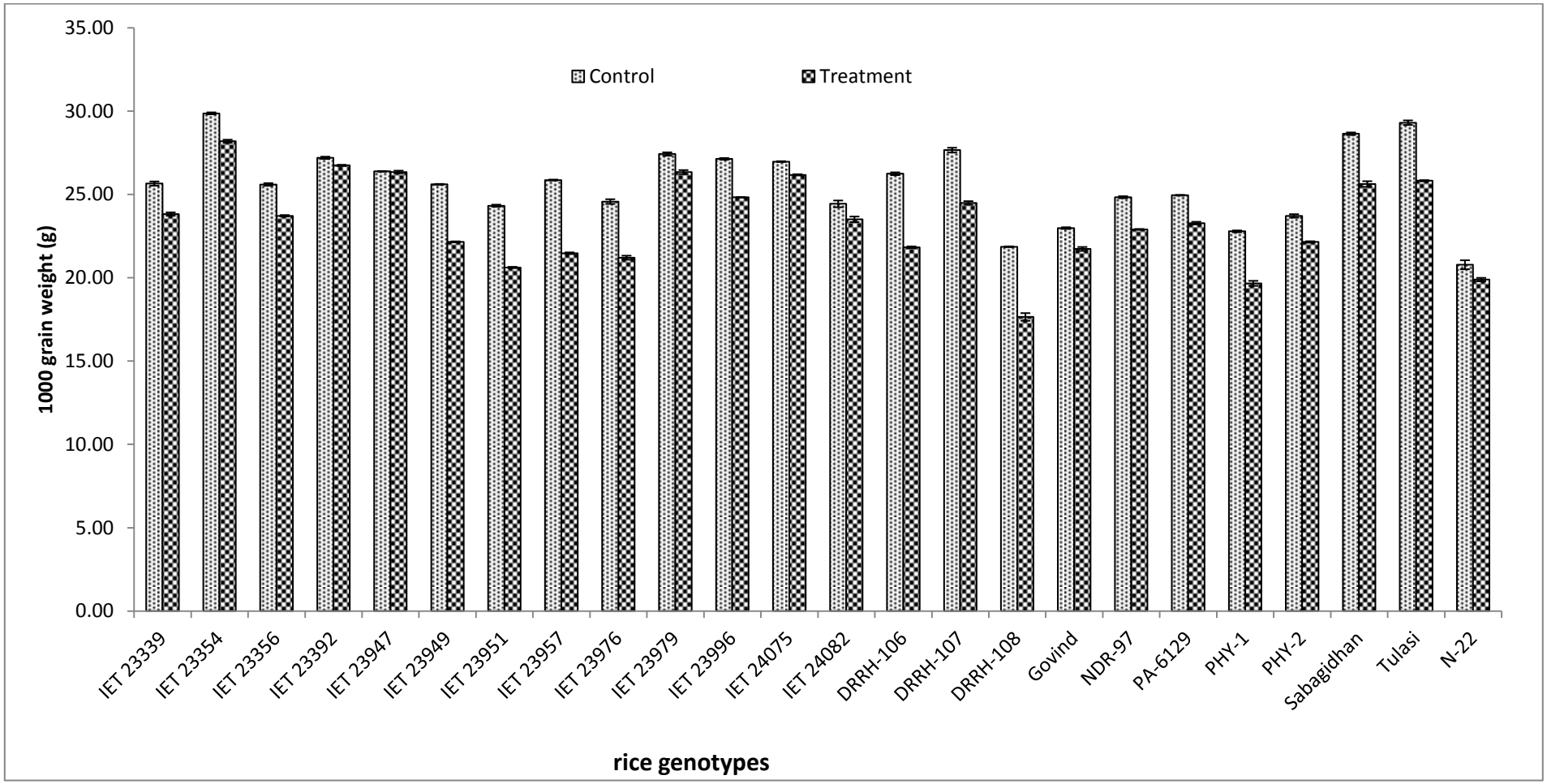


Fig. 10: Effect of heat stress on 1000- grain weight (g) at harvest of different rice genotypes

Table 10: Effect of heat stress on 1000 grain weight (g) at maturity of different rice genotypes

Genotypes	1000 grain weight (g)	1000 grain weight (g)
	Control	Treatment
IET 23339	25.65±0.13	23.82±0.10
IET 23354	29.86±0.06	28.19±0.09
IET 23356	25.59±0.08	23.71±0.04
IET 23392	27.19±0.07	26.74±0.04
IET 23947	26.38±0.02	26.34±0.08
IET 23949	25.60±0.03	22.15±0.03
IET 23951	24.32±0.06	20.61±0.04
IET 23957	25.86±0.03	21.47±0.05
IET 23976	24.57±0.14	21.20±0.12
IET 23979	27.42±0.10	26.34±0.12
IET 23996	27.13±0.05	24.82±0.01
IET 24075	26.97±0.02	26.17±0.04
IET 24082	24.43±0.20	23.50±0.17
DRRH-106	26.24±0.08	21.82±0.05
DRRH-107	27.65±0.14	24.49±0.10
DRRH-108	21.86±0.02	17.64±0.23
Govind	22.98±0.05	21.72±0.12
NDR-97	24.83±0.06	22.90±0.03
PA-6129	24.95±0.02	23.27±0.08
PHY-1	22.78±0.06	19.66±0.15
PHY-2	23.71±0.10	22.14±0.04
Sabagidhan	28.64±0.08	25.62±0.17
Tulasi	29.30±0.14	25.82±0.04
N-22	20.78±0.27	19.89±0.10
	SEM±	**CD at 5%**
Treatment (T)	0.020	0.057
Genotypes (G)	0.070	0.199
T×G	0.100	0.281

Table 11: Effect of heat stress on number of filled and unfilled grains/panicle at maturity of different rice genotypes

Genotypes	No. of filled grains/panicle		No. of unfilled grains/panicle	
	Control	Treatment	Control	Treatment
IET 23339	115.33±1.33	101.00±3.51	30.33±1.20	59.33±1.33
IET 23354	132.00±6.66	112.33±4.41	28.67±4.10	58.00±7.37
IET 23356	139.61±2.65	122.00±3.51	37.67±6.01	60.00±2.52
IET 23392	139.67±6.39	108.33±10.04	26.33±1.76	58.99±2.51
IET 23947	126.33±7.97	98.33±3.38	14.67±3.28	30.33±2.85
IET 23949	154.67±1.67	132.00±7.00	50.00±4.04	90.67±3.18
IET 23951	179.67±2.40	150.67±9.33	46.67±2.33	73.33±1.86
IET 23957	149.67±3.28	108.00±4.58	39.33±1.20	84.67±3.48
IET 23976	156.67±5.84	101.67±3.48	32.00±4.51	80.00±3.00
IET 23979	135.67±6.33	76.67±3.18	15.67±1.76	57.33±3.53
IET 23996	147.00±3.61	98.00±2.08	25.33±2.85	73.00±4.00
IET 24075	150.67±3.84	96.00±0.58	18.33±1.76	60.67±5.55
IET 24082	155.33±2.40	124.67±10.04	16.67±2.91	35.00±3.06
DRRH-106	152.00±7.21	128.33±3.84	14.67±3.18	85.00±2.08
DRRH-107	170.33±1.67	161.00±1.53	34.00±2.52	60.00±3.79
DRRH-108	205.33±2.60	177.33±3.76	50.67±4.33	76.00±12.17
Govind	111.82±3.33	81.33±2.73	17.48±3.79	44.00±2.65
NDR-97	155.33±3.84	122.67±0.88	23.67±3.76	30.67±4.33
PA-6129	127.00±3.00	77.33±2.85	12.67±0.88	36.00±2.89
PHY-1	175.33±1.76	147.00±6.66	58.67±0.33	88.67±7.88
PHY-2	141.67±1.45	103.33±3.48	18.67±1.45	43.67±4.98
Sabagidhan	118.00±3.51	81.33±3.71	33.00±4.04	60.33±1.20
Tulasi	127.00±3.51	92.33±1.45	44.33±1.20	64.00±1.53
N-22	119.67±0.88	108.00±3.06	11.00±1.15	16.00±1.53
	S. Em±	**CD at 5%**	**S. Em±**	**CD at 5%**
Treatment(T)	0.896	02.516	0.783	02.200
Genotypes(G)	3.104	08.718	2.714	07.623
T×G	4.390	12.329	3.839	10.780

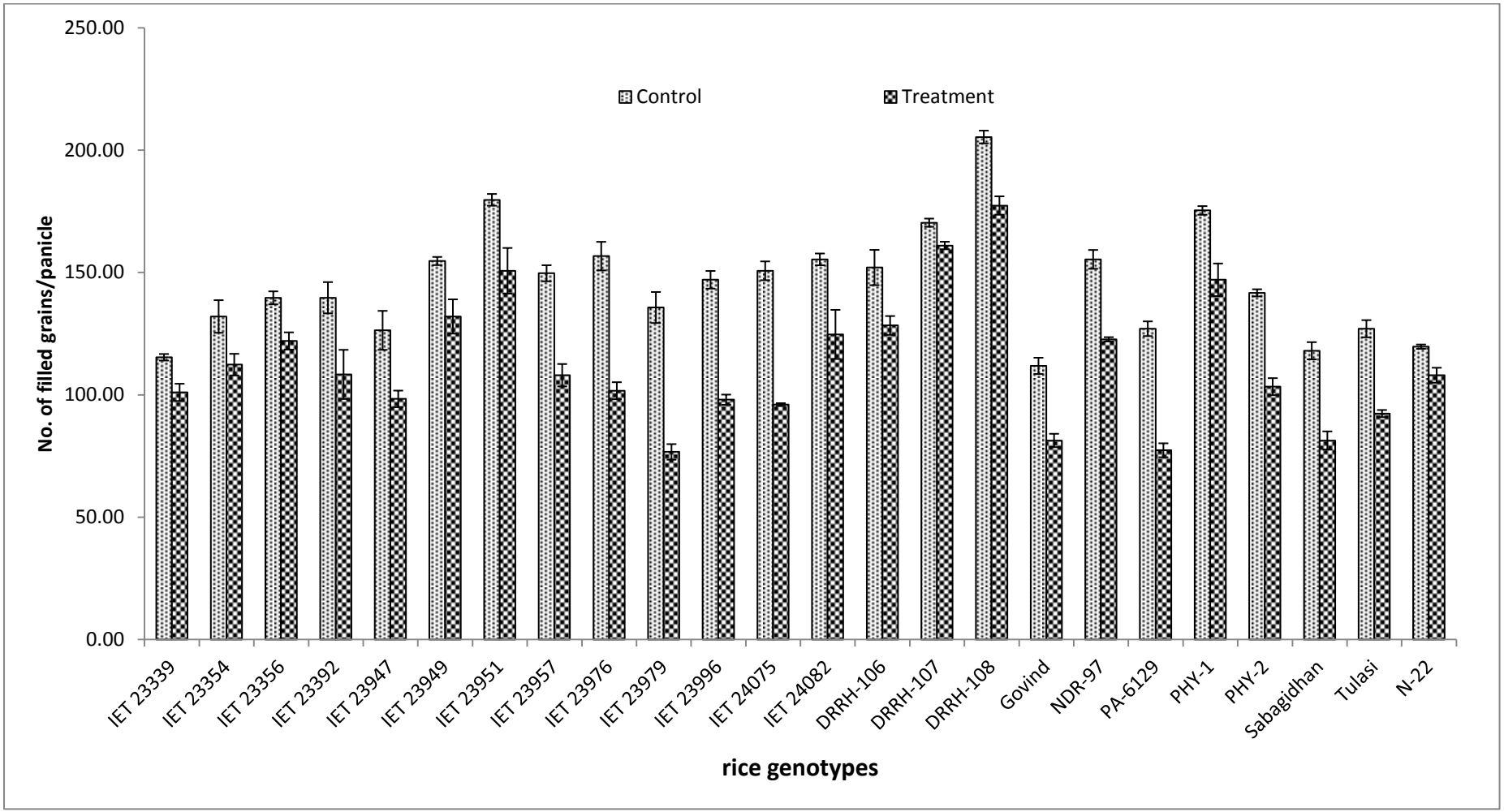


Fig. 11 (a): Effect of heat stress on number of filled grains per panicle at harvest of different rice genotypes

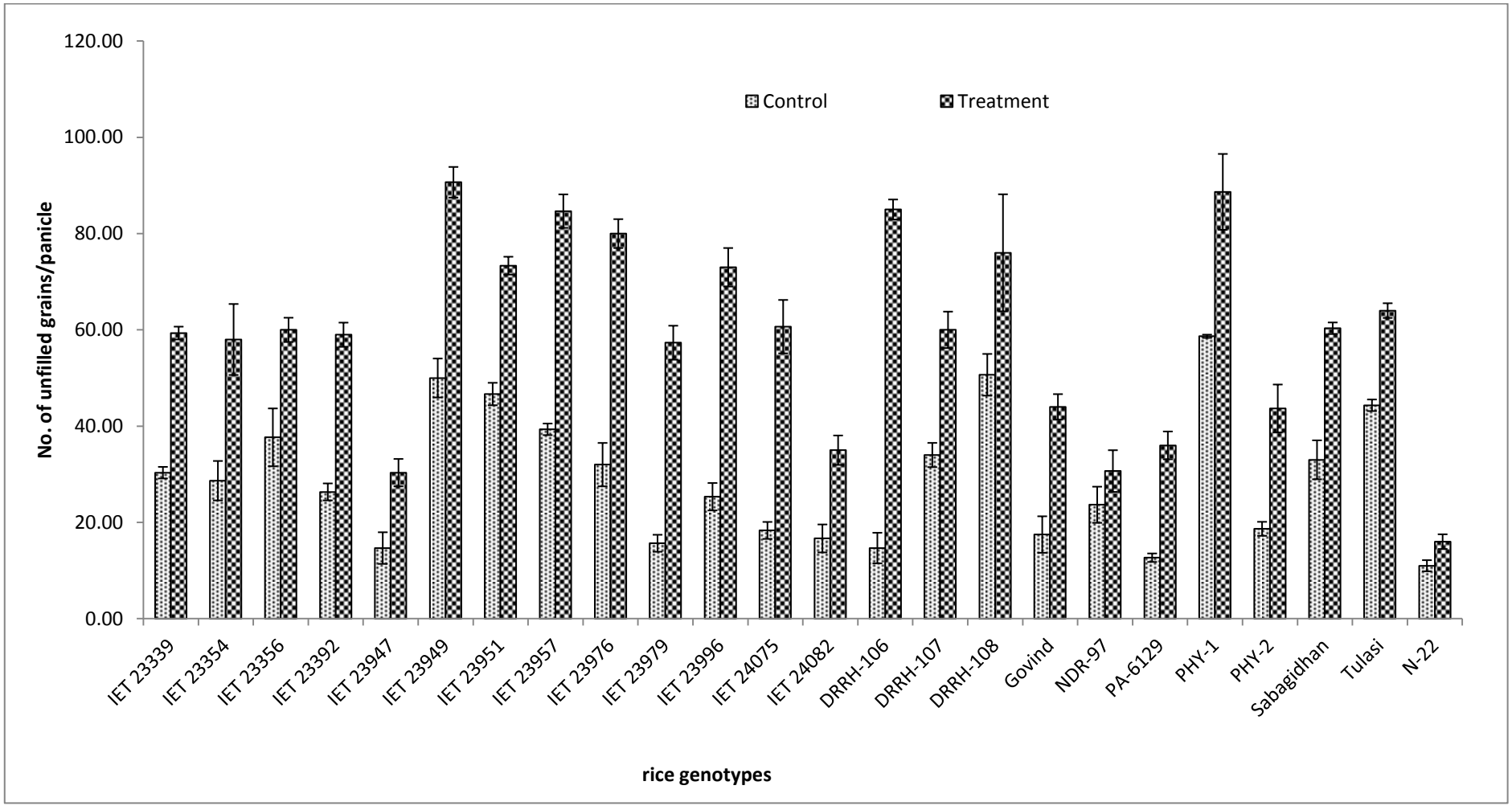


Fig. 11 (b): Effect of heat stress on number of unfilled grains per panicle at harvest of different rice genotypes

adhesion to the stigma and its subsequent germination were negatively affected **(Endo *et al*., 2009).**

4.1.10 Effect of heat stress on grain yield at harvest in rice genotypes

Under heat treatment the grain yields per plant (g) at harvest was decreased in all the rice genotypes. The maximum grain yield per plant was found in rice genotype namely DRRH-107 (18.91g) under heat treatment and minimum in rice genotype namely Tulasi (8.36g). It was statistically non-significant for treatment (T) add for T×G interactions, but significant for genotypes (G).

Under heat treatment the grain yield (g/m^2) at harvest was decreased in all the rice genotypes. The maximum grain yield (g/m^2) was found in rice genotype namely DRRH-107 (1149.07 g/m^2) under heat treatment and the minimum was in rice genotype namely Tulasi (339.52 g/m^2). It was statistically non-significant for treatment (T) and T×G interactions, but significant for genotypes (G).

Morita *et al*. (2005), reported that high night temperatures (22/34 °C, day/night) were more harmful to grain weight in rice than high day temperatures (34/22 °C) and control conditions (22/22 °C) at optimum temperature. The final grain weight which is the product of the rate and duration of grain growth is affected by high temperatures which increase growth rate in the early ripening period but reduce the duration of grain growth and ultimately result in decreased in final grain weight.

Oh-e *et al*. (2007) observed that the rate of grain growth was faster and the grain-filling period was shorter at higher temperatures. High temperatures above 30°C are generally not favorable for ripening. High temperatures at flowering and during grain-filling phase reduce yield by causing spikelet sterility and shortening the duration of grain-filling phase **(Tian *et al*., 2007 and Xie *et al*., 2009).**

4.1.11 Effect of heat stress on Total Dry Matter g/m^2 at harvest in rice genotypes

Under heat treatment, TDM (g/m^2) was decreased in all the rice genotypes. The maximum TDM was found in rice genotype PHY-1(2175.93 g/m^2) and minimum in N 22 (972.22 g/m^2). It was statistically significant for genotypes (G), but non-significant for treatment (T) and T×G interactions.

Guttieri *et al.* (2001) reported that dry matter accumulation decreased due to a

decrease in kernel number, leaf number, kernel weight and acceleration of leaf senescence. Heat stress is one of the most important causes of reduced yield and dry matter production in many crops, including maize and wheat **(Giaveno and Ferrero, 2003).**

4.1.12 Effect of heat stress on chlorophyll fluorescence at flowering of different rice genotypes

Under heat treatment the chlorophyll fluorescence at flowering was decreased in 22 rice genotypes while increased in two genotypes of rice namely PHY-2, Sabagidhan. The maximum chlorophyll fluorescence was found in rice genotype IET 23339 (0.723) under heat treatment and minimum in IET 23996 (0.657). It was statistically non-significant for treatment (T) and T×G interactions, but significant for genotypes (G).

High temperatures reduced chlorophyll fluroscence (Fv) in attached leaves, protoplasts, chloroplasts, or thylakoids of rice. Injury to PSII in photosynthetic organelles and thylakoids and the match between these profiles and Fv, an indicator of damage to PSII and the kinetics of injury over time suggest that the photosystem is susceptible to high-temperature damage in rice **(Al-Khatib and Paulsen, 1999).** The Fv/Fm ratio decreased significantly under high temperature stress, when rice seedlings were treated at 26^0C, 35^0C, 40^0C and 45^0C for 48 h, respectively **(Han *et al.*, 2009).**

4.2 Biochemical Parameters

4.2.1 Effect of heat stress on chlorophyll content (mg/g fresh weight) at flowering of rice genotypes

Under heat treatment the total chlorophyll content (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum total chlorophyll content was found in rice genotype N22 (1.98 mg/g fresh weight) under heat treatment and minimum in IET 23979 (0.91 mg/g fresh weight). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions. Under heat treatment, chlorophyll “a” (mg/g fresh weight) at flowering stage was decreased for all the rice genotypes. The maximum chlorophyll “a” content was found in rice genotype NDR-97 (1.62 mg/g fresh weight) and minimum was in Sabagidhan (0.85 mg/g fresh weight). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions. Under heat treatment the chlorophyll “b” (mg/g fresh weight) at flowering decreased for

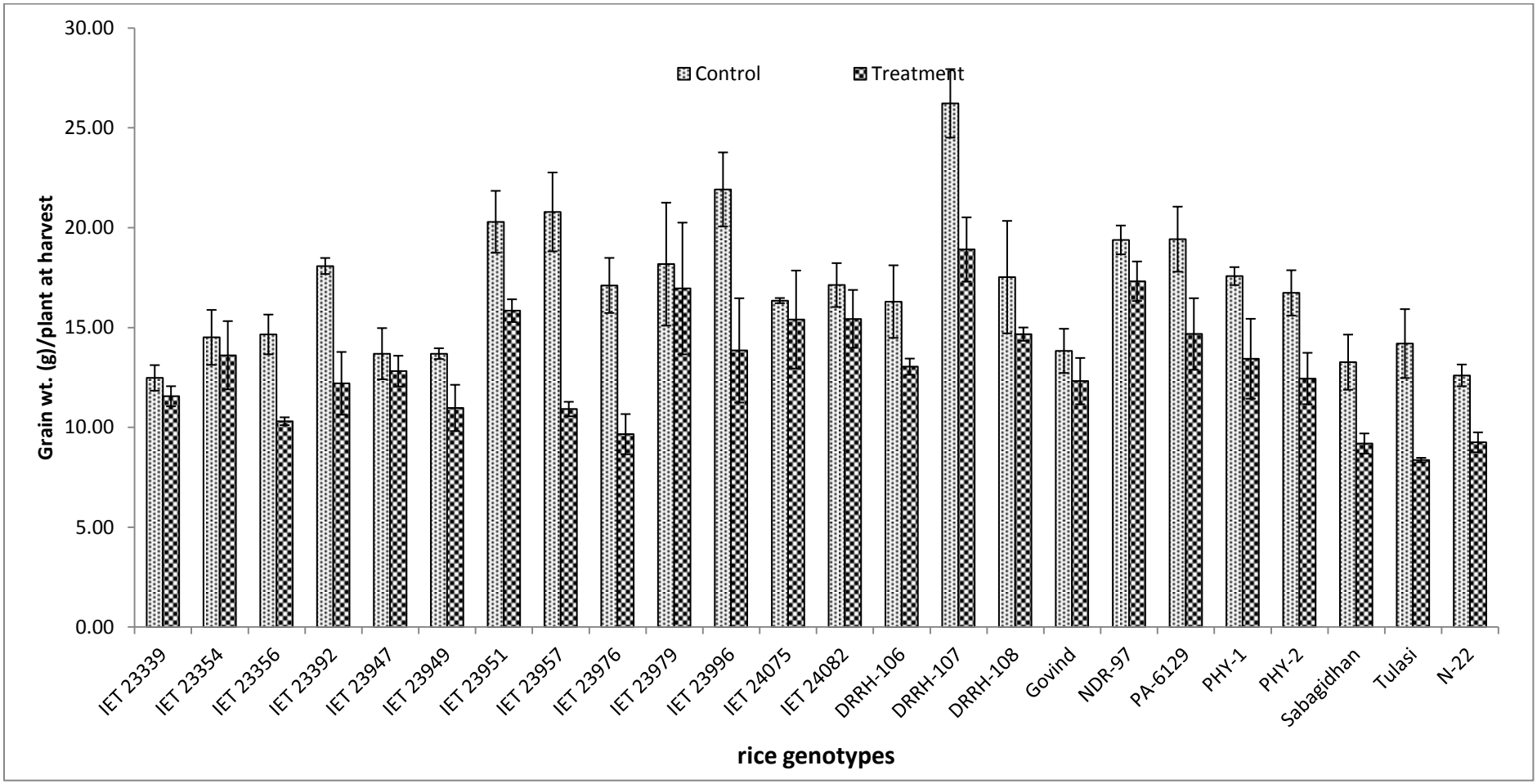


Fig. 12 (a): Effect of heat stress on grain weight (g) per plant at harvest of different rice genotypes

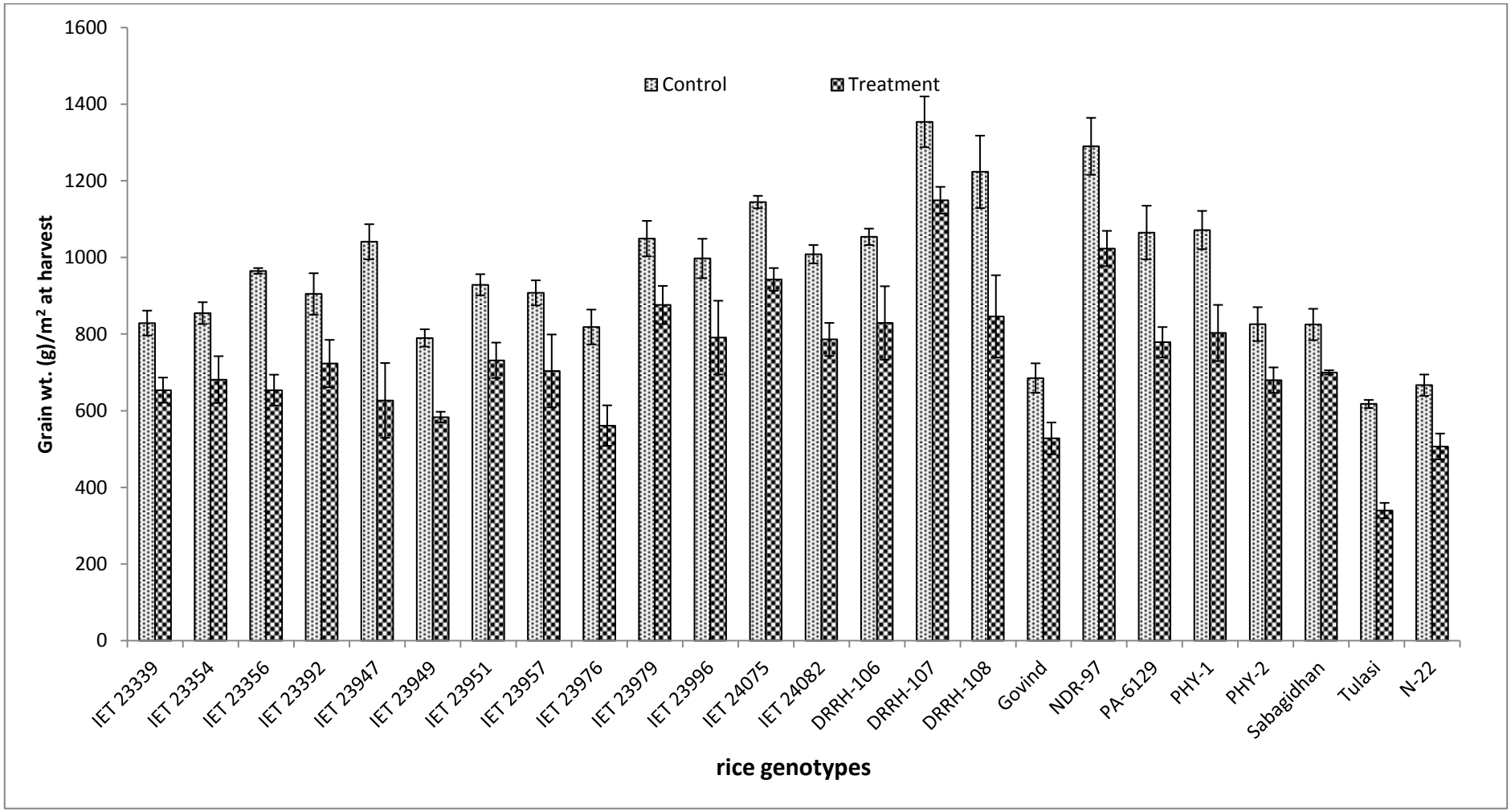


Fig. 12 (b): Effect of heat stress on grain yield (g/m^2) at harvest of different rice genotypes

Table 12: Effect of heat stress on grain weight (g)/plant and grain yield (g)/m^2 at harvest of different rice genotypes

Genotypes	Grain wt. (g)/plant at harvest		Grain wt. (g)/m^2 at harvest	
	Control	Treatment	Control	Treatment
IET 23339	12.48±0.64	11.56±0.50	828.70±32.49	653.70±32.88
IET 23354	14.50±1.38	13.61±1.71	854.63±28.52	681.15±61.06
IET 23356	14.65±0.99	10.31±0.20	964.81±7.41	653.70±40.26
IET 23392	18.08±0.40	12.20±1.57	904.63±54.06	723.15±61.70
IET 23947	13.69±1.28	12.81±0.77	1040.74±45.82	626.85±97.62
IET 23949	13.69±0.27	10.97±1.16	789.81±22.70	583.33±13.98
IET 23951	20.29±1.55	15.84±0.57	928.70±27.51	731.48±46.30
IET 23957	20.79±1.97	10.92±0.36	907.41±32.76	703.70±95.18
IET 23976	17.11±1.38	9.66±1.01	818.52±45.37	561.11±52.92
IET 23979	18.17±3.08	16.95±3.30	1049.08±46.30	875.93±49.75
IET 23996	21.91±1.85	13.85±2.61	997.22±51.45	790.74±96.23
IET 24075	16.35±0.13	15.40±2.45	1144.44±16.28	942.59±29.63
IET 24082	17.13±1.10	15.43±1.45	1008.33±23.95	785.93±43.21
DRRH-106	16.30±1.82	13.04±0.41	1053.70±21.36	828.89±95.85
DRRH-107	26.22±1.72	18.91±1.61	1353.70±66.21	1149.07±35.00
DRRH-108	17.52±2.81	14.67±0.33	1223.15±94.53	846.20±107.32
Govind	13.83±1.11	12.31±1.16	685.19±38.50	527.78±41.48
NDR-97	19.38±0.72	17.31±0.99	1289.81±74.35	1023.15±46.07
PA-6129	19.42±1.63	14.67±1.79	1064.81±70.02	778.70±39.56
PHY-1	17.57±0.45	13.44±2.00	1071.30±50.06	802.78±73.35
PHY-2	16.73±1.14	12.44±1.29	825.93±44.22	679.63±33.38
Sabagidhan	13.26±1.38	9.19±0.50	825.00±40.92	700.00±5.56
Tulasi	14.19±1.72	8.36±0.11	617.59±10.68	339.52±20.01
N-22	12.60±0.54	9.25±0.50	666.59± 27.78	506.75± 33.72
	S. Em±	**CD at 5 %**	**S. Em±**	**CD at 5 %**
Treatment (T)	0.298	0.837	10.815	30.370
Genotypes (G)	1.033	2.901	37.466	105.205
T×H	1.461	4.103	52.985	148.783

Table 13: Effect of heat stress on TDM (g/m^2) at harvest of different rice genotypes

Genotypes	TDM (g/m^2) at harvest	
	Control	Treatment
IET 23339	1481.48±46.30	1203.70±92.59
IET 23354	1759.26±46.30	1296.30±92.59
IET 23356	1527.78±0.00	1274.07±60.55
IET 23392	1712.96±46.30	1527.78±80.19
IET 23947	1759.26±46.30	1388.89±138.89
IET 23949	1481.48±92.59	1250.00±00.00
IET 23951	1666.67±0.00	1388.89±00.00
IET 23957	1712.96±46.30	1435.19±46.30
IET 23976	1527.78±80.19	1296.30±46.30
IET 23979	1944.44±80.19	1620.37±46.30
IET 23996	1759.26±46.30	1481.48±92.59
IET 24075	1851.85±46.30	1666.67±00.00
IET 24082	1805.56±0.00	1342.59±46.30
DRRH-106	1712.96±46.30	1388.89±80.19
DRRH-107	2592.59±201.80	1898.15±46.30
DRRH-108	2314.81±122.49	1898.15±46.30
Govind	1203.70±46.30	1018.52±46.30
NDR-97	2222.22±138.89	1759.26±46.30
PA-6129	1944.44±80.19	1574.07±46.30
PHY-1	2777.78±212.16	2175.93±46.30
PHY-2	1527.78±80.19	1203.70±46.30
Sabagidhan	1712.96±92.59	1435.19±92.59
Tulasi	1435.19±46.30	1203.70±46.30
N-22	1157.41±46.30	972.22±0.00
	SEM±	**CD at 5%**
Treatment (T)	15.694	044.071
Genotypes (G)	54.368	152.668
T×G	76.889	215.905

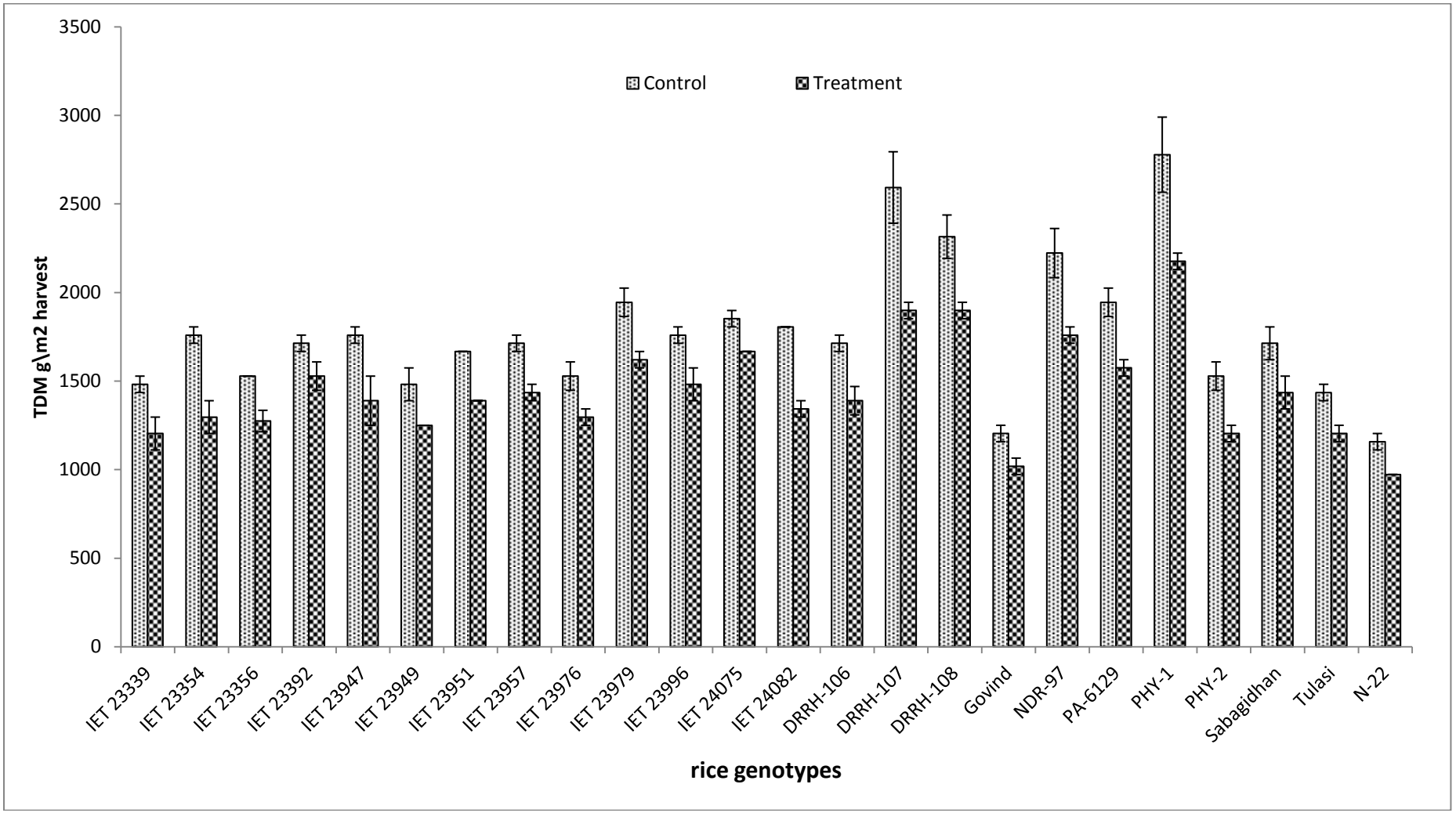


Fig. 13: Effect of heat stress on TDM (g/m^2) at harvest of different rice genotypes

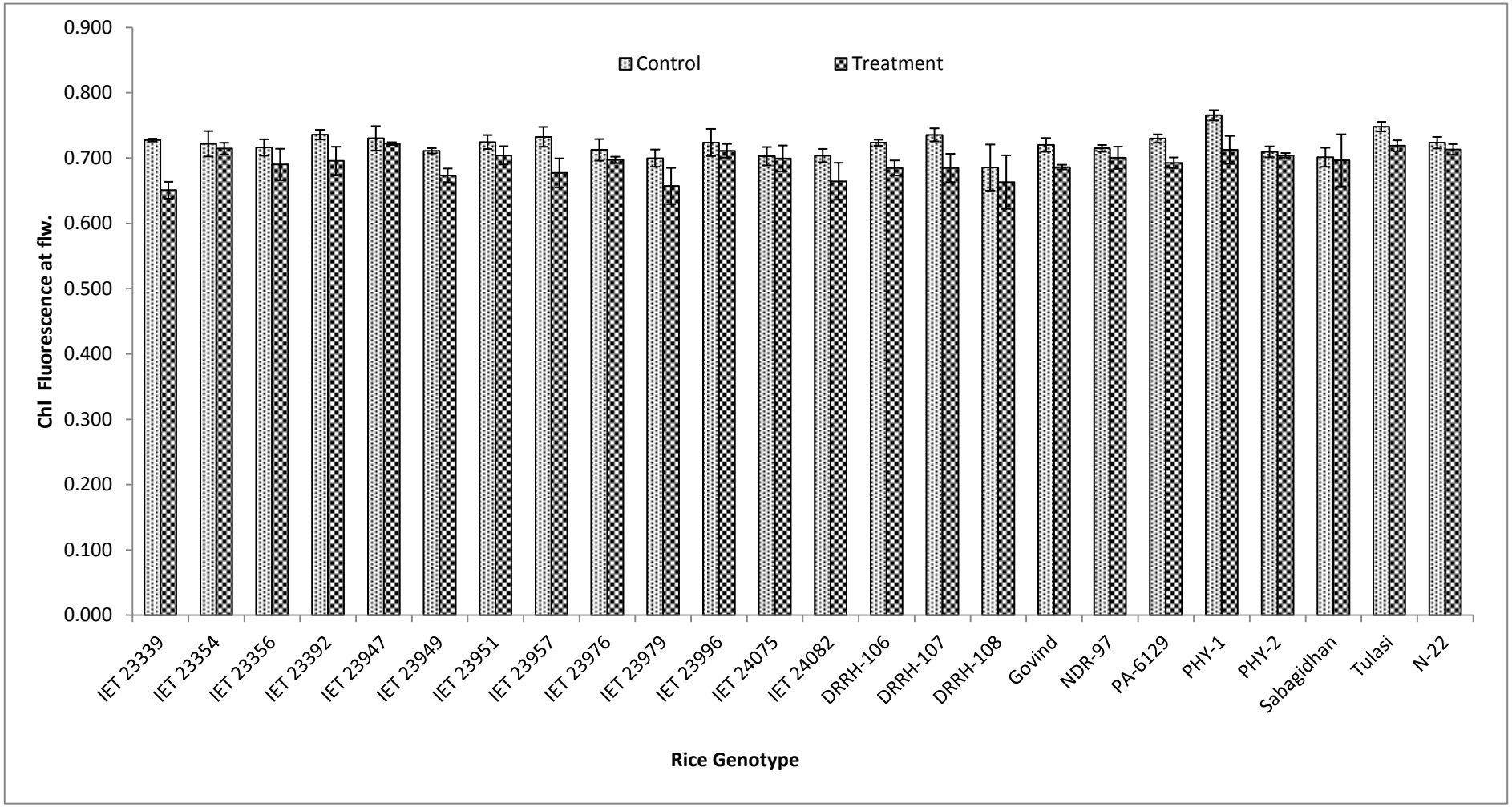


Fig 14 : Effect of heat stress on chlorophyll fluorescence at flowering of different rice genotypes

all the rice genotypes. The maximum chlorophyll "b" was found in rice genotype namely N 22 (0.41 mg/g fresh weight) under heat treatment and minimum in rice genotype namely IET 23976 (0.05 mg/g fresh weight). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions.

Under heat treatment the total chlorophyll content (mg/g fresh weight) at early seedling stages decreased for all the rice genotypes. The maximum total chlorophyll content was found in rice genotype namely DRRH-107 (1.20 mg/g fresh weight) under heat treatment and minimum in rice genotype namely Sabagidhan (0.58 mg/g fresh weight). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions. Under heat treatment the Chlorophyll "a" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "a" was found in rice genotype namely DRRH-107 (1.03 mg/g fresh weight) under heat treatment minimum in rice genotype namely IET 24075 (0.40 mg/g fresh weight). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions. Under heat treatment the chlorophyll "b" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "b" was found in rice genotype namely IET 24075 (0.67 mg/g fresh weight) under heat treatment and minimum in rice genotype namely IET 23339 (0.01 mg/g fresh weight). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions

Under heat treatment, the total chlorophyll content (mg/g fresh weight) at late seedling stages decreased for all the rice genotypes. The maximum total chlorophyll content was found in rice genotype namely DRRH-107 (0.79 mg/g fresh weight) under heat treatment and minimum in rice genotype namely IET 23951 (0.22 mg/g fresh weight). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions. Under heat treatment the Chlorophyll "a" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "a" was found in rice genotype DRRH-107 (0.68 mg/g fresh weight) under heat treatment minimum in IET 23951 (0.20 mg/g fresh weight). It was statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions. Under heat treatment the chlorophyll "b" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "b" was found in rice genotype IET 23949, PA-6129 (0.20 mg/g fresh weight) under heat treatment and minimum in IET 24075 (0.02 mg/g fresh weight). It was

statistically non-significant for treatment (T), but significant for genotypes (G) and T×G interactions. **Xie *et al.* (2012)** reported that high air temperature during heading stage negatively influenced SPAD value (relative content of chlorophyll) in rice flag leaves, significant reduction occurring with the continuous increment of air temperature. The reduction in photosynthesis could result from structural and functional disruptions of chloroplasts and reduction of chlorophyll accumulation under high temperature stress. The reduction of photosynthesis by high temperature stress is also related to inactivation of many chloroplast enzymes, mainly induced by oxidative stress **(Dekov *et al.*, 2000; Langjun *et al.*, 2006)**

4.2.2 Effect of heat stress on grain amylose content (%) at harvest in rice genotypes

Under heat treatment the amylose content (%) of rice grain at harvest decreased for all the rice genotypes. The maximum amylose content was found in rice genotype namely NDR-97 (19.64 %) under heat treatment and minimum in rice genotype namely IET 23951 (10.97 %). The maximum amylose (%) decreased in rice genotype IET 23951 (54.59 %) under heat treatment and minimum in rice genotype namely DRRH-108 (13.35 %). It was statistically significant for treatment (T), but non-significant for genotypes (G) and T×G interactions.

The severe loss of starch content upon application of heat stress during the early grain filling stage may be explained by high temperature at this stage disturbing endosperm cell division, reducing amyloplast numbers, deforming starch granules, restricting starch granule formation; high temperature at the late grain filling stage only moderately affect seed storage process **(Commuri and Jones, 1999, 2001).** Starch consists of amylose (linear α-1, 4-polyglucan) and amylopectin (α-1, 6-branched polyglucans) in rice grains. Although amylose synthesis is exclusively governed by granule-bound starch synthase (GBSS), amylopectin is synthesized via concerted reactions catalyzed by multiple isoforms of enzymes: soluble starch synthase (SS), starch branching enzyme (BE), and starch debranching enzyme **(Nakamura, 2002).** In rice, high temperature resulted in a reduction of activity and gene expression for GBSSI and BEs **(Jiang *et al.*, 2003)**, decrease of amylose content and increase of long chain of amylopectin (**Umemoto *et al.*, 1999**). Biochemical analyses of starch showed that the high temperature-ripened grains contained decreased levels of amylose and long chain-enriched amylopectin, which might be attributed to the repressed expression of granule bound starch synthase (GBSSI) and starch

Table 14: Effect of heat stress on chlorophyll fluorescence at flowering of different rice genotypes

Genotypes	Chlorophyll Fluorescence at flowering	
	Control	Treatment
IET 23339	0.727±0.002	0.723±0.012
IET 23354	0.722±0.019	0.651±0.009
IET 23356	0.716±0.012	0.714±0.024
IET 23392	0.736±0.007	0.690±0.021
IET 23947	0.730±0.018	0.696±0.002
IET 23949	0.711±0.004	0.722±0.010
IET 23951	0.724±0.010	0.673±0.014
IET 23957	0.732±0.015	0.704±0.022
IET 23976	0.712±0.016	0.677±0.004
IET 23979	0.700±0.013	0.697±0.027
IET 23996	0.724±0.020	0.657±0.010
IET 24075	0.703±0.014	0.711±0.019
IET 24082	0.704±0.010	0.699±0.028
DRRH-106	0.723±0.004	0.664±0.011
DRRH-107	0.735±0.010	0.685±0.021
DRRH-108	0.685±0.035	0.685±0.041
Govind	0.720±0.010	0.663±0.003
NDR-97	0.715±0.005	0.686±0.017
PA-6129	0.730±0.006	0.700±0.008
PHY-1	0.765±0.007	0.693±0.021
PHY-2	0.709±0.008	0.712±0.003
Sabagidhan	0.701±0.014	0.704±0.039
Tulasi	0.748±0.007	0.696±0.008
N-22	0.727±0.008	0.719±0.008
	SEM±	**CD at 5%**
Treatment (T)	0.003	0.009
Genotypes (G)	0.011	0.033
T×G	0.016	0.047

Table 15: Effect of heat stress on plant height at flowering of different rice genotypes

Genotypes	Plant height at flowering	
	Control	Treatment
IET 23339	101.22±1.85	99.56±1.79
IET 23354	99.00±3.24	106.56±4.92
IET 23356	102.44±3.74	103.33±3.24
IET 23392	100.22±1.28	96.67±3.21
IET 23947	101.00±3.86	100.67±1.00
IET 23949	99.11±1.93	95.11±0.59
IET 23951	103.89±1.25	105.89±0.59
IET 23957	88.56±1.61	88.78±2.38
IET 23976	98.44±0.48	91.56±3.39
IET 23979	101.22±1.25	104.22±2.62
IET 23996	104.33±1.58	102.00±0.88
IET 24075	103.33±0.38	102.33±0.00
IET 24082	99.33±0.19	101.00±1.35
DRRH-106	102.22±0.68	105.33±3.18
DRRH-107	101.00±1.54	103.78±2.75
DRRH-108	100.22±2.78	104.00±3.34
Govind	99.56±1.56	100.56±0.87
NDR-97	101.33±4.35	106.33±2.60
PA-6129	92.78±0.62	95.22±0.62
PHY-1	111.00±2.03	113.00±1.20
PHY-2	106.67±2.52	101.67±5.70
Sabagidhan	93.78±0.29	100.33±1.35
Tulasi	91.56±1.46	95.78±5.76
N-22	139.78±0.97	140.22±5.33
	SEM±	**CD at 5%**
Treatment (T)	0.489	1.373
Genotypes (G)	1.694	4.756
T×G	2.395	6.727

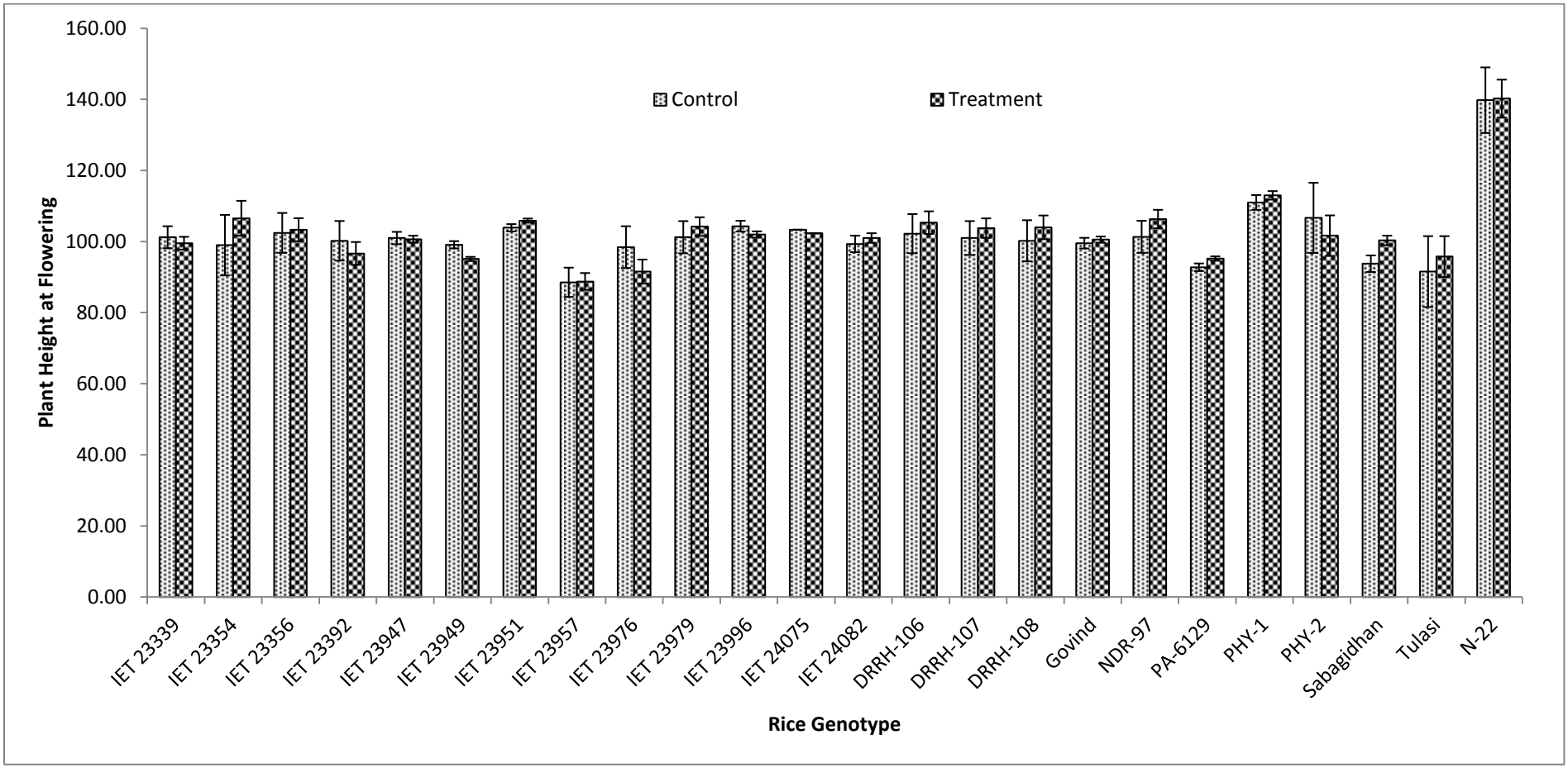


Fig15 : Effect of heat stress on plant height at flowering of different rice genotype

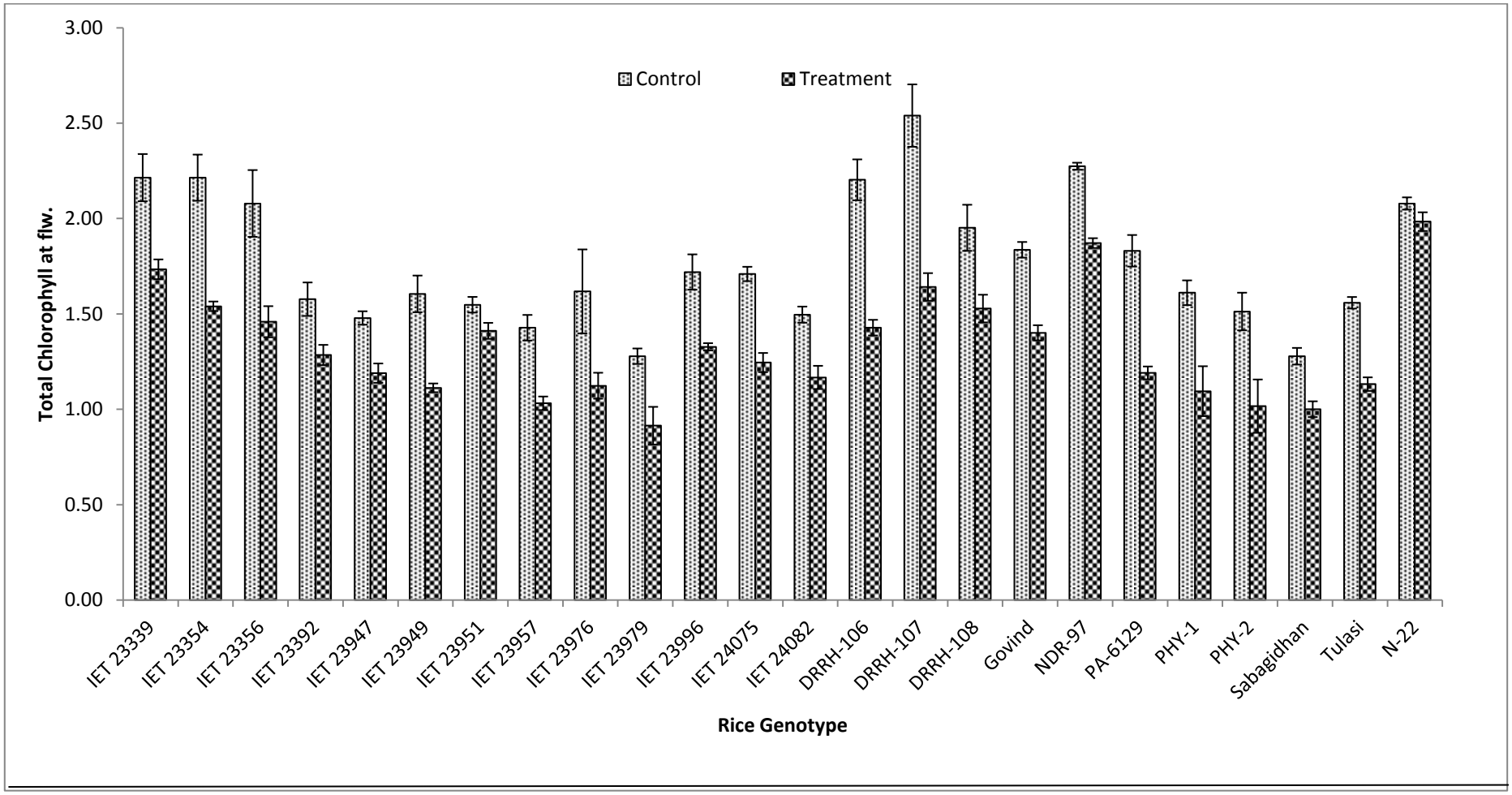


Fig. 16: Effect of heat stress on Total chlorophyll content (mg/g fresh weight) at flowering of different rice genotypes

Table 16 (a): Effect of heat stress on chlorophyll content (mg/g fr. wt.) at flowering stage of different rice genotypes

GENOTYPES	Chlorophyll 'a'		Chlorophyll 'b'		Total Chlorophyll	
	Control	Heat	Control	Heat	Control	Heat
IET 23339	1.96±0.10	1.45±0.06	0.29± 0.02	0.31±0.01	2.21±0.12	1.73±0.05
IET 23354	1.87±0.09	1.28±0.02	0.38± 0.04	0.29±0.00	2.21±0.12	1.54±0.02
IET 23356	1.70±0.13	1.33±0.06	0.41± 0.05	0.15±0.02	2.08±0.18	1.46±0.08
IET 23392	1.40±0.04	1.09±0.04	0.20± 0.07	0.21±0.02	1.58±0.09	1.28±0.05
IET 23947	1.28±0.05	1.01±0.02	0.22± 0.02	0.20±0.03	1.48±0.04	1.19±0.05
IET 23949	1.51±0.08	1.04±0.02	0.12± 0.02	0.09±0.01	1.60±0.10	1.11±0.02
IET 23951	1.45±0.04	1.32±0.04	0.13± 0.01	0.12±0.01	1.55±0.04	1.41±0.04
IET 23957	1.26±0.07	0.90±0.05	0.19± 0.01	0.15±0.03	1.43±0.07	1.03±0.04
IET 23976	1.35±0.04	1.09±0.07	0.29± 0.18	0.05±0.00	1.62±0.22	1.12±0.07
IET 23979	1.16±0.02	0.86±0.08	0.14± 0.02	0.07±0.02	1.28±0.04	0.91±0.10
IET 23996	1.52±0.07	1.20±0.01	0.22± 0.03	0.15±0.01	1.72±0.09	1.33±0.02
IET 24075	1.57±0.02	1.20±0.04	0.17± 0.02	0.07±0.01	1.71±0.04	1.24±0.05
IET 24082	1.38±0.03	1.10±0.06	0.14± 0.03	0.08±0.00	1.50±0.04	1.17±0.06
DRRH-106	1.93±0.08	1.28±0.03	0.31± 0.03	0.17±0.03	2.20±0.11	1.43±0.04
DRRH-107	2.13±0.14	1.43±0.04	0.45± 0.03	0.24±0.04	2.54±0.16	1.64±0.07
DRRH-108	1.66±0.10	1.30±0.07	0.32± 0.04	0.25±0.01	1.95±0.12	1.53±0.07
Govind	1.61±0.04	1.24±0.03	0.25± 0.01	0.19±0.01	1.84±0.04	1.40±0.04
NDR-97	1.93±0.03	1.62±0.03	0.38± 0.02	0.28±0.01	2.27±0.02	1.87±0.03
PA-6129	1.47±0.05	1.10±0.03	0.39± 0.07	0.11±0.01	1.83±0.08	1.19±0.03
PHY-1	1.36±0.05	0.97±0.08	0.27± 0.02	0.14±0.05	1.61±0.06	1.09±0.13
PHY-2	1.34±0.07	0.97±0.12	0.19± 0.05	0.07±0.02	1.51±0.10	1.02±0.14
Sabagidhan	1.08±0.02	0.85±0.04	0.22± 0.02	0.17±0.01	1.28±0.04	1.00±0.04
Tulasi	1.32±0.02	1.04±0.05	0.26± 0.01	0.11±0.04	1.56±0.03	1.13±0.04
N-22	1.73±0.06	1.61±0.04	0.38± 0.03	0.41±0.01	2.08±0.03	1.98±0.05
	SEM±	CD at 5 %	SEM±	CD at 5 %	SEM±	CD at 5 %
Treatment(T)	0.012	0.034	0.008	0.022	0.017	0.047
Genotype(G)	0.043	0.120	0.027	0.077	0.058	0.162
T×G	0.060	0.171	0.038	0.109	0.082	0.230

Table 16 (b): Effect of heat stress on chlorophyll content (mg/g fr.wt.) at early seed filling stage of different rice genotypes

Genotypes	Chlorophyll 'a'		Chlorophyll 'b'		Total Chlorophyll	
	Control	Heat	Control	Heat	Control	Heat
IET 23339	0.87±0.05	0.70±0.00	0.06±0.02	0.01±0.01	0.91±0.06	0.70±0.01
IET 23354	0.94±0.04	0.65±0.03	0.07±0.04	0.08±0.02	0.99±0.06	0.72±0.02
IET 23356	0.69±0.03	0.60±0.01	0.13±0.01	0.08±0.01	0.80±0.04	0.67±0.02
IET 23392	0.93±0.02	0.80±0.03	0.06±0.04	0.05±0.02	0.98±0.06	0.83±0.02
IET 23947	0.70±0.01	0.61±0.01	0.12±0.02	0.06±0.00	0.81±0.03	0.65±0.01
IET 23949	0.88±0.01	0.68±0.03	0.13±0.04	0.06±0.01	1.00±0.05	0.72±0.03
IET 23951	1.14±0.02	0.94±0.02	0.09±0.02	0.07±0.01	1.21±0.00	0.99±0.03
IET 23957	0.78±0.01	0.66±0.02	0.06±0.03	0.06±0.00	0.83±0.04	0.70±0.02
IET 23976	0.05±0.01	0.91±0.02	1.21±0.01	0.05±0.00	1.24±0.01	0.94±0.02
IET 23979	0.01±0.01	0.68±0.02	1.19±0.02	0.07±0.02	1.20±0.02	0.74±0.03
IET 23996	0.03±0.01	0.98±0.07	1.45±0.02	0.17±0.04	1.48±0.02	1.13±0.10
IET 24075	0.70±0.33	0.40±0.34	0.44±0.40	0.67±0.26	1.13±0.07	1.06±0.07
IET 24082	0.95±0.01	0.84±0.06	0.05±0.01	0.02±0.01	0.98±0.02	0.84±0.05
DRRH-106	1.05±0.02	0.85±0.06	0.12±0.02	0.05±0.01	1.15±0.04	0.89±0.07
DRRH-107	1.25±0.05	1.03±0.08	0.24±0.02	0.18±0.01	1.47±0.06	1.20±0.07
DRRH-108	1.10±0.03	0.83±0.02	0.13±0.01	0.14±0.01	1.21±0.04	0.96±0.03
Govind	0.97±0.09	0.82±0.03	0.23±0.05	0.12±0.01	1.18±0.09	0.93±0.04
NDR-97	1.27±0.05	0.91±0.11	0.25±0.01	0.26±0.09	1.50±0.06	1.15±0.06
PA-6129	1.29±0.05	0.90±0.01	0.28±0.01	0.08±0.01	1.55±0.07	0.96±0.02
PHY-1	0.67±0.03	0.52±0.03	0.11±0.01	0.08±0.00	0.76±0.03	0.59±0.02
PHY-2	0.77±0.01	0.57±0.01	0.04±0.00	0.06±0.00	0.79±0.01	0.62±0.01
Sabagidhan	0.65±0.02	0.51±0.02	0.12±0.00	0.09±0.00	0.76±0.02	0.58±0.02
Tulasi	0.87±0.02	0.72±0.01	0.18±0.02	0.12±0.01	1.03±0.03	0.83±0.02
N-22	1.17±0.06	1.00±0.00	0.18±0.01	0.14±0.01	1.33±0.06	1.12±0.01
	SEM±	**CD at 5 %**	**SEM±**	**CD at 5 %**	**SEM±**	**CD at 5 %**
Treatment(T)	0.015	0.044	0.014	0.041	0.010	0.026
Genotype(G)	0.055	0.155	0.051	0.145	0.032	0.090
T×G	0.078	0.219	0.073	0.205	0.045	0.127

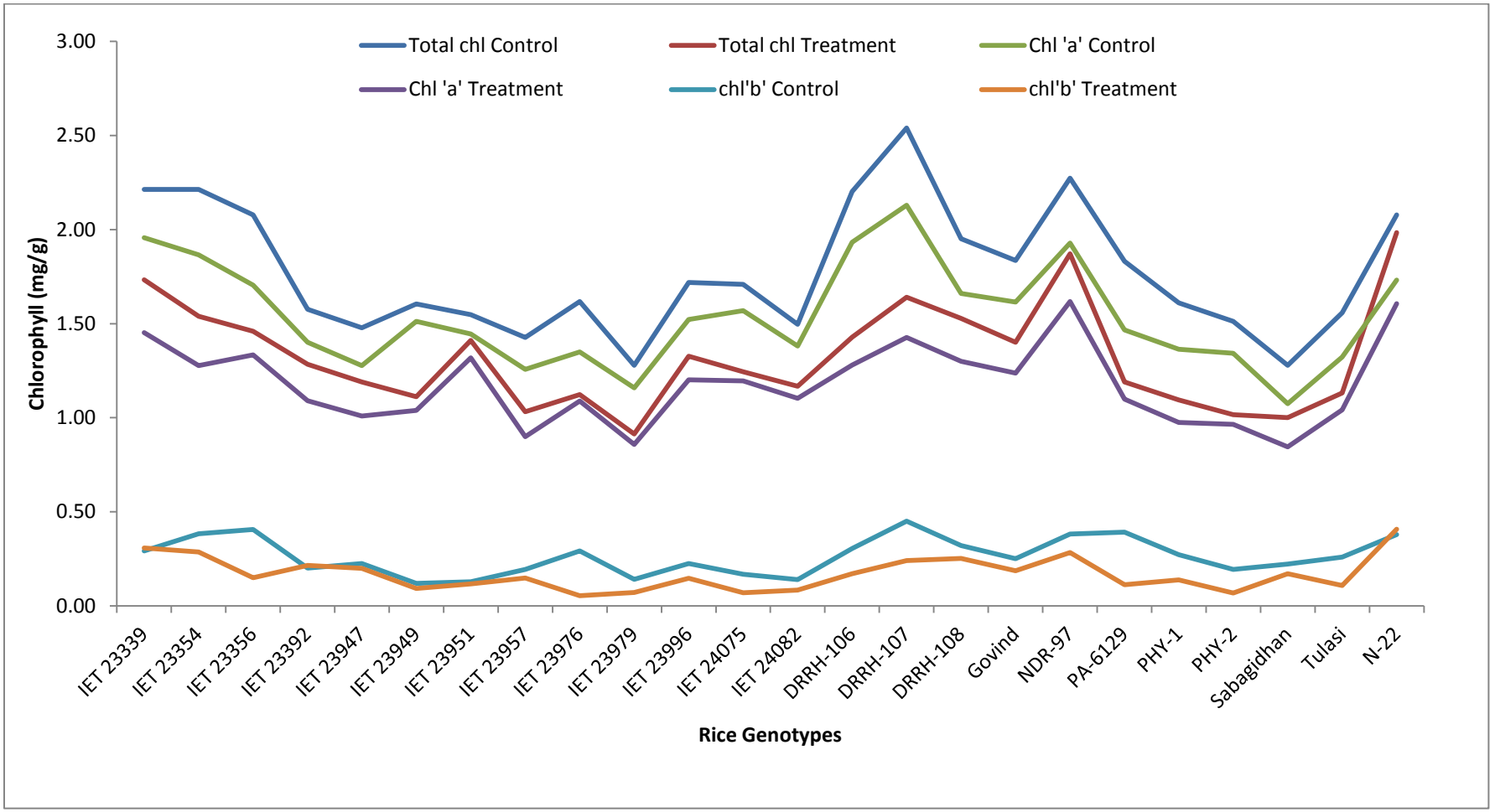


Fig.17: Effect of heat stress on chlorophyll content (mg/g fresh weight) at flowering of different rice genotypes

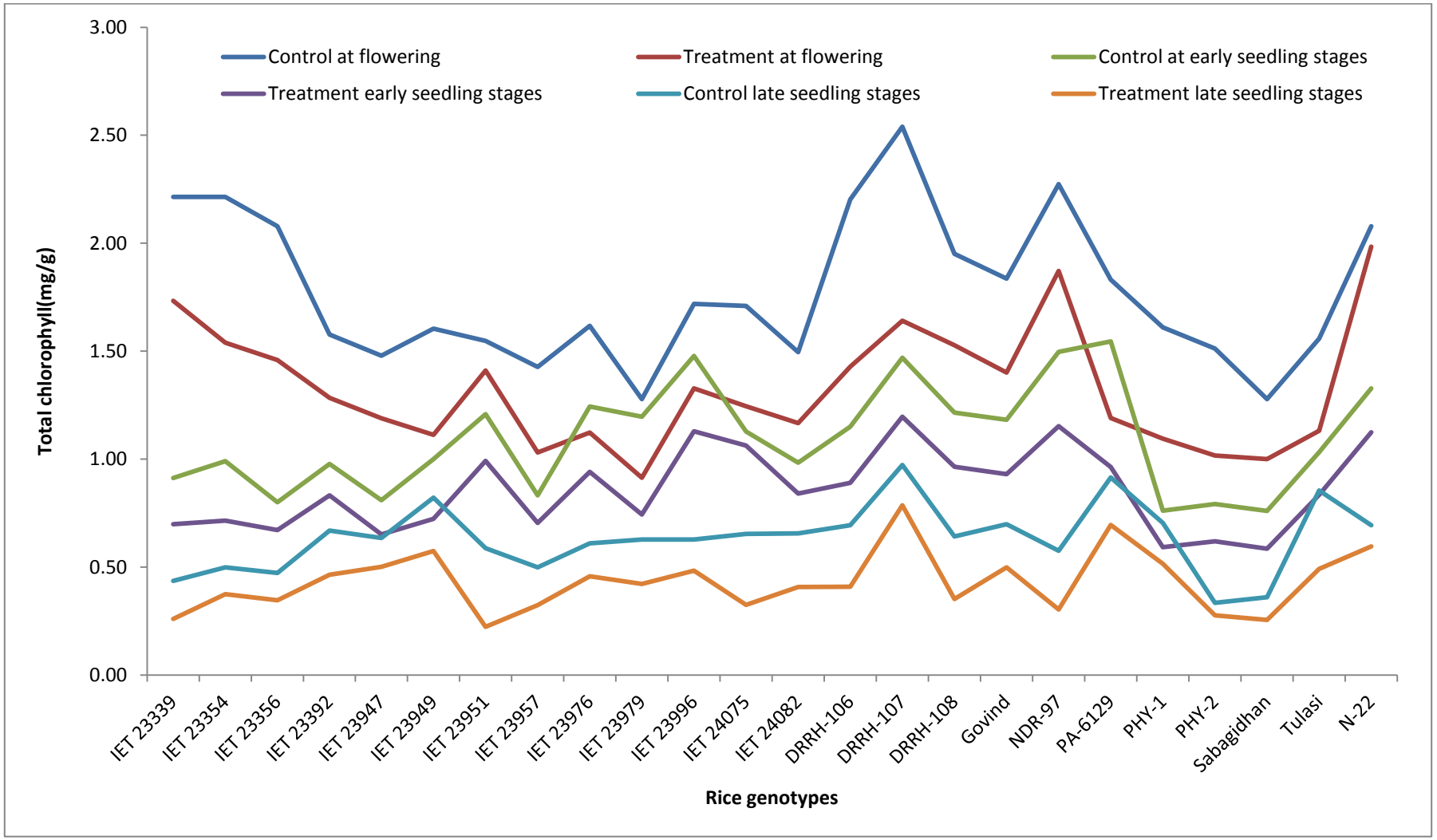


Fig.18: Effect of heat stress on total chlorophyll content (mg/g fresh weight) at different three stages of rice genotypes

Table 16(c): Effect of heat stress on chlorophyll content (mg/g fr.wt.) at late seed filling stage of different rice genotypes

GENOTYPES	Chlorophyll 'a'		Chlorophyll 'b'		Total Chlorophyll	
	Control	Heat	Control	Heat	Control	Heat
IET 23339	0.34±0.01	0.23±0.01	0.10±0.01	0.03±0.00	0.44±0.02	0.26±0.01
IET 23354	0.40±0.02	0.29±0.01	0.11±0.02	0.09±0.01	0.50±0.03	0.37±0.00
IET 23356	0.40±0.02	0.26±0.01	0.08±0.01	0.09±0.01	0.47±0.03	0.35±0.01
IET 23392	0.57±0.01	0.38±0.03	0.11±0.00	0.09±0.02	0.67±0.01	0.46±0.02
IET 23947	0.55±0.02	0.40±0.00	0.10±0.00	0.11±0.01	0.64±0.02	0.50±0.01
IET 23949	0.71±0.02	0.47±0.02	0.13±0.04	0.12±0.02	0.82±0.03	0.57±0.01
IET 23951	0.49±0.01	0.20±0.01	0.10±0.02	0.03±0.01	0.59±0.03	0.22±0.02
IET 23957	0.41±0.02	0.25±0.00	0.09±0.01	0.08±0.01	0.50±0.02	0.32±0.00
IET 23976	0.54±0.01	0.40±0.01	0.08±0.00	0.07±0.01	0.61±0.01	0.46±0.01
IET 23979	0.54±0.01	0.37±0.01	0.09±0.01	0.06±0.01	0.63±0.02	0.42±0.02
IET 23996	0.53±0.02	0.41±0.00	0.11±0.00	0.08±0.00	0.63±0.01	0.48±0.00
IET 24075	0.53±0.01	0.31±0.02	0.14±0.00	0.02±0.00	0.65±0.01	0.32±0.02
IET 24082	0.57±0.00	0.35±0.03	0.09±0.01	0.07±0.02	0.66±0.01	0.41±0.04
DRRH-106	0.60±0.02	0.37±0.02	0.11±0.01	0.05±0.01	0.69±0.02	0.41±0.02
DRRH-107	0.82±0.03	0.68±0.01	0.17±0.02	0.11±0.00	0.97±0.05	0.79±0.01
DRRH-108	0.53±0.01	0.27±0.00	0.12±0.01	0.09±0.00	0.64±0.01	0.35±0.00
Govind	0.60±0.06	0.43±0.01	0.11±0.01	0.07±0.03	0.70±0.07	0.50±0.04
NDR-97	0.46±0.02	0.25±0.02	0.13±0.02	0.06±0.02	0.58±0.03	0.30±0.04
PA-6129	0.77±0.02	0.58±0.01	0.16±0.01	0.12±0.01	0.92±0.04	0.70±0.02
PHY-1	0.63±0.02	0.43±0.01	0.09±0.01	0.09±0.01	0.70±0.01	0.52±0.01
PHY-2	0.28±0.01	0.22±0.01	0.06±0.01	0.06±0.00	0.33±0.02	0.28±0.01
Sabagidhan	0.30±0.02	0.21±0.01	0.07±0.00	0.05±0.01	0.36±0.02	0.26±0.01
Tulasi	0.72±0.01	0.45±0.01	0.15±0.01	0.05±0.01	0.85±0.02	0.49±0.02
N-22	0.61±0.03	0.53±0.02	0.09±0.00	0.07±0.02	0.69±0.03	0.60±0.04
	SEM±	CD at 5 %	SEM±	CD at 5 %	SEM±	CD at 5 %
Treatment(T)	0.003	0.009	0.002	0.007	0.005	0.013
Genotype(G)	0.012	0.034	0.009	0.025	0.016	0.046
T×G	0.017	0.048	0.012	0.036	0.087	0.065

Table 17: The effect of heat stress on grain protein content at harvest of different rice genotypes

Genotypes	Grain protein content of rice genotypes (mg/g freshwt.)	
	Control	Treatment
IET 23356	69.60±6.43	75.51±3.86
IET 23947	76.48±1.98	78.21±3.03
IET 23951	53.40±5.25	60.76±1.44
IET 24082	60.21±4.06	93.64±2.08
DRRH-107	63.34±3.70	87.16±3.82
DRRH-108	72.18±6.11	77.75±3.07
NDR-97	76.94±3.94	73.20±5.86
PA-6129	59.92±1.98	75.64±3.74
PHY-2	48.17±2.49	68.26±3.43
N-22	87.50±3.43	95.59±3.27
	S. Em±	**CD at 5%**
Treatment (T)	0.240	0.689
Genotype (G)	0.538	1.542
T×G	0.761	2.181

Table 18: The effect of heat stress on grain amylose content at of different rice genotypes

Genotypes	Grain amylose content (%) of rice genotypes		
	Control	Treatment	Reduction (%)
IET 23356	20.01±0.95	11.32±0.83	43.43
IET 23947	20.84±0.76	11.16±1.12	46.46
IET 23951	24.15±0.26	10.97±1.70	54.59
IET 24082	23.45±0.73	13.86±0.76	40.87
DRRH-107	24.10±1.22	14.96±1.55	37.92
DRRH-108	21.75±1.79	18.85±1.45	13.35
NDR-97	23.23±0.83	19.64±1.80	15.46
PA-6129	25.17±0.95	15.62±1.01	37.93
PHY-2	23.80±0.69	15.54±1.54	34.69
N-22	23.63±0.72	18.45±0.80	21.90
	Treatment (T)	**Genotypes (G)**	**T×G**
S. Em±	0.494	1.106	1.564
CD at 5 %	1.416	3.166	4.478

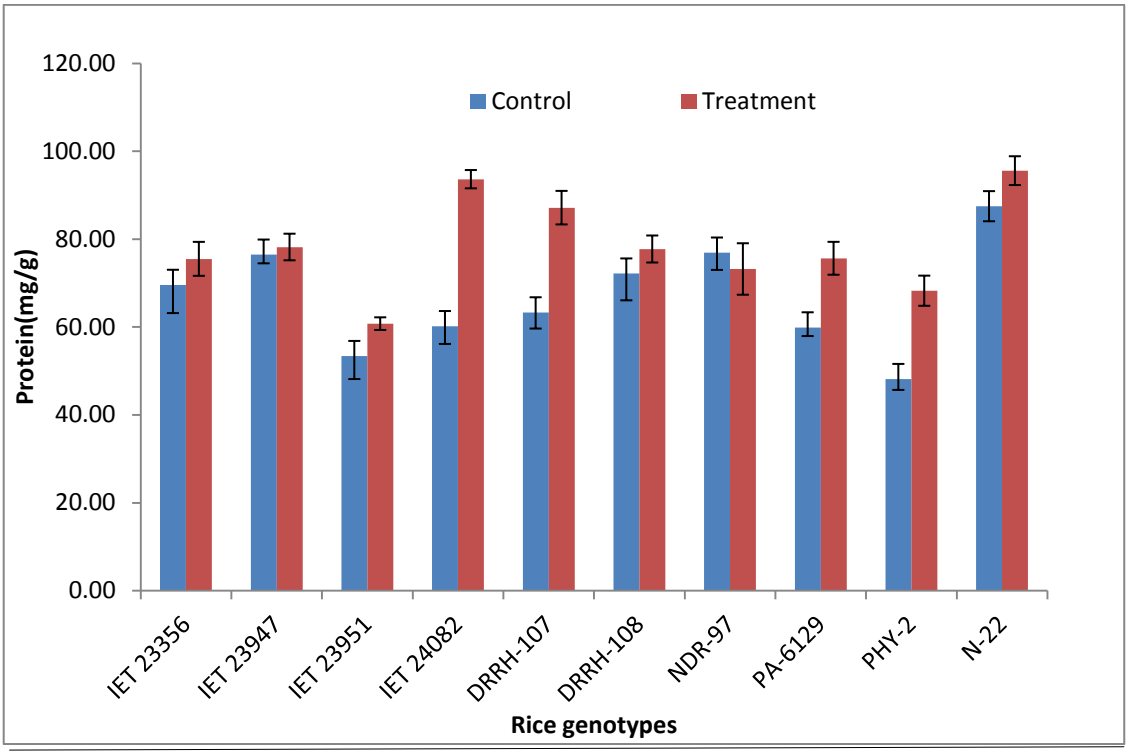


Fig. 19: Effect of heat stress on grain protein content (mg/g fr. wt.) of different rice genotypes

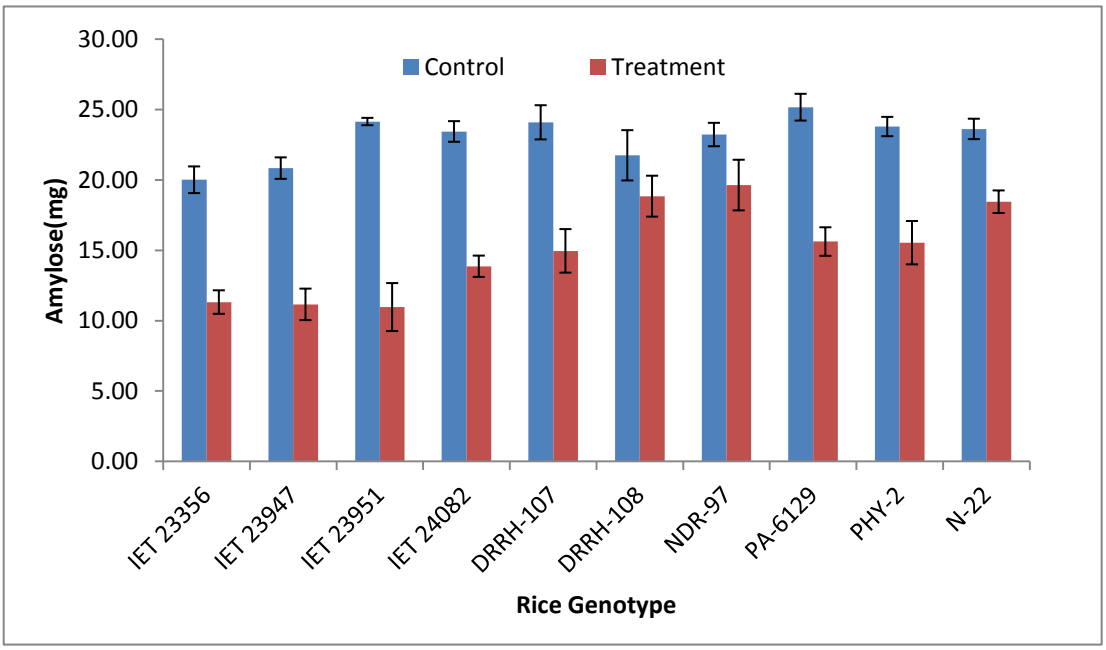


Fig. 20: Effect of heat stress stress on grain amylose content (%) of different rice genotypes

Genotypes	Days to flowering		Days to maturity	
	Control	Treatment	Control	Treatment
IET 23339	85	85	115	116
IET 23354	92	92	124	123
IET 23356	94	93	120	120
IET 23392	93	93	125	125
IET 23947	91	90	125	124
IET 23949	85	86	121	121
IET 23951	86	87	120	122
IET 23957	94	94	124	123
IET 23976	87	87	122	124
IET 23979	89	89	123	124
IET 23996	88	89	125	124
IET 24075	86	86	122	122
IET 24082	91	91	122	124
DRRH-106	86	86	123	122
DRRH-107	95	94	124	124
DRRH-108	95	95	124	123
Govind	81	80	100	100
NDR-97	82	83	114	113
PA-6129	84	84	104	105
PHY-1	97	97	141	141
PHY-2	95	96	138	138
Sabagidhan	97	98	126	126
Tulasi	101	100	136	136
N-22	74	75	94	95

Table 19: Days to flowering and days to maturity in different rice genotypes

branching enzyme (BEIIb), respectively**(Yamakawa *et al*., 2007).**

4.2.3 Effect of heat stress on grain protein content (mg/g) at harvest of rice genotypes

Under heat treatment the protein content (mg/g) of rice grain at harvest was increased for all the rice genotypes. The maximum protein content was found in rice genotype namely N22 (19.12 mg/g) under heat treatment and minimum in rice genotype namely IET 23951(12.15 mg/g). It was statistically significant for treatment (T), but non-significant for genotypes (G) and T×G interactions. Several reviews have indicated that heat stress increases protein contents **(Thitisaksakul *et al*., 2012; Wang and Frei, 2011).** Heat stress increased the protein contents of grains for all the maize varieties, and the increments were higher during the early grain filling stage than during the late grain filling stage. Only protein content in Yunuo7 was similar between the heat stress treatments at early and late stages of grain filling. Similar results have been observed in rice. Higher protein contents were accompanied by lower grain weights and decreased starch accumulation **(Zhang *et al*., 2006).**

Summary and Conclusions

Chapter 5 SUMMARY AND CONCLUSION

The present investigation entitled (Influence of high temperature stress on morpho - physiological characteristics in rice genotypes (*Oryza sativa* L.*)* was performed at Norman E. Bourlog Crop Research Centre of the G. B. Pant University of Agriculture and Technology, Pantnagar, during kharif season of 2015. The salient findings of the experiment are summarized in this chapter.

1. At flowering stage, leaf length (cm) was found maximum in rice genotype namely PHY-1 (56.32 cm) and minimum in rice genotype namely Govind (36.67 cm) under control conditions. Similarly, in heat stress treatment rice genotype namely PHY-1(54.41 cm) showed the maximum and rice genotype namely Govind (35.80 cm) attained minimum plant leaf length. In rice genotype Govind it was decreased (2.37%) under heat treatment as compared to control and in rice genotype namely DRRH-107 it was increased (11.84%) under heat treatment as compared to control.

2. At flowering stage, DRRH-108(1.53cm) attained highest leaf width in both control and heat treatment while rice genotype namely Govind recorded minimum width (0.97cm). In rice genotype Govind it was decreased (3.67%) under heat treatment as compared to control but highest decrease was recorded in rice genotype namely IET 23392 (13.29%) under heat treatment as compared to control and it was increased in rice genotype namely DRRH-106(6.59%) under heat treatment as compared to control.

3. The reduction in leaf area was found in 11 genotypes under heat stress, as compared to control. Under control condition leaf area (cm^2) at flowering was highest in rice genotype namely DRRH-107 (50.12cm^2) and the minimum in rice genotype namely Govind (27.75 cm^2). Similarly, in heat stress treatment rice genotype namely DRRH-107(55.51cm^2) attained the maximum and rice genotype namely Govind (26.09cm^2) attained minimum leaf area (cm^2). In Rice genotype IET 23392 leaf area was reduced (13.21%) under heat stress as compared to control but in IET 23951 it was increased (10.99%) under heat treatment as compared to control.

4. Under heat stress treatment the leaf dry weight (mg) increased in 9 rice genotypes while reduction in the leaf dry weight was observed in rest 15 rice genotypes. The maximum leaf dry weight (mg) was observed in rice genotype namely PHY-1 (276.87mg) and minimum in rice genotype namely Govind (158.89 mg) under heat treatment, but in control rice genotype namely IET 23976 recorded lowest (153.96 mg) leaf dry weight. In rice genotype namely PHY-2 leaf dry weight (mg) reduced (22.15%) under heat stress as compared to control.

5. Under heat treatment the number of tillers per plant at flowering stage was increased in 14 rice genotypes while it decreased in rest of the genotypes. The maximum tillers per plant were observed in rice genotype namely PA-6129 (7.33) also highest in control condition and minimum was found in rice genotype namely Tulasi (3.50) under heat treatment. IET 23947 have around equal no of tiller (4.83) in control as well as heat treatment. In IET 23979, tiller number was increased (32.26%) under heat stress as compared to control.

6. Under heat treatment the stem dry weight (g) per plant at flowering was increased in 9 rice genotypes but decreases in IET 23947, IET 23949, IET 23951, IET 23957, IET 23976, IET 23996, DRRH-106, DRRH-107, DRRH-108, GOVIND, NDR-97, PHY-1, PHY-2, TULASI and N22 rice genotype. The maximum stem dry weight (g) per plant was observed in rice genotype namely PHY-1(20.93g) in treatment but also highest (22.44g) in control whereas minimum stem dry weight per plant was found in rice genotype namely Govind (6.08g) under heat treatment. In rice genotype IET 23976 it was decreased (45.79%) under heat treatment as compared to control.

7. Under heat treatment the stem dry weight (g) per plant at harvest was reduced in 13 rice genotypes and increased in other IET 23339, IET 23354, IET 23356, IET 23949, IET 23979, IET 24075, DRRH-106, DRRH-107, DRRH-108, GOVIND, and in NDR-97.The maximum stem dry weight during harvest was observed in rice genotype PHY-1(16.53g) and minimum was in rice genotype namely Govind (5.88g) under heat treatment. In rice genotype IET 23976 it was decreased (34.35%) under heat treatment as compared to control.

8. The stem dry weight (g/m^2) was recorded by removing leaves and panicle from the plant of rice genotypes at the time of flowering stage. Under heat treatment the stem dry weight (g/m^2) decreased in 20 rice genotypes IET 23339, IET 23354, IET 23356 ,IET 23392, IET 23947, IET 23949, IET 23951, IET 23957, IET 23976, IET 23996, IET 24075, IET 24082, DRRH-106 ,DRRH-107 ,DRRH-108, NDR-97, PHY-1, PHY-2 , Tulasi, N22 while it increased in rest of the genotypes. The maximum stem dry weight (g/m^2) was observed in rice genotype PHY-1(1014.37) and the minimum stem weight (g/m^2) in IET 23976 (319.63) under heat treatment.

9. Under heat treatment the stem dry weight (g/m^2) at harvest decreased in 16 rice genotypes IET 23356 ,IET 23392, IET 23947, IET 23951, IET 23957, IET 23976, IET 23996, , IET 24082, DRRH-106 ,DRRH-107 ,DRRH-108 ,GOVIND, PHY-1, PHY-2 ,SABAGIDHAN, TULASI, N22 while it increased in rest of the genotypes. The maximum stem dry weight (g/m^2) at harvest was observed in rice genotypes, PHY-1 (1111.81) in control and (893.61) in treatment and the minimum stem weight (g/m^2) in Tulasi and N22 (277.08) almost same under heat treatment.

10. Specific leaf area (SLA) is the total area of a leaf area divided by its leaf mass. Under heat treatment the specific leaf area (cm^2/mg) was increased in 10 rice genotypes IET 23339, IET 23356, IET 23392, IET 23949, IET 23957, IET 23976, IET 23979, IET 23996, Govind and N22 while it decreased in rest of the genotypes. The maximum specific leaf area observed in rice genotype namely IET 23392 (6.83) and minimum was in rice genotype namely N22 (3.85) under heat treatment

11. Under heat treatment the specific leaf weight (mg/cm^2) was increased in 14 rice genotypes namely IET 23354, IET 23947, IET 23951, IET 23957, IET 24075, IET 24082, DRRH-106, DRRH-107, DRRH-108, NDR-97, PA-6129, PHY-1, PHY-2, Sabagidhan and Tulasi, while it decreased in rest of the genotypes. The maximum specific leaf weight was found in rice genotype namely N22 (0.26) and minimum in rice genotype namely IET 23392, IET 23349 (0.15) under heat treatment.

12. Under heat treatment the panicle dry weight (g) at flowering decreased for 15 rice

genotypes IET 23339, IET 23356 ,IET 23392, IET 23976, IET 23996, IET 24075, IET 24082, DRRH-107, DRRH-108, NDR-97 ,PA-6129, PHY-1, Sabagidhan, Tulasi, N22.The maximum panicle dry weight was observed in rice genotypes IET 23354, (1.17g) and minimum in IET 23392 (0.62g) under heat treatment. In rice genotype Govind it was increased (34.29%) under heat treatment as compared to control and in IET 23976 it was decreased (40.28%) under heat treatment as compared to control.

13. Under heat treatment the panicle dry weight (g) one week after flowering decreased in almost all 21 rice genotypes but small increase in 3 rice genotype IET 23354, IET 23949, PHY-1 and The maximum panicle dry weight (g) was observed in rice genotype IET 23354 (1.57) and minimum panicle weight was found in IET 23996 (0.97) under heat treatment. In rice genotype IET 23949 it was increased (33.02%) under heat treatment as compared to control and in DRRH-108 it was decreased (40.34%) under heat treatment as compared to control.

14. Under heat treatment the panicle dry weight (g) at maturity stage was decreased in all the rice genotypes. The maximum panicle weight was observed in rice genotype DRRH-107 (4.44) in control and (3.33) in heat treatment and minimum in Govind (1.80) under heat treatment. In rice genotype IET 23957 it was increased (38.34%) under heat treatment as compared to control.

15. Under heat treatment the total dry matter (leaf+stem) at flowering increased in two rice genotypes namely IET23979 and PA-6129 and decreased in rest of genotype. The maximum TDM (leaf+stem) was recorded in rice genotype namely PHY-1(1232.59) and minimum was in IET 23976 (415.54) under heat treatment. In rice genotype namely IET 23339 it was increased (16.48%) under heat treatment as compared to control and in Tulasi it was decreased (39.61%) under heat treatment as compared to control.

16. Under heat treatment the 1000-grain weight (g) decreased for all the rice genotypes. The maximum 1000-grain weight was found in rice genotype namely IET 23354 (28.19g) under heat treatment and the minimum was in rice genotype namely DRRH-108 (17.64g).

In DRRH-108 it was decreased (19.28%) under heat treatment as compared to control.

17. Under heat treatment the number of filled grains per panicle at harvest decreased for all the rice genotypes. The maximum number of filled grains was found in rice genotype DRRH-108(177.33) under heat treatment and minimum was found in rice genotype namely IET 23979(44). In IET 23979 it was decreased (43.49%) under heat treatment as compared to control.

18. Under heat treatment the number of unfilled grains per panicle at harvest increased in all the rice genotypes. The maximum number of unfilled grains was found in rice genotype namely IET 23949 (90.67) under heat treatment and minimum was in rice genotype namely N 22 (16.00). In rice genotype namely DRRH-106 it was increased (479.55%) under heat treatment as compared to control.

19. Under heat treatment the grain yield per plant (g) at harvest decreased in all the rice genotypes. The maximum grain yield per plant was in rice genotype namely DRRH-107 (18.91) under heat treatment and the minimum was in rice genotype namely Tulasi (8.36). In rice genotype namely IET 23957 it was decreased (47.78%) under heat treatment as compared to control.

20. Under heat treatment the grain yield (g/m^2) at harvest decreased in all the rice genotypes. The maximum grain yield (g/m^2) was found in rice genotype namely DRRH-107 (1149.07 g/m^2) under heat treatment and the minimum was in rice genotype namely Tulasi (339.52 g/m^2). In rice genotype Tulasi it was decreased (45.03%) under heat treatment as compared to control.

21. Under heat treatment TDM (g/m2) under heat treatment decreased for all the rice genotypes. The maximum TDM was found in rice genotype namely PHY-1(2175.93 g/m^2) under heat treatment and minimum in rice genotype namely N 22 (972.22 g/m^2). In rice genotype namely DRRH-107 it was decreased (26.79%) under heat treatment as compared to control.

22. Under heat treatment the total chlorophyll content (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum total chlorophyll content was found in rice genotype namely N22 (1.98 mg/g fresh weight) under heat treatment and minimum in rice genotype namely IET 23979 (0.91 mg/g fresh weight). Under heat treatment the Chlorophyll "a" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "a" was found in rice genotype NDR-97 (1.62 mg/g fresh weight) under heat treatment while minimum in rice genotype namely Sabagidhan (0.85 mg/g fresh weight). Under heat treatment the chlorophyll "b" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "b" was found in rice genotype N 22 (0.41 mg/g fresh weight) under heat treatment and minimum in rice genotype namely IET 23976 (0.05 mg/g fresh weight).

23. Under heat treatment the total chlorophyll content (mg/g fresh weight) at early seedling stages decreased for all the rice genotypes. The maximum total chlorophyll content was found in rice genotype namely rice genotype namely DRRH-107 (1.20 mg/g fresh weight) under heat treatment and minimum in rice genotype namely Sabagidhan (0.58 mg/g fresh weight). Under heat treatment the chlorophyll "a" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "a" was found in rice genotype namely DRRH-107 (1.03 mg/g fresh weight) under heat treatment minimum in rice genotype namely IET 24075 (0.40 mg/g fresh weight). Under heat treatment the chlorophyll "b" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "b" was found in rice genotype IET 24075 (0.67 mg/g fresh weight) under heat treatment and minimum in rice genotype namely IET 23339 (0.01 mg/g fresh weight).

24. Under heat treatment the total chlorophyll content (mg/g fresh weight) at late seedling stages decreased for all the rice genotypes. The maximum total chlorophyll content was found in rice genotype namely DRRH-107 (0.79 mg/g fresh weight) under heat treatment and minimum in rice genotype namely IET 23951 (0.22 mg/g fresh weight). Under heat treatment the Chlorophyll "a" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "a" was found in rice genotype DRRH-107 (0.68 mg/g fresh weight) under heat treatment minimum in rice genotype

namely IET 23951 (0.20 mg/g fresh weight). Under heat treatment the chlorophyll "b" (mg/g fresh weight) at flowering decreased for all the rice genotypes. The maximum chlorophyll "b" was found in rice genotypes namely IET 23949, PA-6129 (0.20 mg/g fresh weight)

25. Under heat treatment the amylose content (%) of rice grain at harvest decreased for all the rice genotypes. The maximum amylose content was found in rice genotype namely NDR-97 (19.64 %) under heat treatment and minimum in rice genotype namely IET 23951 (10.97 %). The maximum amylose (%) decreased in rice genotype namely IET 23951 (54.59 %) under heat treatment and minimum in rice genotype namely DRRH-108 (13.35 %).

26. Under heat treatment the protein content (mg/g) of rice grain at harvest increased for all the rice genotypes except NDR-97. The maximum protein content was found in rice genotype namely N-22 (95.59 mg/g) under heat treatment and minimum in rice genotype namely IET 23951(60.76 mg/g). In rice genotype PHY-2 it was decreased (41.74%) under heat treatment as compared to control.

Conclusion

Heat stress reduced leaf area, stem dry weight at harvest, panicle dry weight, 1000-grain weight, and number of filled grain, fertility (%) of panicle, grain yield, total dry matter production, chlorophyll content and amylose content of different rice genotypes. While heat stress in few rice genotypes increased stem dry weight per plant at flowering. Total dry matter (leaf and stem) at flowering, and number of unfilled grains and protein content of different rice genotypes. Out of twenty four genotypes of rice, the ten rice genotypes namely IET 23356, IET 23947, IET 23951, IET 24082, DRRH-107, DRRH-108, NDR-97, PA-6129, PHY-2 and N 22 performed better under heat stress treatment under the poly sheet tunnel in tiller numbers per plant, filled grains per panicle, fertility (%) and grain yield as compared to rest of different rice genotypes. These tolerant rice genotypes can further be explored for the molecular mechanism, responsible for heat tolerance and breeders can use them in their experimental methods to incorporation of tolerant traits and development of heat tolerant verities.

Literature Cited

LITERATURE CITED

Adams, R.P., Flournoy, L.E., Singh, R.L., Johnson, H. and Mayeux, H. 1998. Invasion of grasslands by Juniperus ashei: a new theory based on random amplified polymorphic DNAs (RAPDs). *Biochem. Syst. Ecol*, **26:** 371–377.

Afuakwa, J.J. and Crookston, R.K. 1984. Using the kernel milk line to visually monitor grain maturity in maize. *Aust. J. Crop Sci*., **24(4):** 687-691.

Ahamed, K.U., Nahar, K. and Fujita, M. 2010. Sowing date mediated heat stress affects the leaf growth and dry matter partitioning in some spring wheat (*Triticum aestivum* L.) cultivars. *IIOAB J.* **1:** 3.

Al-Khatib, K. and Paulsen, G.M. 1999. High-temperature effects on photosynthetic processes in temperate and tropical cereals. *Aust. J. Crop Sci.*, **39(1):** 119-125.

Almeselmani, M., Deshmukh, P.S., Sairam, R.K., Kushwaha, S.R. and Singh, T.P. 2006. Protective role of antioxidant enzymes under high temperature stress. *Plant Sci*. **171:** 382-388.

Altenbach, S.B., DuPont, F.M., Kothari, K.M., Chan, R., Johnson, E.L. and Lieu, D. 2003. Temperature, water and fertilizer influence the timing of key events during graindevelopment in US spring wheat. *J. Cereal Sci.*, **37:** 9–20.

Asaoka, M., Okuno, K., Sugimoto, Y. and Fuwa, H. 1985. Developmental changes in the structure of endosperm starch of rice (*Oryza sativa* L.*). Int. J. Agric. Biol. Eng*., **49(7):** 1973-1978.

Bahuguna, R.N. and Jagadish, K.S. 2015. Temperature regulation of plant phonological development. *Environ. Exp. Bot.*, **111:** 83-90.

Baker, J.T., Allen, L.H.Jr. and Boote, K.J. 1990. Growth and yield response of rice to carbon dioxide concentration. *J. Agri. Sci.,* **115:** 313–320.

Baker, J.T., Allen, L.H.Jr. and Boote, K.J. 1992. Response of rice to carbon dioxide and temperature. *Agri. For. Meteorol*, **60:** 153–166.

Battisti, D.S. and Naylor, R.L. 2009. Historical warnings of future food insecurity with unprecedented seasonal heat. *Science,* **323(5911):** 240-244.

Cairns, J.E., Sonder, K., Zaidi, P.H., Verhulst, N., Mahuku, G. and Babu, R. 2012. Maize production in a changing climate: Impacts, adaptation, and mitigation strategies. In S. ADonald (Ed.), Advances in Agronomy Burlington: Academic Press. **114:** 1-58.

Camejo, D., Rodríguez, P., Morales, M.A., Dell'Amico, J.M., Torrecillas, A. and Alarcón, J. J. 2005. High temperature effects on photosynthetic activity of two tomato cultivars with different heat susceptibility. *J. plant physiol.,* **162(3):** 281-289**.**

Cao, Y., Yang, Z., Xu, C., Li, X., Wang, S. and Zhang, Q. 2001. Xa26, a gene conferring resistance to Xanthomonas oryzae pv. oryzae in rice, encodes an LRR receptor kinase-like protein. *J. Plant Sci.*, **37(4):** 517-527.

Carter, G.A. and Spiering, B.A. 2002. Optical properties of intact leaves for estimating chlorophyll concentration. *J. Environ Qual.,* **31(5):** 1424-1432.

Cechin, I., Rossi, S.C., Oliveira, V.C. and Fumis, T.F. 2006. Photosynthetic responses and proline content of mature and young leaves of sunflower plants under water deficit. *Photosyn.* **44:** 143-146.

Cellier, F., Conejero, G., Breitler, J.C. and Casse, F. 1998. Molecular and physiological responses to water deficit in drought tolerant and drought sensitive lines of sunflower: Accumulation of dehydrin transcripts correlates with tolerance. *J. Plant Physiol.*, **116(1):** 319-328.

Chakrabarti, B., Aggarwal, P.K., Singh, S.D., Nagarajan, S. and Pathak, H. 2010. Impact of high temperature on pollen germination and spikelet sterility in rice: comparison between basmati and non-basmati varieties. *Crop Past. Sci.*, **61(5):** 363-368.

Chaudhary, T.N. and Ghildyal, B.P. 1970. Influence of submerged soil temperature regimes on growth, yield, and nutrient composition of rice plant. *J. Agronomy,* **62(2):** 281-285.

Chauhan, H., Khurana, N., Agarwal, P. and Khurana, P. 2011. Heat shock factors in rice (*Oryza sativa* L.): Genome-wide expression analysis during reproductive development and abiotic stress. *Mol. Genet. Genom***, 286:** 171–187.

Chen, X., Lin, S., Liu, Q., Huang, J., Zhang, W., Lin, J., Wang, Y., Ke, Y. and Huaqin, H., 2014. Expression and interaction of small heat shock proteins (sHsps) in rice in response to heat stress, *Biochimicaet Biophysica Acta,* **1844**: 818-828.

Cho, J. and Oki. T. 2012. Application of temperature, water stress, CO_2 in rice growth modules. *Rice*, **5**: 10.

Christiansen, M.N. 1978. The physiology of plant tolerance to temperature extremes. In "Crop Tolerance to Suboptimal land Conditions" (Ed. G.A. Jung), 173–191. American Society of Agronomy, Madison, WI.

Commuri, P.D. and Jones, R.J. 1999. Ultrastructural characterization of maize (*Zea mays* L.) kernels exposed to high temperature during endosperm cell division. *Plant Cell Environ.*, **22(4)**: 375-385.

Commuri, P.D. and Jones, R.J. 2001. High temperatures during endosperm cell division in maize. *Crop Sci.* **41:** 1122–1130.

Cooper, N.T.W., Siebenmorgen, T.J. and Counce, P.A. 2008. Effects of nighttime temperature during kernel development on rice physicochemical properties. *Cereal Chem.*, **85(3**): 276-282.

Cooper, N.T.W., Siebenmorgen, T.J., Counce, P.A. and Meullenet, J.F. 2006. Explaining rice milling quality variation using historical weather data analysis. *Cereal Chem.*, **83(4)**: 447-450.

Counce, P.A., Bryant, R.J., Bergman, C.J., Bautista, R.C., Wang, Y.J., Siebenmorgen, T.J., Modenhauer, K.A.K. and Meullenet, J.F.C. 2005. Rice milling quality, grain dimensions,and starch branching as affected by high night temperatures. *Cereal Chem.*, **82:** 645–648.

Cuevas, R.P., Daygon, V.D., Corpuz, H.M., Nora, L., Reinke, R.F., Waters, D.L. and Fitzgerald, M.A. 2010. Melting the secrets of gelatinisation temperature in rice. *Funct. Plant Biol.*, **37(5):** 439-447.

Dekov, I., Tsonev, T. and Yordanov, I. 2000. Effects of water stress and high temperature stress on the structure and activity of photosynthetic apparatus of *Zea mays* and *Helianthus annuus. Photosynthetica*, **38:** 361-366.

Deming, J., Moukadiri, O., Connor, J.E., and Cornejo, M.J. 1995. Phenotypic characterization of the progenies of rice plants derived from cryopreserved calli. *Plant cell reports*, **18(7-8):** 625-632.

Desiraju, S. and Neelamraju, S. 2013. Characterization of a Nagina 22 rice mutant development, dry matter production and some growth characteristics. *Jap. J. Crop*enzyme. *Phytochem.* **63**: 53-59

Dinar, M. and Rudich, J. 1985. Effect of heat stress on assimilate partitioning in tomato. *Ann. Bot.***, 56(2):** 239-248.

Djanaguiraman, M., Prasad, P.V.V. and Al-Khatib, K. 2011. Ethylene perception inhibitor 1- MCP decreases oxidative damage of leaves through enhanced antioxidant defence mechanisms in soybean plants grown under high temperature stress. *Environ. Exp. Bot.* **71:** 215–223.

Egeh, A.O., Ingram, K.T. and Zamora, O.B. 1992. High temperature effects on leaf gas exchange of four rice cultivars. *Philipp. J. Crop Sci.*, **17:** 21–26.

Endo, M., Tsuchiya, T., Hamada, K., Kawamura, S., Yanko, K., Ohshima, M., Higashitani, A.,Watanabe, M. and Kawagishi-Kobayashi, M. 2009. High temperatures cause male sterilityin rice plants with transcriptional alterations during pollen development. *Plant and Cell Physiol*, **50:** 1911–1922.

FAO. 2013. The state of Food Insecurity in the World: Food and Agriculture Organization of the United Nations Rome.

Farrell, A.E., Plevin, R.J., Turner, B.T., Jones, A.D., O'hare, M. and Kammen, D.M. 2006. Ethanol can contribute to energy and environmental goals. *Science*, **311(5760):** 506-508.

Farrell, 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 Research,* **98(2),** 178-194.

Fedina, I.S., Georgieva, K. and Grigorova, I. 2002. Light-dark changes in proline content of barley leaves under salt stress. *Biologia plantarum***, 45(1):** 59-63.

Fisher, R.A., Rees, D., Sayre, K.D., Lu, Z.M., Condon, A.G. and Savedra, A.L. 1998. Wheat yield progress associated with higher stomatal conductance and photosyntheticrate, and cooler canopies. *Crop Sci.*, **38**: 1467-1475.

Fitzgerald, M.A., Bergman, C.J., Resurreccion, A.P., Möller, J., Jimenez, R., Reinke, R.F. and Kuri, V. 2009. Addressing the dilemmas of measuring amylose in rice. *Cereal Chem.*, **86(5):** 492-498.

Fourre, J.L. and Lhoest, J. 1989. Protein synthesis and modification by heat in rice cell culture. *Plant Science*, **61(1):** 69-74.

Frantz, J.M., Pinnock, D., Klassen, S. and Bugbee, B. 2004. Characterizing the environmental response of a gibberellic acid–deficient rice for use as a model crop. *J. Agrono.*, **96(4):** 1172-1181.

Fujimori, M., Soliman, W.S., Tase, K. and Sugiyama, S.I. 2011. Oxidative stress andphysiological damage under prolonged heat stress in C3 grass *Lolium perenne*. *Grassland Sci.***, 57:** 101–106.

Gao, L., Jin, Z., Huang, Y. and Zhang, L. 1992. Rice clock model—a computer model to simulate rice development. *Agri. For. Meteorol,* **60(1):** 1-16.

Giaveno, C. and Ferrero, J. 2003. Introduction of tropical maize genotypes to increasesilage production in the central area of Santa Fe, Argentina. *Crop Breed. App. Biotech***, 3**: 89-94.

Guo-hua, L., Yong-feng, W., Wen-bo, B., Bao, M.A., Chun-yan, W. and Ji-qing, S. 2013. Influence of high temperature stress on net photosynthesis, dry matter partitioning and rice grain yield at flowering and grain filling stages. *J. Inter. Agri.*, **12:** 603-609.

Guttieri, M.J., Stark, J.C., O'Brien, K. and Souza, E., 2001. Relative sensitivity of springwheat grain yield and quality parameters to moisture deficit. *Crop Sci*., **41:** 327-335.

Hakata, M., Kuroda, M., Miyashita, T., Yamaguchi, T., Kojima, M., Sakakibara, H. and Yamakawa, H. 2012. Suppression of α-amylase genes improves quality of rice grainripened under high temperature. *Plant Biotect. J.*, **10(9):** 1110-1117.

Han, B., Zheng, X., Chen, B. and Lu, G. 2009. Overexpression of a NAC transcription factor enhances rice drought and salt tolerance. *Biochem. Biophys. Res. Commun*. **379(4):** 985-989.

Han, Y., Fan, S., Zhang, Q. and Wang, Y. 2013. Effect of heat stress on the MDA, proline and soluble sugar content in leaf lettuce seedling. *Agri. Sci*., **4:** 112-115.

Hare, J.B.M. and Pai, S.V. 1999. Predicting heats of formation of energetic materials using quantum mechanical calculations. *Combust. flame*, **118(3**): 445-458.

Hare, P.D., Cress, W.A. and Staden, J.V. 1998. Dissecting the roles of osmolytes accumulation during stress. *Plant Cell Environ.* **21:** 535-553.

Hasanuzzaman, M., Nahar, K., Alam. M.M., Roychowdhury, R. and Fujita M. 2013. Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. *Int. J. Mol. Sci***., 14**: 9643-9684.

Hasegawa, S., Numata, O., Yazaki, S., Matsunaga, M., Boku, N., & Ino, H., 2000. Influence of emission from rice straw burning on bronchial asthma in children. *Pediatrics International*, **42(2):** 143-150.

Heckathorn, S.A., Ryan, S.L., Baylis, J.A., Wang, D.F., Hamilton, E.W., Cundiff, L. and Luthe, D.S. 2002. In vivo evidence from an *agrostis stolonifera* selection genotype thatchloplast small heat-shock proteins can protect photosystem II during heat stress. *Funct. Plant Biol.*, **29(8):** 935-946.

Hirai, A., Tsuji, H., Tsutsumi, N., Sasaki, T. and Nakazono, M. 2003. Organ-specific expressions and chromosomal locations of two mitochondrial aldehyde dehydrogenase genes from rice (*Oryza sativa* L.), ALDH2a and ALDH2b. *Gene*, **305(2):** 195-204.

Hirano, H.Y., Eiguchi, M. and Sano, Y. 1998. A single base change altered the regulation of the Waxy gene at the posttranscriptional level during the domestication of rice. *Mol. Biol. Evol.*, **15(8):** 978-987.

Hong, M. M .,Wang, Z. Y., Zheng, F. Q., Shen, G. Z., Gao, J. P., Snustad, D. P., & Li, M. G., 1995. The amylose content in rice endosperm is related to the post-transcriptional regulation of the Waxy gene. *Plant J.,* **7(4):** 613-622.

Hosoi, N. and Tamagata, N. 1973. The study of interaction of environmental factors for rice plant heading. *Jpn. J. Breed*., **23:** 110–111.

Hurkman, W.J., Vensel, W.H., Tanaka, C.K., Whitehand, L. and Altenbach, S.B. 2009. Effect of high temperature on albumin and globulin accumulation in the endosperm proteome of the developing wheat grain. *J. Cereal Sci*., **49**: 12–23.

Inaba, K. and Sato, K. 1976. High temperature injury of ripening in rice plant. VI. Enzyme activities of kernel as influenced by high temperature. *Proc. Crop Sci. Soc. Jpn*., **45:** 162–167.

IPCC (Intergovernmental Panel on Climate Change) 2014. Climate change 2007: Impacts, adaptation and vulnerability. (Parry, M.L., Canziani, O.S., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. eds.), In "Contribution of working group 2 to fourth assessment report of the Intergovernmental Panel on Climate Change". Cambridge University Press, Cambridge, United Kingdom, pp- 1000.

Iqbal, N., Farooq, S., Arshad, R. and Hameed, A. 2010. Differential accumulation of high and low molecular weight heat shock proteins in basmati rice (*Oryza sativa* L.) cultivars. *Genet Resour. Crop Evol*., **57:** 65–70.

IRRI 2012 IRRI - Annual Report (2012*)* irri.org/resources/publications/annual-reports/annual-report-2012

Jagadish, S.V.K., Craufurd, P.Q. and Wheeler, T.R. 2007. High temperature stress and spikelet fertility in rice (*Oryza sativa* L.). *J. Experi. Bot*., **58:** 1627–1635.

Jagadish, S.V.K., Muthurajan, R., Oane, R., Wheeler, T.R., Heuer, S., Bennett, J. and Craufurd, P.Q. 2010. Physiological and proteomic approaches to address heat tolerance during anthesis in rice (*Oryza sativa* L.). *J. Exp. Bot*, **61:** 143–156.

Jagadish, S.V.K., Muthurajan, R., Rang, Z.W., Malo, R., Heuer, S., Bennett, J. and Craufurd, P.Q. 2011. Spikelet proteomic response to combined water deficit and heatstress in rice (*Oryza sativa)* cv. N22. *Rice*, **4:** 1–11.

James, B., and Caniato, F., 2003. Building a secure and resilient supply network. *supply chain management review, **7(5)** :22-30.*

Jeon, J.S., Hossain, M.A., Lee, Y., Cho, J.I., Ahn, C.H., Lee, S. K., & Park, P. B. 2010. The ZIP transcription factor OsABF1 is an ABA responsive element binding factor that enhances abiotic stress signaling in rice. *Plant Mol. Biol.*, **72(4-5):** 557-566.

Jiang, H., Dian, W. and Wu, P. 2003. Effect of high temperature on fine structure of amylopectin in rice endosperm by reducing the activity of the starch branching enzyme. *Phytochem.* **63:** 53-59.

Julia, C. and Dingkuhn, M. 2012. Variation in time of day of anthesis in rice in different climatic environ., *Europ. J. Agro*., **43**: 166–174.

Julia, C. and Dingkuhn, M. 2013. Predicting temperature induced sterility of rice spikelets requires simulation of crop-generated microclimate. *Europ. J. Agron*. **49:** 50-60.

Kim H.R. and You, Y. 2010. The effects of the elevated CO2 concentration and increasedtemperature on growth, yield and physiological responses of rice (*Oryza sativa* L. cv.Junam). *Adv. in Biores*., **1:** 46-50.

Kim, D.M., Lee, H.S., Kwon, S.J., Fabreag, M.E. Kang, J.W., Yun, T.Y.,Chung, C.T. and Ahn, S.N. 1969. High-density mapping of quantitative trait loci for grain weight and spikelet number in rice. *Rice*, **7**: 1-14.

Kim, H.Y., Horie, T., Nakagawa, H. and Wada, K. 1996a. Effect of elevated CO_2 concentration and high temperature on growth and yield of rice. 1. The effect on development, dry matter production and some growth characteristics. *Jap. J. Crop Sci.*, **65**: 634-643.

Kobata, T. and Uemuki, N. 2004. High temperatures during the grain-filling period do not reduce the potential grain dry matter increase of rice. *Agron. J.*, **96:** 406–414.

Kobata, T., Uemuki, N., Inamura, T., and Kagata, H. 2004. Shortage of assimilate supply to grain increases the proportion of milky white rice kernels under high temperatures. *Jpn. J. Crop Sci*., **73:** 315–322.

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

Kun, L., Chen, S., Yao, H., Han, J., Liu, C., Song, J. and Shi, L. 2010. Validation of the ITS2 region as a novel DNA barcode for identifying medicinal plant species. *PloS one*, ***5*(1):** 8613.

Kurek, I., Chang, T.K., Bertain, S.M., Madrigal, A., Liu, L., Lassner, M.W. and Zhu, G. 2007. Enhanced thermostability of Arabidopsis Rubisco activase improves photosynthesis and growth rates under moderate heat stress. *The Plant Cell*, **19(10):** 3230-3241.

Langjun, CUI, Jianlong, LI, Yamin, FAN, Sheng, XU, and Zhen, ZHANG, 2006. Effects of heat acclimation pretreatment on changes of membrane lipid peroxidation, antioxidant metabolites, and ultrastructure of chloroplasts in two cool-season turfgrass species under heat stress. *Environ. Exp. Bot.,* **56:** 274–285.

Larkin, P.D. and Park, W.D. 1999. Transcript accumulation and utilization of alternate and non-consensus splice sites in rice granule-bound starch synthase are temperature-sensitive and controlled by a single-nucleotide polymorphism. *Plant Mol. Biol.*, **40(4):** 719-727.

Larkindale, J., Michael, M. and Elizabeth, V. 2005. Plant responses to high temperature. In: Jenks, M.A., Hasegawa, P.M. eds. Plant Abiotic Stress. Blackwell Publishing, Oxford. pp- 100–144.

Lee, D.H., Kim, Y.S. and Lee, C.B. 2001. The inductive responses of the antioxidant enzymes by salt stress in the rice (Oryza sativa L.). *J. plant physiol.*, **158(6):** 737-745.

Li, H., Chen, Z., Hu, M., Wang, Z., Hua, H., Yin, C. and Zeng, H. 2011. Different effects of night versus day high temperature on rice quality and accumulation profiling of rice grain proteins during grain filling. *Plant Cell Rep*., **30:** 1641–1659.

Liu, C., Chen, S., Yao, H., Han, J., Song, J., Shi, L. and Luo, K. 2010. Validation of the ITS2 region as a novel DNA barcode for identifying medicinal plant species. *Plos one*, ***5*(1):** 8613.

Liu, J.X., Liao, D.Q., Oane, R., Estenor, L., Yang, X.E., Li, Z.C. and Bennett, J., 2006. Genetic variation in the sensitivity of anther dehiscence to drought stress in rice. *Field Crops Res.***, 97:** 87–100.

Liu, Q.H., Wu, X., Li, T., Jia-Qing Ma, J.Q. and Zhou, X.B. 2013. Effects of elevated air temperature on physiological characteristics of flag leaves and grain yield in rice. *Chilean J. Agri. Res***.** doi:10.4067/S0718-58392013000200001.

Liu, X., Xiong, G., Liu, H., Chen, F., Wang, L., & Yi, W. 2013. DWARF 53 acts as a repressor of strigolactone signaling in rice. *Nat.*, **504(7480):** 401-405.

Lobell, D.B. and Asner, G.P. 2003. Climate and management contributions to recent trends in US agricultural yields. *Sci.*. Doi:10.1126/science.1078475.

Lobell, D.B., Schlenker, W. and Costa-Roberts, J. 2011. Climate trends and global crop production since 1980. *Sci*.**, 333:** 616–620.

Lou, J., Chen, L., Yue, G., Lou, Q., Mei, H., Xiong, L. and Luo, L. 2009. QTL mapping of grain quality traits in rice. *J. Cere. Sci*., **50:** 145-151.

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

Manzo J.T., de Wit, C. W., Frenkel, S., Hoover, M. A., Hoy, J. F., Ireland, L. M., Isern, T. D., & Lewis, G. H. 1999. *The taste of American place: a reader on regional and ethnic foods*. Rowman & Littlefield Publishers.

Maraseni, T.N., Mushtaq, S. and Maroulis, J. 2009. Greenhouse gas emissions from rice farming inputs: a cross-country assessment. *J. Agri. Sci.*, **147(02):** 117-126.

Martin, M. and Fitzgerald, M.A., 2002. Proteins in rice grain influence cooking properties. *J. Cereal. Sci.*, **36:** 285-294.

Matsui, T. and Kagata, H. 2003. Characteristics of floral organs related to reliable self - pollination in rice (*Oryza sativa* L.). *Ann. Bot*., **91:** 473-477.

Matsui, T., Namuco, O.S., Ziska, L.H. and Horie, T. 1997. Effects of high temperature and CO_2 concentration on spikelet sterility in indica rice. *Field Crops Res.*, **51:** 213–219.

Matsui, T., Omasa, K. and Horie, T. 1997. High temperature-induced spikelet sterility of japonica rice at flowering in relation to air temperature, humidity and wind velocity conditions. *Jap. J. Crop Sci*., **66:** 449-455.

Matsui, T., Omasa, K. and Horie, T. 1999. Mechanism of anther dehiscence in rice (*Oryza sativa* L.). *Ann. Bot.*, **84:** 501–506.

Matsui, T., Omasa, 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:** 430–434.

Matsui, T., Omasa, K. and Horie, T. 2001. The difference in sterility due to high temperature during the flowering period among Japonica rice varieties. *Plant Prod.Sci.,* **4:** 90-93.

Michael, G. and Beringer, H. 1980. role of hormones in yield formation. In Physiological aspects of crop productivity: proceedings of the 15th Colloquium of the International Potash Institute held in Wageningen, The Netherlands. Bern: International Potash Institute, 1980.

Mohammed, A.R. and Tarpley, L. 2009. Impact of high night time temperature on respiration, membrane stability, antioxidant capacity, and yield of rice plants. *Crop Sci.* **49:** 313-322.

Mohammed, A.R. and Tarpley, L. 2010. Effects of high night temperature and spikeletposition on yield-related parameters of rice (*Oryza sativa* L.) plants. *Europ. J. Agro.***, 33:** 117–123.

Mohanty, R.K., Jena, S.K., Thakur, A.K. and Patil, D.U. 2009. Impact of high-density stocking and selective harvesting on yield and water productivity of deep water rice–fish systems. *Agri. water manag.*, **96(12):** 1844-1850.

Morimoto, R.I. 1997. The heat shock response: regulation and functions of heat-shock proteins and molecular chaperones. *Essays Biochem.*, **32:** 17–29.

Morita, S., Jun-Ichi, Y. and Jun-Ichi, T. 2005. Growth and endosperm cell size under high night temperatures in rice (*Oryza sativa* L.). *Ann. Bot.* **95:** 695–701.

Morita, S., Shiratsuchi, H., Takanashi, J.I. and Fujita, K. 2004. Effect of high temperature on grain ripening in rice plants: Analysis of the effects of high night and high day temperatures applied to the panicle and other parts of the plant. *Jpn. J. Crop Sci*., **73:** 77–83.

Mostajeran, A. and Rahimi-Eichi, V. 2009. Effects of drought stress on growth and yield of rice *(Oryza sativa L.)* cultivars and accumulation of proline and soluble sugars in sheath and blades of their different ages leaves. *American-Eurasian J. Agric. Environ. Sci.* **5(2):** 264-272.

Murai-Hatano, M., Kuwagata, T., Sakurai, J., Nonami, H., Arifa Ahamed, A., Nagasuga, K., Matsunami, T., Fukushi, K., Maeshima, M. and Okada, M. 2008. Effect of low root temperature on hydraulic conductivity of rice plants and the possible role of aquaporins. *Plant Cell Physiol.*, **49:** 1294–1305.

Nagata, K., Takita, T., Yoshinaga, S., Terashima, K. and Fukuda, A. 2004. Effect of air temperature during the early grain-filling stage on grain fissuring in rice (*Oryza sativa*). *Jap. J. Crop Sci., (Japan).*

Nakagawa, H., Horie, T. and Matsui, T. 2003. Effects of climate change on rice production and adaptive technologies. In Rice Science: Innovations and Impact for Livelihood. Proceedings of the International Rice Research Conference, Beijing, China, 16–19 September 2002 (Eds T.W. Mew, D. S. Brar, S. Peng, D. Dawe& B. Hardy), Manila, The Philippines: IRRI pp. 635–658.

Nakamura, Y. 2002. Towards a better understanding of the metabolic system for amylopectin biosynthesis in plants: rice endosperm as a model tissue. ***Plant Cell Physiol.***, **43:** 718–725.

Nanzo, J.T., de Wit, C.W., Frenkel, S., Hoover, M.A., Hoy, J.F., Ireland, L.M., Isern, T.D. and Lewis, G.H. 1999. *The taste of American place: a reader on regional and ethnic foods*. Rowman & Littlefield Publishers.

Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R. and Msangi, S. 2010. *Food security, farming, and climate change to 2050: Scenarios, results, policy options* (Vol. 172). *Intl Food Policy Res Inst***. (IFPRI 2010)**.

Newman, Y. C., Sollenberger, L. E., Boote, K. J., Allen, L. H. Jr., and Littell, R. C. 2001. Carbon dioxide and temperature effects on forage dry matter production. *Crop Sci.*, **41:** 399–406.

Nishiyama, I. and Satake, T. 1981. High temperature damages in rice plants (*Oryza sativa*). *Jap. J. Trop. Agri.* **19(1):** 45-48.

Oh, A., Takei, K., Ikai, M., Kasaoka, S. and Kiriyama, S. 1997. Cholesterol-lowering effects of soybean, potato and rice proteins depend on their low methionine contents in rats fed a cholesterol-free purified diet. *J. nutrition*, **127(3):** 470-477.

Oh, M.K., Kim, B.K., Shin, M.S., Choung, J.I., Kim, K.Y., Ko, J.C., Ko, J.K. and Choi, I.S. 2005. Yearly variation of panicle characters in japonica rice (*Oryza sativa* L.). *Korean J.Breed. Sci.* **37:** 43-48.

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:** 412–422.

Ou, J., Lu, B., Yuan, Y., Zhang, C., Zhou, W. and Lin, Q. 2005. Modulation of key enzymes involved in ammonium assimilation and carbon metabolism by low temperature in rice (*Oryza sativa* L.) roots. *Plant Sci.*, **169(2):** 295-302.

Pagamas, P. and Nawata, E. 2008. Sensitive stages of fruit and seed development of chilli pepper (*Capsicum annuum* L. var. Shishito) exposed to high-temperature stress. *Sci. Hort.* **117:** 21–25.

Panigrahy, M., Neelamraju, S., Rao, D. N. and Ramanan, R. 2011. Heat tolerance in rice mutants is associated with reduced accumulation of reactive oxygen species. *Biologia Plantarum*, **55(4):** 721-724.

Pareek, A., Singla, S.L. and Grover, A. 1995. Immunological evidence for accumulation of two high-molecular-weights (104 and 90 k Da) HSPs in response to different stresses in rice and in response to high temperature stress in diverse plant genera. *Plant Mol.Biol.,* **29:** 293–301.

Patindol, J. and Wang, Y.J. 2002. Fine structures of starches from long-grain rice cultivars with different functionality. *Cereal Chem.,* **79(3):** 465-469.

Paulsen, G.M. 1987. Wheat stand establishment. In: Heyne, E.G. (Ed.), Wheat and wheat improvement. American Society of Agronomy Monograph, Madison, WI, USA, 384–391.

Peng, S.B., Huang, J.L., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X.H., Centeno, G.S., Khush, G.S. and Cassman, K.G. 2004. Rice yields decline with higher night temperature from global warming. *Proc. Natl. Acad. Sci. USA.,* **101:** 9917-9975.

Phan, T.T.T., Ishibashi, Y., Miyazaki, M., Tran, H.T., Okamura, K., Tanaka, S., & Iwaya-Inoue, M. 2013. High Temperature-Induced Repression of the Rice Sucrose Transporter (OsSUT1) and Starch Synthesis-Related Genes in Sink and Source Organs at Milky Ripening Stage Causes Chalky Grains. *J. Agron. Crop Sci.,* **199(3):** 178-188.

Pirdashti, H., Sarvestani, Z.T. and Bahmanyar, M.A. 2009. Comparison of physiological responses among four contrast rice cultivars under drought stress conditions. *World Acade. Sci.,* **49:** 52-53.

Prasad, P.V.V., Boote, K.J., Allen Jr.L.H., Sheehy, J.E. and Thomsa, 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:** 398– 411.

Reddy, K.R., Ali, S.Z. and Bhattacharya, K.R. 1993. The fine structure of rice-starch amylopectin and its relation to the texture of cooked rice. *Carbohydrate polym.,* **22(4):** 267-275.

Poli, Y., Basava, RK.,Panigrahy, M., Vinukonda, VP., Dokula, NR., Voleti, SR., Desiraju, S. and Neelamraju, S. 2013. Characterization of a Nagina 22 rice mutant for heat tolerance and mapping of yield traits. *Rice* **6:** 36.

Resurreccion, A.P., Hara, T., Juliano, B.O. and Yoshida, S. 1977. Effect of temperature during ripening on grain quality of rice. *Soil sci. plant nutri.*, **23(1):** 109-112.

Reynolds, R.L., Tuttle, M.L., Rice, C.A., Fishman, N.S., Karachewski, J.A. and Sherman, D.M. 1994. Magnetization and geochemistry of greigite-bearing Cretaceous strata, North Slope Basin, Alaska. *Am. J. Sci.*, **294(4):** 485-528.

Ritchie, J.T., Singh, U. and Godwin, D.C. 1993. A users guide to cereals rice, AL, USA: International Fertilizer Development Center. *Sci.*, **4:** 90-93.

Ruelland, E. and Zachowski, A. 2010. How plants sense temperature. *Environ. Exp. Bot.*, **69:** 225–232.

Sairam, R.K. and Tyagi, A. 2004. Physiology and molecular biology of salinity stress tolerance in plants. *Curr. Sci. Bang.*, **86(3):** 407-421.

Sakamoto, A. and Murata, N. 2002. The role of glycine betaine in the protection of plantsfrom stress: clues from transgenic plants. *Plant Cell Environ.*, **25:** 163-171.

Salem, M.A., Kakani, V.G., Koti, S. and Reddy, K.R. 2007. Pollen-based screening of soybean genotypes for high temperatures. *Crop Sci.*, **47(1):** 219-231.

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

Sato, K., Inaba, K. and Tozawa, M. 1973. High temperature injury of ripening in rice plant. I. The effects of high temperature treatments at different stages of panicle development on the ripening. *Proc. Crop Sci. Soc. Jpn*., **42:** 207–213.

Sayad, A., Bashir, K., Husnain, T., Fatima, T., Latif, Z. and Riazuddin, S. 2004. Field evaluation and risk assessment of transgenic indica basmati rice. *Mol. Breeding*, **13(4):** 301-312.

Scafaro, A.P., Chick, J.M., George, I.S., Van Sluyter, S.C., Gygi, S.P., & Haynes, P. A. (2010). The influence of signals from chilled roots on the proteome of shoot tissues in rice seedlings. *Proteomics*, **13(12-13):** 1922-1933.

Scafaro, A.P., Yamori, W., Carmo-Silva, A.E., Salvucci, M.E., Von Caemmerer, S. and Atwell, B.J. 2012. Rubisco activity is associated with photosynthetic thermotolerance in a wild rice (*Oryza meridionalis*), *Physiologia plantarum*, **146(1):** 99-109.

Sharma, P., & Dubey, R. S. 2004. Ascorbate peroxidase from rice seedlings: properties of enzyme isoforms, effects of stresses and protective roles of osmolytes. *Plant Science*, ***167*(3):** 541-550.

Shashukova, A. V., Mapelli, S., Shevyakova, N. I., & Kuznetsov, V. V. 1997. Proline controls the level of polyamines in common sage plants under normal conditions and at UV-B irradiation. *J. Plant Physiol.*, ***57*(3):** 422-429.

Sheehy, J.E., Dionora, M.J.A. and Mitchell, P.L. 2001. Spikelet numbers, sink size and potential yield in rice. *Field Crops Res.* **71:** 77–78.

Shi, H. &Zhang, J. L., (2013). Physiological and molecular mechanisms of plant salt tolerance. *Photosyn. res.*, **115(1)**: 1-22.

Singla, S.L., Pareek, A. and Grover, A. 1997. High temperature. In: Prasad, M.N.V. (Ed.), *Plant Ecophysiology*. John Wiley and Sons, New York, USA, pp. 101– 127.

Smith, P., & Olesen, J. E. 2010. Synergies between the mitigation of, and adaptation to, climate change in agriculture. *J. Agri. Sci.*, **148(05):** 543-552.

Song, L., Ding, W., Zhao, M., Sun, B., Zhang, L. 2006. Nitric oxide protects against oxidative stress under heat stress in the calluses from two ecotypes of reed. Plant Sci. **171:** 449–458.

Song, L., Yue, L., Zhao, H. and Hou, M. 2013. Protection effect of nitric oxide on photosynthesis in rice under heat stress. *Acta. Physiol. Plant.* **35:** 3323–3333.

Spano, G., Di Fonzo, N., Perrotta, C., Platani, C., Ronga, G., Lawlor, D. W., & Shewry, P. R. 2003. Physiological characterization of 'stay green'mutants in durum wheat. *J. Exp Bot.*, ***54*(386):** 1415-1420.

Sreenivasulu, N., & Wobus, U. 2013. Seed-development programs: a systems biology–based comparison between dicots and monocots. *Plant Biol.*, pp. 64.

Stansel, J. W. 1975. Rice plant--its development and yield. *Research monograph Texas Agri. Exp. Sta*., pp. 43-50.

Suleyman, I., Allakhverdiev, Vladimir, D. Kreslavski, Vyacheslav, V., Klimov, Dmitry, A., Los, Carpentier, R. and Mohanty, P. 2008. Heat stress: an overview of molecular responses in photosynthesis. *Photosyn. Res*. **98:** 541–550.

Sun, H., & Siebenmorgen, T. J. 1993. Milling characteristics of various rough rice kernel thickness fractions.*Cereal chem.*, **70:** 727-727.

Sun, Q., Spiegelman, D., van Dam, R. M., Holmes, M. D., Malik, V. S., Willett, W. C., & Hu, F. B. (2010). White rice, brown rice, and risk of type 2 diabetes in US men and women. *Arch. Inter. Medi.*, **170(11):** 961-969.

Sung, D.Y., Vierling, E. and Guy, C.L. 2001. Comprehensive expression profile analysis of the Arabidopsis HSP70 gene family. *Plant Physiol.* **126:** 789-800.

Suwa, R., Hakata, H., Hara, H., El-Shemy, H.A., Adu-Gyamfi, J.J., Nguyen, N.T., Kanai, S., Lightfoot, D.A., Mohapatra, P.K. and Fujita, K. 2010. High temperature effects on photosynthetic partitioning and sugar metabolism during ear expansion in maize (*Zea mays* L.) genotypes. *Plant Physiol. Biochem.*, **48:** 124–130.

Suzuki, M. 1980. Studies on distinctive patterns of dry matter production in the building process of grain yields in rice plants grown in the worm region in Japan. *Bull. Kyushu Nat. Agri. Exp. Sta.*, **20:** 429-494.

Suzuki, N., Koussevitzky, S., Mittler, R. and Miller, G. 2012. ROS and redox signalling in the response of plants to abiotic stress. *Plant Cell Environ*., **35:** 259–270.

Takeoka, Y., Mamun, A. A., Wada, T., & Kaufman, P. B. 1992.*Reproductive adaptation of rice to environmental stress*. Elsevier Science Publishers.

Talwar, D., Nayak, N. R., Khanna, H. K., & Grover, M. 2002. Field evaluation and generation of two-gene Bt transgenics of indica rice.*Abstract Intl. Rice Cong., Bejing, China*, pp. 287.

Tashiro, T., & Wardlaw, I. F. 1991. The effect of high temperature on kernel dimensions and the type and occurrence of kernel damage in rice. *Crop Past. Sci.*, **42(3):** 485-496.

Thitisaksakul, M., Jiménez, R. C., Arias, M. C., & Beckles, D. M. 2012. Effects of environmental factors on cereal starch biosynthesis and composition. *J. Cereal Sci.*, **56(1):** 67-80.

Tian, X., Matsui, T., Li, S.H. and Lin, J.C. 2007. High temperature stress on rice anthesis:Research progress and prospects. *Chin. J. Appl. Ecol.* **18:** 2632–2636.

Timperio, A. M., Egidi, M. G., & Zolla, L. 2008. Proteomics applied on plant abiotic stresses: role of heat shock proteins (HSP). *J. Proteomics*, **71(4):** 391 411.

Tsukaguchi, T., and Iida, Y. 2008. Effects of assimilate supply and high temperature during grain-filling period on the occurrence of various types of chalky kernels in rice plants (Oryza sativa L.). *Plant Prod. Sci.* **11:** 203–210.

Ubaidullah, Raziuddin, Mohammad T., Hafeezullah, Sardar A. and Nassimi, A.W. 2006. Screening of wheat (*Triticum aestivium* L.) genotypes for some important traits against natural terminal heat stress. *Pak. J. Biol. Sci*. **9:** 2069–2075.

Umemoto, T., Nakamura, Y., Satoh, H. and Terashima, K. 1999. Differences inamylopectin structure between two rice varieties in relation to the effects oftemperature during grain-filling. *Starch,* **51:** 58–62.

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

Vijayalakshmi, K., Fritz, A., Paulsen, G., Bai, G., Pandravada, S. and Gill, B. 2007. Modeling and mapping QTL for senescence-related traits in winter wheat under high temperature. *Mol. Breed.*, **26**: 163–175

Wahid, A. 2007. Physiological implications of metabolites biosynthesis in net assimilation and heat stress tolerance of sugarcane (*Saccharum officinarum)* sprouts. *J. Plant Rese.***120:** 219-228.

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

Wahid, A., Perveen, M., Close, S., & Basra, S. M. (2007). Pretreatment of seed with H 2 O 2 improves salt tolerance of wheat seedlings by alleviation of oxidative damage and expression of stress proteins. *J. Plant Physiol.*, **164(3):** 283-294.

Wakamatsu, K., Wada, H., Nonami, H., Yabuoshi, Y., Maruyama, A., Tanaka, A and Morita, S. 2007. Increased ring-shaped chalkiness and osmotic adjustment when growing rice grains under foehn-induced dry wind condition. *Crop sci.,* **51(4):** 1703-1715.

Wang, Y., and Frei, M. 2011. Stressed food: The impact of abiotic environmental stresses on crop quality. *Agri. Eco. Environ.* **141:** 271–286.

Wardlaw I.F. and Moncur, L. 1995. The response of wheat to high temperature following anthesis. The rate and duration of kernel filling. *Aust. J. Plant Physiol*. **22:** 391–397.

Wassmann, R., & Dobermann, A. 2007. Climate change adaptation through rice production in regions with high poverty levels. *J. Sem. Tropi. Agri. Res.*, **4(1):** 1-24.

Wassmann, R., Jagadish, S.V.K., Heuer, S., Ismail, A., Redona, E., Serraj, R., Singh, R.K.,Howell, G., Pathak, H. and Sumfleth, K. 2009. Climate change affecting rice production: The physiological and agronomic basis for possible adaptation strategies. *Adv. Agron.* **101:** 59-122.

Watanabe, S., Kojima, K., Ide, Y. and Satohiko, S. 2000. Effects of saline and osmotic stress on proline and sugar accumulation in *Populus euphratica in vitro. Plant Cell, Tissue, Organcul*.**3 (3):** 199-206.

Weerakoon, W.M.W., Maruyama, A. and Ohba, K. 2008. Impact of humidity on temperature induced grain sterility in rice (*Oryza sativa* L.). *J. Agron. Crop Sci*. **194:** 135–140.

Wei, K.S., Yang,W.L., Jilani, G., Zhou, W.J. Liu, G.K., Chaudhry, A.N., Cao, Z.Z. and Cheng, F.M. 2012. Effect of high temperature on the enzymatic activities and transcriptional expression of starch debranching enzyme (DBE) multiple isoforms in developing rice endosperms. *J. Animal Plant Sci.* **22:** 97-107.

Wei, X., Sang, T., Zhao, Q., Feng, Q., Zhao, Y., & Li, M. 2010. Genome-wide association studies of 14 agronomic traits in rice landraces. *Nat. genetics*, **42(11):** 961-967.

Welch, J.R., Vincent, J.R., Auffhammer, M., Moya, P.M., Dobermann, A. and Dawe, D. 2010. Rice yield in tropical/subtropical exhibit large but apposing sensitivities to minimum and maximum temperatures. *Proc. Natl. Acad. Sci. USA.*

Werner, J. E., & Finkelstein, R. R. 1995. Arabidopsis mutants with reduced response to NaCl and osmotic stress. *Physiologia Plantarum*, ***93*(4),** 659-666.

Wu, Z., Zhang, X., He, B., Diao, L., Sheng, S., Wang, J., & Wang, C. 2007. A chlorophyll-deficient rice mutant with impaired chlorophyllide esterification in chlorophyll biosynthesis. *Plant Physiol.*, **145(1),** 29-40.

X., Tang, S., Hiroshi, F., Yuan, M., Luo, D., Han, B. and Li, J., 2003. Control of tillering in rice. *Nat.* **422:** 618–621.

Xie, X. J., Shen, S. H. H., Li, Y. X., Zhao X. Y., Liand, B. B. and Xu, D. F. 2011. Effect of photosynthetic characteristic and dry matter accumulation of rice under high temperature atheading stage. *Afric. J. Agri. Res.* **6:** 1931-1940.

Xie, X.J., Li, B.B., Li, Y.X. and Shen, S.H. 2009. High temperature harm at flowering inYangtze River basin in recent 55 years.*Jiangsu. J. Agric. Sci.* **25:** 28-32.

Xie, X.J., Li, B.B., Zhu, H.X., Yang, S.B. and Shen, S.H. 2012. Impact of high temperature at heading stage on rice photosynthetic characteristic and dry matter accumulation. *Chinese J. Agromet.* **33:** 457-461.

Xie, X.J., Li, B.B., Zhu, H.X., Yang, S.B. and Shen, S.H. 2012. Impact of high temperature at heading stage on rice photosynthetic characteristic and dry matter accumulation. *Chinese J. Agromet.* **33:** 457-461.

Xie, X.J., Shen, S.H.H., Li, Y.X., Zhao, X.Y. Li, B.B. and Xu, D.F. 2011. Effect of photosynthetic characteristic and dry matter accumulation of rice under high temperature at heading stage. *African J. Agri. Res*. **6:** 1931-1940.

Xu, D., Duan, X., Wang, B., Hong, B., Ho, T. H. D. and Wu, R. 1995. Expression of a late embryogenesis abundant protein gene, HVA1, from barley confers tolerance to water deficit and salt stress in transgenic rice. *Plant physiol.*, **110(1),** 249-257.

Xu, Y., Zhan, C. and Huang, B. 2008. Heat shock proteins in association with heat tolerance in grasses. *Int. J. Proteomics.* 1-11.

Yamakawa, H., Hirose, T., Kuroda, M. and Yamaguchi, T. 2007. Comprehensive expression profiling of rice grain filling-related genes under high temperature using DNA microarray. *Plant Physiol*. **144:** 258–277.

Yamamoto, K. T., Nagatani, A. and Furuya, M. 1985. Characterization of green tissue-specific phytochrome isolated immunochemically from pea seedlings. *Plant cell physiol.*, **26(7),** 1387-1399.

Yan ,M.,Jiao, Y., Wang, Y., Xue, D., Wang, J., Liu, G., & Qian, Q. 2010. Regulation of OsSPL14 by OsmiR156 defines ideal plant architecture in rice. *Nat. genetics*, **42(6),** 541-544.

Yao, F., Xu, Y., Lin, E., Yokozawa, M., and Zhang, J. 2007. Assessing the impacts of climate change on rice yields in the main rice areas of China. *Climatic Change*, **80(3-4),** 395-409.

Ying.C.Y., Hua, D., Nian, Y.L., Qing, W.Z., Jun, L.L. and Chang, Y.J. 2009.Effect of high temperature during heading and early filling on grain yield and physiological characteristics in indica rice. *Acta. Agron. Sinica*.**35:** 512-521.

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

Yoshida, H. and Nagato, Y. 2011. Flower development in rice. *J. Exp. Bot.* **62:** 4719-4730.

Yoshida, S. 1978. Tropical Climate and its Influence on Rice. IRRI Research Paper Series 20. Los Banos, The Philippines: IRRI

Yoshida, S. 1981. Physiological analysis of yield. *In:* Fundamentals of rice crop science.Makita City (Philippines): International Rice Research Institute, pp. 231-251.

Yoshida, S. 1983. Zinc deficiency in rice. II. Studies on two varieties differing in susceptibility to zinc deficiency. *Plant Soil*.**42:** 551-563.

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

Yoshida, S., & Ahn, S. B. (1968). The accumulation process of carbohydrate in rice varieties in relation to their response to nitrogen in the tropics. *Soil Sci. Plant Nutri.,* **14(4):** 153-161.

Yoshida, S., Satake, T., Mackill and D. S. 1978. High temperature stress in rice. IRRI Research Paper Series 67. Los Banos, The Philippines: IRRI

Yoshioka, Y., Iwata, H., Tabata, M., Ninomiya, S., and Ohsawa, R. (2007). Chalkiness in rice: Potential for evaluation with image analysis. *Crop Sci*. **47:** 2113–2120.

Yun-Ying, C., Hua, D., Li-Nian, Y., Zhi-Qinq, W., Li-Jun. and Jian-chang, Y. 2009. Effect of high temperature during heading and early filling on grain yield and physiological characteristics in *Indica* rice. *Acta Agron Sin.* **35:** 512-521.

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

Zeigler, R. S.. Li, J.Y., & Wang, J. 2014. The 3,000 rice genomes project: new opportunities and challenges for future rice research. *Giga Sci.,* **3(1**): 1.

Zhang, G. L., Chen, L. Y., Zhang, S. T. Liu, G. H., Tang, Z. 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. *Sci. Agric. Sci*.**40:** 1345-1352.

Zhang, G. L., Chen, L. Y., Zhang, S. T. Liu, G. H., Tang, Z. 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. *Sci. Agric. Sci*.**40:** 1345-1352.

Zhang, G., Wang, Z., You, J., Wang, Q., Ding, Y., & Ji, Z. 2006. Effect of higher temperature indifferent filling stages on rice qualities. *Acta Agro. Sinica,* **32:** 283–287.

Zhu, C.. Ding, Y., & Chen, Z. 2011. Microarray-based analysis of cadmium-responsive microRNAs in rice (Oryza sativa). *J. Exp. Bot.*, pp. 46.

Zhu, P., Yang, S. M., Ma, J., Li, S. X. and Chen, Y. 2005. Effect of shading on thephotosynthetic characteristics and yield at later growth stage of hybrid ricecombination. *Acta. Agron. Sin.,* **34:** 20-23.

Ziska, L.H., Manalo, P.A., and Ordonez, R.A., 1992. Intraspecific variation in the response of rice (*Oryza sativa* L.) to increased CO_2 and temperature: Growth and yield response of 17 cultivars. *J. Exp. Bot.,* **47:** 1353–1359.

Appendix

APPENDIX

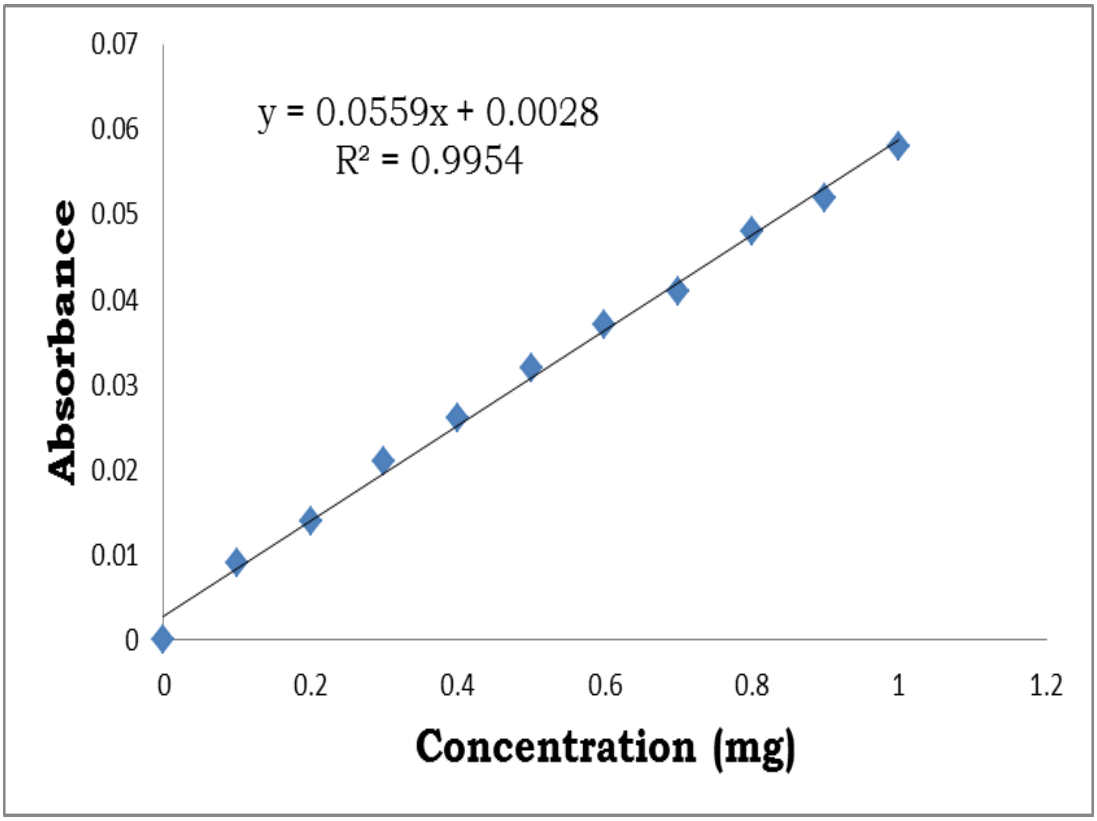


Fig.1: Standard Curve of amylose content

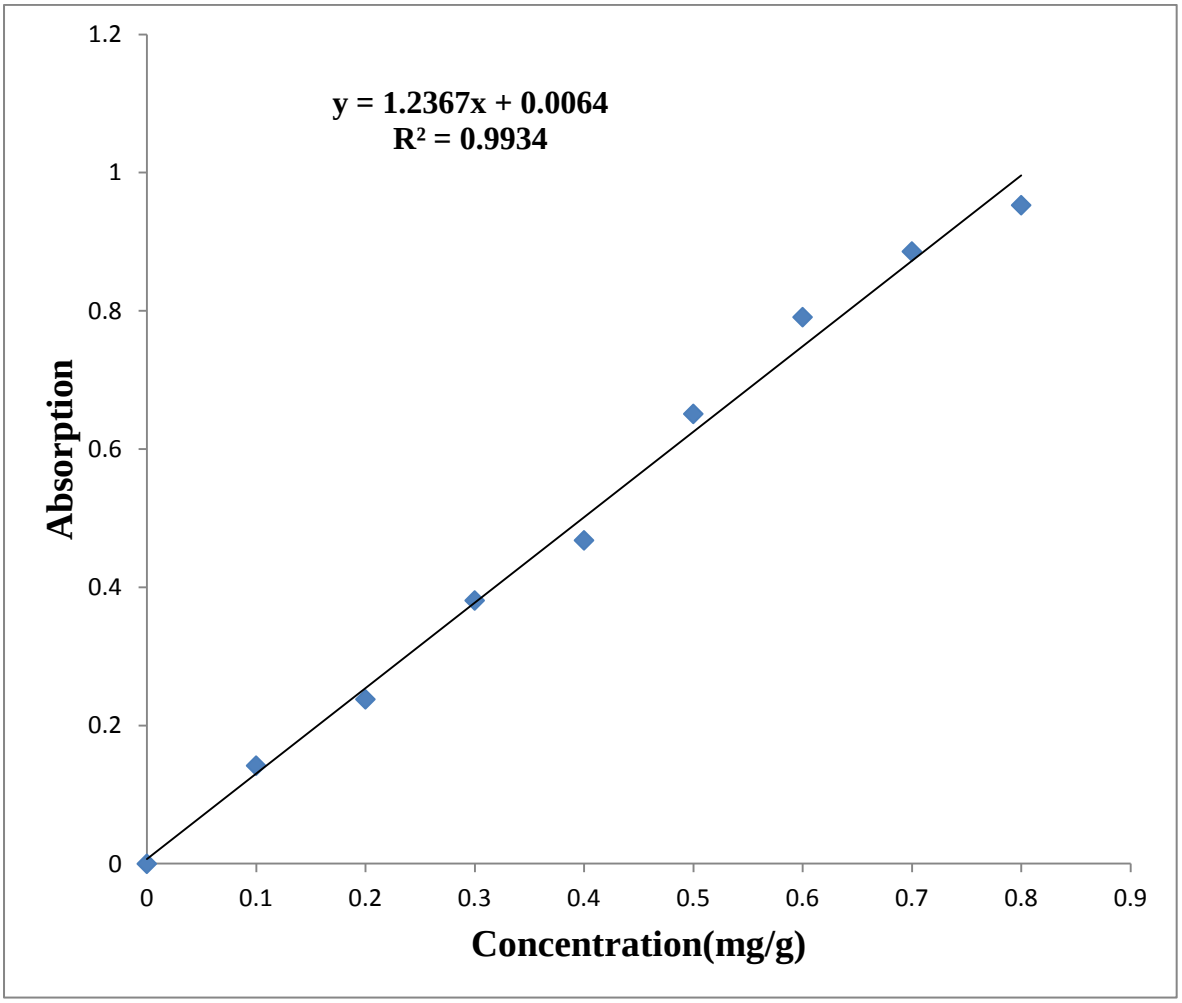


Fig.2: Standard Curve of protein content

Weekly weather data

STATION NAME : PANTNAGAR **LONGITUDE : 79 deg. 30' E**
LATITUDE : 29 deg. N **ALTITUDE : 243.84 m. AMSL**

Month	Date	Year	Metro Week No. (2012)	Temperature (^{o}C)		Relative Humidity (%)		Rainfall (mm)	No. of Rainy Days	Sun-Shine Hrs.	Wind Velocity (km/hr.)	Evap. (mm)
				Max.	Min.	0712 am	1412 pm					
May-Jun	**28-03**	**2015**	22	39.6	22.2	63	31	000.0	0	08.3	6.3	9.3
Jun	**04-10**	**2015**	23	40.9	24.5	62	30	000.0	0	09.7	7.8	10.6
Jun	**11-17**	**2015**	24	38.0	25.5	62	38	000.8	1	07.4	8.8	10.7
Jun	**18-24**	**2015**	25	35.1	26.5	73	53	072.2	4	06.2	7.2	6.4
Jun-Jul	**25-01**	**2015**	26	32.0	23.8	90	76	324.8	4	05.0	8.5	5.5
Jul	**02-08**	**2015**	27	32.4	25.7	87	72	100.0	6	03.1	6.7	3.6
Jul	**09-15**	**2015**	28	31.7	25.4	88	72	114.8	5	04.9	7.0	5.5
Jul	**16-22**	**2015**	29	32.7	26.1	84	72	089.8	4	04.2	5.8	4.0
Jul	**23-29**	**2015**	30	33.6	25.9	83	63	006.4	2	08.5	7.5	5.7
Jul-Aug	**30-05**	**2015**	31	31.5	25.7	87	74	079.8	4	05.0	5.3	4.3
Aug	**06-12**	**2015**	32	30.2	25.4	91	76	158.9	6	02.3	5.5	3.8
Aug	**13-19**	**2015**	33	32.7	26.1	90	67	037.8	2	04.8	3.7	3.9
Aug	**20-26**	**2015**	34	32.4	24.9	89	69	039.0	5	05.2	6.5	3.8
Aug-Sep	**27-02**	**2015**	35	33.4	25.4	92	65	024.4	2	06.7	5.6	4.7
Sep	**03-09**	**2015**	36	33.6	23.8	91	60	000.0	0	07.5	4.9	7.0
Sep	**10-16**	**2015**	37	34.1	25.0	87	61	000.0	0	08.4	3.1	4.7
Sep	**17-23**	**2015**	38	34.0	24.9	84	62	112.0	2	06.6	3.8	4.2
Sep	**24-30**	**2015**	39	31.7	21.4	90	61	000.0	0	08.1	5.0	4.0
Oct	**01-07**	**2015**	40	32.9	20.2	83	51	000.0	0	09.5	2.1	4.7
Oct	**08-14**	**2015**	41	32.5	20.3	83	52	000.0	0	07.5	2.4	4.6
Oct	**15-21**	**2015**	42	31.5	19.3	86	51	000.0	0	05.1	3.1	3.5
Oct	**22-28**	**2015**	43	31.2	13.9	88	48	000.0	0	08.7	3.0	4.0
Oct-Nov	**29-04**	**2015**	44	29.0	13.7	90	43	005.0	1	06.2	2.9	3.0
Nov	**05-11**	**2015**	45	28.0	12.1	91	43	002.0	1	06.6	3.0	2.5
Nov	**12-18**	**2015**	46	29.0	11.9	91	38	000.0	0	07.8	2.8	2.7
Nov	**19-25**	**2015**	47	27.7	11.3	92	41	000.0	0	07.2	1.6	2.3
Nov-Dec	**26-02**	**2015**	48	26.7	12.6	91	46	000.0	0	03.7	2.7	2.1
Dec	**03-09**	**2015**	49	24.6	10.2	96	49	000.0	0	01.8	2.3	1.6
Dec	**10-16**	**2015**	50	21.1	10.3	94	64	000.0	0	02.1	4.3	1.3
Dec	**17-23**	**2015**	51	20.5	4.6	96	50	000.0	0	05.3	2.5	1.5
Dec	**24-31**	**2015**	52	21.0	5.0	95	46	000.0	0	06.1	3.0	1.5

Appendix.....

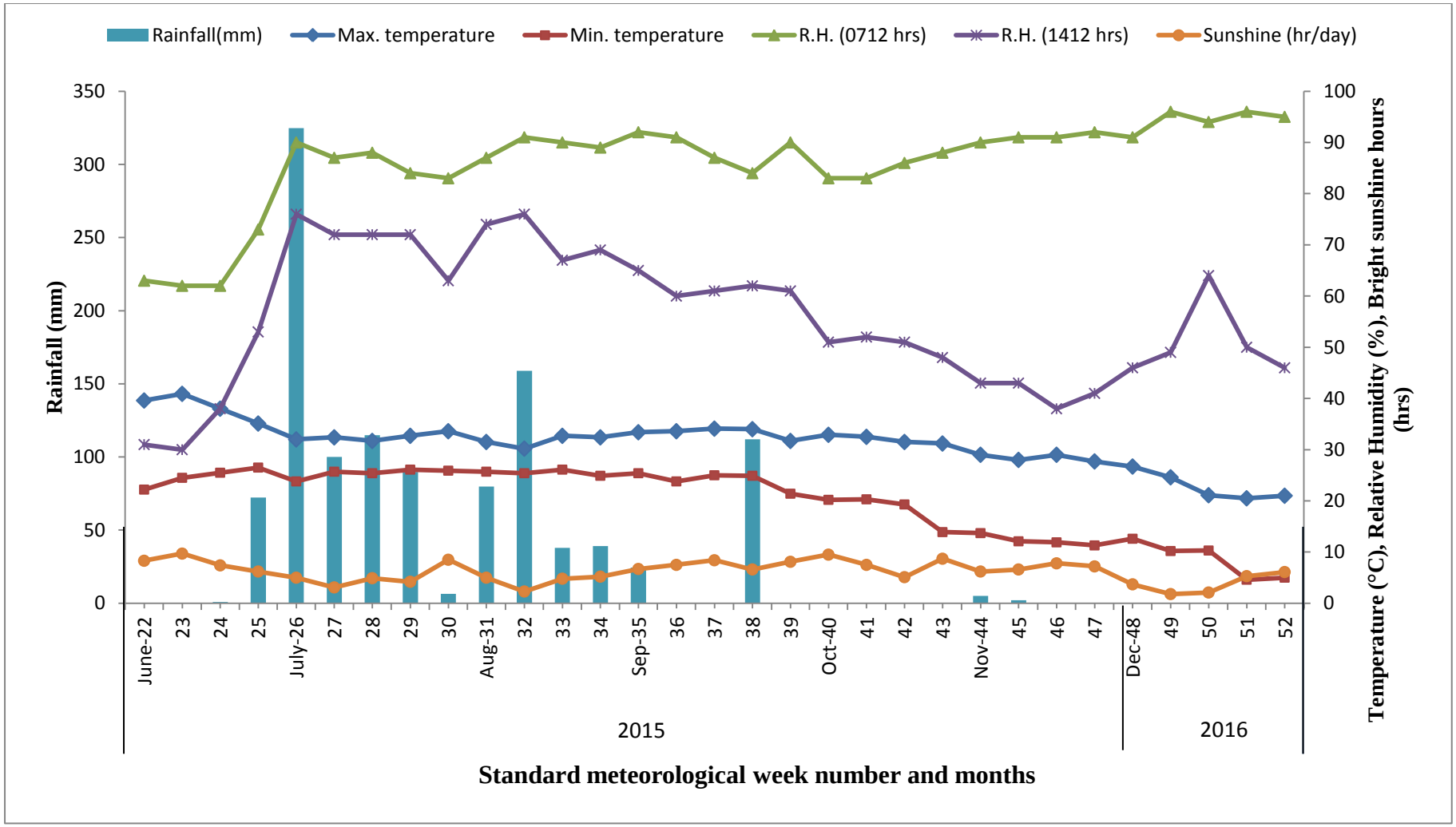


Fig: Weekly weather data during the crop period 2015

VITA

Maneesh Lingwan, the author was born on 12 February, 1994 in Kanda (lostu), Tehri Garhwal (Uttarakhand). He completed his secondary and higher secondary examination in 2008 and 2010 from Jawahar Navodaya Vidyalaya, Tehri Garhwal (Uttarakhand). After that he completed his B.Sc. from Hemwati Nandan Bahuguna Garhwal University in the year 2014. Thereafter he took admission in M.Sc. Program in the department of Plant Physiology, College of Post Graduate Studies in G.B. Pant University of Agriculture and Technology, Pantnagar in 2014-2015.

Address

Maneesh Lingwan
S/o Ravindar Singh Lingwan
Village- Kanda(lostu)
Post- Ghaniyaldhar
District- Tehri Garhwal
Uttarakhand- 249161
Email: maneeshlingwan7@gmail.com

Name	**:**	Maneesh Lingwan	**Id. No.**	**:**	47013
Sem & Year of admission	**:**	1st, 2014-2015	**Degree**	**:**	M.Sc.
Major	**:**	Plant Physiology	**Deptt.**	**:**	Plant Physiology
Thesis Title	**:**	**"INFLUENCE OF HIGH TEMPERATURE STRESS ON MORPHO - PHYSIOLOGICAL CHARACTERISTICS IN RICE GENOTYPES (*Oryza sativa* L.)"**			
Advisor	**:**	Dr. Atul Kumar			

ABSTRACT

Rice (*Oryza sativa* L.) is a globally important cereal crop, and primary source of food. As the growth of word's population is increasing, so more demand of rice will be required. There is a challenge to achieve more production of rice. Heat stress is major factor which greatly affects the growth, development and productivity of rice. To evaluate the morphological and biochemical response of rice genotypes under heat stress, a field experiment was conducted in Norman E. Bourlog Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar during kharif season 2015 with 24 rice genotypes, namely- IET 23339, IET 23354, IET 23356,IET 23392, IET 23947, IET 23949, IET 23951, IET 23957, IET 23976 IET 23979, IET 23996, IET 24075, IET 24082, DRRH-106 ,DRRH-107 ,DRRH-108,Govind, NDR-97,PA-6129, PHY-1,PHY-2 ,Sabagidhan, Tulasi, N22. These genotypes were transplanted into two blocks, one for control and another for imposing heat stress by a poly sheet tunnel supported by bamboo sticks. The heat stress treatment was given at the time of anthesis. A maximum and minimum temperature thermometer was fixed to record the daily maximum and minimum temperature inside the poly sheet tunnel.

A number of parameters such as leaf length, width, leaf area, leaf dry weight, stem dry weight, panicle weight, total dry matter production, 1000-grain weight, grain yield, chlorophyll content, grain protein and amylose content were recorded in different rice genotypes. Heat stress reduced leaf area, stem dry weight at harvest, panicle dry weight, 1000-grain weight, and number of filled grain, grain yield, total dry matter production, chlorophyll content and amylose content of different rice genotypes. While heat stress increased stem dry weight per plant at flowering, total dry matter (leaf and stem) at flowering, and number of unfilled grains and protein content of different rice genotypes. Out of twenty four genotypes of rice, the rice genotypes namely DRRH-107, DRRH-108, PA-6129, PHY-2 and N 22 performed better under heat stress treatment under the poly sheet tunnel in tiller numbers per plant, filled grains per panicle, fertility (%) and grain yield as compared to rest of different rice genotypes. These tolerance rice genotypes can further explored for the molecular mechanism, responsible for heat tolerance and better yield.

(Atul Kumar)
Advisor

(Maneesh Lingwan)
Author

नम : मनीष लिंगवाण परिचयांक : 47013
षट्मास एवं प्रवेश वर्ष : प्रथम, 2014–15 उपाधि : स्नातकोत्तर
मुख्य विषय : पादप कार्यिकी विभाग : पादप कार्यिकी
शोध शीषक : "उच्च ताप तनाव का धान (*ओराइजा स्टाइवा* एल.) की प्रजातियों में संरचनात्मक व कार्यिकी लक्षणो पर प्रभाव"
सलाहकार : डा0 अतुल कुमार

सारांश

धान विश्व स्तर पर भोजन का प्राथमिक स्त्रोत एवं महत्वपूर्ण अनाज वाली फसल हैं यह तीन अरब जनसंख्या के पोषण का आधार हैं। विश्व की जनसंख्या निरन्तर बडने से अनाज की आवश्कता भी अधिक होगी। धान का अधिक उत्पादन करना एक चुनौती हैं क्योंकि ताप तनाव धान की वृद्धि, विकास और उत्पादकता को प्रभावित करता हैं। अधिक ताप तनाव के प्रयोग के लिए धान की प्रजातियो के संरचनात्मक एवं कार्यिकी का मूल्याकंन करने के लिए गो0 ब0 पन्त कृषि एंव प्रौद्योगिकी विश्वविद्यालय, पन्तनगर के नार्मन ई0 बॉरलाग फसल अनुसंधान केन्द्र में प्रयोग किया जिसमें धान की 24 प्रजातियों जैसे IET 23339, IET 23354, IET 23356,IET 23392, IET 23947, IET 23949, IET 23951, IET 23957, IET 23976 IET 23979, IET 23996, IET 24075, IET 24082, DRRH-106 ,DRRH-107 ,DRRH-108, गोविन्द, साभागीधान, तुलसी NDR-97,PA-6129, PHY-1,PHY-2, ,ao N22 को दो ब्लाकों में रोपित किया गया। एक ब्लाक को नियंत्रित फसल के लिए एंव दूसरे ब्लाक को बॉस की छड़ो से पॉलीथीन की सुरंग बनाकर ताप तनाव दिया गया। प्रतिदिन के अधिकत्तम एंव न्यूनत्तम तापमान के मापन के लिए तापमान थर्मामीटर सुरंग क अन्दर लगाया गया। धान की विभिन्न प्रजातियों में विभिन्न मानक जैसे पत्ती की लम्बाई, पत्ती की चौडाई, पत्ती का क्षेत्रफल, सूखी पत्तियों का वजन तना, पुश्पगच्छ, कुल सूखे पदार्थ एंव हजार दानो का वजन की जाच की गयी। ताप तनाव अनाज की पैदावार, पर्णहरित की मात्रा और अमाईलोज की मात्रा को कम करता हैं एवं ताप तनाव पुष्प अवस्था के समय तने का भार और रिक्त दानों की संख्या, प्रोटीन की मात्रा को बढाता हैं। धान को कुल 24 प्रजातियों में से कमशः DRRH-107, DRRH-108, PA-6129, PHY-2 एवं N 22 में प्रत्येक पौधे में कल्लों की संख्या, भरे दानों की संख्या, प्रजनन प्रतिषत और अनाज उत्पादन में पालीथीन की सुरंग के अन्दर ताप तनाव में अन्य विभिन्न प्रजातियों की तुलना में अच्छा प्रर्दषन किया। ताप सहिष्णुता वाले इन धान की प्रजातियो को ताप सहिष्णु और बेहतर उपज के लिए जिम्मेंदार आणविक प्रकिया के लिए खोजा जा सकता हैं।

(अतुल कुमार)
सलाहकार

(मनीष लिगंवाण)
लेखक