MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL ASSESSMENT OF HEAT TOLERANCE IN VARIOUS RICE (*Oryza sativa* L.) GENOTYPES

Thesis

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By

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Research is an evolving concept. My endeavour in this regard is challenging as well as exhilarating. It implies the testing of our nerves. Every result arrived at is a modest beginning for a higher goal. My work in the same spirit is just a step in the ladder. The words at my command are indeed not adequate, either in the form of spirit or to express the depth of my humbleness, before Almighty God, whose endless blessings have made me to carry on this tedious task. The beauty of the destination is half veiled and the fragrance of the success half dull until the traces of all those enlightening the path are left to fly with the wind spreading word of thankfulness".

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February, 2021 **(Roshan Suresh Thakur)**
Pantnagar *Author*

CERTIFICATE

This is to certify that the thesis entitled **“MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL ASSESSMENT OF HEAT TOLERANCE IN VARIOUS RICE (*Oryza sativa* L.) GENOTYPES”,** submitted in partial fulfilment of the requirements for the degree of **Master of Science in Agriculture** with major in **Plant Physiology,** of the college of Post Graduate Studies, G.B. Pant University of Agriculture & Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. Roshan Suresh Thakur,** Id. No. **54224,** 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 investigation have been acknowledged.

12-2-2021

(S. C. Shankhdhar)
Chairman
Advisory Committee

Pantnagar
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CERTIFICATE

We, the undersigned members of Advisory Committee of **Mr. Roshan Suresh Thakur,** Id. No. **54224,** a candidate for the degree of **Master of Science in Agriculture** with major in **Plant Physiology** agree that the thesis entitled **“MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL ASSESSMENT OF HEAT TOLERANCE IN VARIOUS RICE (*Oryza sativa* L.) GENOTYPES”,** may be submitted in partial fulfilment of the requirements for the degree.

(S. C. Shankhdhar)
Chairman

(Atul Kumar) Member	**(Gurdeep Bains)** Member	**(B.R. Singh)** Member

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LIST OF ABBREVIATIONS

% : Per cent
µg : Microgram
µl : Microliter
BSA : Bovine serum albumin
C : Contol
C. D. : Critical Difference
CCB-G : Coomassie brilliant blue G-250 dye
cm^2 : Centimeter square
et.al : Etalia, (Co-worker)
Fig. : Figure
Fr. : Fresh
g : Gram
G : Genotype
h : hours
ha : hectares
HCl : Hydrochloric acid
m^2 : Meter square
mg : Miligram
PEA : Photosynthetic efficiency analyser
SAR : Shade avoidance response
SEm.± : Standard Error of mean
SOD : Super oxide dismutase
T : Treatment
TDM : Total dry matter
Wt. : Weight

Introduction

There are three groups of (*Oryza sativa* L.) i.e. indica, japonica and javanica, out of which indica cultivar is the most widely grown in tropical South-East Asia and is a rich source of carbohydrates, proteins, lipids and minerals. 30-80% daily calories consumed are supplied by it **(Yoshida, 1981).** Rice has been cultivated under wide range of climatic conditions. Growing rice in irrigated cropping systems allows its production in the warmer, high radiation, off season post-monsoon and summer months. Rice production has also intensified in areas of rainfed-lowland and dryland (upland) cropping systems, many of which are prone to drought and high temperature stress **(Jagadish *et al.,* 2007).** Globally, the harvested rice area had increased from 120.1 million ha in 1960 to 161.6 million ha in 2018. During this time, the average rice yield doubled from 1.84 to 4.51 tons ha^{-1} **(http://ricestat.irri.org:8080/wrsv3/entrypoint.htm).**

Rice is a diverse crop grown under various levels of altitude and climate. It is grown more than 3000m elevation in Bhutan and Nepal, also 3m under sea level in Kerala in India. The geographical distribution of rice-growing regions on the planet shows that rice is cultivated from 50° North in Manchuria in China and Central Czechoslovakia, on the equator to 35° South in New South Wales in Australia and Uruguay. It is cultivated in locales with more than 3000 mm rainfall, but also in desert locales with less than 50 mm rainfall during the growing season. In the Sindh regions of Pakistan and Punjab, rice is cultivated in regions with mean monthly temperatures of higher than 33℃, while the average season temperature in northern Japan is not much higher than 17℃ **(Krishnan *et al.*, 2011).** Growing the rice in irrigated cropping systems allows its production in the warmer, high radiation, off season post monsoon and summer months. Rice serves the lives of around three billion individuals and a significant portion of its production just as utilization is focused in Asia out of around one-tenth of the arable land **(Kumar *et al.,* 2018).**

Because of the increasing population growth in rice consuming countries, there is increasing demand for rice consumption also. The cultivation is vulnerable in the temperate, tropical, and subtropical areas due to repetitive circumstances of high and low temperatures **(Hussain *et al*., 2019).** Rice is a critical food crop produced second most elevated on the planet and has been spread worldwide under wide scope of climatic conditions. Rice production has escalated in dryland territories i.e. rainfed-lowland and upland cropping systems, a considerable lot of which are inclined to high temperature and drought stresses **(Wang *et al*., 2019).** Rice sustains the lives of about three billion people and a major share of its production as well as consumption is centered in Asia (growing on ~90% acreage) out of around one tenth of the arable land **(Wang *et al.*, 2020).**

Crop period, productivity and stability are important aspects of rice cultivation which are affected by various climatic factors. For example, sea level rise causing flooding and salinity intrusion may affect Asia's mega-deltas (Ganges-Brahmaputra in Bangladesh; Irrawady in Myanmar; and Mekong and Red River in Vietnam) limiting future production. This thus, alongside other environmental change effects will influence domestic rice markets just as global exchange. In addition, rice is likewise grown in rainfed lowland regions that are prone to drought and flood. Production risks will increase under aggravating climatic limits, in these areas. Rice yields will likewise be contrarily influenced by higher night-time temperatures (a decline of 10% for every 1ºC temperature increment) (**IRRI, 2012**).

Extreme risk of crop damage is found in continents at high altitudes, especially in the Northern Hemisphere between 40 and 60 °N. Central and Eastern Asia, Central-North America and the Northern part of the Indian subcontinent have large suitable cropping areas under heat stress risk. Temperate and subtropical agricultural areas may suffer significant crop losses due to extreme temperatures and highlight the need to develop strategies to adapt to agricultural policies that can reduce the effects of heat stress on global food supply **(Teixiera *et al.,* 2013).**

About 10% reduction in rice yield will occur for every 1°C increase in average temperature (**Peng *et al*., 2004).** The **IPCC (2014)** has predicted that in the upcoming years, there would be huge increment in global temperature stress. The demand for food increases with the increase in population and buying power of densely populated countries **(FAO, 2017).** According to **IPCC special report 2018,** in recent 30 years the impact of global warming has resulted in the increment of the average total temperature by 1.5°C. The year 2019 was the second warmest year amongst the 140-years, with a global land and ocean surface temperature departure from average of +0.95°C (+1.71°F) **(www.ncdc.noaa.gov).** Rice is produced in near-about seventeen nations in Asia and the Pacific, nine nations in North and South America as well as eight nations in Africa. Global rice production was at peak in the year 2018-19 (507.3 million tonnes) and, it was found to be less than 0.8% in succeeding year i.e. 2019-20 (501.4 million tonnes) **(FAO, 2019).** Rice production in 2020-21 has been raised by 2.2 million tonnes, i.e., from 508.4 million tonnes to 510.6 million tonnes **(FAO update, 2021).**

Heat stress is detrimental to many plant species in terms of growth and productivity, especially in the summer months and in warm and temperate climatic regions. Global warming is increasing the frequency of heat stress **(Porter, 2005).** Rising temperatures may prompt changed topographical dispersion and developing period of agricultural crops by permitting the threshold temperature for the beginning of the season and crop maturity to reach earlier **(Gornall, 2010).**

Global warming has increased the frequency of extreme high temperature events **(Shi *et al.,* 2015).** Global warming associated with gaseous emissions due to human activities may increase the world's average ambient temperature, exacerbating the problem of heat stress. According to predictions of the intergovernmental panel on climatic change, global temperature will rise 0.3 ^{0}C per decade **(Kumar *et al.,* 2017).** High temperature is a major abiotic stress that limits the growth and production of plants. Therefore, the plant response to heat stress (HS) has been a focus of research. However, the plant response to HS involves complex physiological traits and molecular or gene networks that are not fully understood **(Zhao *et al.*, 2021).**

Rice thrives in various environmental conditions as hot and dry to humid climates. Extreme heat episodes can irreversibly damage rice grain quality, yield and plant processes such as germination and fertilization **(Singhal *et al.,* 2016).** Rice plants are obstinately exposed to a wide-range of abiotic and biotic stresses. To overcome these challenges, they have developed mechanisms to recognize external signals and to manifest tolerant and adaptive reactions with appropriate physiological and morphological changes **(Wani *et al.,* 2016).** So, information about various physiological parameters and yield attributing characteristics which are responsible for yield variation and for heat tolerance is important. Heat stress tolerance can be defined based on the relative yield of a genotype, compared with other genotypes subjected to the same stress, and where avoidance is not a major factor **(Prasad *et al.*, 2017).**

Heat stress at anthesis causes an uncommon diminishing in grain yield in view of pollen sterility, unfilled or vacant grains, reduced grain weight, and poor seed setting. Also, high temperature causes drastic decrease in amylose content and grain size **(Cheabu *et al.*, 2018).** HT stress alters chlorophyll a/b ratio, decreases leaf chlorophyll content. Temperature beyond the critical level could reduce tiller number, plant height, and total dry weight. Higher rates of sterility were observed in warm humid as compared to dry conditions because of humidity effects on transpiration cooling **(Kumar *et al.*, 2019).**

Rice crop exposed to 3.6 to 7.0°C higher temperature than ambient conditions, from heading to middle ripening stage was found to decrease photosynthesis by 11.2-35.6% by changing the structural organization of thylakoids and specifically the grana stacking in the chloroplast or even its ability to swell **(Nagai *et al.*, 2009).** High temperature stress also decreases leaf chlorophyll content. The loss of chlorophyll during high temperature stress resulted in change in the chlorophyll a:b ratio due to premature leaf senescence. The degradation of chlorophyll molecules may be associated with production of reactive oxygen species under high temperature stress **(Makino *et al.*, 2010).**

High temperature affects various common quality attributes like reduction in grain filling, decreased weight of grain, increase in the percentage of white chalky rice and milky white rice. In addition, it can cause reduction in grain size and amylose content leading to reduced yield of quality rice. High temperature can adversely affected rice yields in two principal ways, viz., (i) In combination with high humidity, high temperature affects spikelet sterility and grain quality (ii) increased night temperatures that might lead to reduction in assimilate accumulation **(Jagadish *et al.*, 2007).** High temperature can also disrupt the movement of water, ions as well as organic solutes across the various membranes which eventually interfere with the plant processes like photosynthesis and respiration. When plants are subjected to a more than ambient temperature, electrolyte leakage may occur from leaves which finally disturb the yield performance as the thermal stability of cell membrane is positively associated with yield **(Wassmann *et al.,* 2009).**

Although high temperature has shown harmful effects on the plant, there are certain rice cultivars that can be grown in extremely hot environments, such rice germplasm has developed traits for heat resistance or tolerance. The results of tolerance that is obtained in a crop under high temperature stress are actually because of certain changes at biochemical level like synthesis of osmolytes, soluble sugars and various enzymatic and nonenzymatic antioxidants to scavenge the reactive oxygen species **(Jagadish *et al.,* 2009).** Through a variety of reactions, oxygen, leads to the formation of peroxide, hydroxide and other ROS and under stressed conditions the steady state balance between generation and elimination of reactive oxygen species is altered and become deleterious which can cause significant damage to the structure of cell they eventually cause oxidative stress and leading to cell death. It has been estimated that 1-2% of O_2 consumption leads to the formation of ROS in plant tissues during stress conditions **(Kumar *et al*, 2015).**

High temperature stress can be easily sensed by physico-chemical perturbations of various biomolecules in the cytosol, plasma membrane and subcellular organelles of plant cells, which generate particular signals for a heat shock response. In addition to this, heat shock can lead to a dramatic reprogramming in cellular metabolism, as well as affect the cells at the nucleic acid and the cytoskeleton level **(Kotak *et al.,* 2007).** The accumulation of heat shock proteins (HSPs) is assumed to play a central role in the response to heat stress and in acquired thermotolerane in plants and other organisms. Besides HSPs, numerous other proteins have been found to play important role in stress response like dehydrins. Expression of stress proteins is an important adaptation to cope the various stresses **(Jagadish *et al.,* 2010).** HSPs can play a crucial role in protecting plants against stress conditions by reestablishing a normal protein conformation and thus cellular homeostasis. They act as molecular chaperons and are responsible to repair and aid in the renaturation of stress-damaged proteins **(Hasanuzzaman *et al.,* 2013).**

The response behaviour of different rice genotypes to high temperatures differ according to the developmental stages with tolerance to high temperature, as tolerance in one stage does not necessarily account for tolerance in other stage. Therefore, the effect of high temperature during the different developmental stages has to be partitioned and evaluated separately for assessment, identification and characterization for genetic manipulation of various tolerance mechanisms. During the vegetative stage, culminating in panicle initiation, can tolerate relatively high temperatures (35/25°C; expressing day night temperature regime). Temperatures beyond the critical level could lead to reduced plant height, tiller number and total dry weight **(Prasad *et al.,* 2017).**

Rice is highly susceptible to high temperature, particularly during the reproductive and ripening stages. Extremely high temperatures, even for a few hours, during flowering can lead to complete sterility, while high temperatures during ripening can lead to reduced grain filling, reduced yield and poor milling quality i.e more broken grains **(Makino *et al.,* 2010).** Rice crop showed reduction in pollen activity, pollen germination and floret fertility at high temperature. Reduction of the pollen quality traits under any stress condition might induce morphological disturbances on pollen. The decrement in the number of filled pollen could be attributed to various reasons such as young microspores fail to differentiate, decline in the amount of dehisced anthers and supression of anther development **(Kumar *et al.,* 2015).** Pollen development abortion and pollen viability is result of heat stress induced male sterility in various plants. Studies on both high day temperatures and night temperatures found negative effects on rice spikelet fertility and yields. Temperatures over 35.8°C at anthesis stage in rice caused approx. 15% spikelet sterility, where 38°C induced 8-63% spikelet sterility across 7 diverse rice genotypes **(Kumar *et al*., 2019).**

As discussed earlier that the reproductive stages (anthesis and grain filling stages) in rice are far more susceptible to high temperature than the vegetative stages. During the reproductive stage the process of appearance of the anthers which is followed by micro gametogenesis are most sensitive to high temperature **(Jagadish *et al.,* 2007).** As a result it severely affects the spikelet fertility and deteriorate the grain quality by influencing the related cellular and developmental processes. The fertility of spikelets is not only dependent on the temperature limit but also on the exposure duration **(Wassmann *et al.,* 2009).**

To survive and adapt to new conditions, most of the plants redirect their growth through various morphological, physiological and biochemical responses that minimize stress exposure, limit damage or facilitate the repair of damaged systems. Specifically, cooperative activity of the different phytohormones, osmoprotectants, etc. alongwith stress-induced ROS signals assigns plant development with plant reactions to natural changes. In other words, plants have managed to acquire an escape or survival strategy to deal with stress by modifying some of their morphological and physiological traits **(Zhao *et al.*, 2021).**

Keeping in view the impacts of heat stress in rice, the experiment will deal with the following objectives:-

- To evaluate the effect of high temperature stress on morpho-physiological and biochemical parameters of different rice genotypes.
- To study the yield attributes of different rice genotypes under heat stress.

Review
of
Literature

Chapter 2 REVIEW OF LITERATURE

Rice (*Oryza sativa* L.) is the most important food item and, across the globe, it is the staple food for millions. In tropical and subtropical Asia, major consumption of rice takes place. Around the world, rice is grown either as upland and/or lowland crop. Irrigated lowland rice contributes nearly 76% of the global rice production but it covers only about 57% of the land under rice cultivation **(Matsui *et al*. 2001).** Rice is a monocot and usually grown as an annual plant while it can survive as a perennial plant in the tropical areas and can grow a ratoon crop for up to 30 years. It serves as a major source of calories for the large part of the world's population. As a result of increasing human population, globally, the expected demand for crop production can double by 2050 **(Peng *et al*., 2004).**

To feed this increasing human population and to meet this global demand for food, there is a need of the enhancement of crop yield rather than clearing more land for crop production which is the most promising approach for maintaining food security with less environmental impact. Currently, the rice yield is increasing at a rate of 1% which is less than 2.4% per year which is required to double its production by 2050. Therefore, there is a need for the development of new varieties which have higher yield potential **(Sang *et al.,* 2007).**

India occupied the largest area under rice cultivation and, for the rice farming, it is an important Centre. In the Indian subcontinent, rice occupied more than a quarter of the cultivated land during 2011-12. In the eastern and southern parts of India, rice is an essential part of the daily meal. Around the world, for thousands of millions of peoples, rice plays an essential role in shaping the diets, culture, and economics. For more than 50% of the world population, "rice is life" this statement will not be out of place. It serves as a staple food crop for more than 50% of the world's population. Beyond this, rice husk, straw and bran are also used as cattle feed and in cottage industry for preparation of mats, hats, ropes, sound absorbents, strawboard and as a litter material and fuel sources. Keeping the importance of rice in view, the year 2004 was designated as the "International Year of Rice" by the United Nation **(Jagadish *et al.,* 2012).**

India contributes about 20% of total world rice production and it is one of the world's largest producers of the rice and brown rice. In India, rice is the prominent crop and for the people of southern and eastern part of the country, it is the staple food. In 1950-51, 30.81 million/ha area was under the rice crop which increased to 43.86 million hectares in 2014-15 which is nearly 142 percent higher. From 1950-51 to 2014-15, remarkable increase registered in rice production which went upto nearly 5 times from 20.58 million tonnes to 104.86 million tonnes, respectively. There is an increase in rice productivity which was 668 kg/ha in 1950-51 and increased to 2390 kg/ha during 2014-15 **(Agricultural Statistics at a glance, 2015).** Rice is fundamentally a Kharif crop in India and is mainly grown in rainfed areas which receive a heavy annual rainfall and requires more than 100 cm rainfall and temperature around 25°C and above.

Crop production has been significantly threatened in recent years due to global environmental changes **(Lobell *et al.*, 2011).** According to United Nations estimates, the world population is expected to reach around eight billion by 2024 without an increase in arable land, imposing serious threat to sustainable food production for the planet **(Usman *et al.*, 2014).** Therefore, more emphases should be there on food availability for increasing population under changing environmental conditions. Rice is a widespread farming system in many environments considered to be 'hot spots' of climate change impacts **(Wani *et al.*, 2016).**

Among the ever-changing components of the environment, the constantly escalating ambient temperature is seemed to be one of the most detrimental. It is assumed that each 1°C increase in temperature will cause about 10% decline in rice grain yield **(Wang *et al.*, 2019).** Global climate change is liable to exacerbate the current vulnerability of the crop to climate, with a forecasted global average surface temperature increase of 1.4–5.8°C by 2100 and the possibility of increased variability about this mean **(www.climate.gov, 2019).** It is predicted that, an incline by 2°C to 4°C till 2050 can be recorded due to overwhelming global warming. Because of that, it can lead to alleviation of the earth's surface temperature. High temperatures terminate in alarming detrimental impacts on rice production. The planting pattern has progressively transformed from double-season to single-season planting to save time

& money as well as efforts, and to generate more profit within less time **(Wang *et al.*, 2019).**

For every one billion people added to the world's population, 100 million more tons of rice need to be produced each year. But the challenges facing rice production are great. To help ensure food security, reduce poverty, and help vulnerable populations adapt to the effects of climate change, more rice needs to be produced on less land, with less water and less labor. Rice production systems need to be more equitable, efficient, environmentally-friendly, and more resilient to climate change, while contributing less to greenhouse gas emissions **(Xu *et al.,* 2020).**

2.1 Factors Affecting Crop Growth and Yield

Various Environmental factors such as sunlight, temperature, salinity, flooding, drought and air affect the grain yield and biomass and play a crucial role in crop growth and productivity **(Peng *et al.*, 2004).** The production of crops is mostly based on natural parameters, such as solar radiation, temperature, available water resources and soil fertility but unfortunately, with the environmental pollution and climate change crop cultivation has had to face serious problems in producing higher yields, for example, reduced sunlight intensity caused by air pollution is one of the major factor which affect the growth and yield of the plant **(Gornall, 2010).**

2.2 Effects of High Temperature

Due to continuous increment in temperature the atmosphere directly affect growth quality as well as quantity of the crops. Such changes in the climate alter phenology, physiology and yield components. Plant responses to high temperature vary with the degree of temperature, duration and plant type. At extremely high temperature, cellular damage or cell death may occur within minutes, which may lead to a catastrophic collapse of cellular organization **(Prasad *et al.*, 2017).** High temperature affects nearly all the growth stages of rice from emergence to ripening and harvesting. Temperature with photoperiod is one of the main driving forces for crop development. The developmental stage at which the plant is exposed to heat stress determines the severity of the possible damage to the crop. The optimum temperature for the normal development of rice ranges from 27℃ to 32℃ **(Rai *et al.*, 2018).**

Each organism responds to different optimum temperatures for their growth, development, and reproduction. Rice grows within the range of 25° to 35℃, considered as moderate temperature. Temperature beyond optimum is injurious for rice and negatively impacts growth, development and eventually reduces the grain yield. High temperature is problematic in tropical and subtropical regions. The factors like timing of stress, duration, and intensity are responsible for high temperature stress effects; still, it is more detrimental during reproductive stage. High temperature affects include retarding the pollination, defective spikelet sterility and anther dehiscence, and decrease in root elongation and plant height **(Hussain *et al.*, 2019).**

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

Growth stage	**Temperature requirement (℃)**	**Symptoms**
Vegetative	18-30	White leaf tip, chlorotic bands and blotches, white bands and specks, reduced tillering, reduced height.
Reproductive anthesis	30-33	Reduced spikelet number, sterility.
Ripening	20-29	Reduced grain filling.

(Adopted from Yoshida, 1981)

High temperatures can cause considerable pre-harvest and post-harvest damages, including scorching of twigs & leaves, sunburns on stems, branches & leaves, leaf senescence and abscission, root and shoot growth inhibition, fruit damage & discoloration and reduction in yield. In tropical climates, high temperatures and excess of radiation are often the most limiting factors influencing plant growth and final crop yield. Heat stress induced modifications in plants may be indirect in altering the pattern of development or direct as on existing physiological processes **(Kumar *et al.,* 2018).**

At different times during the life cycle, rice plant is differentially sensitive to temperature stress. Therefore, critically low and high temperatures, normally below

20℃ and 30℃, vary from one growth stage to another. Critical temperatures differ according to cultivars, diurnal changes, duration of critical temperature, and physiological status of the plant. Rice is affected adversely by high temperature in the lower elevations of the tropics and by lower temperature in the temperate regions **(Hussain *et al*., 2019).**

In temperate regions, heat stress has been reported as one of the most significant causes of production of dry matter and reduction in yield in many crops, including rice. These responses can differ from one phenological stage to another. In most plants, reproductive processes are markedly affected by high temperatures which ultimately affect fertilization and post-fertilization processes ultimately leading to reduction in crop yield. Long-term effects of elevated temperature on developing seeds may include loss of vigor or delayed germination, which ultimately lead to reduced emergence and establishment of seedling **(Kumar *et al*., 2019).**

There is a general tendency of reduction in cell size, stomata closure and decrease in loss of water, increased trichomatous & stomatal densities, greater xylem vessels of both shoot & root at the whole plant level. Both female & male gametophytes are sensitive to high temperature and response varies with genotype; still, ovules are normally more heat tolerant than pollen in rice **(Wang *et al.*, 2020).**

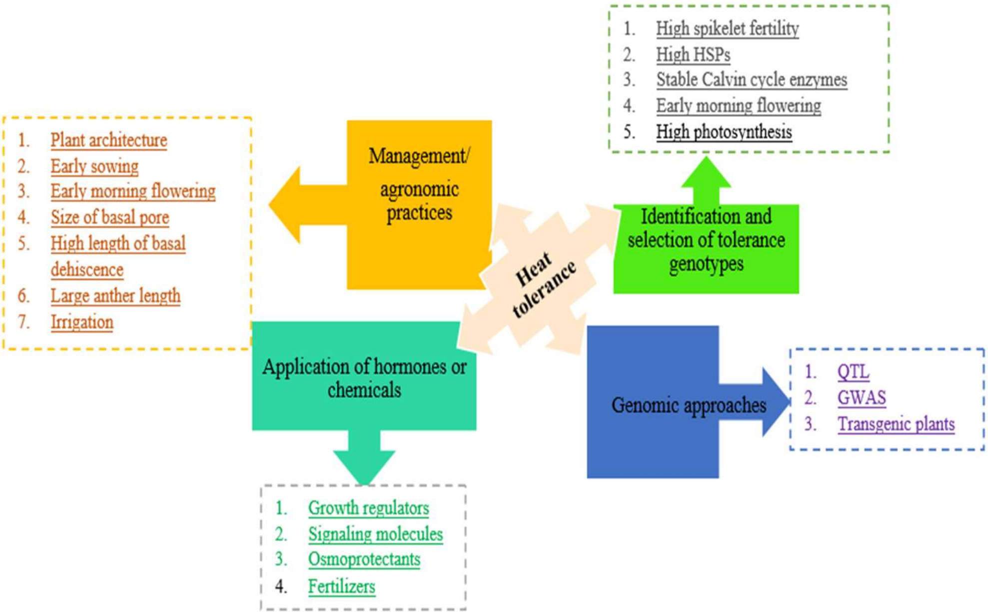

Figure 2.1: Major effects of High Temperature stress (adopted from Khan *et al.*, 2019)

Phenological changes

Various changes in the plant phenology in response to high temperature stress are useful to reveal an improved understanding of the interactions between stress atmosphere and the plant. Different phenological stages have difference in their sensitivity to high temperature. However, this also depends on the species and genotype as there are inter and intra-specific variations. High temperature stress during the period of grain filling adversely affected the duration of anthesis to maturity in wheat **(Sharma and Tandon, 1997).** It was reported that under late sowing, early flowering early and maturation occurred by 10-24 days and 19-40 days respectively compared to that of normal sowing. Delayed sowing in rice crop (10th Jan) not only resulted in reduction in total maturity period, but also reduced the vegetative and reproductive phases by 20-13 days respectively **(Singh and Ahmed, 1997).** However, heat units consumed during reproductive phase increased with lower thermal use efficiency of grain and crop biomass in wheat **(Dogiwal, 1999).** Similar results were reported, wherein 38 days delay in sowing reduced 20 days crop duration particularly phenol phases i.e. flag leaf emergence and anthesis in wheat **(Munjal *et al.,* 2002).** In another investigation high temperatures in rice significantly decline growth and phenology due to marked reduction in growth and critical growth stages of the crop. In optimum temperature conditions rice crop accumulate more biomass, compared to late sown crop plants that manifested into higher grain per plant **(Porter, 2005).**

The fifteen wheat cultivars were exposed to different date of sowing, optimum (November 30) and late (December 30) in a field experiment. Under late sown condition, the grain filling duration was decreased by 5 days in the heat tolerant genotypes and about 12 days in heat sensitive genotypes as compared to normal growing conditions. Less variations in the pre-anthesis growth duration in the heat tolerant and heat susceptible genotypes showed more or less response to the changing of their growth condition. More extent of reduction of the post-anthesis growth duration was found due to the late planting in sensitive genotypes compared to tolerant genotypes **(Haque *et al.* 2008).**

Anatomical changes

At the whole plant level, there is a general tendency of reduced cell size, closure of stomata and curtailed loss of water, increased stomatal and trichomatous densities, and greater xylem vessels of both root and shoot in *Lotus creticus* plants **(Banon *et al.*, 2004)**. High temperature severely damaged the mesophyll cells and increased permeability of plasma membrane in rice plants **(Zhang *et al.*, 2005)**. In rice under high temperature stress resistant line 996 showed tightly arranged mesophyll cells, fully developed vascular bundles and some closed stomata in the flag leaves while in susceptible line 4628 loosely arranged and damaged mesophyll cells, under developed vascular bundles were seen (**Zhang *et al.*, 2009)**. Anatomical changes in plants under high ambient temperatures are generally similar to those under drought stress. Both male and female gametophytes are sensitive to high temperature and response varies with genotype; however, ovules are generally less heat sensitive than pollen. A temperature of 40-45 ºC showed swelling of chloroplast, expansion of matrix and loosening of lamella in citron. High temperature damages cardiolipin in mitochondria which leads to decreased activity of cytochrome c oxidase **(Ali *et al.*, 2018).**

Morphological changes

High temperature can cause considerable pre and post-harvest damages, including scorching of leaves, sunburns on leaves, branches and stems, leaf senescence, shoot and root growth inhibition, fruit discoloration, damage, reduced yield, reduced TDM and grain filling in cereals. Both plant growth and developments are affected by temperature **(Porter, 2005)**. Reduced leaf area, increased tiller number and plant height is also observed. Many hydrophilic globular proteins accumulate in seeds during the maturation phase, when the seeds are developing desiccation tolerance. The plant responses to high temperature vary with plant species/varieties and phenological stages. Transpiration was more influenced than photosynthesis at the beginning of drying period. Irrigation induced a rapid resumption of transpiration and photosynthesis, simultaneously with the leaf unrolling and progressive stomatal opening (**Kondamudi *et al.,* 2012).** Different stresses might require conflicting or antagonistic responses. It is quite often observed that during the heat stress, plants open their stomata to cool their leaves by transpiration. However, if heat stress is combined with drought the plants are unable to open their stomata, as a result leaf temperature remains higher in *Arabidopsis*. Smaller panicle size and chaffy grains are produced under high temperature stress **(Reddy, 2017).**

2.2.1 Heat shock proteins

High temperature induced constitutive expression of most of the proteins provides protection to intracellular proteins from denaturation and preserve their stability and function through protein folding; so, it act as chaperones. Heat stress is responsible for up-regulation of some heat inducible genes commonly referred as "heat shock genes" (HSGs) that encode heat shock proteins (HSPs) and these active products are very much necessary for survival of the plant under lethal high temperature. Well-characterized HSPs can be grouped into five different families in plants: HSP 20 (or small HSP, sHSP), HSP60 (or GroE), HSP70 (or DnaK), HSP90, and HSP100 (or ClpB). The expression of different HSPs is restricted to certain developmental stages of plant like seed germination, embryogenesis, microsporogenesis and fruit maturation in rice **(Prasad *et al.*, 2017).**

Overexpressing OsHsp 18.0 in rice not only increased the tolerance to heat and salt stresses but also caused resistance to *Xanthomonas oryzae pv. Oryzae* (Bacterial leaf blight) assigning a new function for OsHsps in rice. OsHsp18, a class II small HSP may function as a molecular chaperone to increase the thermotolerance of *E. coli* cells in vivo and preventing thermal aggregation of a client protein **(Kumar *et al.*, 2019).**

2.2.2 Effects on germination

Germination is profoundly increased by temperature. Major impacts caused by heat stress on rice plant to varying temperature at different growth stages include reduced germination percentage, plant emergence, poor seedling vigor, abnormal seedlings, reduced radical & plumule growth of germinated seedlings **(Satake and Yoshida, 1978).** Loss of seed viability is often attributed to the loss of integrity of plasma lemma leading to electrolyte leakage **(Naeem and Muhammad, 2006).** Temperature has profound influence on germination. It was found that incubation of 6 days was found necessary for 90% germination at 25℃ temperature, 2 days at 31–36℃ temperature, and an extended period at a low temperature of 0–5℃. Over a long time if the seeds germinate arbitrarily, the growth of seedling will not be uniform and plants will mature over more longer period. Linearly increase in growth occurs between 22 and 31℃ (**Mohammad and Tarpley, 2010).**

The losses in seed viability are mainly due to the fact that the cellular membranes are primarily composed of various proteins and lipids. During the stress condition seed deterioration takes place mainly due to disorganization of proteins and lipid phase transitions which influence the membrane Ill structure and integrity, consequently seed viability **(Menezes *et al.,* 2014).** In study, the seeds of different rice species were experimentally subjected to high temperature stress and humidity conditions to obtain non-germinating seeds and it was found that germination percent of *O. alta* and *O. rhizomatis* decreased by 34 and 23% respectively **(Das *et al.,* 2017).** Major impacts caused by heat stress on rice plant to varying temperature at different growth stages include reduced germination percentage, plant emergence, abnormal seedlings, poor seedling vigor, reduced radical and plumule growth of germinated seedlings **(Zhang *et al.* 2017).**

2.2.3 Vegetative growth

High temperature has proved to have a very sensitive effect on the seedling growth in the first week after germination. Higher than 70% of the growth during this week occurs mainly due to enzymatic breakdown of the seed reserves, after first week there is a less influence of temperature **(Yoshida, 1978)**. A 22℃ or less temperature it is considered subnormal for seedling growth. The growth of seedling is reasoned to be good up to a temperature of 35° C, above which it declines sharply and at more than 40℃, death of seedling occurs. It is estimated that 7° to 16℃ is the critical minimum temperature required for shoot elongation and that for root elongation is from 12° to 16℃ **(Nishiyama, 1977)**. Hence, about 10℃ is considered critical minimum temperature for elongation of both shoot and root. However, critical temperatures may vary depending on the cultivars, seed history, and cultural management practices.

Sometimes there is an increase in number of tillers under high temperature stress. The yield potential of a rice plant can be determined by its tillering capacity. As plants with more tillers have greater inconsistency in mobilizing assimilates and nutrients leads to changes in development of grain and yield among tillers **(Yoshida,**

1981). Since, the development of one leaf requires about 100 degree days air temperature before the initiation of panicle primordial and, about 170 degree days thereafter. Therefore, when rice plants are grows at 20°C before panicle primordial initiation, leaves emerge every 5 days and when it grown at 25°C, they emerge every 4 days. Hence, near the apical meristem leaf appearance is controlled by temperature **(Ritchie, 1993)**.

Thus, a linear relation occurs between the emergence of main stems and tillers and further, between tillers themselves. Further, this mobilization of assimilates and nutrients among tillers may be affected by increased temperature stress **(Krishnan *et al.,* 2011)**. While, it was also reported that plant height increased with the rise in temperature within the range of 30-35 ^{0}C **(Shah *et al.*, 2011)**. It was also observed that tiller number has positive correlation with panicle dry weight per unit area and due to high temperature more than 33 ^{0}C reduced tiller numbers, panicle number and panicle length were found. This is because temperature above 33 ^{0}C was found to be unfavorable for tiller formation **(Poli *et al.*, 2013)**.

2.2.4 Plant chlorophyll content and Photosynthetic rate

Photosynthetic pigments (chl a, b and carotenoids) decreased under heat stress in most of the rice genotypes. Heat stress also led to the reduction in Chl b in leaves of several rice genotypes. The highest percent increase was found in the heat tolerant genotypes. So it can be inferred that high chl b content is linked with heat tolerance and can be used as an important physiological marker for heat tolerance in rice. The degradation of chlorophyll molecules may be associated with production of reactive oxygen species under high temperature stress. Photosynthetic rate at anthesis stage has positive correlation with heat tolerance in rice **(Rai *et al.*, 2018).** It can be suggested that the genotypes with high photosynthetic pigments including chlorophyll a, b and carotenoids under heat stress have better heat tolerance in rice and other crops. *Oryza meridionalis Ng.* a wild relative of cultivated rice, *Oryza sativa* L., was reported to be a heat tolerant rice variety because it showed high photosynthetic rate and leaf elongation **(Cheabu *et al.*, 2018).**

The loss of chlorophyll during high temperature stress resulted in change in the chlorophyll a:b ratio due to premature leaf senescence. Both high and low temperature stresses inhibit the flag leaf photosynthesis, because high and low temperature both had impact on the various processes of photosynthesis both in light and dark reactions **(Hussain *et al.*, 2019).** Plant chlorophyll content and photosynthetic rate are closely related to the change in temperature. Under both high and low temperature stress conditions chlorophyll content in flag leaf was lower than the control up to 21 DAF, indicating a reduction of chlorophyll content caused by both high and low temperature treatments **(Khan *et al.*, 2019).**

2.2.5 Effects on plant water status

High temperature stress along with limited water availability can significantly impair photosynthesis and finally reduce the amount of assimilates available to the grain. In rice water deficiency disturbs photosynthetic processes in vegetative plant tissues, particularly in leaves, resulting in a reduction in the water-soluble carbohydrate level in the anthers and in the expression of the gene responsible for the synthesis of the acidic invertase enzyme **(Sharkey, 2005)**. At the time of grain filling water stress reduces photosynthesis, induces early senescence and shortens the grain-filling period, but increases the remobilization of assimilates from the straw to the grains (**Mohammad and Tarpley, 2010).** Stem reserve mobilization is an important process supporting grain filling under heat stress conditions. Therefore, under stress conditions, stored carbohydrates may become the predominant source contributing to as much as 75–100% to the grain yield in rice (**Kondamudi *et al.,* 2012).**

Leaf fresh weight was also reduced under heat. The reason for this reduced in LFW seems to be the fact that the leaf was directly exposed and most affected plant part under high temperature stress and high temperature may have increased the transpiration rate from leaves **(Ahmad *et al.,* 2016).** LFW had significant positive correlation with Relative water content under heat stress **(Prasad *et al.,* 2017)**. Shoot fresh weight also has a significant positive correlation with chlorophyll a under heat stress in rice, the reason for this decrease in shoot fresh weight may be the reduced photosynthesis under heat stress due to the destruction of photosynthetic pigments **(Zafar *et al.,* 2017).**

Plant water status is the most important variable under changing ambient temperatures. Leaf fresh weight was generally reduced under heat. The reason for reduced LFW seems to be the fact that the leaf was directly exposed and most affected plant part under high temperature stress and high temperature may have increased the transpiration rate from leaves. LFW had significant positive correlation with Relative water content under heat stress **(Zafar *et al.*, 2018).** Under field conditions, high temperature stress is frequently associated with reduced water availability. High temperatures seem to cause more water loss in plants during daytime than night time. During vegetative stage, high day temperature can damage leaf gas exchange properties. In general, during day time enhanced transpiration induces water deficiency in plants, causing a decrease in water potential and leading to perturbation of various physiological processes. Plants tend to maintain stable tissue water status regardless of temperature when moisture is ample; however, high temperatures severely impair this tendency in plants when water is limiting **(Fahad *et al.*, 2019).**

2.2.6 Antioxidative capacity

Tolerant plants entail a tendency of protection against the damaging effects of reactive oxygen species (ROS) with the synthesis of various enzymatic and non-enzymatic ROS scavenging and detoxification systems. Tolerance of crops to heat stress in crop plants has been associated with an increase in antioxidative capacity. Activities of different antioxidant enzymes are temperature sensitive and activation occurs at different temperature ranges however the activities of these enzymes increase with increasing temperature **(Rai *et al.*, 2018).**

It was observed that enzymes ascorbate peroxidase (APX), superoxide dismutase (SOD) & catalase (CAT) showed an initial increase before declining at 50℃, while glutathione reductase (GR) & peroxidase (POX) activities declined at all temperatures ranging from 20 to 50℃. In addition, total antioxidant activity was at a maximum at 35–40℃ in the tolerant varieties and at 30℃ in the susceptible ones. The activities of different enzymes also differ depending upon susceptibility or tolerance of different crop varieties, their growth stages and growing season. Peroxidase (POX) is important for plants to survive under abiotic stress by scavenging excess ROS to maintain redox homeostasis **(Zhao *et al.*, 2018).**

2.2.7 Flowering and spikelet development

Rice plants are most sensitive to high temperature during the flowering i.e. anthesis and fertilization and to a lesser extent the preceding stage booting i.e.

microsporogenesis **(Satake and Yoshida, 1978).** High temperature negatively affects anther dehiscence, pollination, and pollen germination, which then leads to spikelet sterility and yield loss **(Yoshida *et al.,* 1981).** In a study high temperature reduced up to 75% of pollen viability in rice cultivars. Such reductions in pollen production at elevated temperatures were attributed to impaired cell division of microspore mother cell (**Prasad *et al.,* 2000**). It was also reported that the heat tolerant cultivar Nipponbare, which had higher spikelet fertility with well-developed cultivars in anthers and thick locule walls which enabled easy rupture of the septa in response to swollen pollen. This mechanism resulted in better anther dehiscence and pollen shed of heat tolerant cultivars **(Matsui *et al.* 2001).**

During reproduction, a short period of heat stress can cause significant increases in floral buds and opened flower abortion; however, there are great variations in sensitivity within and among plant species **(Young *et al.*, 2004)**. Growth chamber and greenhouse studies suggest that high temperature is most deleterious at the time when flowers are first visible and sensitivity continues for 10-15 days. Reproductive phases most sensitive to high temperature are gametogenesis (8-9 days before anthesis) and fertilization (1-3 days after anthesis) in various plants **(Foolad, 2005)**. The staple cereals can withstand only narrow ranges of temperature, thus if temperature exceeded during the flowering phase it can damage fertilization resulting in reduced grain yield **(Porter, 2005).**

In a study rice cultivars TRIUNA and IET 20734 recorded high percentage of reduction in pollen viability; there was 30-40% reduction noticed in pollen viability in these genotypes and reduction in spikelet fertility under high temperature stress, within a range of 60- 80% over control. In contrast, tolerant cultivar JAYA, IET 20926 and IET 20915 recorded lower values of reduction in pollen viability **(Reddy, 2011**). Impairment of development of pollen and anther/ by elevated temperatures is another important factor contributing to decreased fruit set in many crops at moderate to-high temperatures. High temperature at this stage significantly decreases spikelet sterility in rice, or can even lead to no harvest. Upto 90% reduction in seed setting was observed in the suceptible cultivar Zhong 9B and about 50% reduction in seed setting in tolerant cultivar R207, due to anther dehiscence, pollen sterility and failed germination on the stigma **(Sebastian *et al.*, 2017).**

Growth chamber and greenhouse studies suggest that high temperature is most deleterious at the time when flowers are first visible and sensitivity continues for 10-15 days. Reproductive phases most sensitive to high temperature are gametogenesis (i.e. 8-9 days before anthesis) and fertilization (i.e. 1-3 days after anthesis) in various plants. Impairment of pollen and anther development by elevated temperatures is another important factor contributing to decreased fruit set in many crops at moderate to-high temperatures. High temperature at this stage significantly decreases spikelet sterility in rice, or can even lead to no harvest, which can be mainly ascribed to inhibitions of anther dehiscence, pollen sterility and failed germination on the stigma **(Prasad *et al.*, 2017).** High temperature stress induced male sterility is caused by abortion of pollen development and pollen viability in diverse plants such as rice, wheat, tomato, cowpea and Arabidopsis. Elevated temperatures for 4 days or more during the early phase of anther development caused abortion of pollen grains and thus complete male sterility in rice. Maximum temperatures over 35.8℃ at rice anthesis stage caused about 15% spikelet sterility, while 38℃ induced 8–63% spikelet sterility across seven diverse rice genotypes **(Cheabu *et al.*, 2018).**

Cessation of pollen tube elongation in the pistil is another important factor causing pollination failure under heat stress factors resulting in spikelet sterility in rice, especially in high temperature susceptible cultivars (**Zhang *et al.,* 2018**). Cessation of pollen tube elongation in the pistil is another important factor causing pollination failure under heat stress factors resulting in spikelet sterility in rice, especially in high temperature susceptible cultivars **(Rai *et al.*, 2018).** During reproduction, a short period of heat stress can cause significant increases in floral buds and opened flower abortion; however, there are great variations insensitivity within and among plant species. The sexual reproductive phase is predicted to be vulnerable to the instability of rice yields even in temperate regions, mainly due to the increased probability of male sterility induced by high temperatures **(Wang *et al.*, 2019).**

In particular, the sexual reproductive phase is predicted to be vulnerable to the instability of rice yields even in temperate regions, mainly due to the increased probability of male sterility induced by high temperatures. Elevated temperatures for 4 days or more during the early phase of anther development caused abortion of pollen grains and thus complete male sterility in rice **(Abiko *et al.*, 2005).** The reduction in spikelet fertility at high temperature could be due to decreased pollen production, pollen viability and stigma receptivity. Lower spikelet fertility at elevated temperature resulting in fewer filled grains, lower grain weight per panicle, and decreased harvest index were reported by many workers. The higher values of spikelet fertility were attributed to successful pollination under high. temperature conditions indicative of thermotolerance. Well developed anthers and better developed cavities for dehiscence and thicker locule walls of the anthers were reported to leading to spikelet fertility under high temperature stress **(Gui-lian *et al.* 2009).** At anthesis even for less than an hour at 33.7^{0}C may result in spikelet sterility while temperatures over 35.8 ℃ at rice heading stage caused about 15% spikelet sterility and with increase in temperature upto 38 ℃, 8–63% spikelet sterility was induced across seven diverse rice genotypes (**Mohammad and Tarpley, 2010).**

High temperature stress leads to male sterility in the flower which is caused by abortion of pollen development and pollen viability in diverse plants such as rice, wheat, tomato, cowpea and Arabidopsis **(Jagadish *et al.*, 2013)**. High temperature stress at this stage not only inhibits the anther dehiscence and pollen germination on the stigma, but also interrupts the pollen tube elongation in the pistils. Accordingly, heat stress may inhibit the development of fertilized ovum, rather than pollen tube elongation when the spikelets are subjected to heat stress for about 2 h after flowering. Since the flowering spikelets subjected to heat stress were about 5–10 min later, the spikelet sterility caused by heat stress was due to cessation of pollen tube elongation in the pistil, rather than poor anther dehiscence or lower pollen germination on the stigma **(Song *et al.* 2015).** As compared to susceptible genotypes some high temperature tolerant rice genotypes, viz., IET 21513 and IET 20925 less reduction in spikelet fertility (10%) was observed compared to control under terminal heat stress conditions **(Reddy, 2017).**

2.2.8 Effects on photosynthesis

Heat stress may lead to the dissociation of oxygen evolving complex (OEC), resulting in an imbalance between the electron flow from OEC toward the acceptor side of PSII in the direction of PSI reaction center in crops such as transgenic soybean, arabidopsis & rice. PSII is highly thermolabile, and its activity is greatly reduced or even partially stopped under high temperatures, that might be due to the properties of thylakoid membranes where PSII is located (**De Ronde *et al.,* 2004).** Photosynthesis is a very heat sensitive process and significantly contributes in plant growth and yield. Heat shock reduced the photosynthetic pigments and rate of photosynthesis in plants which held to the reduction in vegetative growth (**Khan *et al.*, 2019).** Any constraint in photosynthesis can limit plant growth at increased temperatures. Photochemical reactions in thylakoid lamellae and carbon metabolism in the stroma of chloroplast have been suggested as the primary sites of injury due to heat stress. Alterations in various photosynthetic attributes under high temperature are good indicators of thermotolerance of the plant as they show correlations with growth **(Kumar *et al.*, 2019).**

2.2.9 Membrane Thermostability

Heat stress causes the lipid peroxidation of cell membrane which is estimated in terms of MDA. Increased lipid peroxidation showed that oxidative stress was frequently produced in rice leaves after high temperature exposure. The MDA has significant negative correlation with SFW, CMTS and RWC which were considered important indicators of heat tolerance. The increased MDA content showed high membrane deterioration due to heat stress **(Zafar *et al.*, 2018)**. Cell membrane thermostability can be used as a good indicator of heat tolerance in plants. The mesophyll cells were severely damaged and permeability of plasma membrane was increased by high temperature in plants (**Khan *et al.*, 2019).**

2.2.10 Assimilate Partitioning

Heat stress reduces the time of assimilate translocation during grain filling. Under heat stress, reduced grain filling in temperate rice cultivars was not due to the lack of assimilates, but to the premature senescence of leaves. A higher rate of sterility was observed in rice in warm humid as compared to hot arid environments due to humidity effects on transpiration cooling **(Krishnan *et al.*, 2011)**. Sterile grains in panicles of rice crop always stay green before harvest, while the fertilized grains turn yellow in the process of ripening. High temperature at reproductive stage often causes poor pollination and fertilization, which will lead to a great loss of sink activity. In such situations, the translocation of assimilates from leaves to grains will be limited and the leaf senescence will be delayed **(Shi *et al.*, 2015).**

2.2.11 Effects on yield parameters

Generally, the cultivars of rice with high yield potential have grain weights in the range of 20–30 g which follows the order of maturity within a panicle, the first maturing grain being the heaviest. High temperature also increased the grain growth rate, but decreased the grain filling period. Longer period of effective grain filling and longer duration of green leaf area were needed for active canopy photosynthesis to match the grain-filling duration. Hence, identification of yield components responsible for variations and sensitive to high temperature becomes very important to sustain and increase grain yield in the future predicted warmer climate **(Akita, 1989).** Immature seeds lose viability faster than mature seeds under similar storage conditions. In developing seeds after the end of the grain-filling period maximum potential longevity was attained which is, defined as mass maturity **(Ellis and Pieta Filho, 1992)**.

The decrease in the ratio of panicle weight to green leaf area suggests that the source/sink ratio may have been affected. The accumulation of leaf carbohydrate and increase in specific leaf weight indicate feedback inhibition. Moreover, reduction in the number of filled grain per panicle greatly decreases grain yield **(Ziska and Manalo, 1996)**. The extent of sterility can vary from a few empty glumes to the entire panicle having unfilled grains under high temperature. Seed set and panicle weight of rice plants grown at higher temperatures (ambient 4^{0}C) were significantly reduced while green leaf area was increased, relative to those plants that are grown under ambient temperatures **(Lin *et al.*, 1997)**.

Heat stress during grain development enhances the rate and diminishes the grain filling duration, leading to low grain weight and grain yield. High temperature at the time of flowering and grain filling, decreases grain yield due to spikelet sterility and a shorter grain-filling period. High night-time temperature of $22/34^{0}$C highly suppressed the grain weight, as compared with high daytime temperature of $34/22^{0}$C and the control ($22/22^{0}$C) **(Morita *et al.,* 2005)**. Under increased night or day temperature panicles and plants grain quality becomes very poor. When there is an increase nighttime temperature from 18 to 30^{0}C from 12 midnight to 5 a.m., yield of rice decreases significantly, grain dimensions generally decrease, and the amylose content gets lowered, but the grain mass, total brown rice lipid, and protein contents do not vary, albeit with some differences among rice cultivars **(Cooper *et al.*, 2008)**. With respect to elevated [CO_2] considerably increase in brown rice yield, but high night temperature decreases yield, with a significant interaction of night temperature and [CO_2] **(Cheng *et al.*, 2009)**.

High temperatures during grain filling can influence flour and bread quality and other physico-chemical properties of rice grain. High temperature stress at flowering causes a serious reduction in grain yield due to pollen sterility, empty or unfilled grains, low grain weight, and poor seed setting. In addition, high temperature causes serious reduction in grain size and amylose content in rice **(Ying *et al.*, 2009)**. It was considered that even after flowering high temperature decreases final viscosity and the amylose content to some extent. On the contrary, high temperatures can increase the maximum viscosity and breakdown values and hardness versus adhesion ratio of cooked rice **(Tanaka *et al.*, 2009)**. Storage of rice grains under high temperatures changes the textural profile of the cooked rice grain with increased hardness, reduced adhesiveness, lower leaching of starch components, particularly amylose, and rougher surfaces. It was reported that starch structure and physiochemical properties were affected by rough rice stored at three temperatures (4, 21, and 38 ^{0}C) for 9 months **(Krishnan *et al.*, 2011)**.

Under the heat stress during initial growth phases, i.e., booting and flowering, greater yield reduction was noticed due to reduction in all the important yield components i.e., fertile spikelets, 1000 grain weight and increase in sterile and aborted spikelets per panicle. However, heat stress has no effect on the later growth stage (ripening). Temperatures higher than the optimum induced floret sterility and thus decreased rice yield **(Kabir *et al.,* 2014).**

High night-time temperature of 22/34℃ highly suppressed the grain weight, as compared with high daytime temperature of 34/22℃ and the control (22/22℃) was found in rice crop. Under the heat stress during initial growth phases, i.e., booting and flowering, greater yield reduction was noticed due to reduction in all the important yield components i.e., fertile spikelets, 1000 grain weight and increase in sterile and aborted spikelets per panicle. Temperatures higher than the optimum induced floret sterility and thus decreased rice yield. Under heat stress, reduced grain filling in temperate rice cultivars was not due to the lack of assimilates, but to the premature senescence of leaves **(Hussain *et al.*, 2018).**

Table 2.2: Critical temperature at different growth stages of rice

Growth stages	**Critical temperature (°C)**		
	Low	**Optimum**	**High**
Germination	10	20-35	45
Tillering	9-16	25-31	33
Panicle initiation	15	-	-
Anthesis	22	30-33	35
Ripening	12-18	20-25	30

(Adopted from Yoshida, 1981)

The grains ripened under high day/night temperature showed poor rice quality. These heat treatments could cause reduction of the grain maturity weight, brown rice rate, milled rice rate, amylose content and gel consistency, while degree of chalkiness increased. Degree of chalkiness is mainly determined by the appearance quality of rice. Chalkiness (%) was greatly affected by different temperature regimes. It was considered that under high temperature treatment the degree of chalkiness was 61.11% and under low temperature it was 22.59%. However, in the control condition, chalkiness was in between high and low temperature treatment which was 47.81% **(Ali *et al.,* 2018)**. Heat stress has no direct effect on the later growth stage i.e. ripening. High temperatures during grain filling can influence other physico-chemical properties of rice grain. Heat stress reduces the time of assimilate translocation during grain filling. Heat stress during grain development enhances the rate and diminishes the grain filling duration, leading to low grain weight and grain yield. High temperature at the time of anthesis and grain filling decreases grain yield due to spikelet sterility and a shorter grain-filling period **(Fahad *et al.,* 2019).**

Materials
&
Methods

MATERIALS AND METHODS

The details regarding the material used, procedures performed experimental approach and techniques used during the course of investigation and experimentation are recounted in this chapter.

3.1 Experimental Site

To study the effect of high temperature stress on growth, development and yield of various rice *(Oryza sativa L.)* genotypes, a field experiment was conducted in the year 2019 during kharif season in the rice physiology B1 block of Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, in the district U.S. Nagar (Uttarakhand) and later the laboratory experiments were conducted in the Department of Plant Physiology, College of Basic Sciences and Humanities, GBPUA&T, Pantnagar. Geographically, Pantnagar lies in tarai plain belt about 30 km southwards of foot hills of Shivalik range of Himalayas at 29° N latitude, 79° 29'E longitude and at an altitude of 243.8 meter above mean sea level with humid and hot climate in summers.

3.2 Climate and Weather Conditions

The Pantnagar tarai region experiences a sub-tropical climate with hot and dry summers during March-April, which continues till June, later hot and humid climate prevails followed by a cool winter season from the month of November to March almost every year. Generally, monsoon sets in the third week of June and continues up to the end of September. Weather parameters of the year 2019 viz. maximum and minimum temperatures, relative humidity, rainfall and sunshine hours during the period of experimentation were procured from the Meteorological Observatory located at Norman E. Borlaug Crop Research Centre of the University.

3.3 Experimental Material

The seeds of thirty rice genotypes were obtained from the Indian Institute of Rice Research (IIRR), Rajendranagar, Hyderabad, viz., IET 28384, IET 28386, IET 28387, IET 28390, IET 27668, IET 28393, IET 28397, IET 28400, IET 28402, IET 28403, Gontra Bidhan-3, IET 28407, IET 28408, IET 28409, IET 28411, IET 28412,

IET 28417, IET 28422, IET 28423, IET 28425, IET 28427, IET 28429, IET 28432, IET 27908, IET 27876, IET 25713, IET 26468, IET 26780, N-22, Vandana. Out of which, five genotypes were selected for this investigation on the basis of their sensitivity to high temperature and based on yield attributes as highly tolerant, moderately tolerant and highly susceptible genotypes namely: - Vandana, IET 28417, N-22, IET 28409 and IET 27908.

3.4 Statistical Design and Field Layout

The experiment was performed in two separate blocks in the field, one of them was used for control and another block was for treatment of heat stress with Split-Plot design. All the genotypes were transplanted in these plots with three replications for each control and heat treatment.

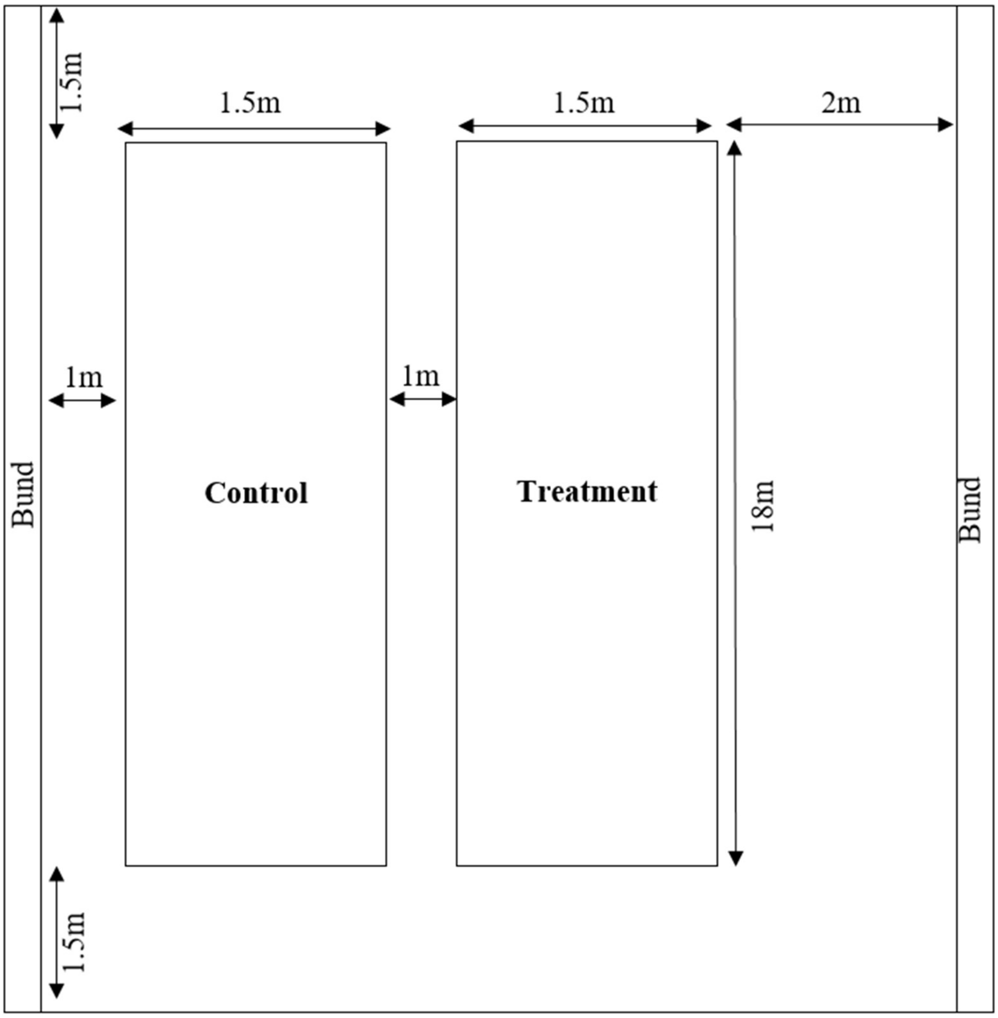

Fig 3.1: Land Layout

3.5 Nursery Preparation, Uprooting, Transplanting and Water Management

Nursery beds were made by ploughing and leveling the field then given seeds were line sown as one variety in one row. Thereafter adequate fertilizer dose was given, irrigation and weeding was done at frequent intervals. Before uprooting the bed was irrigated in order to make the soil soft to prevent root damage on pulling the seedlings individually. The mud from the roots of the uprooted seedlings was removed by gently. Then the seedlings were transplanted in the prepared field. A thin film of standing water was maintained in the field during transplanting up to the establishment of seedling. About a week after transplanting, gap filling was done for the missing or poorly grown seedlings.

3.6 Main Treatment

Nursery beds were prepared with sufficient water supply and seeds were sown on 27th June, 2019 by opening furrows in the field. The genotypes were then transplanted 21 days after sowing in separate blocks, one for control and other for imposing high temperature. High temperature was maintained during flowering before anthesis till maturity by covering one block with transparent polythene sheet making a tunnel which was supported by bamboo sticks. Each day the minimum and maximum temperatures were recorded using the minimum and maximum thermometer installed the tunnel from flowering till harvesting. The block of control was kept uncovered.

3.7 Weeding, Harvesting and Threshing

Weeding was done manually at regular intervals during crop growth. When the crop attained the phase of maturity i.e. about 90% of the panicles were fully yellow ripened, the crop was harvested manually. After sun drying of the harvested crop individual genotypes were threshed manually.

3.8 Experimental Details

Date of nursery sowing : 27-06-2019

Date of Transplanting : 16-07-2019

Polytunnel installation : 13/09/2019

Polytunnnel removed : 4/11/2019

Experimental design : Split-Plot design

Number of treatments : Two (High temperature and Ambient temperature)

Number of replications : Three

Number of varieties : 30

Plot Size : 21m x 7m

Spacing : 20cm (row to row) x 10cm (plant to plant)

No. of rows for each variety : 3

No. of plants in each row : 15

Length of each row : 1.5 m

Fertilizer Dose : 100N- 45P_2O_5- 60K_2O kg/ha. (P & K as basal dose)

N Splits : 1st 50% at 10-15 DAP

2nd 25% at active tillering

3rd 25% at panicle initiation (PI)

3.9 Morphological and Physiological Parameters

3.9.1 Plant height (cm)

Average height of plants was recorded in centimetres by randomly selecting three plants one from each row (replicate) from soil base of the plant up to the base of top most fully expanded leaf was recorded using the meter scale at the flowering stage under both the treatments and control.

3.9.2 Leaf area index (LAI)

LAI was recorded at flowering stage. From a single hill, number of large, medium and small leaves were counted and their length, width was measured with help of a meter scale. LAI was calculated by using the formulae given in **Yoshida 1981.**

$A = ((L1 \times W1 \times CF) \times (L2 \times W2 \times CF) \times (L3 \times W3 \times CF) / 3)$

$LAI = ((A \times \text{Number of leaves per hill}) / 200)$

Final LAI of genotypes = $((LAI\ 1 + LAI\ 2 + LAI\ 3) / 3)$

Where,

L1= Average of the length of three large leaves of the hill

L2= Average of the length of three medium leaves of the hill

L3= Average of the length of three short leaves of the hill

W1= Average of the width of three large leaves of the hill

W2= Average of the width of three medium leaves of the hill

W3= Average of the width of three short leaves of the hill

CF= Correction factor (0.75)

3.9.3 Chlorophyll Fluorescence

Chlorophyll fluorescence was measured by using a portable fluorimeter (Handy, PEA, Hansatch, UK). Data were taken by selecting various position of leaf, in the forenoon hours around time 10:00 am to avoid the problem of photo inhibition. The initial fluorescence (F_0) was recorded on the leaves adapted to darkness for the time interval of more than 10 minutes this was achieved by using leaf clips of Hansatech instruments Ltd, UK. Leaf clips given were attached to mid portion of each flag leaf.

The shading (dark adaptation) of the leaf surface was prevented from the fiber optics of the fluorimeter. The fluorimeter probe was connected to leaf clip holder. Metal surface was slided to expose dark adapted surface to the probe. A single saturating pulse of actinic light was incident by the fluorimeter to obtain the maximum fluorescence (Fm) when all the PSII reaction centers were in reduced form. The maximum efficiency of the PSII photochemistry in dark adapted state (Fv/Fm) was calculated. The maximum fluorescence level (Fm) of the closed PS-II reaction centre was determined by providing a 1.5sec saturating pulse of red light at 300µ mol $m^{-2}s^{-1}$ on the dark adapted leaves. Fv/Fmax ratio was recorded from handy PEA [$Fv/Fm=(Fm-F_0)/Fm$].

3.10 Biomass Production Parameters

3.10.1 Panicle dry weight per unit area (g/m^2)

Panicle dry weight was measured at both flowering and maturity stage. It was recorded by taking the whole panicles present in a hill of the plant and then after air drying, placing them in the oven at 65°C temperature for three days until constant weight is achieved.

3.10.2 Leaf dry weight per unit area (g/m^2)

Leaf dry weight was recorded at the stage of flowering by taking whole leaves per hill and after air drying placing them in an oven at 65°C for three days (until constant weight is achieved).

3.10.3 Stem dry weight per unit area (g/m^2)

Stem dry weight consist of weight of culm without leaves. It was measured at flowering stage by taking stems of whole hills of three randomly selected plants of each genotype and after air drying placing them in an oven at 65°C for three days until constant weight is achieved.

3.10.4 Shoot dry weight per unit area (g/m^2)

Shoot weight was measured by weighing the randomly selected plants of each genotype after air drying them and placing them in the oven at the temperature of 65°C for 3 days until constant weight is achieved. Tiller and leaf weight together constitute the shoot weight.

3.11 Yield Attributes

3.11.1 Panicle number

At maturity the panicle number was recorded by counting the total number of panicles per hill in 3 random samples per replications of each genotype.

3.11.2 Spikelet number per panicle and number of filled grains per panicle and spikelet fertility (%)

Three panicles at the time of maturity were taken from a hill, total spikelet number per panicle and number of filled grains per panicle was counted and average was taken to estimate the parameter. The number of filled and unfilled spikelet per panicle was recorded by counting chaffy and unchaffy grains.

The spikelet fertility percentage was calculated as follows:

$$\text{Spikelet fertility (\%)} = \frac{\text{Number of filled spikelets per panicle}}{\text{Total Number of spikelets per panicle}} \times 100$$

3.11.3 Total dry matter (g/m^2)

The total plant dry matter of plant of each replication of each genotype was calculated by uprooting the complete plant and then placing the plant sample in the oven at 65° C for three days at flowering and maturing stage.

3.11.4 Thousand grain weight (g)

A random sample of 500 grains were taken from the each replicate of each genotype and their weights were recorded and computed to present thousand grain weight in gram.

3.11.5 Grain yield (g/m^2)

The total weight of grains (economic yield) harvested from each replicate of each genotype was recorded and finally expressed as g/m^2 after harvesting.

3.11.6 Biological yield (g/m^2)

At maturity each plant was uprooted from ground level and after drying, weight of intact plant was determined before thrashing and total weight of plant was recorded as biological yield.

3.11.7 Harvest index (%)

The following formula was used to calculate harvest index (%):

HI (%) = (Economic yield / Biological yield) x 100

3.12 Biochemical Analysis

3.12.1 Chlorophyll and Carotenoid content

Chlorophyll and carotenoid content was estimated in fresh flag leaves at flowering stage by the DMSO method described by **Hiscox and Israelsham (1979) and Sumanta *et al.* (2014).**

Reagent:

Dimethyl sulfoxide (DMSO)

Estimation of chlorophyll and carotenoid content:

For estimation of chlorophyll content 50 mg of finely chopped flag leaves were taken in a test tube along with that 10 ml of dimethyl sulfoxide (DMSO) was added in each test tube and incubated at the temperature of 65° C for three hours in an oven. After incubation, absorbance of DMSO containing chlorophyll extract was determined at 663 and 645 nm and for carotenoids at 470 nm using a spectrophotometer. Pure DMSO was used as blank. The chlorophyll and carotenoid content was then calculated by using following formula:

Arnon's (1949) equations:

$$\text{Chlorophyll a} = \frac{(12.7 \times A663 - 2.69 \times A645) \times V}{\text{Weight (g)} \times 1000}$$

$$\text{Chlorophyll b} = \frac{(22.9 \times A645 - 4.68 \times A663) \times V}{\text{Weight (g)} \times 1000}$$

$$\text{Total Chlorophyll} = \frac{(20.2 \times A645 - 8.02 \times A663) \times V}{\text{Weight (g)} \times 1000}$$

$$\text{Carotenoids} = \frac{(1000\ A470 - 1.82\ \text{Chl a} - 85.02\ \text{Chl b}) \times V}{\text{Weight (g)} \times 1000 \times 198}$$

A= Absorbance of chlorophyll extract at specific wavelength

V= Final volume of the sample

W= Weight of tissue extracted on fresh weight basis

3.12.2 Protein estimation

Estimation of protein content of the in rice grains was done by using the method described by **Bradford (1976).**

Reagents:

1. Bradford dye: 100 mg coomassie brilliant blue, 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 stored at 4^{o} C in dark coloured bottle.

2. Bovine Serum Albumin standard ppm: 20 mg BSA was dissolved in 20 ml protein extraction buffer.

3. Protein extraction buffer (EB) (pH 7.2) was prepared as follows:

Phosphate Buffer - 0.3 M

EDTA - 5 mM

NaCl - 50 mM

Na Phosphate - 25 mM

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 the final volume of 300 µl with extraction buffer/double distilled water was made. Then 3.0 ml of Bradford dye was added in each tube and absorbance was recorded at 595 nm. For blank, 300 µl extraction buffer/double distilled water was mixed with 3.0 ml Bradford dye. The standard curve was prepared and used for protein estimation.

Protein extraction

Rice grains were dehulled 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° C and 10,000 rpm for 15 minute. Then 20 µl supernatant was taken from each sample separately in test tube and then made up to 300 µl extraction buffer and thereafter 3.0 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 prepared from BSA was used for the estimation of protein and expressed in µg/g**.**

3.12.3 Total carbohydrate estimation

Total carbohydrate content was estimated in rice grain by using the Anthrone method **(Hodge and Hofreiter, 1962).**

Reagents:

2.5 N HCl

Anthrone reagent: It was freshly prepared before use. 200mg anthrone was dissolved in 100 ml of ice cold 95% H_2SO_4.

Standard glucose:

Stock- 100 mg glucose was dissolved in 100ml distilled water.

Working solution – 10 ml of stock diluted to 100 ml distilled water and was refrigerated after adding few drops of toluene.

Standard curve

Glucose standards were prepared by taking 0.2, 0.4, 0.6, 0.8 and 1.0 ml of working standard (For blank 1.0 ml distilled water was taken). Volume was made to 1.0 ml in all tubes by adding distilled water. Then, 4.0 ml of anthrone reagent was added to each tube and tubes were heated for eight minutes in boiling water bath. Tubes were cooled rapidly and green color was formed in the tubes. Absorbance was recorded at 630 nm and standard curve was prepared on X axis versus absorbance on the Y axis.

Extraction of carbohydrates

Rice grains were dehulled and ground with pestle and mortar. 100 mg of the sample was taken in test tubes and was hydrolysed in boiling water bath for three hours with 5 ml of 2.5 N HCl and cooled to room temperature. Then it was neutralized with solid sodium carbonate until effervescence ceases and volume was made upto 100 ml and centrifuged. 0.5 and 1.0 ml of aliquots were taken from supernatant for analysis and volume was made to 1.0 ml with distilled water, then 4 ml anthrone reagent was added and heated for eight minutes in boiling water bath, cooled rapidly and absorbance was taken at 630 nm. Total carbohydrate was calculated by using standard graph and expressed in mg/g.

3.13 Statistical Analysis

Data presented in the final results are the averages of the three replicates of different genotypes. The data from the experiments were subjected to two-way Analysis of Variance (ANOVA) for control and heat treatment. Their interaction of control x heat treatment in split-plot design was analyzed using OPSTAT Online Agriculture Data Analysis tool and SPSS statistical software. Standard error of each mean and critical difference was calculated at 5% level of significance.

Plate 1: Transplanting of various rice genotypes

Plate 2: Control of various rice genotypes

Plate 3: Treatment of various rice genotypes

Plate 4: Constructing of Poly-tunnel

Plate 5: Field visit of AICRIP officer during research work

Results
&
Discussion

Chapter 4 RESULTS AND DISCUSSION

The present investigation was carried out during Kharif season of 2019 to evaluate the effect of high temperature on morpho-physiological, biochemical parameters and yield component of thirty selected rice genotypes viz. IET 28384, IET 28386, IET 28387, IET 28390, IET 27668, IET 28393, IET 28397, IET 28400, IET 28402, IET 28403, Gontra Bidhan-3, IET 28407, IET 28408, IET 28409, IET 28411, IET 28412, IET 28417, IET 28422, IET 28423, IET 28425, IET 28427, IET 28429, IET 28432, IET 27908, IET 27876, IET 25713, IET 26468, IET 26780, N-22 and Vandana based on their yield attributes. Out of these, five genotypes were selected for this investigation on the basis of their sensitivity to high temperature and based on yield attributes as highly tolerant, moderately tolerant and highly susceptible genotypes namely: - Vandana, IET 28417, N-22, IET 28409 and IET 27908. Grain yield of these genotypes was compared with N-22 which was a check/control.

The maximum and minimum ambient air temperature in 2019 during day varied from 23°C to 40°C and in night 9.9°C to 29.9°C, respectively; likewise, inside the tunnel it varied from 38°C to 51°C and 14°C to 24°C respectively. The morpho-physiological parameters includes plant height, tiller number, leaf area index (LAI), total chlorophyll, chlorophyll a and b, carotenoids, chlorophyll fluorescence, leaf weight, shoot weight and stem weight, yield and yield attributes include panicle weight, panicle number per meter square, grain number per panicle, grain number per meter square, spikelet fertility, TDM, 1000 grain weight, grain yield and harvest index at maturity were recorded. Besides these biochemical parameters include- protein and total carbohydrate content in rice grains were also recorded.

4.1 Morpho-physiological parameters

4.1.1 Plant height (cm) of different rice genotypes at the time of heat stress after flowering

The height of rice plant was recorded from upper most part of flag leaf to the base of the plant in centimeters. Plant height (cm) was decreased in IET 28409 and IET 27908; while it was increased in rest of the genotypes under high temperature stress as compared to control. The maximum plant height, under high temperature stress, was observed in IET 28417 (112cm) and minimum in IET 28409 (96.67cm). However, under control condition it was maximum in IET 27908 (135.5cm) and minimum in N-22 (93.67cm). The maximum percent increase in plant height was observed in IET 28417 (14.67%) and maximum percent decrease in IET 27908 (24.23%). On the basis of plant height, IET 28417 and N-22 were found to be tolerant; while IET 28409 and IET 27908 were found to be susceptible to high temperature stress. Non-significant difference observed between Vandana (100.33cm) and IET 28409 (101.67cm) under control. Non-significant difference was also observed among Vandana (101cm), N-22 (103.67cm) and IET 27908 (102.67cm) under treatment. Non-significant difference was observed in Vandana under control (100.33cm) and treatment (101cm). Plant height was statistically significant for rest all genotypes (G), treatment (T) and TxG interaction **(Table 4.1 and Figure 4.1).**

Table 4.1: Plant height (cm) of different rice genotypes at the time of heat stress after flowering, ± sign indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Genotypes	Plant Height (cm)		
	Control	**Heat Treatment**	**%Change**
Vandana	100.33±1.2	101±4.4	↑ 0.66
IET 28417	97.67±0.9	112±3.2	↑14.68
N-22	93.67±0.9	103.67±2.3	↑10.68
IET 28409	101.67±5.4	96.67±2.6	↓ 4.92
IET 27908	135.5±1.15	102.67±1.8	↓24.23
	Treatment (T)	**Genotypes (G)**	**TxG**
S.Em±	0.4	2.16	0.91
CD at 5%	2.67	6.53	9.47

The height of rice plant after flowering was induced under high temperature stress condition in almost all the genotypes. This might be due to accelerated growth and development during initial stress. However, high temperature reduces the plant height at vegetative stage in IR 26 and Calrose **(Yoshida, 1981).** Its variation depends on genotype and its thermotolerance capacity. A period of 8 days at 35℃ at vegetative stage reduced the plant elongation after 50 days of treatment **(Yang and Heilmann, 1993).** While it was also reported that plant height increased with the rise in temperature within the range of 30-35℃. As the high temperature treatment was given after flowering stage it did not show much effect on height in rice **(Shah *et al.*, 2011)**. High temperature positively affected plant height, tiller number, leaf area, and leaf number. However, rice genotypes displayed genetic diversity in response to high temperatures **(Reddy *et al.*, 2021).**

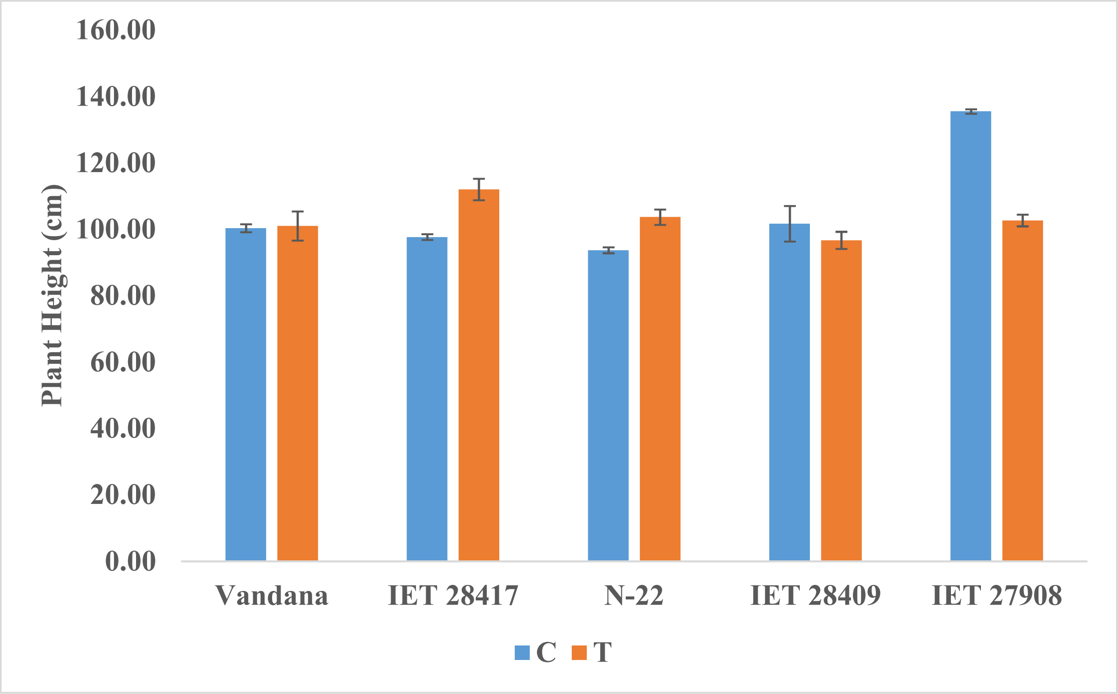

Figure 4.1: Plant height (cm) of different rice genotypes at the time of heat stress after flowering (vertical bar represents ± standard error of mean)

4.1.2 Number of effective tillers per plant of different rice genotypes at the time of heat stress after flowering.

Under high temperature the number of effective tillers per plant at flowering was increased in two genotypes viz. Vandana and N-22 while decreased in rest of the genotypes. The maximum effective tillers per plant in control condition were observed in IET 28417 (7) and minimum in Vandana (4.33) also under high temperature stress it was maximum in IET 28409 (6) and minimum in IET 27908 (5.33) and Vandana (5.33). Maximum percent increase in number of effective tillers per plant was observed in Vandana (23.08%) and maximum percent decrease in IET 28417 (19.05%). On the basis of number of effective tillers per plant, Vandana and N-22 were found to be tolerant; while IET 28417 and IET 27908 were found to be susceptible to high temperature stress. The tiller number per plant was found to be statistically non-significant between IET 27908 (5) and N-22 (5) under control; between Vandana (5.33) and IET 27908 (5.33); also between IET 28417 (5.67) and N-22 (5.67) under treatment. Non-significant difference was observed in IET 28409 under control (6) and treatment (6). The effective tiller number per plant was found to be statistically significant for all other genotypes (G) and non-significant for TxG interaction and treatment (T) **(Table 4.2 & Figure 4.2).**

Table 4.2: Number of effective tillers per plant of different rice genotypes at the time of heat stress after flowering, ± sign indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Genotypes	**Effective tillers/Plant**		
	Control	**Heat Treatment**	**%Change**
Vandana	4.33±0.3	5.33±0.8	↑ 23.08
IET 28417	7±0.6	5.67±0.8	↓19.05
N-22	5±1.15	5.67±0.7	↑13.33
IET 28409	6±1.15	6±1.15	0
IET 27908	5±1.2	5.33±0.9	↓6.67
	Treatment (T)	**Genotypes (G)**	**TxG**
S.Em±	0.29	0.7	0.64
CD at 5%	NS	NS	NS

After 3-5 weeks of sowing, the temperature causes slight influence in the tillering rate and relative growth rate. Under low light condition, high temperature might increase the rate of leaf emergence and also provides more tillering bud but it might not necessarily develop into tillers while in normal light, high temperature increases tillering during vegetative stage but in certain cases reduced tillering was observed in IR26, Calrose and BKN624-46-2 **(Yoshida, 1973 and 1981).** Generally, the tiller number per unit area was found to be more under high temperature stress conditions during early growth period and the stage of maximum tillering was reached earlier in high temperature condition than control conditions **(Oh *et al.*, 2007)**. Tillering was restrained in rice initially at 35℃ but it was attained by the plants grown at 25℃ after 70 days showing the positive effect of short term high temperature after vegetative stage **(Jagadish *et al.*, 2009).** On the other hand it was also observed that tiller number has positive correlation with panicle dry weight per unit area and due to high temperature more than 33℃ reduced tiller numbers, panicle number and panicle length were found this is because temperature above 33℃ which was found to be unfavorable for tiller formation **(Poli *et al.*, 2013)**. In various studies it has been observed that temperatures above 33℃ might be unfavorable for tillering **(Piveta *et al.*, 2020)**.

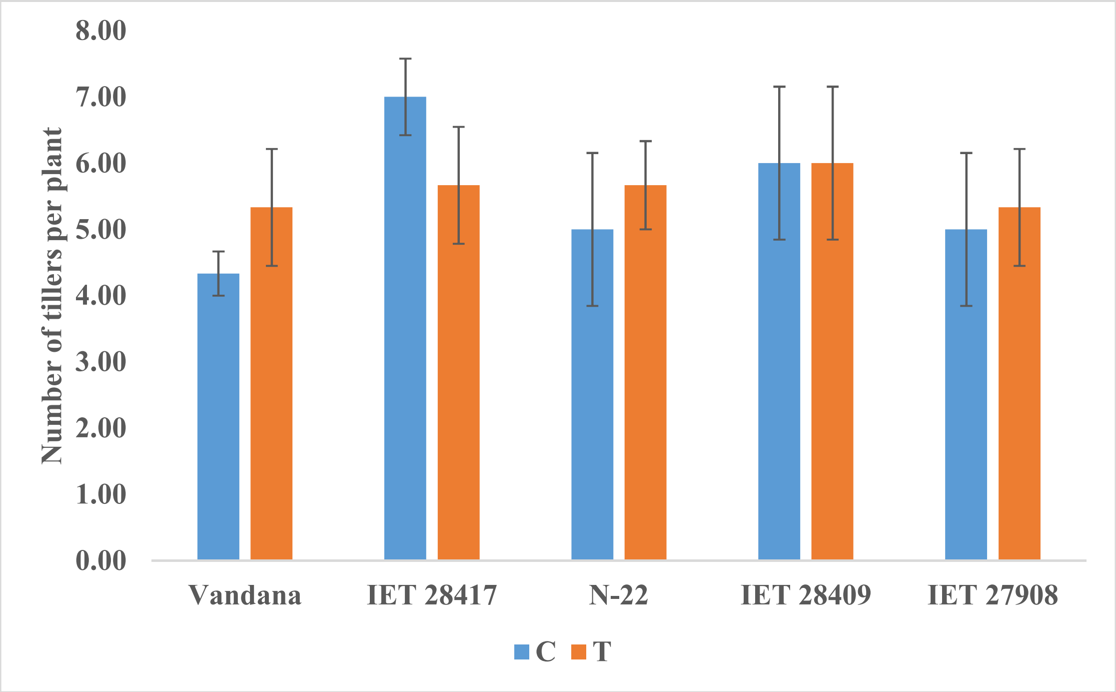

Figure 4.2: Number of effective tillers per plant of different rice genotypes at the time of heat stress after flowering (vertical bar represents ± standard error of mean)

4.1.3 Effect of high temperature on Leaf Area Index (LAI) in different rice genotypes after flowering.

LAI is measured as ratio of leaf area with the ground area of rice plant during flowering. Under high temperature stress conditions, LAI was increased in all five genotypes during flowering. Under control condition, maximum LAI was observed in IET 28409 (5.23) whereas minimum in N-22 (2.53). However under high temperature, the maximum LAI was observed in rice IET 28409 (6.43) whereas minimum in N-22 (3.73). Maximum percent increase in the LAI was observed in IET 28417 (50.25%); while minimum percent increase in IET 28409 (22.96%). On the basis of LAI, IET 28417 and N-22 were found to be highly tolerant to the high temperature stress. Non-significant difference was observed between IET 28417 (4.03) and IET 27908 (4.08) under treatment. The LAI was found to be statistically significant for all other genotypes (G) and treatment (T) but non-significant for TxG interaction **(Table 4.3 & Figure 4.3).**

Table 4.3: Effect of high temperature stress on Leaf area index of different rice genotypes after flowering, ± sign indicates standard error of mean, ↑/↓ indicates percent increase/decrease respectively

Genotypes	**Leaf area index**		
	Control	**Heat Treatment**	**%Change**
Vandana	3.37±0.15	4.57±0.15	↑ 35.61
IET 28417	2.68±0	4.03±0.09	↑ 50.25
N-22	2.53±0.1	3.73±0.07	↑ 47.37
IET 28409	5.23±0.2	6.43±0.12	↑ 22.96
IET 27908	2.88±0.1	4.08±0.06	↑ 41.67
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	0.01	0.07	0.03
CD at 5%	0.08	0.23	NS

Leaf area signifies the assimilating area of the plant. Increment in the temperature adversely affects photosynthetic rate and also reduces stomatal conductance due to accumulation of high CO_2 **(Shah and Paulsen, 2003)**. High temperature strongly reduces photosynthesis rate of the leaf (50-60%) in wheat at the stage of late tillering. With the increase in temperature, reduction in photosynthesis was also observed by reduced LAI. Initiation and expansion of leaves, tillers, branches, shoots and roots as well as reproductive organs are strongly driven by high temperature **(Chakrabarti *et al.*, 2013)**.

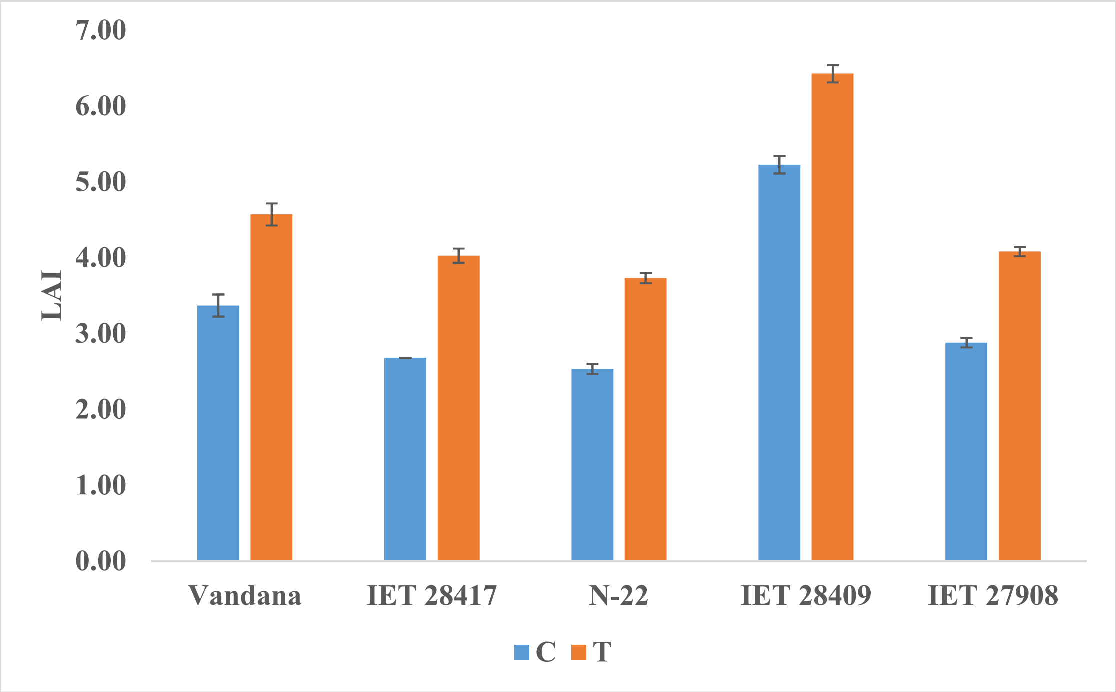

Figure 4.3: Effect of high temperature stress on LAI of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

The decrease in the ratio of panicle weight to green leaf area suggests that the source/sink ratio may have been affected. The accumulation of leaf carbohydrate and increase in specific leaf weight indicate feedback inhibition. Moreover, reduction in the number of filled grain per panicle greatly decreases grain yield **(Nadeem *et al.*, 2018)**

4.2 Biomass production parameters

4.2.1 Effect of high temperature on leaf dry weight (g/m^2) in different rice genotypes after flowering

Leaf weight per unit ground area (g/m^2) was measured by weighing total leaves (dry weight) of a particular rice plant. Under high temperature condition, the leaf weight at flowering decreased in all the genotypes as compared to control. Under control condition, maximum leaf weight was observed in IET 27908 (540.56 g/m^2), whereas the minimum leaf weight was observed in Vandana (220.73 g/m^2). Under high temperature stress, the maximum leaf weight (g/m^2) was observed in IET 27908 (521.46 g/m^2), while minimum was in Vandana (160 g/m^2). Maximum percent decrease was observed in Vandana (27.19 %); while, minimum percent decrease in IET 27908 (3.53%). On the basis of leaf dry weight, Vandana and N-22 were found to be highly susceptible to the high temperature stress. The leaf weight was found to be statistically significant for all genotypes (G) but non-significant for treatment (T) and TxG interaction **(Table 4.4 & Figure 4.4).**

It is reported that terminal or long term high temperature affects the leaf photosynthesis which is associated with senescence of leaf and protein degradation which results to reduced leaf dry weight in wheat **(Marino *et al.*, 2010).** During the maturity stage, the increment in leaf weight might be due to poor translocation and assimilation of photosynthates from vegetative regions (shoots) to reproductive parts (panicle and grains) because of poor sink development. Thus, the organic nutrients in the plant might get accumulated in leaves and led to increment in its dry weight instead of contributing to increase in the grain weight **(Johnson *et al.*, 2011)**.

Table 4.4: Effect of high temperature on leaf dry weight (g/m^2) of different rice genotypes after flowering, the sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease.

Leaf dry weight (g/m^2)			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	220.73±12.7	160.72±27.2	↓ 27.19
IET 28417	296.78±24.4	266.69±10.1	↓ 10.14
N-22	351.35±6.4	291.04±17.2	↓ 17.17
IET 28409	468.96±15.5	448.21±4.4	↓ 4.42
IET 27908	540.56±3.3	521.47±3.5	↓ 3.53
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	7.01	13	15.68
CD at 5%	NS	39.33	NS

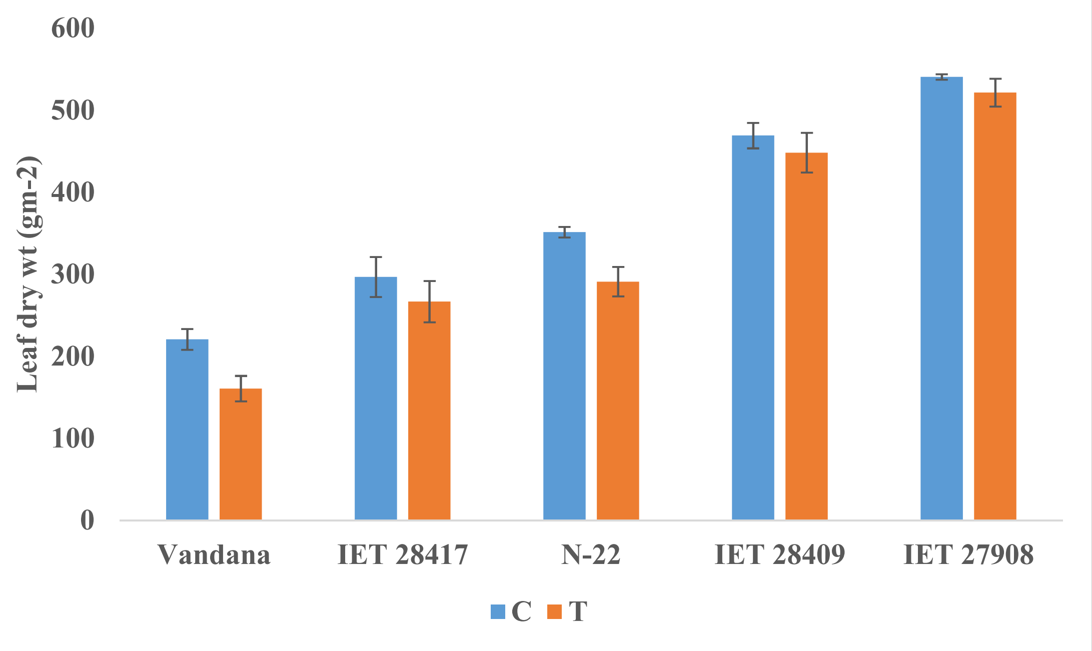

Figure 4.4: Effect of high temperature on leaf dry weight (g/m^2) of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

Leaf fresh weight was also reduced under heat. The reason for this reduced in LFW seems to be the fact that the leaf was directly exposed and most affected plant part under high temperature stress and high temperature may have increased the transpiration rate from leaves **(Xu *et al.*, 2020).**

4.2.2 Effect of high temperature on stem dry weight (g/m^2) after flowering and on shoot weight (g/m^2) of heat treated rice genotypes at maturity

Stem weight (g/m^2) during flowering was taken by taking the weight of the main culm of different rice genotypes. Under high temperature stress, stem weight decreased in all of the genotypes. Under control condition, the maximum stem weight was observed in IET 27908 (1081.12 g/m^2) whereas minimum in Vandana (441.46g/m^2). However, under high temperature stress, the maximum stem weight was recorded in IET 27908 (1042.93 g/m^2), and minimum stem weight in Vandana (321.44 g/m^2). Maximum percent reduction in stem weight was recorded in Vandana (27.19%) and minimum percent reduction was recorded in IET 27908 (3.43%). On the basis of stem dry weight, Vandana and N-22 were found to be highly susceptible to the high temperature stress. The stem weight was found to be statistically significant for all genotypes (G) but non-significant for TxG interaction and treatment (T) **(Table 4.5 (a) & Figure 4.5 (a)).**

Table 4.5 (a): Effect of high temperature stress on stem dry weight (g/m^2) of different rice genotypes after flowering, the sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease.

Stem dry weight (g/m^2)			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	441.46±25.4	321.44±31	↓ 27.19
IET 28417	593.56±48.8	533.38±50.3	↓ 10.14
N-22	702.69±12.7	582.07±35.8	↓ 17.86
IET 28409	937.92±30.9	896.43±48.4	↓ 4.42
IET 27908	1081.12±6.7	1042.93±33.9	↓ 3.53
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	14.02	26.01	3.35
CD at 5%	NS	78.66	NS

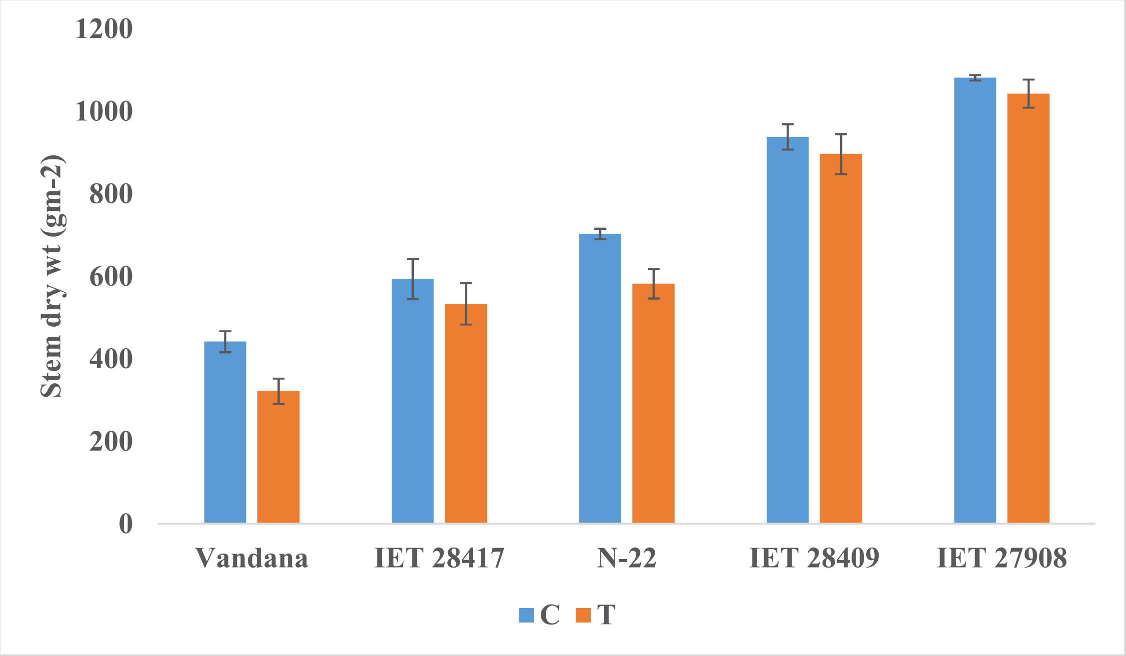

Figure 4.5 (a): Effect of high temperature on stem dry weight (g/m^2) of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

At the time of maturity, shoot weight (g/m^2) was taken by weighing tillers with panicle in a hill of rice plants. Under high temperature stress, shoot weight decreased in the all of the genotypes. In control condition, maximum shoot weight was recorded in IET 27908 (2265.64 g/m^2) whereas minimum in Vandana (994.4 g/m^2). Under high temperature, maximum shoot weight was recorded in the IET 27908 (2038.79 g/m^2), whereas the minimum was in Vandana (769.08 g/m^2). Maximum percent decrease in shoot weight was observed in Vandana (31.7%) and minimum percent decrease in IET 27908 (10.01%) in heat treated genotypes as compared to control. On the basis of shoot dry weight, Vandana and N-22 were found to be highly susceptible to high temperature stress. The shoot weight was found to be statistically significant for all genotypes (G) and treatment (T) but non-significant for TxG interaction **(Table 4.5 (b) & Figure 4.5 (b))**.

Under high temperature due to accumulation of assimilation products in leaves and culms there is reduction in dry matter in the panicle after heading stage. The optimum temperature needed for ripening of rice grain is lower than that for maximum tillering at anthesis stage therefore, it has been estimated that as rice plant grows, ambient temperature shifts to relatively lower temperatures but under high temperature panicle weight is known to decrease **(Newman *et al.*, 2001)**. The change in stem weight under high temperature stress might be due to the partitioning and translocation of organic nutrients and assimilation of CO_2 which was found to be low because of inadequate grain filling under stress condition. The photosynthate have accumulated in vegetative shoots and finally added to dry weight of stem **(Wahid *et al.*, 2007)**.

However, during grain-filling, high temperature stress for longer period accelerated the speed of grain filling resulting in shortage of grain filling period, which leads to decrease in single-grain weight and accumulation more nutrients in culm of plant. These account for increased dry weight of stem in the form of straw under high temperature stress especially at flowering stage **(Lu *et al.*, 2013)**. Stem reserve mobilization is an important process supporting grain filling under heat stress conditions. Therefore, under stress conditions, stored carbohydrates may become the predominant source contributing to as much as 75–100% to the grain yield in rice **(Lippmann *et al.,* 2019)**

Table 4.5 (b): Effect of high temperature on shoot dry weight (g/m^2) at maturity stage, the sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease.

Shoot dry weight (g/m^2)			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	994.4±105.6	679.083±56.4	↓ 31.7
IET 28417	1187.04±45	1009.48±68.4	↓ 14.96
N-22	1492.42±14	1154.35±56.2	↓ 22.65
IET 28409	2026.27±53	1797.87±77.8	↓ 11.27
IET 27908	2265.64±34.5	2038.79±56.6	↓ 10.01
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	4.7	46.65	10.53
CD at 5%	30.85	141.07	NS

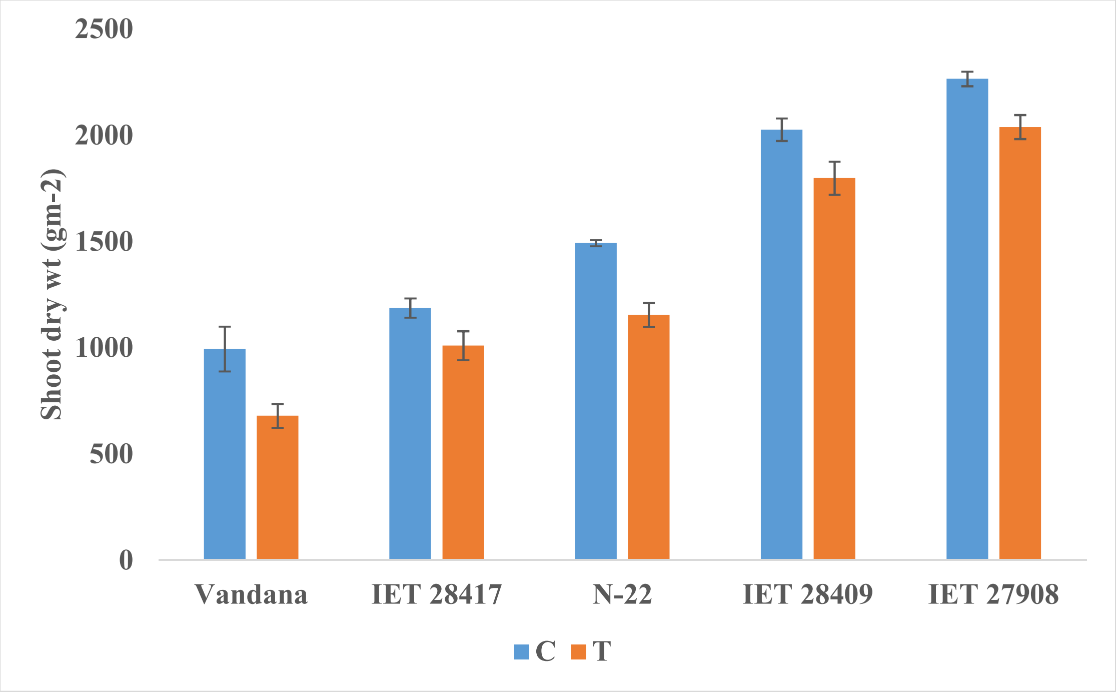

Figure 4.5 (b): Effect of high temperature on shoot dry weight (g/m^2) of rice genotypes at maturity (vertical bar represents ± standard error of mean)

4.2.4 Effect of high temperature on Total Dry Matter (TDM) in rice genotypes after flowering and at maturity

Total Dry Matter (TDM) (g/m^2) was measured by weighing the total number of leaves, tillers and panicles in a hill of rice plant during the stages of flowering and maturity. Under high temperature stress, TDM of all the genotypes was reduced after flowering. Under control condition, the maximum TDM was observed in IET 27908 (2208.64 g/m^2) whereas minimum in Vandana (942.4 g/m^2). Under high temperature stress condition, maximum TDM was observed in rice IET 27908 (198.79 g/m^2), whereas the minimum in Vandana (627.08 g/m^2). Maximum percent decrease in TDM at flowering was observed in Vandana (33.46 %) and minimum in IET 27908 (10.27 %). On the basis of TDM, Vandana and N-22 were found to be highly susceptible to the high temperature stress. The TDM was found to be statistically significant for treatment (T) and all genotypes (G) but nonsignificant for TxG interaction **(Table 4.6 (a) & Figure 4.6 (a)).**

Table 4.6 (a): Effect of high temperature on total dry matter (g/m^2) of rice genotypes after flowering, the sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

TDM after flowering (g/m^2)			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	942.4±105.6	627.08±56.4	↓33.46
IET 28417	1137.04±45	959.48±68.4	↓15.62
N-22	1433.42±14	1095.35±56.2	↓23.58
IET 28409	1974.27±53	1745.87±77.8	↓11.57
IET 27908	2208.64±34.5	1981.79±56.6	↓10.27
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	4.7	46.65	10.53
CD at 5%	30.85	141.07	NS

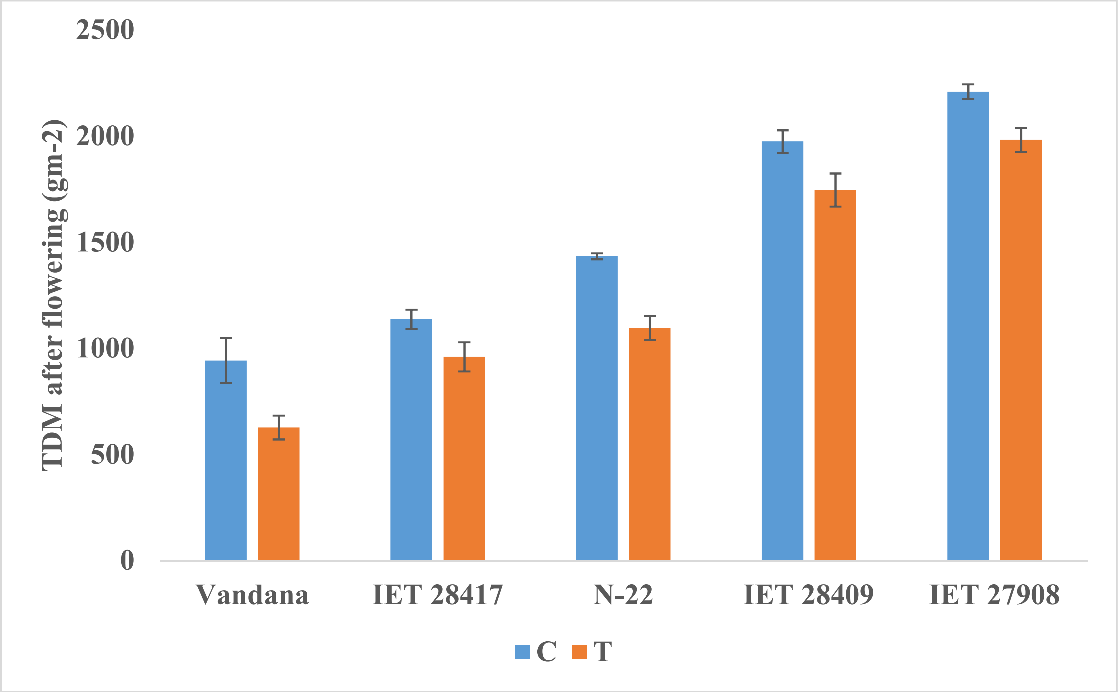

Figure 4.6 (a): Effect of high temperature on total dry weight (g/m^2) of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

At maturity, high temperature was decreased the TDM of all the genotypes as compared to control. Under control condition, the maximum TDM was found in IET 27908 (3615.64 g/m^2) whereas minimum in Vandana (1638.89 g/m^2). Under high temperature stress condition, the maximum TDM was observed in rice IET 27908 (2998.79 g/m^2), whereas the minimum in Vandana (1012.42 g/m^2). At maturity maximum percent reduction in TDM was observed in Vandana (38.22 %) and minimum percent reduction in IET 27908 (17.06 %) under high temperature stress as compared to control. On the basis of TDM, Vandana and N-22 were found to be highly susceptible to the high temperature stress. TDM was found to be statistically significant for all genotypes (G) and treatment (T) and non-significant for TxG interaction **(Table 4.6 (b) & Figure 4.6 (b)).**

In a study it was revealed that tillering leaf expansion and uptake of nutrient were high during early growth stages which shows significant effects on biomass production under high temperature stress **(Shao *et al*., 2008)** but in later stages there is reduction of biomass due to larger burden of increased maintenance respiration associated with excessive growth, faster senescence and shortened growth period.

Duration of green leaves and leaf area vary due to genotypic difference **(Ishikawa *et al*., 2014).**

Table 4.6 (b): Effect of high temperature on total dry matter (g/m^2) of rice genotypes at maturity, the sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

TDM at maturity (g/m^2)			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	1638.89±281	1012.42±80.1	↓38.23
IET 28417	1754.47±26.5	1376.15±52.4	↓21.56
N-22	2365.01±50.1	1665.52±65.9	↓29.58
IET 28409	3331.27±73.6	2720.70±65.9	↓18.33
IET 27908	3615.64±92.1	2998.79±75	↓17.06
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	41.95	79.34	93.8
CD at 5%	274.835	239.9	NS

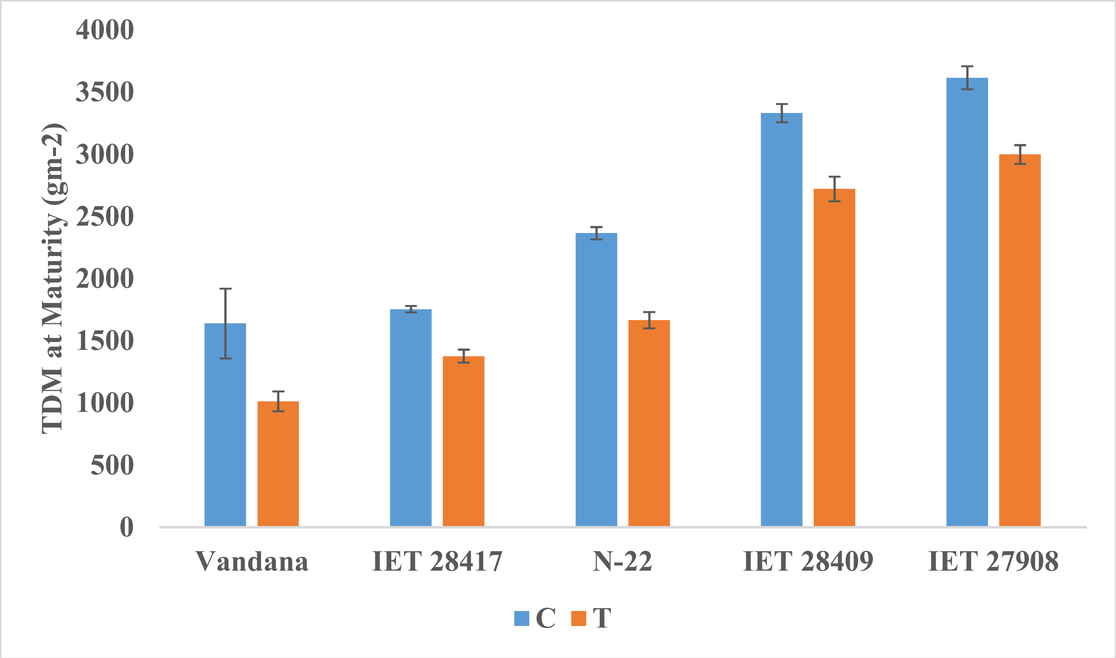

Figure 4.6 (b): Effect of high temperature on total dry matter (g/m^2) of rice genotypes at maturity, (vertical bar represents ± standard error of mean)

Reduction in dry matter accumulation occurs under this high temperature which may be due to decrease in leaf number, leaf area index and accelerated leaf senescence. It may also be due to CO_2 concentration, which decreases stomatal conductance and increases water use efficiency through regulation in transpiration process and photorespiration which ultimately promotes photosynthetic capacity **(Nachimuthu *et al.*, 2017).** Dry matter increased significantly across genotypes at high temperature but declined as temperature treatments decreased relative to optimum temperature conditions (**Reddy *et al.,* 2021).**

4.3 Yield and Yield Attributes

4.3.1 Effect of high temperature on panicle dry weight (g/m^2) in different rice genotypes after flowering and at maturity

Panicle weight (g/m^2) at flowering and maturity was recorded by weighing the total number of panicles in a given plant of different rice genotype. Under high temperature, panicle weight was decreased in all the genotypes after flowering. Under control condition, maximum panicle weight was observed in IET 27908 (596.96 g/m^2) whereas minimum in IET 28417 (246.7 g/m^2). Under high temperature stress, maximum panicle weight was observed in IET 27908 (417.39 g/m^2), whereas the minimum was observed in Vandana (144.93 g/m^2). Maximum percent decrease in panicle weight at flowering was observed in Vandana (48.28%) and minimum percent decrease in IET 27908 (28.89%). On the basis of panicle dry weight, Vandana and N-22 were found to be highly susceptible to high temperature stress. Non-significant difference was observed between IET 28409 (401.23 g/m^2) and IET 27908 (417.39 g/m^2) under treatment. The panicle weight was found to be statistically significant for all genotypes (G) and treatment (T) but non-significant for TxG interaction **(Table 4.7 (a) & Figure 4.7 (a)).**

At maturity, the panicle weight was decreased in all the genotypes. Under control condition, the maximum panicle weight was observed in IET 27908 (1350 g/m^2) and minimum in IET 28417 (567.42 g/m^2). Under high temperature stress, maximum panicle weight was observed in IET 27908 (960 g/m^2), whereas the minimum in Vandana (33.33 g/m^2). Maximum and minimum percent decrease in panicle weight at maturity was observed in Vandana (48.28%) and IET 27908 (28.89%), respectively during high temperature as compared to control. On the basis of panicle dry weight, Vandana and N-22 were found to be highly susceptible to high temperature stress. The panicle weight was found to be statistically significant for all genotypes (G) and treatment (T) but non-significant for TxG interaction **(Table 4.7 (b) & Figure 4.7 (b)).**

Table 4.7 (a): Effect of high temperature on panicle dry weight (g/m^2) of different rice genotypes after flowering, ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease.

Panicle dry weight after flowering (g/m^2)			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	280.21±77.4	144.93±10.7	↓48.28
IET 28417	246.71±28.9	159.42±7.25	↓35.38
N-22	379.38±18.9	222.25±8.5	↓41.42
IET 28409	567.39±12	401.23±16.1	↓29.28
IET 27908	586.96±25.1	417.39±11.5	↓28.89
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	18.88	18.56	42.2
CD at 5%	123.66	56.12	NS

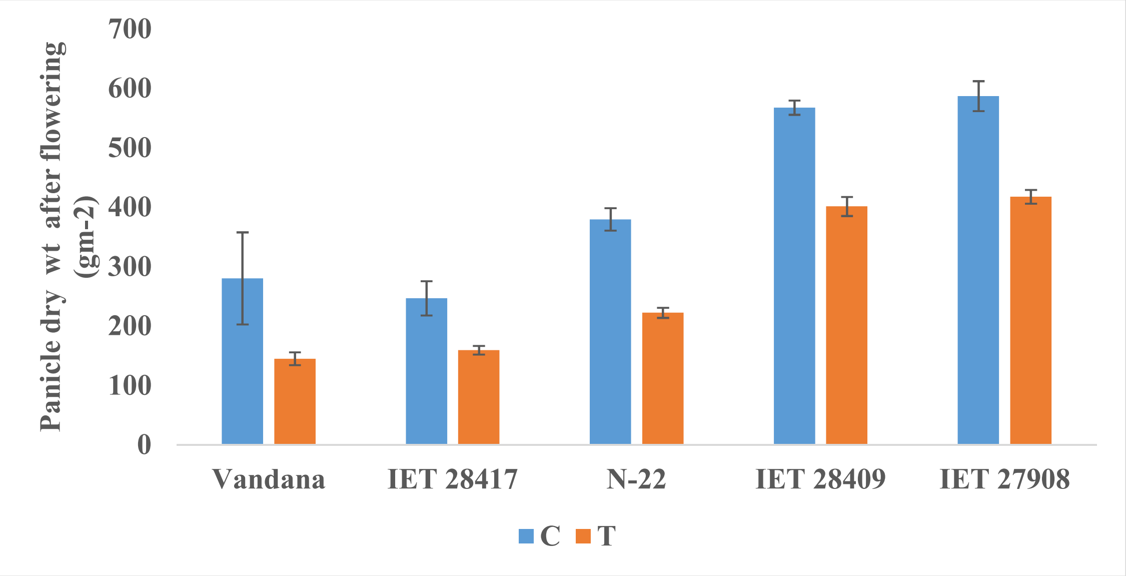

Figure 4.7 (a): Effect of high temperature on panicle dry weight (g/m^2) of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

Table 4.7 (b): Effect of high temperature on panicle dry weight (g/m^2) of rice genotypes at maturity, sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease.

Panicle dry wt(g/m^2) at maturity			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	644.48±178.02	333.33±24.6	↓48.28
IET 28417	567.42±66.5	366.67±16.7	↓35.38
N-22	872.58±43.4	511.17±19.5	↓41.42
IET 28409	1305±27.5	922.83±36.9	↓29.28
IET 27908	1350 ±57.7	960 ±26.5	↓28.89
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	43.41	42.67	97.07
CD at 5%	284.41	129.07	NS

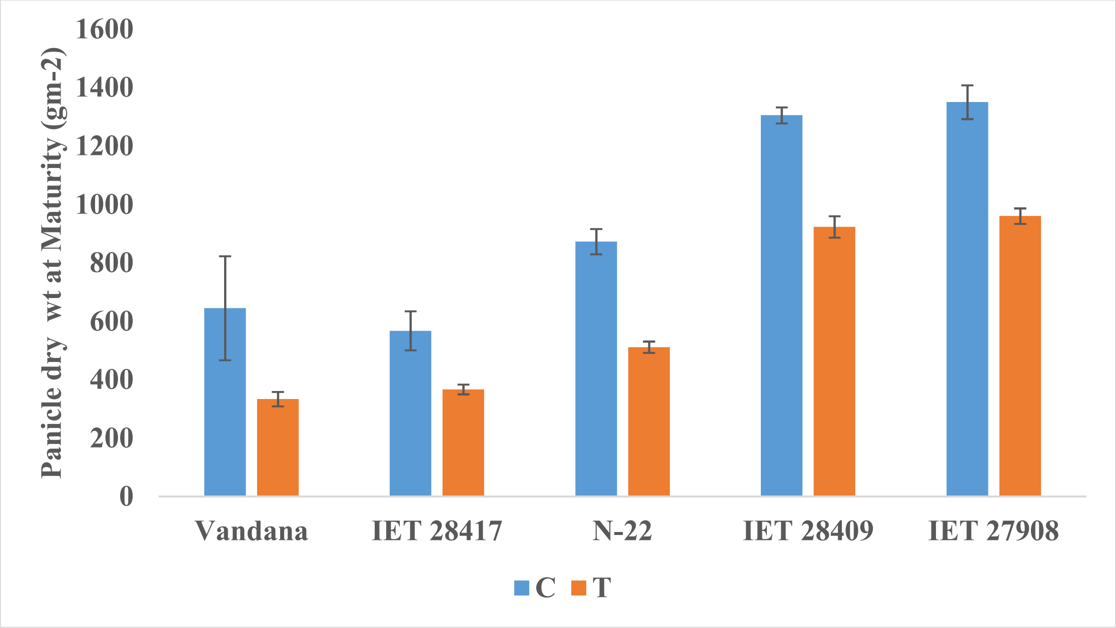

Figure 4.7 (b): Effect of high temperature stress on panicle dry weight (g/m^2) of rice genotypes at maturity (vertical bar represents ± standard error of mean)

In a study the mean grain number per panicle, grain weight per panicle decreased significantly in all the genotypes under heat stress leading to reduced panicle weight **(Sharma *et al.*, 2018).** Lower seed yield in rice grown under heat stress condition and high temperatures during panicle development, anthesis and seed set, adversely affect crop physiological parameters and yield attributing parameters, causing drastic reduction in seed yield of summer rice **(Das *et al.,* 2020).**

4.3.2 Effect of high temperature on panicle number per m^2 in different rice genotypes at maturity

Panicle number per m^2 was taken by counting total number of panicles in a hill at maturity. Under high temperature, panicle number were decreased in three genotypes namely, Vandana and IET 27908 as compared to control. Under control condition, the maximum panicle number was observed in IET 27908 (350 per m^2) whereas minimum in IET 28417 (216.67 per m^2). Maximum panicle number was reported in N-22 (366.67 per m^2), whereas the minimum in Vandana (250 per m^2) under high temperature stress. Maximum percent reduction in panicle number at maturity was observed in Vandana (16.67%) and maximum increase in IET 28417 (23.08%) during high temperature as compared to control. On the basis of panicle number per m^2, IET 28417 and N-22 were found to be tolerant and Vandana found to be highly susceptible to high temperature stress. Non-significant difference was observed between Vandana (300) and N-22 (316) under control; whereas, non-significant difference was found between Vandana (250) and IET 28417 under treatment. Panicle number was found to be statistically non-significant for genotypes (G), treatment (T) and TxG interaction **(Table 4.8 & Figure 4.8).**

Table 4.8: Effect of high temperature on panicle number per m^{2}of different rice genotypes at maturity, sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Panicle number per m^2			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	300±28.9	250±28.9	↓16.67
IET 28417	216.67±66.7	266.67±33.3	↑23.07
N-22	316.67±33.3	366.67±33.3	↑15.79
IET 28409	266.67±44.1	283.33±44.1	↑6.25
IET 27908	350±50	333.33±16.7	↓4.77
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	14.72	28.8	32.91
CD at 5%	NS	NS	NS

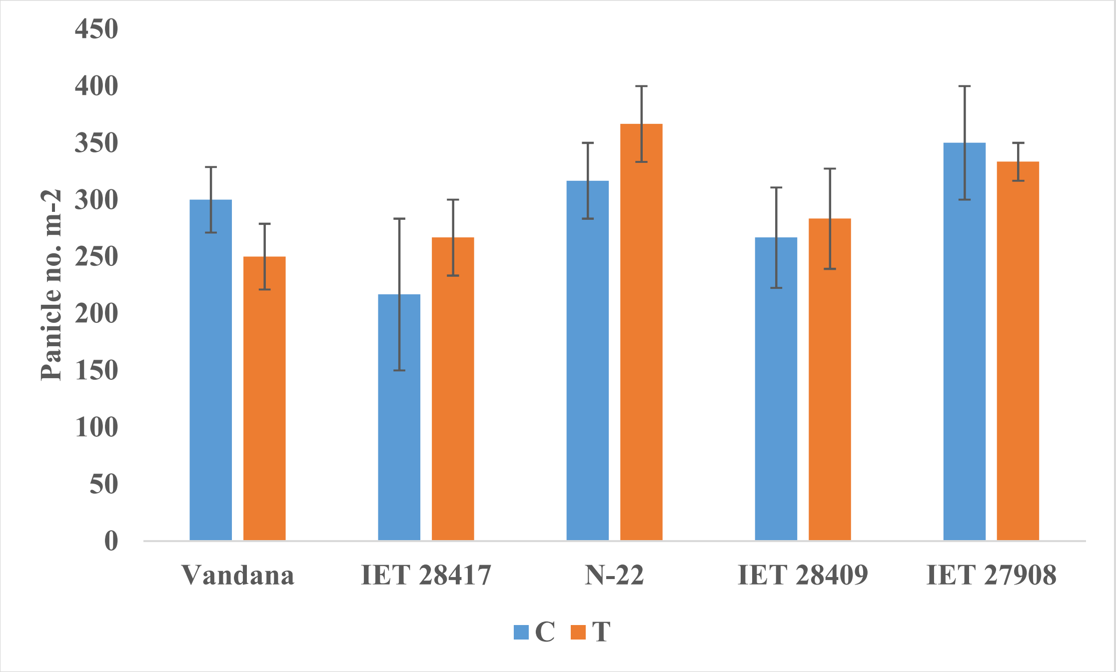

Figure 4.8: Effect of high temperature on panicle number per m^2 of different rice genotypes at maturity (vertical bar represents ± standard error of mean)

4.3.3 Effect of high temperature on number of filled grains per panicle, number of filled grains per m^2 and spikelet number per m^2 in different rice genotypes at maturity

Number of filled grains per panicle was recorded by counting the total number of filled grains present in a panicle of rice plant. Under high temperature stress, the number of filled grains per panicle were decreased in all genotypes; except IET 28417 as compared to control. Under control condition, the maximum number of filled grains per panicle were observed in IET 28417 (142.33) whereas minimum in Vandana (114). Under high temperature stress condition, the maximum number of filled grains per panicle were observed in IET 28417 (147) whereas minimum in Vandana (84). Maximum percent reduction in number of filled grains per panicle at maturity was observed in IET 27908 (26.17%) and maximum percent increase in number of filled grains per panicle at maturity were observed in IET 28417 (3.51%) during high temperature as compared to control. On the basis of grain number per panicle, IET 28417 was found to be tolerant and IET 27908 found to be highly susceptible to high temperature stress. Non-significant difference was observed in IET 28409 under control (141.33) and treatment (140). The number of filled grains per panicle was statistically significant for all genotypes (G) and TxG interaction **(Table 4.9 (a) & Figure 4.9 (a)).**

Table 4.9 (a): Effect of high temperature on number of filled grains per panicle of different rice genotypes at maturity, sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Number of filled grains per panicle			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	114±6.4	84.67±2.4	↓25.73
IET 28417	142.33±4.3	147.33±9.8	↑3.51
N-22	134.67±3.2	116.67±1.7	↓13.37
IET 28409	141.33±6.1	140±1.5	↓0.94
IET 27908	128.67±3.5	95±4.04	↓26.17
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	1.97	3.59	4.41
CD at 5%	12.93	10.87	18.21

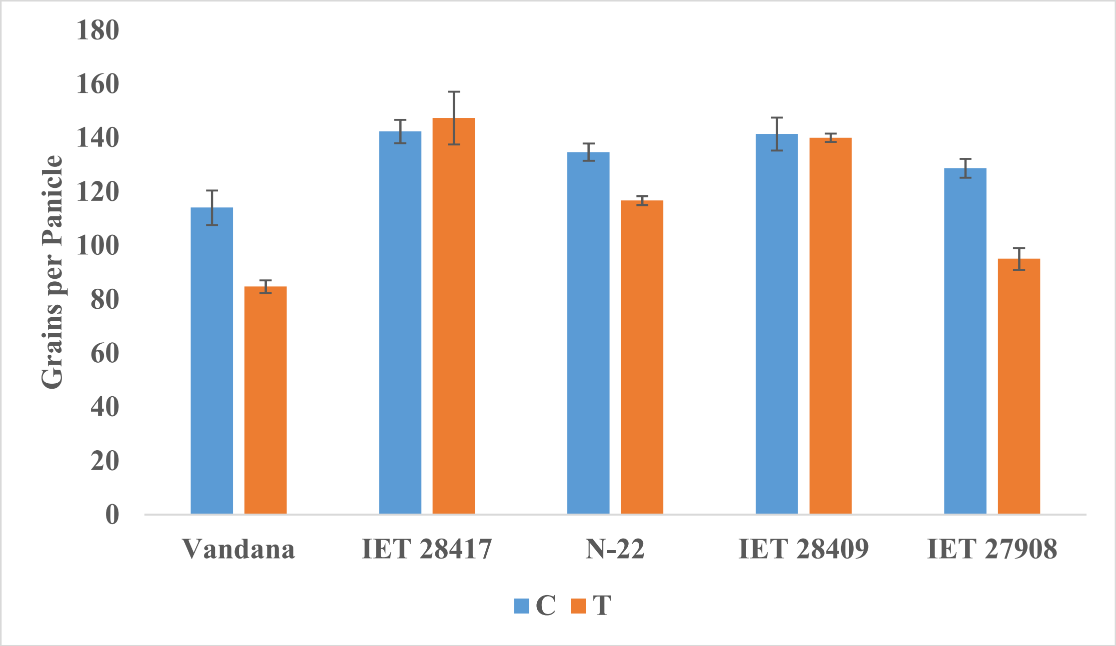

Figure 4.9 (a): Effect of high temperature on number of filled grains per panicle of different rice genotypes at maturity (vertical bar represents ± standard error of mean)

High temperature stress condition decreased the number of filled grains per m^2 in Vandana and IET 27908; whereas increases in rest of the genotypes as compared to control. Under control condition, the maximum number of filled grains per m^2 were observed in IET 27908 (45316.67) whereas minimum in IET 28417 (30350). Under high temperature, the maximum number of filled grains per m^2 were observed in rice N-22 (42833.33), whereas the minimum were in Vandana (21300). Maximum percent reduction in number of filled grains per m^2 was observed in Vandana (37.96%); while minimum percent reduction in IET 28417 (27.62%) during high temperature as compared to control. On the basis of grain number per m^2, IET 28417 was found to be tolerant, whereas Vandana and IET 27908 were found to be highly susceptible to high temperature stress. Non-significant difference was observed in N-22 under control (42466.67) and treatment (42833.33); also in IET 28409 under control (37933.33) and treatment (39666.67). Number of filled grains per m^2 were found to be statistically non-significant for all genotypes (G), treatment (T) and TxG interaction **(Table 4.9 (b) & Figure 4.9 (b)).**

Table 4.9 (b): Effect of high temperature on number of filled grains per m^2 of rice genotypes at maturity, sign ± indicates standard error of mean,↑/↓ indicates percent increase/decrease

Number of grains per m^2			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	34333.33±4186.2	21300±3003.9	↓37.96
IET 28417	30350±8457.1	38733.33±3351.3	↑27.62
N-22	42466.67±3782.2	42833.33±4206.5	↑0.86
IET 28409	37933.33±6943.2	39666.67±6134.7	↑4.57
IET 27908	45316.67±7328	31616.67±1718.6	↓30.23
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	2251.3	3735.18	5034.05
CD at 5%	NS	NS	NS

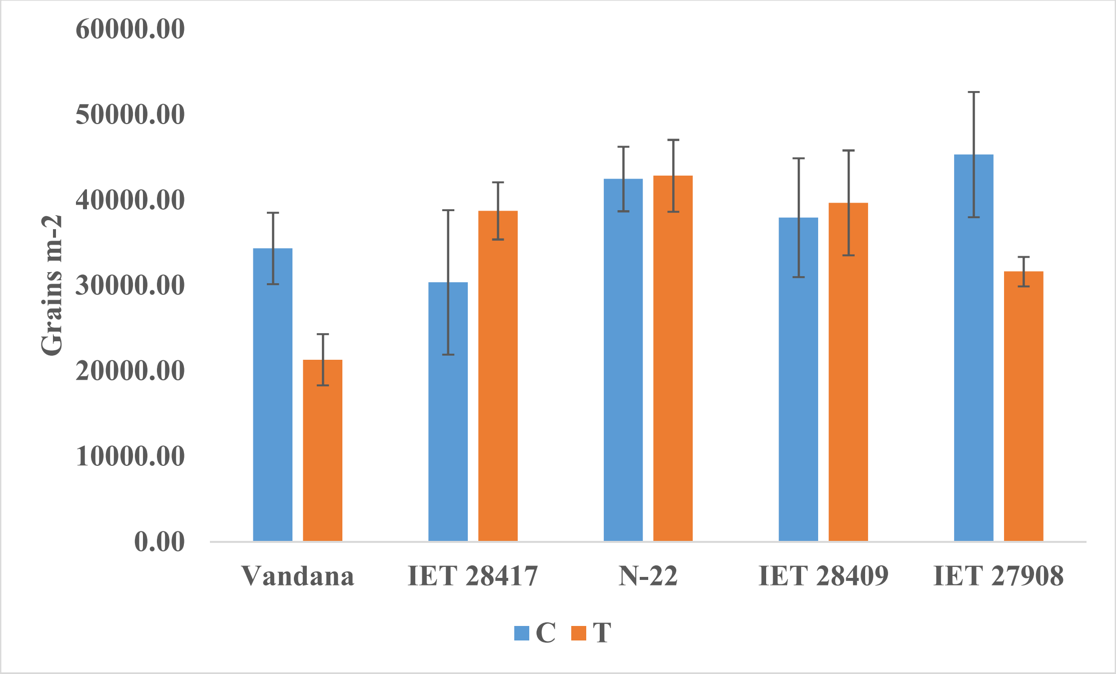

Figure 4.9(b): **Effect of high temperature on number of filled grains per m^2 of rice genotypes at maturity (vertical bar represents ± standard error of mean)**

Spikelet number per m^2 was oserved by counting the total number of filled and unfilled grains in a panicle per unit area in rice crop. Under high temperature stress condition, spikelet number per m^2 were decreased in Vandana and IET 27908; whereas increases in rest of the genotypes as compared to control. Under control condition, the maximum spikelet number per m^2 was observed in namely IET 27908 (52700) whereas minimum in IET 28417 (35416). Under high temperature stress condition, the maximum spikelet number per m^2 was observed in IET 28409 (72416.67), whereas the minimum in Vandana (37350). Maximum percent reduction in spikelet number per m^2 at maturity was observed in Vandana (19.45%) and maximum percent increase in IET 28409 (48.85%) during high temperature as compared to control. On the basis of Spikelet number per m^2, IET 28417 and IET 28409 were found to be tolerant, whereas Vandana and IET 27908 were found to be highly susceptible to high temperature stress. Non-significant difference was observed between Vandana (46366.67) and N-22 (46583.33) under control. Spikelet number per m^2 were found to be statistically significant for other genotypes (G) treatment (T) and TxG interaction **(Table 4.9 (c) & Figure 4.9 (c)).**

Table 4.9 (c): Effect of high temperature on spikelet number per m^2 of rice genotypes at maturity, ± sign indicates standard error of mean,↑/↓ indicates percent increase/decrease.

Spikelet number per m^2			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	46366.67±5358	37350±5043.06	↓19.45
IET 28417	35416.67±9780.5	48800±3950.95	↑37.79
N-22	46583.33±4210.5	50533.33±4900.8	↑8.48
IET 28409	48650±13925.9	72416.67±10690.1	↑48.85
IET 27908	52700±8100	44166.67±2074.5	↓16.19
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	1232.57	2134.88	3697.73
CD at 5%	3494.82	6053.20	10484.46

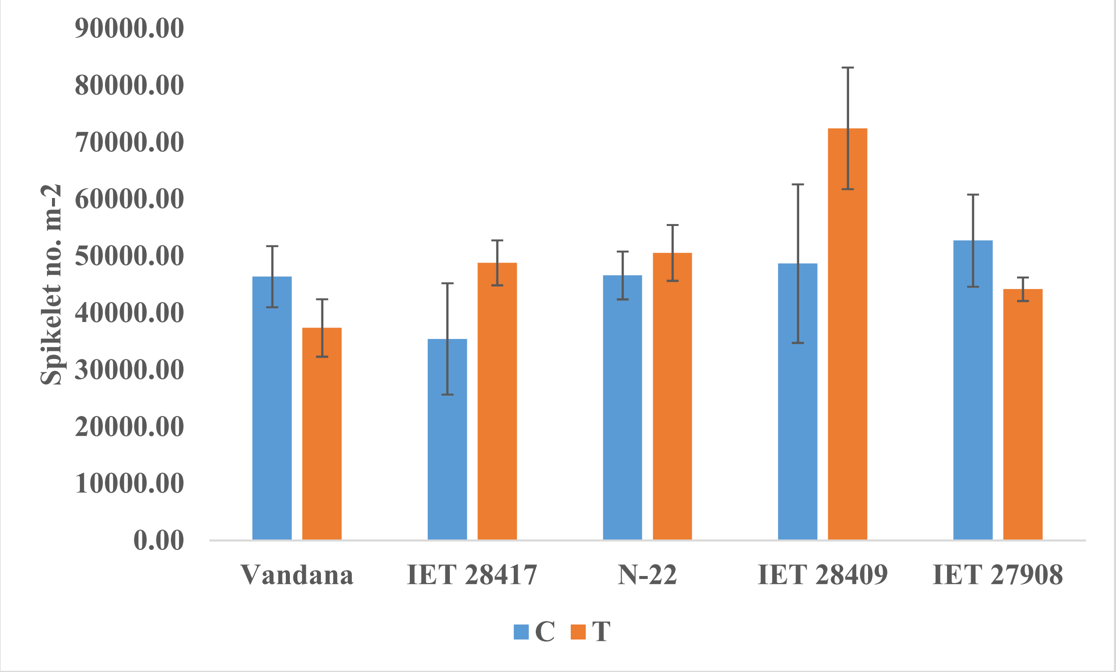

Figure 4.9 (c): Effect of high temperature on spikelet number per m^2 of rice genotypes at maturity (vertical bar represents ± standard error of mean)

Reduction in floret sterility and reduction in grain yield occurs at temperature more than optimal temperature. Spikelet sterility majorly occurs at temperature higher than 35℃. 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 relative humidity (RH), possibly due to the increase in transpiration at low relative humidity (RH) **(Prasad *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 fertilized spikelet **(Endo *et al.*, 2009).**

Rice pollens could not tolerate elevated temperature that leads to sterility and finally causes a decline in grain yield. The present study observed economic loss in terms of grain yield due to elevated temperature. This loss is the results of abnormality (shrinkage) in pollen morphology that induces a reduction in the grain filling process **(Kumar *et al.,* 2019).** The stress-induced reduction in assimilate supply strongly influences grain development. Heat stress can significantly influence seed development and thus decreases seed yield in several crops including cereals. Seed filling is closely related to the process of whole-plant senescence. Usually, drought and heat stress during seed filling causes early senescence and reduces seed-filling duration, and enhances assimilate remobilization from the source to sink**,** however, the combined effects of drought and temperature are more severe **(Aswathi *et al.,* 2021).**

4.3.4 Effect of high temperature on spikelet fertility (%) and test weight (g) in different rice genotypes at maturity

Spikelet fertility (%) was decreased in all the genotypes at maturity under high temperature stress as compared to control. Under control conditions, the maximum spikelet fertility (%) was observed in N-22 (91.19%) whereas minimum in IET 26803 (72.01%). Under high temperature stress condition, the maximum spikelet fertility was observed in IET 26794 (74.63%), whereas the minimum in IET 26803 (57.7%). Maximum percent decrease in spikelet fertility at maturity was observed in PR-124 (20.88%) during high temperature as compared to control. On the basis of spikelet fertility (%), IET 28409 and Vandana were found to be susceptible to high temperature stress. Spikelet fertility was found to be statistically significant for all genotypes (G), treatment (T) and TxG interaction **(Table 4.10 (a) & Figure 4.10 (a)).**

Table 4.10 (a): Effect of high temperature on spikelet fertility (%) of rice genotypes at maturity, sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Spikelet fertility (%) per panicle			
Genotypes	**Control**	**Heat Treatment**	**%Reduction**
Vandana	73.93±1.5	56.95±0.5	22.97
IET 28417	85.60±0.4	79.32±0.9	7.34
N-22	91.19±0.2	84.74±0.2	7.07
IET 28409	82.51±8.1	54.63±0.8	33.79
IET 27908	85.76±1.5	71.55±1.01	16.57
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	1.54	1.8	3.45
CD at 5%	10.1	5.45	1.54

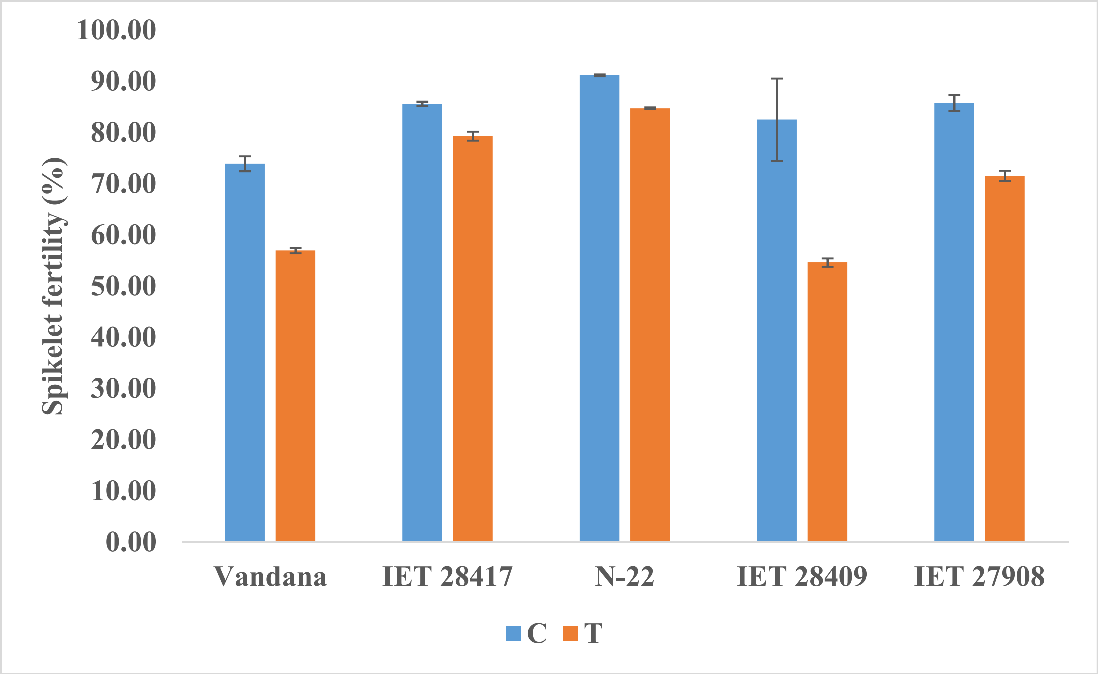

Figure 4.10 (a): Effect of high temperature on spikelet fertility (%) of rice genotypes at maturity (vertical bar represents ± standard error of mean)

Under high temperature stress, at maturity test weight (g) was decreased in two genotypes namely N-22 and IET 28409; and was increased in rest of the genotypes. Under control conditions, the maximum test weight was observed in N-22 (29.17 g) whereas minimum in IET 27908 (20 g). Under high temperature stress, maximum test weight was observed in IET 28417 (30.37 g), whereas the minimum in IET 27908 (28417 g). Maximum percent increase in 1000 grain weight at maturity was observed in IET 28417 (35.97%) and maximum percent decrease in N-22 (10.86%) during high temperature as compared to control. On the basis of test weight (g), IET 28417 and Vandana were found to be tolerant, whereas N-22 and IET 27908 were found to be highly susceptible to high temperature stress. Non-significant difference was observed in IET 28409 under control (25.67g) and treatment (24.83g); also, in IET 27908 under control (20g) and treatment (20.87g). Test weight was found to be statistically significant for all genotypes (G), treatment (T) and TxG interaction **(Table 4.10 (b) & Figure 4.10 (b)).**

Table 4.10 (b): Effect of high temperature on thousand grain weight (g) of rice genotypes at maturity, sign ± indicates standard error of mean, ↑ /↓ indicates percent increase/decrease

Test weight			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	24.60±0.35	27.33±0.17	↑11.11
IET 28417	22.33±0.6	30.37±0.2	↑35.97
N-22	29.17±0.6	26±0	↓10.86
IET 28409	25.67±0.7	24.83±0.2	↓3.25
IET 27908	20±0	20.87±0.13	↑4.33
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	0.18	0.25	0.4
CD at 5%	1.18	0.761	1.38

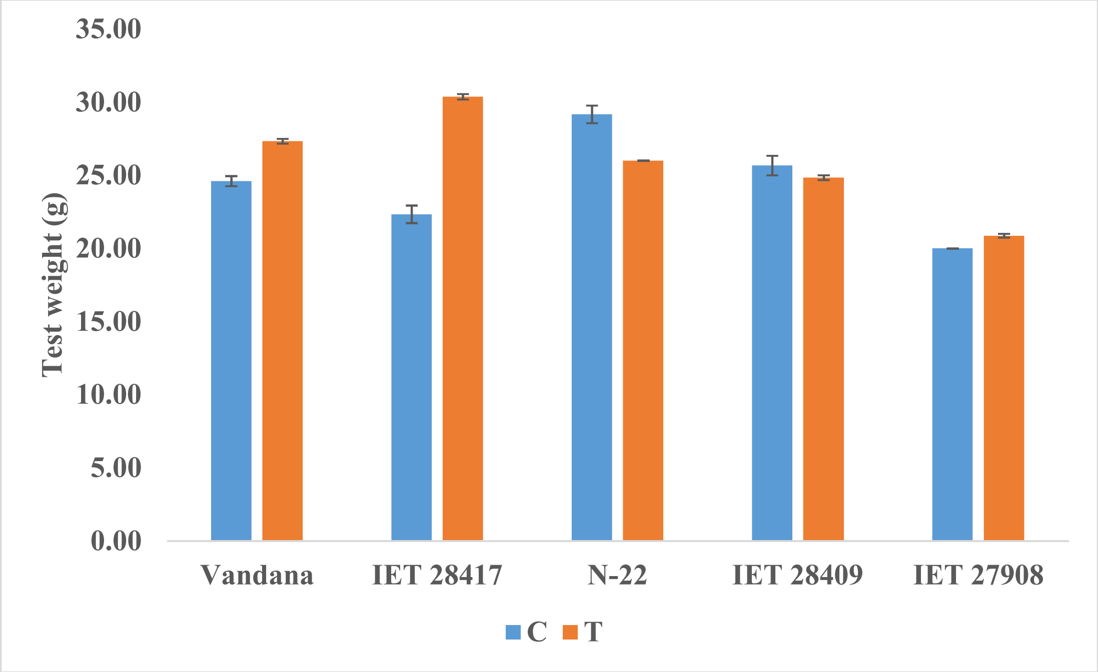

Figure 4.10 (b): Effect of high temperature on test weight (g) of rice genotypes at maturity (vertical bar represents ± standard error of mean)

The number of spikelet's per panicle, seed-setting rate, and 1000-grain weight were significantly decreased under heat stress for both cultivars, leading to a significant reduction in grain yield, with more reduction in Shuanggui 1 than in Huanghuazhan. Heat stress treatment significantly decreased grain width of Shuanggui 1 and obviously increased the ratio of length to width of grain, whereas it less affected those of Huanghuazhan **(Ying *et al*., 2004**).

At high night temperature, reduction in spikelet sterility (61%), grain length (2%), grain width (2%) and grain weight results in about 90% decrease in grain yield. Development of hull and endosperm determines the 1000 grain weight because due to high temperature stress abnormal development of spikelets shows lessening in hull size and endosperm development and ultimately leads to reduction in grain weight. Grain filling stage shows more serious effects as compared to flowering stage on 1000 grain weight at high temperature condition **(Mohammad and Tarpley, 2010).**

In another study, the mean spikelet fertility was drastically reduced from 83% in control to 30% under high temperature in kharif 2012. Maximum increase was observed in N22, Rasi and Balal. Similar results were obtained in high temperature in kharif 2013. Heat stress also reduced the mean 1000 grain weight of rice genotypes significantly in 13 out of 18 genotypes during 2012 **(Horie *et al*., 2019).**

4.3.5 Effect of high temperature on grain yield (g/m^2) in different rice genotypes at maturity

Grain yield (g/m^2) was recorded by weighing the total amount of seed after the harvesting of rice crop. Under high temperature stress condition, the grain yield was decreased in all the genotypes as compared to control at maturity. Under control condition, the maximum grain yield was observed in IET 27908 (1200g/m^2) whereas minimum in Vandana (494.48g/m^2). Under high temperature stress condition, the maximum grain yield was observed in IET 27908 (810g/m^2), whereas the minimum in Vandana (183.33g/m^2). Maximum percent reduction in grain yield at maturity was observed in Vandana (62.92%) and minimum percent reduction in IET 27809 (32.5%), during high temperature as compared to control. On the basis of grain yield (g/m^2), IET 28417 and Vandana were found to be highly susceptible to high temperature stress. Grain yield was found to be statistically significant for all genotypes (G), treatment (T) and non- significant for TxG interaction **(Table 4.11 & Figure 4.11).**

Table 4.11: Effect of high temperature on grain yield (g/m^2) of different rice genotypes at maturity, sign ± indicates standard error of mean

Grain Yield (g/m^2)			
Genotypes	**Control**	**Heat Treatment**	**%Decrease**
Vandana	494.48±177.8	183.33±20.85	62.92
IET 28417	450.76±99.6	216.67±21.9	51.93
N-22	722.58±37.6	361.17±19.86	50.02
IET 28409	1155±21.8	772.83±41.5	33.09
IET 27908	1200±52	810±28.9	32.50
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	47.35	44.16	105.89
CD at 5%	310.23	133.54	NS

The grain yield was greatly affected by high temperature (35℃) at the flowering and ripening stages. The grain yield reduced due to spikelet sterility and shortening of the time period of grain filling. In early and middle stages of grain filling, delay in sowing and high temperature stress in stage of grain filling can also lower biological yield and decrease in final grain weight **(Tian *et al.*, 2009)**.

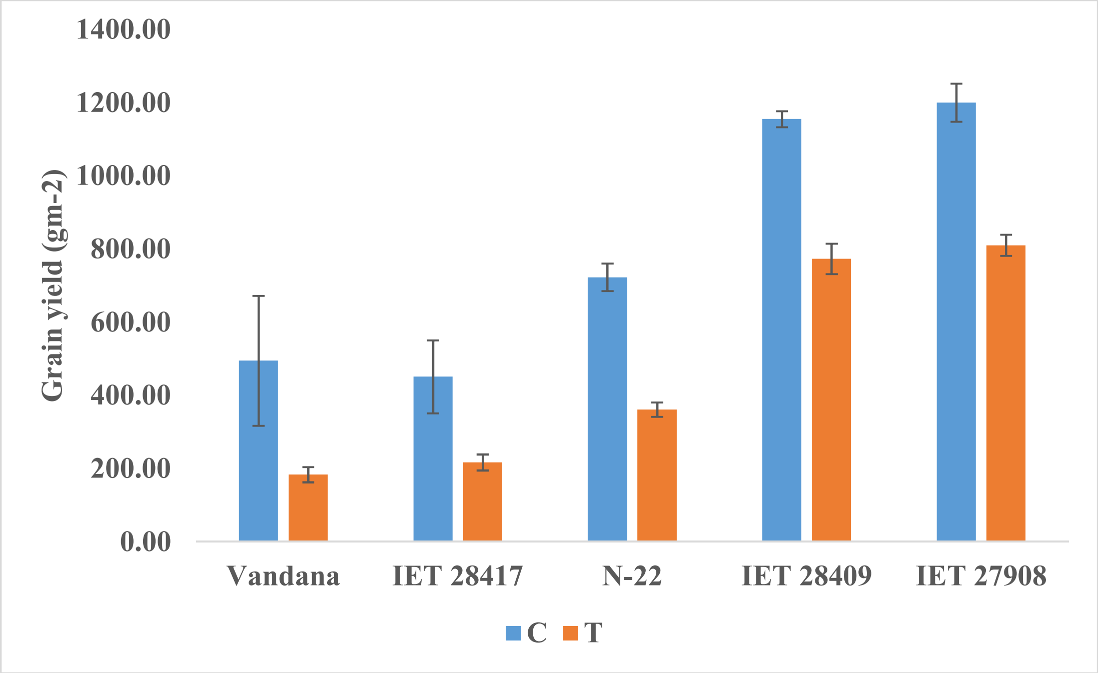

Figure 4.11: Effect of high temperature on grain yield (g/m^2) of different rice genotypes at maturity (vertical bar represents ± standard error of mean)

Two traits mainly seed filling rate and potential seed weight may be considered as a selection criteria for heat stress tolerance. The sensitivity of seed filling to heat stress may differ according to different crop species **(Wani *et al.*, 2016).** High-temperature stress may speed up the rate of seed filling by reducing the duration of this stage and therefore the yield potential. Increase in seed-filling rate resulted in smaller and wrinkled seeds in chickpea and lentil, which mainly occurred due to reductions in the remobilization and translocation of photosynthesis to developing seeds (**Xu *et al.*, 2020).**

4.3.6 Effect of high temperature on harvest index (%) in different rice genotypes at maturity

Harvest index (%) was calculated by taking the ratio of biological yield and economic yield in percentage. Under high temperature, harvest index was decreased in all genotypes as compared to control. Under control condition, the maximum harvest index was observed in IET 28409 (34.68%) whereas minimum in IET 28417 (25.56%).

Under high temperature stress condition, the maximum harvest index was observed in IET 28409 (28.41%), whereas the minimum in IET 28417 (15.91%). Maximum percent decrease in harvest index was observed in IET 28417 (37.74%); while minimum percent decrease in IET 28409 (18.08%) during high temperature as compared to control. On the basis of Harvest index (%), IET 28417 and Vandana were found to be highly susceptible to high temperature stress. Non-significant difference was observed under control between IET 28409 (34.68%) and IET 27908 (33.16%); as well as under treatment between IET 28409 (28.41%) and IET 27908 (27.01%). Harvest index was found to be statistically significant for all other genotypes (G) but non- significant for TxG interaction and treatment (T) **(Table 4.12 & Figure 4.12).**

Table 4.12: Effect of high temperature on harvest index (%) of rice genotypes at maturity, sign ± indicates standard error of mean,↑/↓ indicates percent increase/decrease

Harvest index (%)			
Genotypes	**Control**	**Heat Treatment**	**%Decrease**
Vandana	28.4	18.01	36.66
IET 28417	25.6	15.9	37.74
N-22	30.5	21.7	28.96
IET 28409	34.7	28.4	18.08
IET 27908	33.2	27	18.54
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	1.82	1.54	4.03
CD at 5%	NS	4.65	NS

A study revealed that, yield attributes such as panicle size, dry matter production and harvest index, were significantly reduced under high temperature stress in rice. Genotypes which are higher values of pollen viability, spikelet fertility and secondary branches in panicles recorded higher grain yield and harvest index were IET 20926, IET 20893, JAYA, and IET 21510 **(Krishnan *et al.*, 2011).** Poor grain development and diversion of nutrients from vegetative shoot to panicle may possibly be one of the reason for poor harvest index in plants subjected to high temperature stress. Further, due to enhancement in spikelet sterility, there is reduction in grain yield which was mainly attributed by a marked decline in the number of grains per panicle **(Gadakh, 2013).** In another study in rice the mean grain number per panicle, grain weight per panicle, spikelet fertility and grain yield per plant and harvest index decreased significantly in all the genotypes under heat stress **(Piveta *et al.*, 2018).**

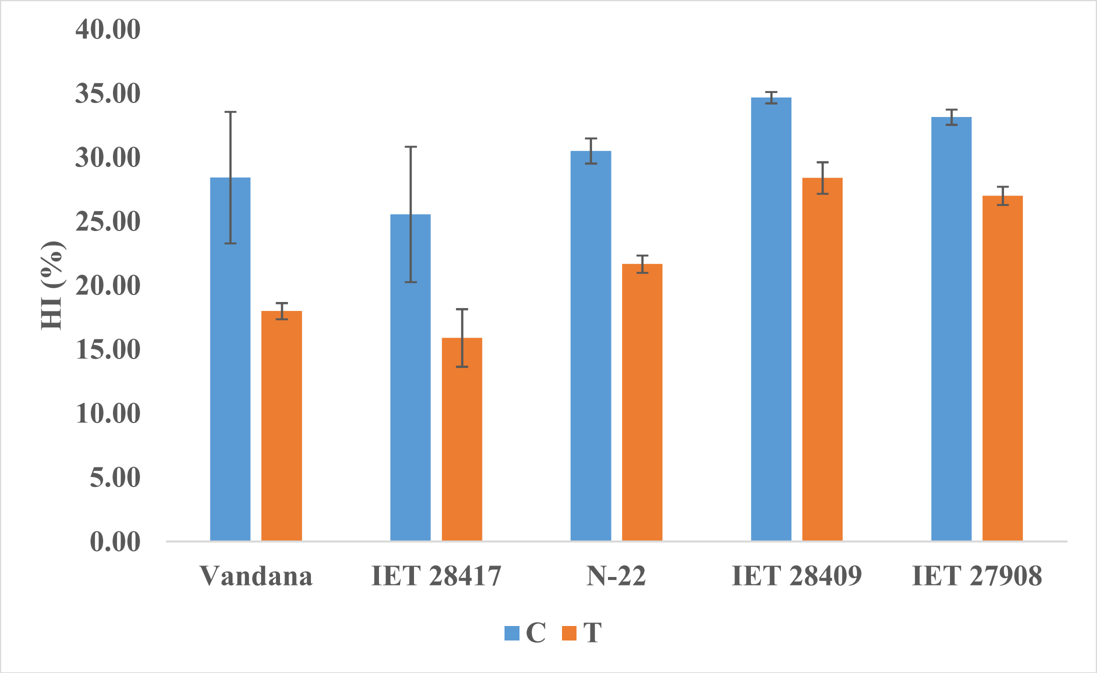

Figure 4.12: Effect of high temperature on harvest index (%) of different rice genotypes at maturity (vertical bar represents ± standard error of mean)

4.4 Biochemical Parameters

4.4.1 Effect of high temperature on total chlorophyll content (mg/g fw), chlorophyll fluorescence, chlorophyll a (mg/g fw), chlorophyll b (mg/g fw) and caretenoids (mg/g fw), in different rice genotypes after flowering

Total chlorophyll content (mg/g fw) was increased in all rice genotypes except in IET 27908 under high temperature as compared to control. Under control condition, the maximum total chlorophyll content was recorded in IET 27908 (2.59 mg/g fw) whereas minimum in N-22 (1.53 mg/g fw). Under high temperature stress condition, the maximum total chlorophyll content was recorded in IET 28409 (2.4 mg/g fw) whereas minimum in genotype N-22 (1.82 mg/g fw). Maximum percent increase in total chlorophyll was recorded in Vandana (25.46%) and maximum percent decrease in IET 27908 (8.15%) during high temperature as compared to control. On the basis of total chlorophyll content, Vandana and IET 28417 were found to be highly tolerant; while IET 27908 was found to be susceptible to high temperature stress. Non-significant difference was observed between Vandana (2.1 mg/g fw) and IET 28417 (2.18 mg/g fw); also between IET 28409 (2.4 mg/g fw) and IET 27908 (2.38 mg/g fw) under treatment. Total chlorophyll content was found to be statistically non-significant for all other genotypes (G), treatment (T) and TxG interaction **(Table 4.13 (a) & Figure 4.13 (a)).**

Table 4.13 (a): Effect of high temperature on total chlorophyll content (mg/g fw) of different rice genotypes after flowering, sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Total Chlorophyll content (mg/g fw)			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	1.82±0.3	2.10±0.4	↑25.46
IET 28417	1.78±0.7	2.18±0.6	↑22.70
N-22	1.53±0.2	1.82±0.4	↑18.99
IET 28409	2.14±0.5	2.40±0.4	↑12.33
IET 27908	2.59±0.5	2.38±0.1	↓8.15
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	0.17	0.43	0.38
CD at 5%	NS	NS	NS

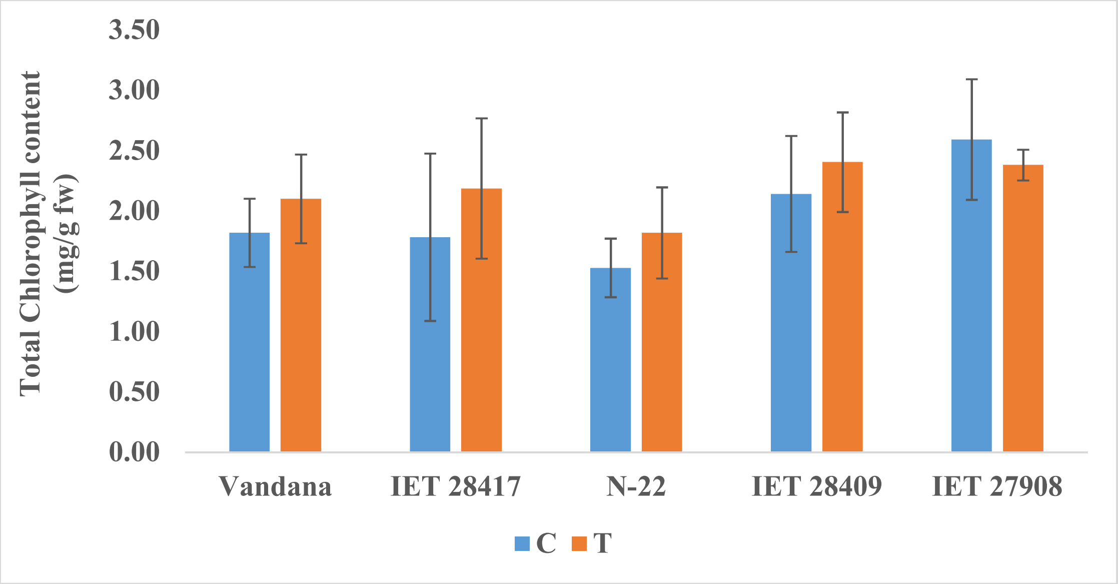

Figure 4.13 (a): Effect of high temperature on total chlorophyll content (mg/g fw) of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

Chlorophyll ‘a’ content (mg/g fw) was increased in all rice genotypes except IET 27908 under high temperature stress as compared to control. Under control, the maximum chlorophyll ‘a’ content was recorded in IET 27908 (1.9 mg/g fw) whereas minimum in N-22 (1.03 mg/g fw). Under high temperature stress, the maximum chlorophyll ‘a’ content was recorded in IET 27908 (1.73 mg/g fw) whereas minimum in N-22 (1.29 mg/g fw). The maximum percent decrease of about (8.72%) in chlorophyll ‘a’ was observed in IET 27908. Maximum percent increase of 24.98% in chlorophyll ‘a’ was observed in N-22. On the basis of total chlorophyll ‘a’ content, N-22 and IET 28417 were found to be highly tolerant; while IET 27908 was found to be susceptible to high temperature stress. Non significant difference was observed between Vandana (1.22 mg/g fw) and IET 28417 (1.26 mg/g fw) under control; non significant difference was observed between IET 28409 (1.7 mg/g fw) and IET 27908 (1.73 mg/g fw) under treatment. Chlorophyll ‘a’ was found to be statistically non-significant for all genotypes (G), treatment (T) and TxG interaction **(Table 4.13 (b) & Figure 4.13 (b)).**

Table 4.13 (b): Effect of high temperature on chlorophyll ‘a’ and ‘b’content (mg/g fw) of different rice genotypes after flowering, sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Genotypes	**Chlorophyll a (mg/g fw)**			**Chlorophyll b (mg/g fw)**		
	Control	**Heat Treatment**	**%Change**	**Control**	**Heat Treatment**	**%Change**
Vandana	1.22±0.3	1.48±0.3	↑21.92	0.60±0.05	0.62±0.1	↑2.37
IET 28417	1.26±0.6	1.52±0.5	↑20.27	0.52±0.1	0.67±0.07	↑28.53
N-22	1.03±0.1	1.29±0.3	↑24.98	0.49±0.12	0.53±0.04	↑6.48
IET 28409	1.57±0.4	1.70±0.3	↑8.36	0.57±0.1	0.70±0.2	↑23.23
IET 27908	1.90±0.5	1.73±0.2	↓8.72	0.69±0.01	0.65±0.1	↓6.59
	Treatment (T)	**Genotype (G)**	**TxG**	**Treatment (T)**	**Genotype (G)**	**TxG**
S.Em±	0.16	0.24	0.35	0.03	0.07	0.06
CD at 5%	NS	NS	NS	NS	NS	NS

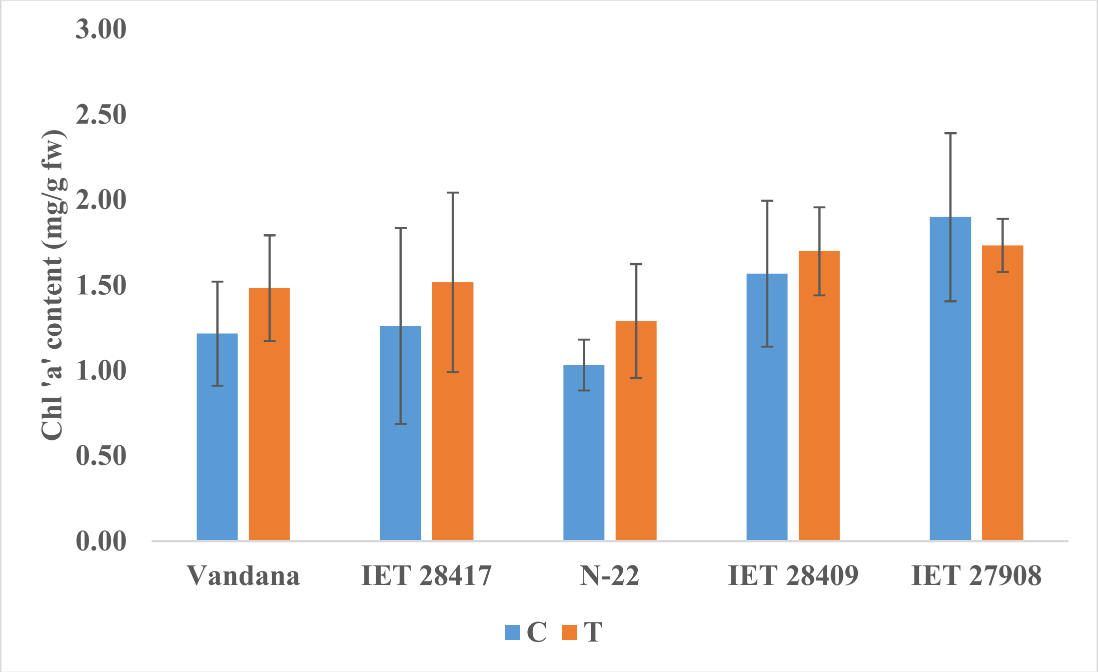

Figure 4.13 (b): Effect of high temperature on chlorophyll 'a' content (mg/g fw.) of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

Chlorophyll 'b' content (mg/g fw) was increased in all rice genotypes except IET 27908 under high temperature stress as compared to control. Under control condition, the maximum chlorophyll 'b' content was recorded in IET 27908 (0.69 mg/g fw) whereas minimum in N-22 (0.49 mg/g fw). Under high temperature stress, the maximum chlorophyll 'b' content was recorded in IET 28409 (0.7 mg/g fw) whereas minimum in N-22 (0.5 mg/g fw). Maximum percent increase in chlorophyll 'b' was observed in IET 28417 (28.53%) and maximum percent decrease in IET 6.59 (13.72 %). On the basis of total chlorophyll 'b' content, IET 28409 and IET 28417 were found to be highly tolerant; while IET 27908 was found to be highly susceptible to high temperature stress. Non significant difference was observed among Vandana (0.62 mg/g fw), IET 28417 (0.67 mg/g fw) and IET 27908 (0.65 mg/g fw) under treatment; whereas non significant difference was observed between Vandana (0.6 mg/g fw) and IET 27908 (0.69 mg/g fw) as well as between IET 28409 (0.57 mg/g fw) and IET 28417 (0.52 mg/g fw). Also non-significant difference was observed in Vandana under both, control (0.6 mg/g fw) and treatment (0.62 mg/g fw) also in IET 27908 under both, control (0.69 mg/g fw) and treatment (0.65 mg/g fw). Chlorophyll b content was found to be statistically non-significant for genotypes (G), treatment (T) and TxG interaction **(Table 4.13 (b) & Figure 4.13 (c)).**

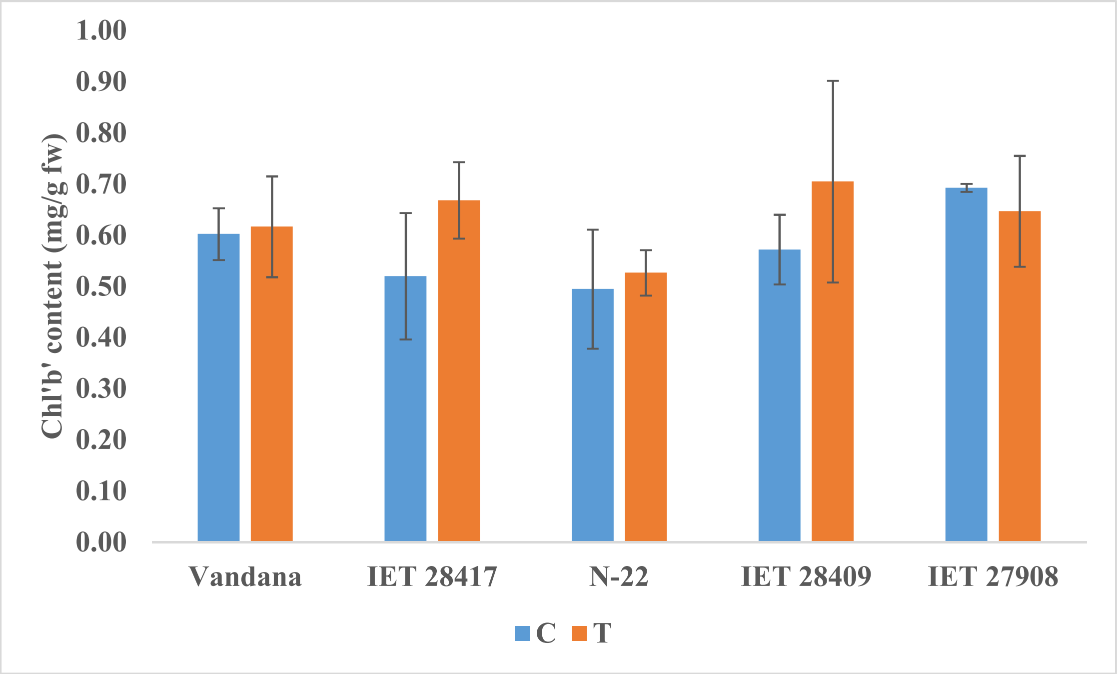

Figure 4.13 (c): Effect of high temperature on chlorophyll 'b' content (mg/g fw) of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

Carotenoid content (mg/g fw) was increased in all rice genotypes under high temperature stress as compared to control. Under control, the maximum carotenoid content was observed in IET 27908 (3.33 mg/g fw) whereas minimum was observed in N-22 (2.42 mg/g fw). Under high temperature stress condition, the maximum carotenoid content was observed in IET 28409 (3.82 mg/g fw) whereas minimum in N-22 (2.41 mg/g fw). Maximum percent increase in total carotenoid content was observed in IET 28417 (142.52%) and minimum percent increase in N-22 (8.71%) during high temperature as compared to control. On the basis of carotenoid content, IET 28417 was found to be highly tolerant; while N-22 was found to be slightly tolerant to high temperature stress. Non significant difference was observed in N-22 under control (2.42 mg/g fw) and treatment (2.41 mg/g fw). Carotenoid content was found to be statistically significant forall other genotypes (G) treatment (T) and TxG interaction **(Table 4.13 (c) & Figure 4.13 (d)).**

Table 4.13 (c): Effect of high temperature of carotenoid content (mg/g fw) of different rice genotypes after flowering, sign ± indicates standard error of mean

Genotypes	Carotenoid content (mg/g fw)		
	Control	**Heat Treatment**	**%Increase**
Vandana	2.92±0.5	2.62±0.6	25.36
IET 28417	2.53±0.7	3.08±0.2	142.52
N-22	2.42±0.8	2.41±0.2	8.71
IET 28409	2.87±0.2	3.821.8	20.02
IET 27908	3.33±0.3	3.55±0.8	26.22
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	0.17	0.36	0.51
CD at 5%	0.49	1.04	1.47

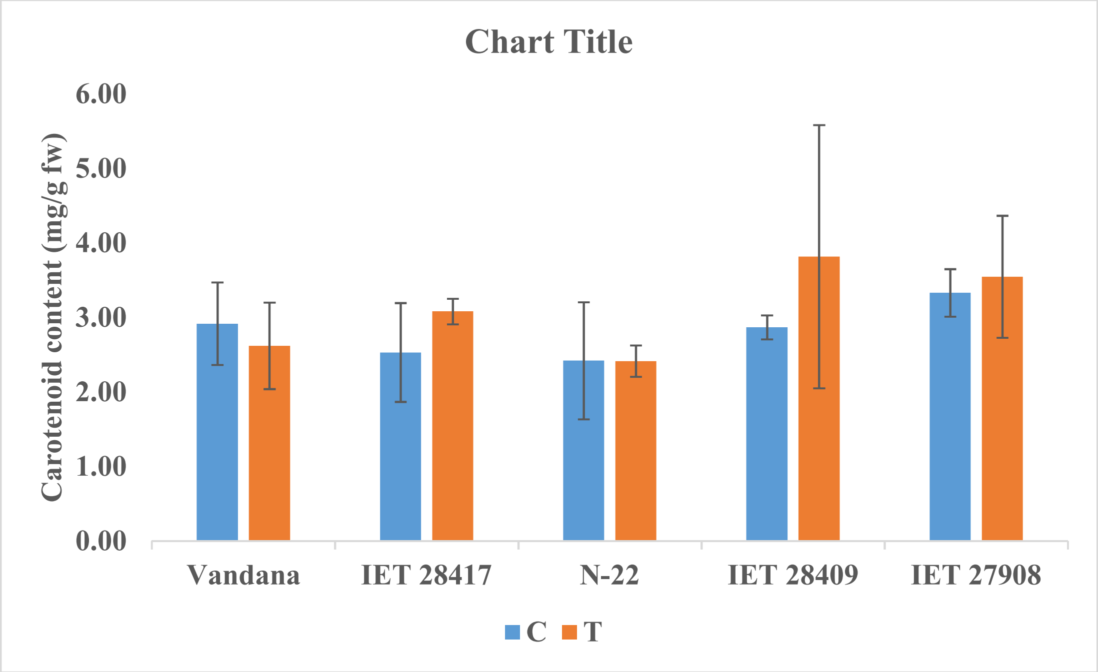

Figure 4.13 (d): Effect of high temperature on carotenoid content (mg/g fw) of different rice genotypes after flowering (vertical bar represents ± standard error of mean)

Chlorophyll fluorescence decreased in all the rice genotypes under high temperature stress condition as compared to control. Under the control condition, the maximum chlorophyll fluorescence was observed in IET 28417 (0.82) whereas minimum was observed in IET 27908 (0.7). Under high temperature stress, the maximum chlorophyll fluorescence was observed in IET 28417 (0.79) whereas minimum was observed in IET 27908 (0.68). Maximum percent reduction in chlorophyll fluorescence was observed in N-22 (7.66%) in high temperature as compared to control. On the basis of chlorophyll fluorescence, N-22 and IET 28409 were found to be highly susceptible to high temperature stress. Non significant difference was observed among Vandana (0.77), IET 28409 (0.76) and N-22 (0.78) under control; while, non-significant difference was observed among Vandana (0.73), N-22 (0.72) and IET 28409 (0.71) under treatment. Also, non significant difference was observed in IET 27908 under control (0.7) and treatment (0.68). The chlorophyll fluoroscence was found to be statistically significant for treatment (T) and all other genotypes (G) but non-significant for TxG interaction **(Table 4.13 (d) & Figure 4.13 (e)).**

Table 4.13 (d): Effect of high temperature on chlorophyll fluorescence of different rice genotypes at grain filling, the sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Genotypes	**Chlorophyll Fluorescence**		
	Control	**Heat Treatment**	**%Decrease**
Vandana	0.77±0.01	0.73±0.02	4.78
IET 28417	0.82±0.01	0.79±0.02	3.64
N-22	0.78±0.02	0.72±0.01	7.66
IET 28409	0.76±0.02	0.71±0.01	6.99
IET 27908	0.70±0.02	0.68±0.01	2.86
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	0.005	0.01	0.01
CD at 5%	0.03	0.03	NS

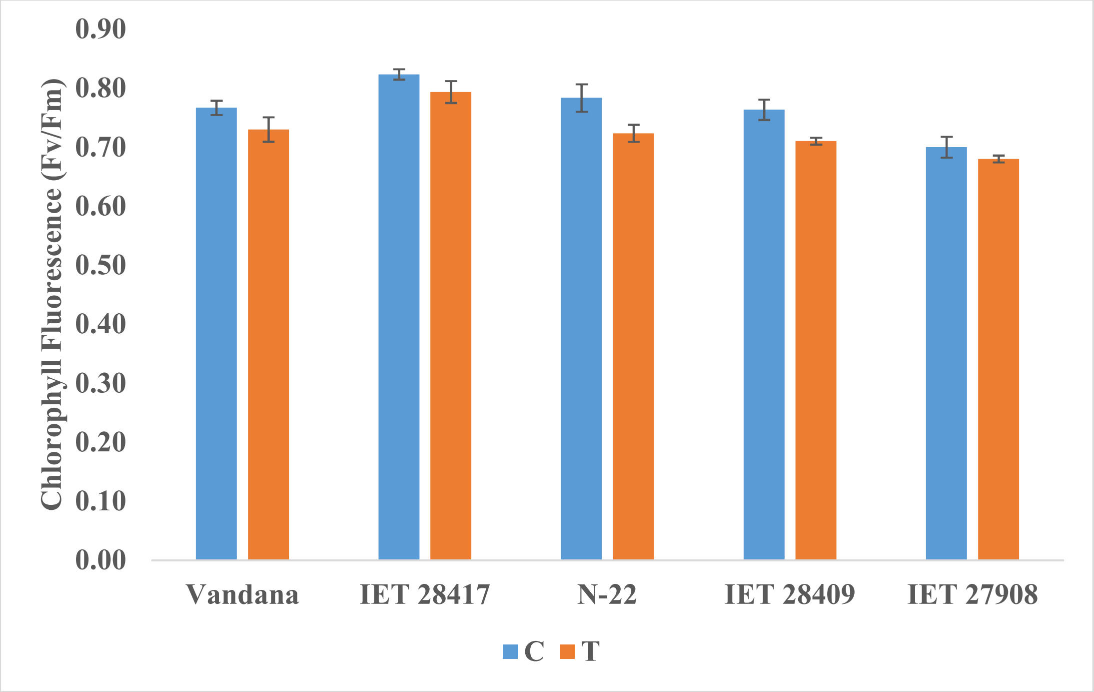

Figure 4.13 (e): Effect of high temperature on chlorophyll fluorescence of different rice genotypes at grain filling (vertical bar represents ± standard error of mean)

Stress hinders the chlorophyll fluorescence in the plant therefore due to increase in temperature, there was a reduction in chlorophyll fluroscence (Fv/Fm) in the leaves, protoplasts, chloroplasts or thylakoids of rice plant. Furthermore, in the photosynthetic organelles and thylakoids, injury to PSII under high temperature stress significantly decrease Fv/Fm ratio when treated at temperatures of 26℃, 35℃, 40℃ and 45℃ for 48 hours respectively **(Zheng *et al.*, 2009)**. The decrease in activity of photosynthesis leads to structural and functional disruptions of chloroplasts and also reduction of chlorophyll accumulation under high temperature stress. Further, the reduction of photosynthesis by high temperature stress is also related to inactivation of many chloroplast enzymes, mainly induced by oxidative stress **(Makino, 2010).**

The decrease in chlorophyll content occur under high temperature stress because it may affect the biosynthesis of two intermediate products of chlorophyll biosynthesis i.e., 5-aminolevulinic acid (ALA) and protoporphyrin LX (PPIX). ROS production also increases under high temperature stress, which accelerates the oxidation of cell membranes and results in reduction of chlorophyll content **(Alves *et al.*, 2015).**

Chlorophyll a and b content of rice leaves decrease by 28% and 48% at the day/night temperature of 40/35℃, respectively. Chlorophyll ‘b’ content of leaves has been more affected than the chlorophyll ‘a’ under high temperature stress. Total chlorophyll content decreased approximately 30% at the 40/35℃ day/night temperature. Chlorophyll b content was higher in rice crop plants grown at high temperature. On the other hand chlorophyll b content in wheat was higher in plants grown at medium temperature **(Aien *et al.*, 2011)**.

Carotenoids, non-enzymatic lipophilic antioxidants, have the ability to detoxify H_2O_2. In addition to direct deactivation of H_2O_2, carotenoids also quench triplet sensitizers and excited. When plants are exposed to a continuous stress, the equilibrium between H_2O_2 production and the activity of antioxidant mechanisms becomes unbalanced, leading to excessive accumulation of H_2O_2 in the plant body. This excess accumulation of H_2O_2 further increases the levels of CAT, APX and carotenoids, as they are continuously involved in rebalancing the equilibrium. Reductions in chlorophyll pigments under heat stress were suggested to be associated with the production of ROS and thereby indirectly represent the stress level of the plants **(Amirjani and Mahdiyeh, 2013).** Additionally, the activity of PSII, which is highly thermolabile, is significantly reduced under high temperatures. The high concentrations of chl a chl b for *E. nuttallii* exposed to moderate (30°C) temperature indicate an improvement in the chlorophyll pigments. Any alterations in plant photosynthetic attributes under heat stress can be considered reliable indicators of thermotolerance in plants. Moreover, the total chlorophyll of *E. nuttallii* and *V. asiatica* showed significant reductions in the mixed cultures in comparison to the monocultures but increased in the mixed culture for *P. crispus* during high temperature **(Prasad, (2017).** Carotenoid content decreased under heat stress in few genotypes but increased in tolerant. Carotenoids are an integral component of photosynthetic membranes and harvest visible light for photosynthesis. Carotenoid also protects plants from oxidative damage by absorbing excited energy from chlorophyll and act as antioxidant by quenching singlet oxygen **(Hussain *et al.*, 2019).**

4.4.2 Effect of high temperature on protein content (µg/g dry wt) of grains in different rice genotypes

Under high temperature stress, protein content (µg/g) was decreased in all genotypes as compared to control. Under control conditions, maximum protein content was observed in N-22 (979.5 µg/g) whereas minimum in IET 28409 (719.36 µg/g). Under high temperature stress condition, the maximum protein content was observed in N-22 (848.39 µg /g), whereas the minimum in IET 27908 (574.64 µg/g). Maximum percent decrease in protein content was observed in IET 27908 (28.65%) and minimum percent decrease was observed in IET 26477 (13.39%) during high temperature as compared to control. On the basis of total protein content, Vandana, IET 28417 and IET 27908 were found to be highly susceptible to high temperature stress. Non significant difference was observed between IET 28417 (976 µg/g) and N-22 (979.5 µg/g) under control; also, non significant difference was observed between IET 28409 (579.13 µg/g) and IET 27908 (574.64 µg/g) under treatment. Grain protein content was found to be statistically significant for all other genotypes (G) but non-significant for TxG interaction and treatment (T) **(Table 4.14 & Figure 4.14).**

Table 4.14: Effect of high temperature on protein content (µg/g dry wt) of different rice genotypes at maturity, sign ± indicates standard error of mean,↑/↓ indicates percent increase/decrease

Grain protein (µg/g dry wt)			
Genotypes	**Control**	**Heat Treatment**	**%Reduction**
Vandana	785.11±72	584.60±85.9	25.54
IET 28417	976.00±15.5	728.05±57.8	25.41
N-22	979.50±46.9	848.39±75.2	13.39
IET 28409	719.36±76.6	579.13±45.1	19.49
IET 27908	805.33±74.8	574.64±69.1	28.65
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	1.71	50.93	3.83
CD at 5%	11.23	154.02	NS

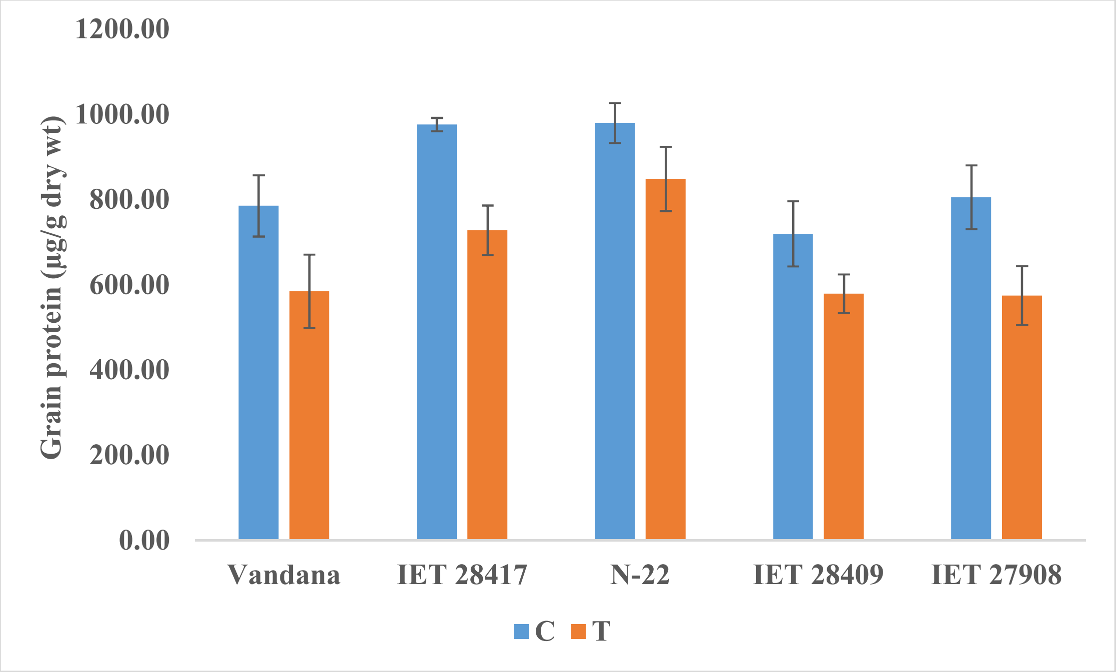

Figure 4.14: Effect of high temperature on protein content (µg/g dry wt) of different rice genotypes at maturity (vertical bar represents ± standard error of mean)

Higher protein were accompanied by lower grain weight and decreased starch accumulation. At temperature higher than 35℃, protein content decreases due to loss of Rubisco as this enzyme act as a regulatory enzyme **(Zeng *et al.*, 2010).** The photosynthetic rate slowed down when leaves were treated with high temperature. Identification of functional proteins in rice might improve heat tolerance in rice. It was observed in rice crop that protein content is high at early grain filling stage as compared to late grain filling stage **(Araus and Cairns, 2014)**.

4.4.3 Effect of high temperature on total carbohydrate content (mg/g dry wt) of grains in different rice genotypes

Under high temperature stress condition, the total carbohydrate content (mg/g) was increased in two genotypes IET 28417 and IET 27908, as compared to control. Under control conditions, maximum total carbohydrate content was observed in namely IET 27908 (37.07 mg/g) whereas minimum in genotype N-22 (26.95 mg /g). Under high temperature stress condition, the maximum total carbohydrate content was observed in IET 27908 (39.47 mg/g), whereas the minimum in IET 28409 (20.25

mg/g). Maximum percent increase in total carbohydrate content was observed in IET 28417 (21.69 %) and maximum percent decrease was observed in IET 28409 (36.55 %) during high temperature as compared to control. On the basis of total carbohydrate content, IET 27409 was found to be highly susceptible; while, IET 28417 was found to be highly tolerant to high temperature stress. Non significant difference was observed between in N-22 under control (26.95 mg/g) and treatment (26.88 mg/g). In all the genotypes the total carbohydrates was found to be statistically non-significant for genotypes (G), treatment (T) and TxG interaction **(Table 4.15 & Figure 4.15).**

Table 4.15: Effect of high temperature on total carbohydrate content (mg/g dry wt) of different rice grains, sign ± indicates standard error of mean, ↑/↓ indicates percent increase/decrease

Total carbohydrate content (mg/g dry wt)			
Genotypes	**Control**	**Heat Treatment**	**%Change**
Vandana	32.47±6.2	29.18±6.5	↓10.15
IET 28417	28.18±7.4	34.29±1.9	↑21.69
N-22	26.95±8.7	26.88±2.3	↓0.27
IET 28409	31.92±1.8	20.25±4.3	↓36.55
IET 27908	37.07±3.5	39.47±9.1	↑6.49
	Treatment (T)	**Genotype (G)**	**TxG**
S.Em±	3.42	4.07	7.66
CD at 5%	NS	NS	NS

Due to enhanced activity of the α-amylase enzyme, rice produce chaffy grains under heat stress environment. The transcripts of the β-glucosidase gene decrease due to heat stress to impact the seed composition in soybean **(Thomas *et al.*, 2003)**. Over 65% of seed dry weight is accounted for by starch, therefore, decrease in seed yield is mainly caused by decline in starch accumulation. Heat stress during grain filling markedly decreased starch accumulation in wheat and rice by altering the expression of starch-related genes, which contributed toward reduction in seed size. Total non-structural carbohydrates also decreased, which changed the proportion of soluble sugars to starch **(Yamakawa and Hakata, 2010).**

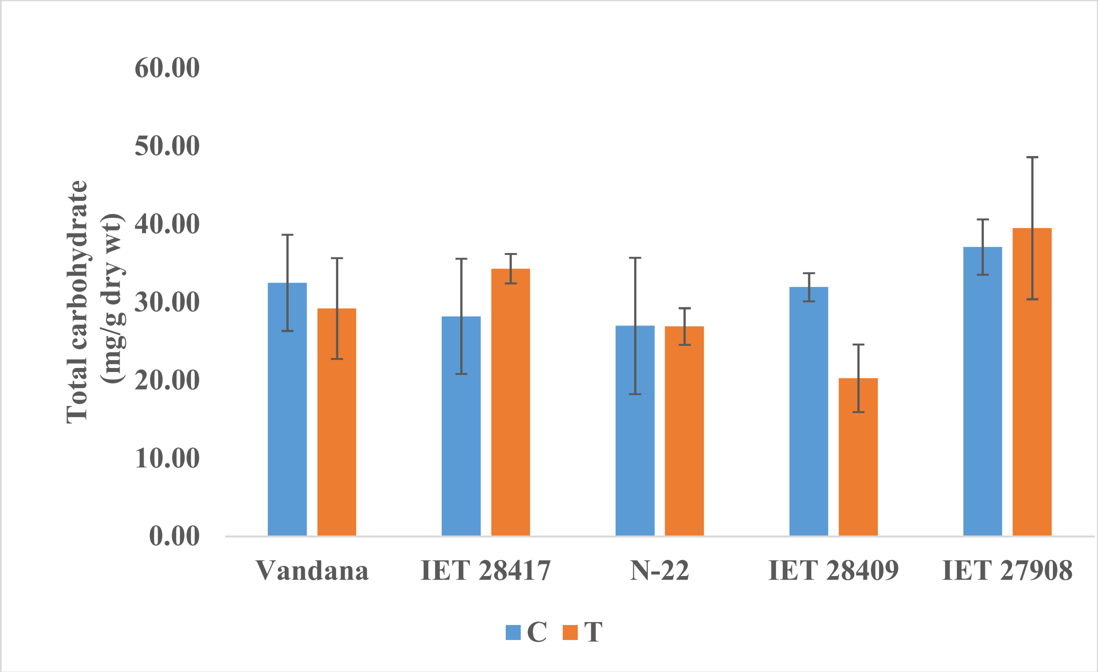

Figure 4.15: Effect of high temperature during high temperature stress on total carbohydrate content (mg/g dry wt) of different rice grains (vertical bar represents ± standard error of mean)

Impairment of photosynthesis during heat stress, reduces the currently available assimilates to the seed. Thus, stem reserves mobilization play a crucial role; hence, the stored carbohydrates become the chief source of transported materials, contributing around 75–100% to grain yield during stress environment. The mobilization of stored reserves from leaves and stem strongly correlates with carbohydrate metabolism, involving synthesis of sucrose and its utilization **(Farooq *et al.*, 2017).** Thus, heat stress adversely affects the accumulation of carbohydrates by influencing their metabolic pathways, the changes are crop-specific, and depend upon exposure to heat stress **(Sehgal *et al.*, 2018).** Rise in temperature inhibited sucrose metabolism in leaves and impaired sucrose supply to developing seeds, as in chickpea and mung bean, which might be a primary reason of shriveled seeds under heat stress. Moreover, the rate of chlorophyll decline from the leaf was strongly coordinated with contents of non-structural carbohydrates and nitrogen as well as their remobilization efficiencies (**Xalxo *et al.*, 2020**).

The correlation was found to be significant at 5% as well as at 1% level of significance in the case of leaf dry weight (flowering), stem dry weight (flowering), shoot dry weight (maturity), total dry matter (flowering), total dry matter (maturity), panicle dry weight per m^2 (flowering), panicle dry weight per m^2 (maturity) and test weight; when compared with grain yield. All other parameters where not significantly correlated with grain yield **(Table 4.16).**

Grain yield was found to be positively correlated with leaf dry weight (flowering), stem dry weight (flowering), shoot dry weight (maturity), total dry matter (flowering), total dry matter (maturity), panicle dry weight per m^2 (flowering), panicle dry weight per m^2 (maturity) and negatively correlated with test weight. Under heat stress, if the grain yield increases, test weight decreases; whereas, increase in the positively correlated parameters is observed with increment in grain yield.

Table 4.16: - Pearson Correlation of all Parameters with Grain Yield

S.N.	PARAMETERS	PEARSON CORRELATION WITH GRAIN YIELD
1.	Plant height (flowering)	0.32
2.	Number of effective tillers (flowering)	-0.02
3.	Leaf Area Index (flowering)	0.09
4.	Leaf dry weight (flowering)	0.84**
5.	Stem dry weight (flowering)	0.81**
6.	Shoot dry weight (maturity)	0.91**
7.	Total dry matter (flowering)	0.93**
8.	Total dry matter (maturity)	0.97**
9.	Panicle dry weight per m^2 (flowering)	0.9**
10.	Panicle dry weight per m^2 (maturity)	0.98**
11.	Panicle number per m^2 (maturity)	0.13
12.	Grain number per panicle	0.22
13.	Grain number per m^2	0.25
14.	Spikelet number per panicle	0.07
15.	Spikelet number per m^2	0.17
16.	Spikelet fertility	0.21
17.	Test weight	-0.5**
18.	Harvest Index	0.89
19.	Total chlorophyll content (leaves)	0.28
20.	Chlorophyll a content (leaves)	0.3
21.	Chlorophyll b content (leaves)	0.1
22.	Carotenoids content (leaves)	0.16
23.	Chlorophyll fluorescence	-0.28
24.	Protein content (grains)	0.002
25.	Carbohydrate content (grains)	0.009

** Correlation is significant at the 0.01 level.

* Correlation is significant at the 0.05 level.

Table 4.17: Daily Poly-House Temperature v/s Daily Ambient Temperature, 2019

Daily Poly House Temperature			**Daily Ambient Temperature**	
Date	**Maximum Temperature (°C)**	**Minimum Temperature (°C)**	**Maximum Temperature (°C)**	**Minimum Temperature (°C)**
09/17/19	47	23	33.0	22.5
09/18/19	47	22	32.5	22.9
09/19/19	50	21	31.5	22.7
09/20/19	48	22	32.0	21.9
09/21/19	45	22	32.5	23.5
09/22/19	43	22	33.0	21.1
09/23/19	48	22	30.0	22.3
09/24/19	47	23	32.5	23.5
09/25/19	48	24	32.0	23.0
09/26/19	47	23	32.5	23.9
09/27/19	41	23	31.0	23.7
09/28/19	41	23	30.0	23.4
09/29/19	41	23	28.3	21.3
09/30/19	51	23	29.8	21.9
10/01/19	46	22	29.0	23.0
10/02/19	48	23	30.0	22.4
10/03/19	50	22	31.5	22.1
10/04/19	48	20	31.6	22.4
10/05/19	47	20	32.0	19.7
10/06/19	46	20	31.5	19.9
10/07/19	50	20	32.0	19.9
10/08/19	49	19	32.0	20.0
10/09/19	47	18	32.5	21.7

Daily Poly House Temperature			**Daily Ambient Temperature**	
Date	**Maximum Temperature (^{o}C)**	**Minimum Temperature (^{o}C)**	**Maximum Temperature (^{o}C)**	**Minimum Temperature (^{o}C)**
10/10/19	45	18	32.4	18.7
10/11/19	43	18	32.0	16.9
10/12/19	40	17	31.0	18.4
10/13/19	39	17	31.6	18.3
10/14/19	38	16	31.5	17.5
10/15/19	45	16	32.0	18.4
10/16/19	40	16	31.5	18
10/17/19	42	17	32.0	17.4
10/18/19	42	17	31.0	18.9
10/19/19	44	16	30.6	17.6
10/20/19	43	16	30.0	19.4
10/21/19	41	15	30.2	16.5
10/22/19	39	15	30.5	13.7
10/23/19	38	14	29.7	15.8
10/24/19	38	14	30.3	17.4
10/25/19	39	15	30.0	16.4
10/26/19	40	14	29.5	17.8
10/27/19	40	14	28.5	15.9
10/28/19	39	14	29.0	16.1
10/29/19	39	15	29.5	17.2

The maximum and minimum ambient air temperature in 2019 during day varied from 23℃ to 40℃ and in night 9.9℃ to 29.9℃, respectively; likewise, inside the tunnel it varied from 38℃ to 51℃ and 14℃ to 24℃ respectively.

Summary
&
Conclusion

Chapter 5

SUMMARY AND CONCLUSION

The present investigation entitled **(Morpho-physiological and biochemical assessment of heat tolerance in various rice (*Oryza sativa* L.) Genotypes**) was performed at Norman E. Borlaug Crop Research Centre of the G.B. Pant University of Agriculture and Technology, Pantnagar during kharif season of 2019.

The salient findings of the experiment are summarized in this chapter:

1. Plant height (cm) was decreased in IET 28409 and IET 27908; while it was increased in rest of the genotypes under high temperature stress as compared to control. The maximum plant height, under high temperature stress, was observed in IET 28417 (112cm) and minimum in IET 28409 (96.67cm). However, under control condition it was maximum in IET 27908 (135.5cm) and minimum in N-22 (93.67cm). The maximum percent increase in plant height was observed in IET 28417 (14.67%) and maximum percent decrease in IET 27908 (24.23%).

2. Under high temperature the number of effective tillers per plant after flowering was increased in two genotypes viz., Vandana and N-22 while decreased in rest of the genotypes. The maximum effective tillers per plant in control condition were observed in IET 28417 (7) and minimum in Vandana (4.33) also under high temperature stress it was maximum in IET 28409 (6) and minimum in IET 27908 (5.33) and Vandana (5.33). Maximum percent increase in number of effective tillers per plant was observed in Vandana (23.08%) and maximum percent decrease in IET 28417 (19.05%).

3. Under high temperature stress conditions, LAI was increased in all five genotypes during flowering. Under control condition, maximum LAI was observed in IET 28409 (5.23) whereas minimum in N-22 (2.53). However under high temperature, the maximum LAI was observed in rice IET 28409 (6.43) whereas minimum in N-22 (3.73). Maximum percent increase in the LAI was observed in IET 28417 (50.25%); while minimum percent increase in IET 28409 (22.96%).

4. Under high temperature condition, the leaf weight after flowering decreased in all the genotypes as compared to control. Under control condition, maximum leaf weight was observed in IET 27908 (540.56 g/m^2), whereas the minimum leaf weight was observed in Vandana (220.73 g/m^2). Under high temperature stress, the maximum leaf weight (g/m^2) was observed in IET 27908 (521.46 g/m^2), while minimum was in Vandana (160 g/m^2). Maximum percent decrease was observed in Vandana (27.19 %); while, minimum percent decrease in IET 27908 (3.53%).

5. Under high temperature stress, stem weight decreased in all of the genotypes. Under control condition, the maximum stem weight was observed in IET 27908 (1081.12 g/m^2) whereas minimum in Vandana (441.46g/m^2). However, under high temperature stress, the maximum stem weight was recorded in IET 27908 (1042.93 g/m^2), and minimum stem weight in Vandana (321.44 g/m^2). Maximum percent reduction in stem weight was recorded in Vandana (27.19%) and minimum percent reduction was recorded in IET 27908 (3.43%).

6. Under high temperature stress, shoot weight decreased in the all of the genotypes. In control condition, maximum shoot weight was recorded in IET 27908 (2265.64 g/m^2) whereas minimum in Vandana (994.4 g/m^2). Under high temperature, maximum shoot weight was recorded in the IET 27908 (2038.79 g/m^2), whereas the minimum was in Vandana (769.08 g/m^2). Maximum percent decrease in shoot weight was observed in Vandana (31.7%) and minimum percent decrease in IET 27908 (10.01%) in heat treated genotypes as compared to control.

7. Under high temperature stress, TDM of all the genotypes was reduced after flowering. Under control condition, the maximum TDM was observed in IET 27908 (2208.64 g/m^2) whereas minimum in Vandana (942.4 g/m^2). Under high temperature stress condition, maximum TDM was observed in rice IET 27908 (198.79 g/m^2), whereas the minimum in Vandana (627.08 g/m^2). Maximum percent decrease in TDM after flowering was observed in Vandana (33.46 %) and minimum in IET 27908 (10.27 %).

8. At maturity, high temperature has decreased the TDM of all the genotypes as compared to control. Under control condition, the maximum TDM was found in IET 27908 (3615.64 g/m^2) whereas minimum in Vandana (1638.89 g/m^2). Under high temperature stress condition, the maximum TDM was observed in rice IET 27908 (2998.79 g/m^2), whereas the minimum in Vandana (1012.42 g/m^2). At maturity maximum percent reduction in TDM was observed in Vandana (38.22 %) and minimum percent reduction in IET 27908 (17.06 %) under high temperature stress as compared to control.

9. Under high temperature, panicle weight was decreased in all the genotypes after flowering. Under control condition, maximum panicle weight was observed in IET 27908 (596.96 g/m^2) whereas minimum in IET 28417 (246.7 g/m^2). Under high temperature stress, maximum panicle weight was observed in IET 27908 (417.39 g/m^2), whereas the minimum was observed in Vandana (144.93 g/m^2). Maximum percent decrease in panicle weight after flowering was observed in Vandana (48.28%) and minimum percent decrease in IET 27908 (28.89%).

10. At maturity, the panicle weight was decreased in all the genotypes. Under control condition, the maximum panicle weight was observed in IET 27908 (1350 g/m^2) and minimum in IET 28417 (567.42 g/m^2). Under high temperature stress, maximum panicle weight was observed in IET 27908 (960 g/m^2), whereas the minimum in Vandana (33.33 g/m^2). Maximum and minimum percent decrease in panicle weight at maturity was observed in Vandana (48.28%) and IET 27908 (28.89%), respectively during high temperature as compared to control.

11. Under high temperature, panicle number were decreased in three genotypes namely, Vandana and IET 27908 as compared to control. Under control condition, the maximum panicle number was observed in IET 27908 (350 per m^2) whereas minimum in IET 28417 (216.67 per m^2). Maximum panicle number was reported in N-22 (366.67 per m^2), whereas the minimum in Vandana (250 per m^2) under high temperature stress. Maximum percent reduction in panicle number at maturity was observed in Vandana (16.67%)

and maximum increase in IET 28417 (23.08%) during high temperature as compared to control.

12. Under high temperature stress, the number of filled grains per panicle were decreased in all genotypes; except IET 28417 as compared to control. Under control condition, the maximum number of filled grains per panicle were observed in IET 28417 (142.33) whereas minimum in Vandana (114). Under high temperature stress condition, the maximum number of filled grains per panicle were observed in IET 28417 (147) whereas minimum in Vandana (84). Maximum percent reduction in number of filled grains per panicle at maturity was observed in IET 27908 (26.17%) and maximum percent increase in number of filled grains per panicle at maturity were observed in IET 28417 (3.51%) during high temperature as compared to control.

13. High temperature stress condition decreased the number of filled grains per m^2 in Vandana and IET 27908; whereas increases in rest of the genotypes as compared to control. Under control condition, the maximum number of filled grains per m^2 were observed in IET 27908 (45316.67) whereas minimum in IET 28417 (30350). Under high temperature, the maximum number of filled grains per m^2 were observed in rice N-22 (42833.33), whereas the minimum were in Vandana (21300). Maximum percent reduction in number of filled grains per m^2 was observed in Vandana (37.96%); while minimum percent reduction in IET 28417 (27.62%) during high temperature as compared to control.

14. Under high temperature stress condition, spikelet number per m^2 were decreased in Vandana and IET 27908; whereas increases in rest of the genotypes as compared to control. Under control condition, the maximum spikelet number per m^2 was observed in namely IET 27908 (52700) whereas minimum in IET 28417 (35416). Under high temperature stress condition, the maximum spikelet number per m^2 was observed in IET 28409 (72416.67), whereas the minimum in Vandana (37350). Maximum percent reduction in spikelet number per m^2 at maturity was observed in Vandana (19.45%) and maximum percent increase in IET 28409 (48.85%) during high temperature as compared to control.

15. Spikelet fertility (%) was decreased in all the genotypes at maturity under high temperature stress as compared to control. Under control conditions, the maximum spikelet fertility (%) was observed in N-22 (91.19%) whereas minimum in IET 26803 (72.01%). Under high temperature stress condition, the maximum spikelet fertility was observed in IET 26794 (74.63%), whereas the minimum in IET 26803 (57.7 %). Maximum percent decrease in spikelet fertility at maturity was observed in PR-124 (20.88%) during high temperature as compared to control.

16. Under high temperature stress, at maturity test weight (g) was decreased in two genotypes namely N-22 and IET 28409; and was increased in rest of the genotypes. Under control conditions, the maximum test weight was observed in N-22 (29.17 g) whereas minimum in IET 27908 (20 g). Under high temperature stress, maximum test weight was observed in IET 28417 (30.37 g), whereas the minimum in IET 27908 (28417 g). Maximum percent increase in 1000 grain weight at maturity was observed in IET 28417 (35.97%) and maximum percent decrease in N-22 (10.86%) during high temperature as compared to control.

17. Under high temperature stress condition, the grain yield was decreased in all the genotypes as compared to control at maturity. Under control condition, the maximum grain yield was observed in IET 27908 (1200g/m^2) whereas minimum in Vandana (494.48g/m^2). Under high temperature stress condition, the maximum grain yield was observed in IET 27908 (810g/m^2), whereas the minimum in Vandana (183.33g/m^2). Maximum percent reduction in grain yield at maturity was observed in Vandana (62.92%) and minimum percent reduction in IET 27809 (32.5%), during high temperature as compared to control.

18. Under high temperature, harvest index was decreased in all genotypes as compared to control. Under control condition, the maximum harvest index was observed in IET 28409 (34.68%) whereas minimum in IET 28417 (25.56%). Under high temperature stress condition, the maximum harvest index was observed in IET 28409 (28.41%), whereas the minimum in IET 28417

(15.91%). Maximum percent decrease in harvest index was observed in IET 28417 (37.74%); while minimum percent decrease in IET 28409 (18.08%) during high temperature as compared to control.

19. Under control condition, the maximum total chlorophyll content was recorded in IET 27908 (2.59 mg/g fw) whereas minimum in N-22 (1.53 mg/g fw). Under high temperature stress condition, the maximum total chlorophyll content was recorded in IET 28409 (2.4 mg/g fw) whereas minimum in genotype N-22 (1.82 mg/g fw). Maximum percent increase in total chlorophyll was recorded in Vandana (25.46%) and maximum percent decrease in IET 27908 (8.15%) during high temperature as compared to control.

20. Chlorophyll ‘a’ content (mg/g fw) was increased in all rice genotypes except IET 27908 under high temperature stress as compared to control. Under control, the maximum chlorophyll ‘a’ content was recorded in IET 27908 (1.9 mg/g fw) whereas minimum in N-22 (1.03 mg/g fw). Under high temperature stress, the maximum chlorophyll ‘a’ content was recorded in IET 27908 (1.73 mg/g fw) whereas minimum in N-22 (1.29 mg/g fw). The maximum percent decrease of about (8.72%) in chlorophyll ‘a’ was observed in IET 27908. Maximum percent increase of 24.98% in chlorophyll ‘a’ was observed in N-22.

21. Chlorophyll ‘b’ content (mg/g fw) was increased in all rice genotypes except IET 27908 under high temperature stress as compared to control. Under control condition, the maximum chlorophyll ‘b’ content was recorded in IET 27908 (0.69 mg/g fw) whereas minimum in N-22 (0.49 mg/g FW). Under high temperature stress, the maximum chlorophyll ‘b’ content was recorded in IET 28409 (0.7 mg/g fw) whereas minimum in N-22 (0.5 mg/g fw). Maximum percent increase in chlorophyll ‘b’ was observed in IET 28417 (28.53%) and maximum percent decrease in IET 6.59 (13.72 %).

22. Carotenoid content (mg/g fw) was increased in all rice genotypes under high temperature stress as compared to control. Under control, the maximum carotenoid content was observed in IET 27908 (3.33 mg/g fw) whereas

minimum was observed in N-22 (2.42 mg/g fw). Under high temperature stress condition, the maximum carotenoid content was observed in IET 28409 (3.82 mg/g fw) whereas minimum in N-22 (2.41 mg/g fw). Maximum percent increase in total carotenoid content was observed in IET 28417 (142.52%) and minimum percent increase in N-22 (8.71%) during high temperature as compared to control.

23. Chlorophyll fluorescence decreased in all the rice genotypes under high temperature stress condition as compared to control. Under the control condition, the maximum chlorophyll fluorescence was observed in IET 28417 (0.82) whereas minimum was observed in IET 27908 (0.7). Under high temperature stress, the maximum chlorophyll fluorescence was observed in IET 28417 (0.79) whereas minimum was observed in IET 27908 (0.68). Maximum percent reduction in chlorophyll fluorescence was observed in N-22 (7.66%) in high temperature as compared to control.

24. Under high temperature stress, protein content (µg/g) was decreased in all genotypes as compared to control. Under control conditions, maximum protein content was observed in N-22 (979.5 µg/g) whereas minimum in IET 28409 (719.36 µg/g). Under high temperature stress condition, the maximum protein content was observed in N-22 (848.39 µg /g), whereas the minimum in IET 27908 (574.64 µg/g). Maximum percent decrease in protein content was observed in IET 27908 (28.65%) and minimum percent decrease was observed in IET 26477 (13.39%) during high temperature as compared to control.

25. Under high temperature stress condition, the total carbohydrate content (mg/g) was increased in two genotypes IET 28417 and IET 27908, as compared to control. Under control conditions, maximum total carbohydrate content was observed in namely IET 27908 (37.07 mg/g) whereas minimum in genotype N-22 (26.95 mg /g). Under high temperature stress condition, the maximum total carbohydrate content was observed in IET 27908 (39.47 mg/g), whereas the minimum in IET 28409 (20.25 mg/g). Maximum percent increase in total carbohydrate content was observed in IET 28417 (21.69 %) and maximum percent decrease was observed in IET 28409 (36.55 %) during high temperature as compared to control.

Conclusions

In the present investigation it was found that, high temperature stress reduces leaf dry weight, panicle dry weight, stem dry weight, chlorophyll fluorescence and TDM after flowering; panicle dry weight, shoot dry weight, TDM, spikelet fertility, grain yield, HI, total carbohydrate content and total protein content at maturity. Increase in plant height, carotenoids content, LAI, panicle number, grain number per m^2, spikelet number per m^2, test weight, total chlorophyll content, chlorophyll a and chlorophyll b under high temperature stress was also observed. Grain yield was found to be significant and positively correlated with leaf dry weight (flowering), stem dry weight (flowering), shoot dry weight (maturity), total dry matter (flowering), total dry matter (maturity), panicle dry weight per m^2 (flowering), panicle dry weight per m^2 (maturity) and negatively correlated with test weight. Under heat stress, if the grain yield increases, test weight decreases; whereas, increase in the positively correlated parameters is observed with increment in grain yield. Out of 5 genotypes, IET 28417 was found to be tolerant for high temperature stress as compared to other genotypes in terms of plant height, panicle number, grain number, grain number per m^2, test weight, chlorophyll b content, carotenoids content and LAI as compared to susceptible genotypes. Vandana was found to be susceptible for high temperature stress in terms of panicle number, grain number per m^2, spikelet number, leaf dry weight, stem dry weight, shoot dry weight, TDM, spikelet fertility, grain yield and panicle dry weight. Also, IET 27908 was found to be susceptible for high temperature stress in terms of plant height, grain number, chlorophyll a content and chlorophyll b content. These genotypes can be further 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 varieties.

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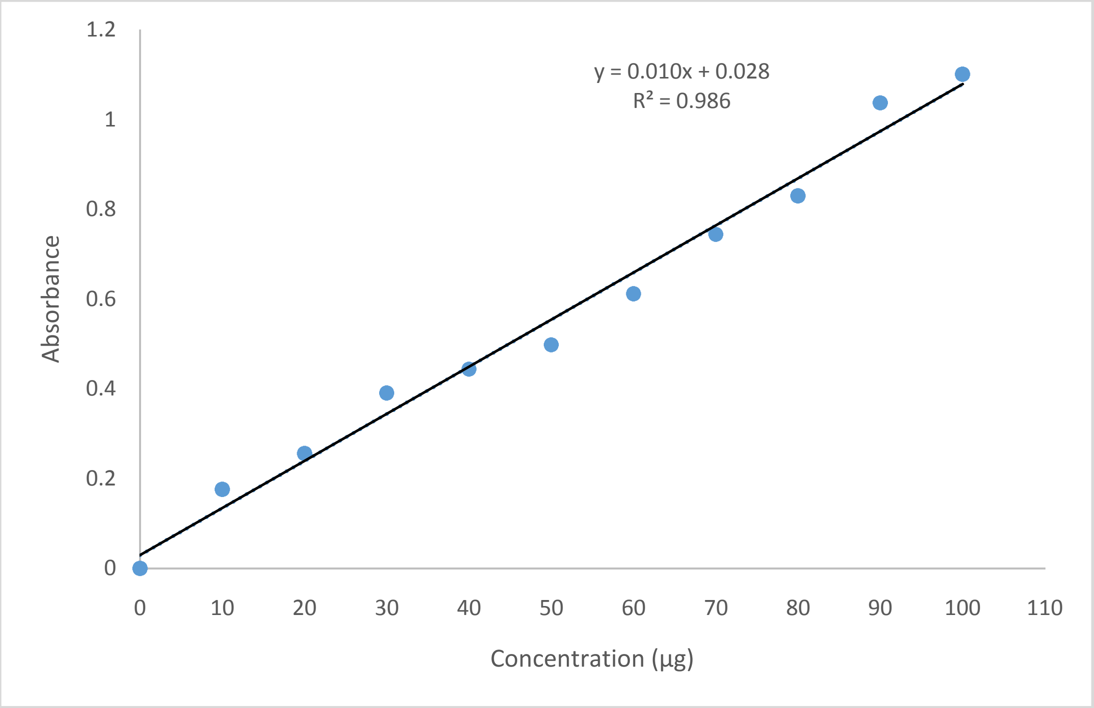
Appendices

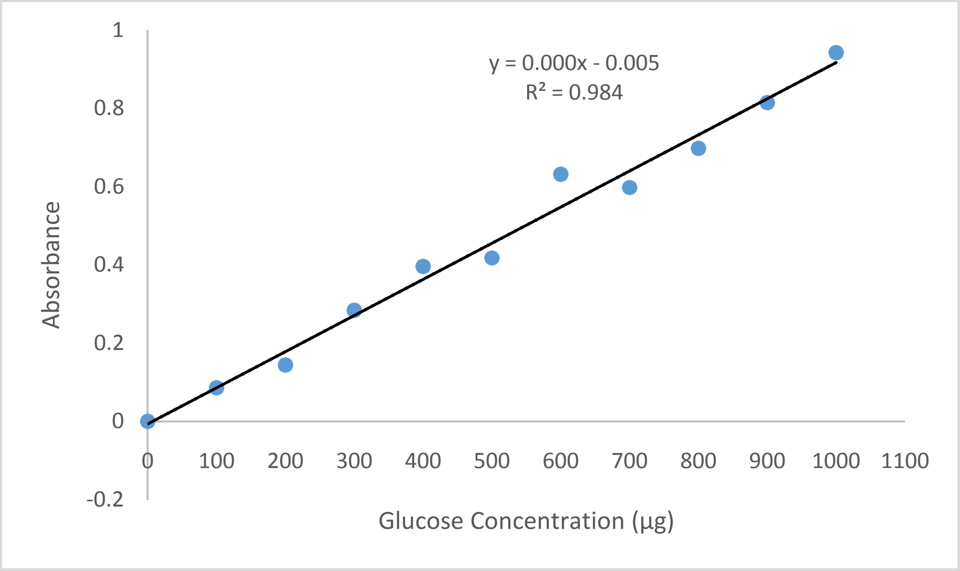
APPENDICES

APPENDIX-I



Standard Curve of Protein Content

APPENDIX-II



Standard Curve of Carbohydrate Content

APPENDIX-III

Weekly Weather Data (2019)

Station Name **Pantnagar** **Longitude** **79° 30’ E**

Latitude **29° N** **Altitude** **243.84. AMSL**

	Date	Year	Metro week No	Temperature		Relative humidity (%)		Rainfall (mm)	No of Rainy days	Sun-Shine Hrs.	Wind Velocity (Km/hr.)	Evap. (mm)
				Max.	Min.	712 am	1412 pm					
Jun	‘04-10	2019	23	38.9	26.0	63.4	37.0	23.4	1	10	6.9	10.1
Jun	‘11-17	2019	24	39.0	25.1	69.3	36.4	18.4	1	9.4	8.6	10.9
Jun	‘18-24	2019	25	35.9	24.2	76.6	52.1	62.2	2	8.2	7	7.2
Jun-Jul	‘25-01	2019	26	34.6	25.6	76.9	54.4	153	1	8.5	5	7.2
Jul	‘02-08	2019	27	33.9	26.1	79.1	68.6	30.8	3	4.7	4.7	5.2
Jul	‘09-15	2019	28	31.0	25.3	94.6	75.6	144.9	5	1.5	5	4.2
Jul	‘16-22	2019	29	32.7	25.7	84.3	64.3	41.2	1	5.4	3	4.2
Jul	‘23-29	2019	30	32.4	26.5	84.9	71.0	16.8	3	3.8	6.7	4.6
Jul-Aug	‘30-05	2019	31	33.3	26.0	88.1	67.4	108.2	4	4.8	5	4.9
Aug	‘06-12	2019	32	32.7	25.8	88.1	70.1	116.5	3	5.1	3.8	4.7
Aug	‘13-19	2019	33	32.0	25.4	89.3	74.1	51.2	4	5.2	5.8	4.8
Aug	‘20-26	2019	34	32.3	24.7	89.9	65.6	37.8	1	5.3	2.4	4.1
Aug-Sep	‘27-02	2019	35	33.8	25.7	85.6	66.1	174.6	2	6.1	1.9	4.5
Sep	‘03-09	2019	36	33.1	25.3	90.0	72.0	112.2	2	5.8	3.5	4.3
Sep	‘10-16	2019	37	33.1	25.7	89.4	69.9	7.8	1	5.5	3.5	4.3
Sep	‘17-23	2019	38	32.1	22.4	88.1	62.4	14.2	2	7	4.5	3.6
Sep	‘24-30	2019	39	30.9	23.0	88.0	65.1	6.2	1	6.1	1.8	3.6
Oct	‘01-07	2019	40	30.9	21.3	92.3	57.3	0	0	7.6	1.9	2.9
Oct	‘08-14	2019	41	31.9	18.8	88.1	47.3	0	0	8.6	2.4	3.2
Oct	‘15-21	2019	42	31.0	18.0	85.7	49.6	0	0	6	1.2	2.7
Oct	‘22-28	2019	43	29.6	16.2	91.9	46.7	0	0	6.5	2.2	2.8
Oct-Nov	‘29-04	2019	44	29.2	17.1	89.4	57.1	0	0	1.2	2.4	2
Nov	‘05-11	2019	45	29.1	14.0	85.3	43.7	0	0	6	2.7	2.4
Nov	‘12-18	2019	46	29.0	13.3	91.4	44.3	0	0	6.6	3.2	2.2
Nov	‘19-25	2019	47	25.0	11.5	94.0	47.3	0	0	4.7	1.8	2.1
Nov-Dec	‘26-02	2019	48	25.6	11.5	91.6	54.0	29.2	1	6.3	3.5	2.6
Jun	‘04-10	2019	23	38.9	26.0	63.4	37.0	23.4	1	10	6.9	10.1
Jun	‘11-17	2019	24	39.0	25.1	69.3	36.4	18.4	1	9.4	8.6	10.9
Jun	‘18-24	2019	25	35.9	24.2	76.6	52.1	62.2	2	8.2	7	7.2
Jun-Jul	‘25-01	2019	26	34.6	25.6	76.9	54.4	153	1	8.5	5	7.2
Jul	‘02-08	2019	27	33.9	26.1	79.1	68.6	30.8	3	4.7	4.7	5.2

APPENDIX-IV

Daily Weather Data June, 2019

Date	Temperature ^{0}C		R. Humidity %		Rainfall (mm)	Sun-shine hrs.	Wind Velocity (Km/hr)	Evap. (mm)
	Max.	Min.	0712 (am)	1412 (pm)				
1	39.5	26.4	52	35	**0.0**	10.5	10.4	12.5
2	38.0	26.9	46	37	**0.0**	9.1	10.8	11.0
3	38.5	23.9	68	44	**Trace**	4.5	9.0	8.7
4	35.0	25.9	61	44	0.0	6.9	9.5	8.8
5	38.5	27.3	55	36	0.0	10.7	6.5	10.0
6	40.9	28.7	65	42	0.0	10.2	8.0	11.5
7	40.0	21.7	67	34	23.4	8.5	9.5	10.8
8	36.5	25.6	72	35	**0.0**	11.5	1.9	9.0
9	40.7	25.4	60	35	0.0	11.3	5.5	10.0
10	41.0	27.4	64	33	**0.0**	11.1	7.4	10.7
11	41.6	29.4	63	40	**0.0**	11.0	9.8	11.6
12	39.5	20.7	83	52	18.4	10.6	10.6	15.6
13	35.5	26.4	79	33	0.0	9.4	5.8	7.5
14	38.5	25.0	65	25	0.0	9.5	7.2	7.6
15	41.0	22.0	72	25	**0.0**	11.3	7.9	9.8
16	42.0	27.5	50	39	0.0	10.9	6.3	11.6
17	35.2	24.5	73	41	0.0	3.0	12.7	12.6
18	36.6	22.8	79	49	2.0	10.9	14.7	5.0
19	35.0	23.0	82	40	0.0	6.5	8.6	7.3
20	35.2	20.4	79	51	0.0	6.8	4.2	7.2
21	34.5	25.2	63	34	0.0	7.7	2.7	6.6
22	39.0	27.9	62	50	0.0	10.3	4.4	8.4
23	37.0	25.5	76	56	17.8	6.8	7.6	7.8
24	34.0	24.7	95	85	42.4	8.7	7.0	7.9
25	25.5	22.4	85	52	153.0	0.0	6.4	OF
26	36.0	26.8	75	56	0.0	10.7	2.7	7.2
27	36.5	26.5	82	52	0.0	10.4	4.6	6.9
28	37.0	25.4	73	42	**Trace**	9.6	3.9	6.8
29	38.0	27.4	79	60	0.0	10.9	5.1	6.6
30	34.5	25.2	72	59	0.0	9.8	5.4	8.2
31	**1120.7**	**757.9**	**2097.0**	**1316.0**	**257.0**	**269.1**	**216.1**	**265.2**
Total	**37.0**	**25.3**	**69.9**	**43.9**	**–**	**9.0**	**7.2**	**9.1**
Averg.	**–**	**–**	**–**	**–**	**325.2**	**–**	**–**	**–**
Prog.	39.5	26.4	52	35	**0.0**	10.5	10.4	12.5

Daily Weather Data July, 2019

Date	**Temperature ^{0}C**		**R. Humidity %**		**Rainfall (mm)**	**Sun-shine hrs.**	**Wind Velocity (Km/hr)**	**Evap. (mm)**
	Max.	**Min.**	**0712 (am)**	**1412 (pm)**				
1	34.5	25.2	72	60	Trace	8.2	7.1	7.4
2	36.0	28.5	69	76	**0.0**	6.4	5.0	8.2
3	35.0	25.0	90	39	**4.2**	5.8	5.4	4.4
4	35.5	28.4	87	63	**0.0**	9.4	3.8	5.9
5	35.0	27.4	35	87	Trace	1.6	3.5	4.8
6	32.0	23.3	96	83	14.2	1.5	7.3	4.9
7	29.2	26.5	85	59	0.0	0.1	2.7	2.8
8	34.5	23.9	92	73	12.4	7.9	5.4	5.4
9	32.5	24.6	98	87	43.2	5.9	5.6	7.0
10	29.2	26.8	92	65	1.4	0.3	3.6	2.8
11	33.5	25.0	93	79	16.2	3.2	6.1	4.6
12	29.2	24.9	96	71	**3.4**	0.0	5.6	3.1
13	32.0	27.2	95	82	**17.3**	1.3	3.8	5.5
14	29.5	24.9	90	76	**1.0**	0.0	5.2	2.4
15	31.0	23.8	98	69	62.4	0.0	5.3	OF
16	30.0	22.2	95	77	**39.6**	2.4	4.2	4.2
17	28.5	24.4	85	69	1.6	0.0	2.9	2.2
18	32.0	25.8	85	69	0.0	4.3	2.4	3.9
19	33.0	26.4	78	59	0.0	7.2	1.3	4.6
20	35.1	26.9	86	55	0.0	7.9	2.5	4.8
21	35.0	27.4	82	57	0.0	7.9	4.1	4.5
22	35.5	26.7	79	64	**0.0**	8.3	3.5	5.4
23	35.0	27.4	85	59	0.0	7.5	1.7	5.0
24	36.0	28.9	84	80	0.0	7.8	5.8	6.5
25	31.0	24.9	92	75	**4.2**	0.2	10.5	4.6
26	29.5	25.3	90	72	**1.8**	0.0	4.8	4.0
27	31.5	26.0	86	85	**7.2**	0.5	9.1	4.7
28	31.0	26.3	82	65	**3.6**	2.1	7.4	2.8
29	33	26.7	75	61	**0.0**	8.2	7.7	4.8
30	33.6	25.9	89	69	**5.8**	8.6	5.5	4.3
31	32.5	25.7	80	65	**trace**	0.6	5.9	5
Total	**1010.8**	**802.3**	**2641.0**	**2150.0**	**239.5**	**125.1**	**154.7**	**140.5**
Averg.	**32.3**	**25.9**	**85.2**	**69.4**	–	**4.0**	**5.0**	**4.7**
Prog.	–	–	–	–	**564.7**	–	–	–

Daily Weather Data August, 2019

Date	Temperature ^{0}C		R. Humidity %		Rainfall (mm)	Sun-shine hrs.	Wind Velocity (Km/hr)	Evap. (mm)
	Max.	Min.	0712 (am)	1412 (pm)				
1	33.5	27.4	86	66	**0.0**	2.9	3.3	5.4
2	33.2	25.9	86	65	**0.0**	3.3	6.4	5.7
3	33.0	24.9	98	75	**33.0**	5.0	5.9	6.0
4	32.6	27.3	86	59	**4.0**	5.3	3.9	2.7
5	34.5	25.0	92	73	**65.4**	7.9	3.8	OF
6	32.5	24.0	95	85	**52.2**	6.8	7.7	5.3
7	29.6	24.9	93	71	**2.3**	1.7	4.2	3.1
8	33.0	27.4	83	63	**0.0**	3.2	3.3	3.4
9	34.5	25.4	86	70	**9.8**	5.50	1.4	5.6
10	32.5	27.4	82	71	**0.0**	5.0	1.4	5.6
11	32.6	26.7	83	60	**0.0**	8.1	5.6	4.0
12	34.0	24.8	95	71	**52.2**	5.5	2.7	6.2
13	32.5	24.8	95	73	**0.0**	2.7	1.3	3.7
14	32.6	26.4	75	57	**0.0**	3.5	2.5	4.6
15	35.0	24.9	92	71	**6.2**	9.6	1.7	5.2
16	32.6	25.9	90	78	**1.2**	8.4	10.3	5.5
17	31.0	26.1	89	76	**6.6**	6.6	12.4	3.9
18	31.2	25.0	92	86	**22.8**	5.2	9.3	6.0
19	29.0	24.9	92	78	**14.4**	0.1	3.1	4.4
20	30.5	24.4	87	66	**36.5**	4.1	2.5	5.3
21	33.5	24.9	87	65	**0.0**	9.8	4.0	4.5
22	33.0	25.0	96	75	**0.0**	7.0	0.6	4.1
23	30.5	23.9	90	61	**0.0**	0.0	0.5	1.8
24	35.0	24.9	90	57	**0.0**	11.1	2.8	5.2
25	31.2	25.9	86	69	**0.0**	0.3	3.8	3.5
26	32.3	23.7	93	66	**1.3**	4.7	2.7	4.1
27	33.5	25.4	75	53	**0.0**	6.0	0.3	3.8
28	36.0	26.9	79	58	**0.0**	11.5	0.9	4.4
29	35.5	27.2	86	70	**0.0**	10.0	1.3	5.7
30	31.6	25.2	83	63	**24.4**	1.6	1.8	4.4
31	34.5	26.8	86	84	**0.0**	8.1	1.7	5.6
Total	**1016.5**	**793.3**	**2728.0**	**2135.0**	**332.3**	**170.5**	**113.1**	**138.7**
Averg.	**32.0**	**25.6**	**88.0**	**68.9**	**–**	**5.5**	**3.6**	**4.6**
Prog.	–	–	–	–	**897**	–	–	–

Daily Weather Data September, 2019

Date	Temperature ^{0}C		R. Humidity %		Rainfall (mm)	Wind Velocity (Km/hr)	Sun shine hrs.	Evap. (mm)
	Max.	Min.	0712 am	1412 pm				
1	33.5	23.6	98	73	**150.2**	3.0	3.9	OF
2	32.0	25.0	92	62	0.0	2.4	3.3	3.0
3	34.5	26.9	86	60	**0.0**	9.3	1.1	3.6
4	35.0	23.9	95	78	**85.2**	8.6	3.0	OF
5	30.6	26.3	89	63	0.0	3.7	3.4	3.0
6	33.5	25.8	83	67	0.0	6.3	3.4	4.4
7	33.6	22.9	95	87	**27.0**	7.3	2.7	5.8
8	30.5	25.4	90	81	0.0	1.7	3.4	2.5
9	34.0	26.0	92	68	**0.0**	3.6	1.2	4.7
10	33.5	26.8	89	67	0.0	7.3	1.1	4.2
11	34.5	25.5	93	63	0.0	7.5	1.7	4.5
12	34.6	26.4	86	75	**0.0**	6.5	3.3	4.1
13	31.5	26.3	89	67	0.0	0.0	3.5	4.4
14	33.5	23.9	97	71	**6.6**	8.1	6.0	5.0
15	32.0	25.4	86	74	**1.2**	5.1	6.6	3.8
16	32	25.6	86	72	0.0	4.3	2.6	4.1
17	33.0	22.5	90	70	**6.2**	4.9	3.1	3.4
18	32.5	22.9	84	63	0.0	6.8	22.9	3.6
19	31.5	22.7	85	61	0.0	10.6	1.9	4.2
20	32.0	21.9	86	55	0.0	10.5	1.8	4.5
21	32.5	23.5	87	57	**0.0**	6.1	0.8	3.5
22	33.0	21.1	94	71	**8.0**	7.8	0.5	3.8
23	30.0	22.3	91	60	**0.0**	2.2	0.8	2.0
24	32.5	23.5	88	59	**0.0**	7.4	0.6	3.4
25	32.0	23.0	91	66	**0.0**	10.3	0.6	3.6
26	32.5	23.9	88	69	0.0	10.9	0.5	3.7
27	31.0	23.7	81	66	0.0	6.1	3.5	3.8
28	30.0	23.4	90	72	Trace	6.2	5.0	3.5
29	28.3	21.3	88	57	**6.2**	1.3	0.5	3.2
30	29.8	21.9	90	67	0.0	0.5	1.7	3.8
Total	**969.4**	**723.3**	**2679.0**	**2021.0**	**290.6**	**176.3**	**94.4**	**107.1**
Averg.	**31.6**	**24.1**	**89.3**	**67.4**	**–**	**5.9**	**3.1**	**3.8**
Prog.	**–**	**–**	**–**	**–**	**1187.6**	**–**	**–**	**–**

Weather Data October, 2019

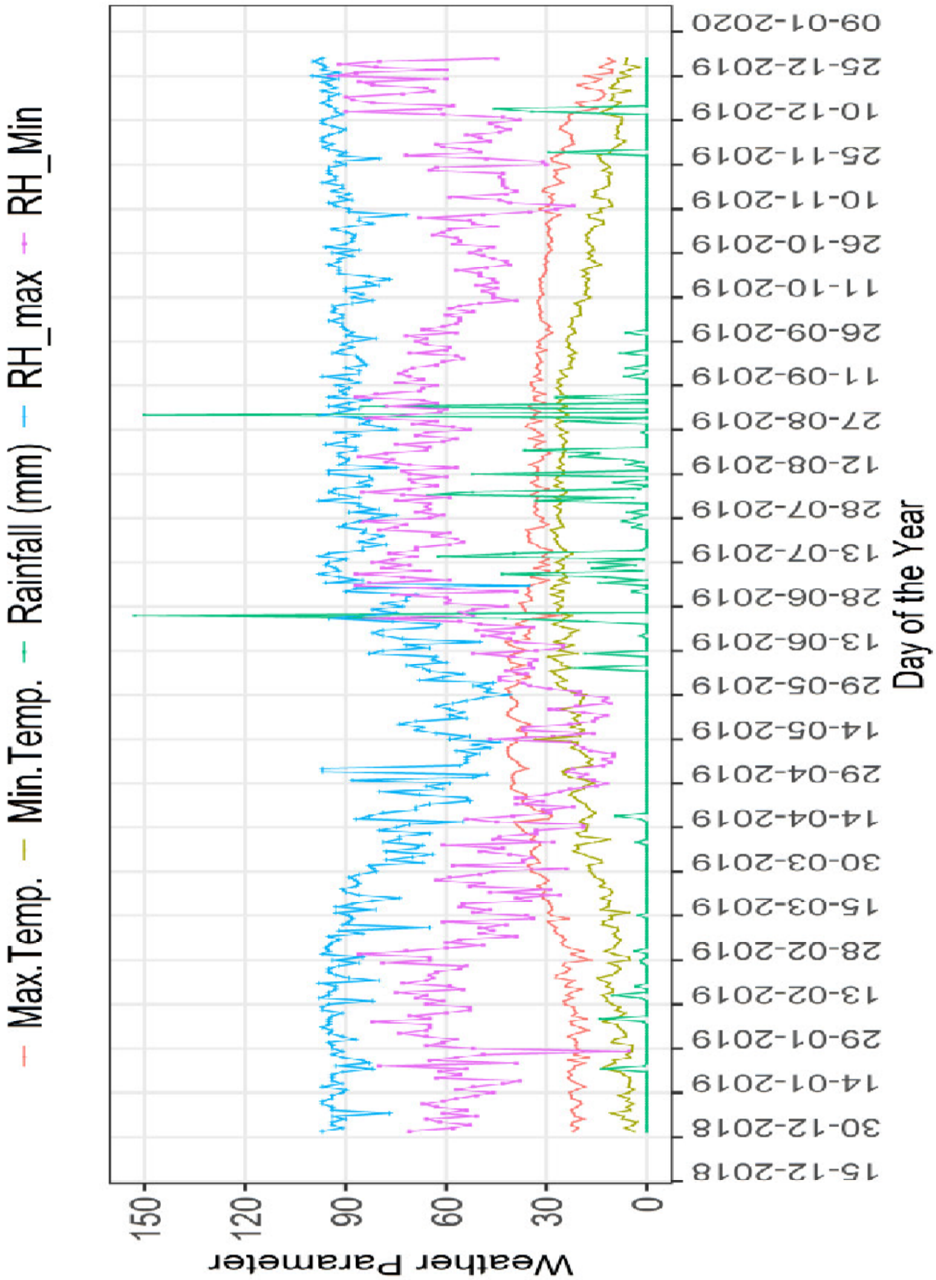
Date	Temperature ^{0}C		R. Humidity %		Rainfall (mm)	Wind Velocity (Km/hr)	Sun shine hrs.	Evap. (mm)
	Max.	Min.	0712 am	1412 pm				
1	29.0	23.0	91	61	Trace	3.6	0.8	2.2
2	30.0	22.4	91	57	0.0	6.6	2.7	2.4
3	31.5	22.1	95	56	0.0	10.1	1.9	2.8
4	31.6	22.4	91	56	0.0	8.3	1.3	3.5
5	32.0	19.7	91	60	0.0	8.5	3.0	3.5
6	31.5	19.9	94	52	0.0	8.2	2.0	2.8
7	32.0`	19.9	93	59	0.0	8.2	1.5	2.9
8	32.0	20.0	94	56	0.0	8.2	3.1	3.2
9	32.5	21.7	88	50	0.0	9.0	1.7	2.6
10	32.4	18.7	82	39	0.0	8.2	2.5	3.4
11	32.0	16.9	88	46	0.0	9.8	2.8	3.2
12	31.0	18.4	85	46	**0.0**	9.2	2.1	3.5
13	31.6	18.3	90	49	0.0	8.0	1.5	3.4
14	31.5	17.5	90	45	0.0	8.1	3.3	3.2
15	32.0	18.4	80	51	0.0	7.9	0.8	3.0
16	31.5	18	84	45	0.0	8.0	0.8	2.6
17	32.0	17.4	77	46	0.0	7.6	0.9	3.0
18	31.0	18.9	83	50	0.0	8.0	1.7	2.8
19	30.6	17.6	92	50	0.0	6.9	1.9	2.7
20	30.0	19.4	92	57	0.0	2.3	1.2	2.5
21	30.2	16.5	92	48	0.0	1.5	1.3	2.4
22	30.5	13.7	95	41	0.0	8.7	2.6	3.5
23	29.7	15.8	92	42	0.0	6.8	1.3	3.0
24	30.3	17.4	92	46	0.0	7.6	3.6	2.7
25	30.0	16.4	88	49	0.0	7.8	2.7	2.5
26	29.5	17.8	94	53	0.0	5.9	1.6	2.8
27	28.5	15.9	86	50	0.0	4.4	1.7	2.8
28	29.0	16.1	96	46	0.0	4.2	1.8	2.6
29	29.5	17.2	90	58	0.0	4.4	2.3	2.0
30	28.4	17.9	88	56	0.0	0.0	1.3	2.2
31	28.6	17.5	88	57	0.0	0.2	1.0	1.7
Total	**919.9**	**572.8**	**2772.0**	**1577.0**	**0.0**	**206.2**	**58.7**	**87.4**
Averg.	**30.9**	**18.5**	**89.4**	**50.9**	**–**	**6.7**	**1.9**	**2.8**
Prog.	**–**	**–**	**–**	**–**	**1187.6**	**–**	**–**	**–**

Weather Data November, 2019

Date	**Temperature ^{0}C**		**R. Humidity %**		**Rainfall (mm)**	**Wind Velocity (Km/hr)**	**Sun shine hrs.**	**Evap. (mm)**
	Max.	**Min.**	**0712 am**	**1412 pm**				
1	29.5	18.4	87	64	0.0	0.0	2.3	2.1
2	29.6	17.0	90	61	0.0	0.5	2.0	2.1
3	29.0	16.4	94	59	0.0	0.0	1.9	1.4
4	29.5	15.4	89	45	**0.0**	3.4	5.9	2.8
5	30.0	12.9	82	52	0.0	6.5	5.4	2.6
6	29.0	13.1	86	53	0.0	5.7	1.5	2.0
7	28.0	17.1	86	68	0.0	4.3	2.0	1.5
8	26.0	17.4	72	49	0.0	0.2	2.5	1.4
9	30.0	13.5	89	35	0.0	8.2	1.7	2.4
10	32.0	13.9	89	27	0.0	8.4	1.1	3.0
11	29.5	10.4	93	22	0.0	8.6	4.6	3.7
12	28.5	10.8	95	41	0.0	8.3	5.6	3.0
13	28.0	11.4	88	44	0.0	7.4	2.4	2.4
14	29.0	16.1	92	59	0.0	7.2	1.2	2.0
15	28.0	15.1	89	42	0.0	1.3	1.9	1.7
16	31	15.4	94	39	0.0	7.1	1.6	2.1
17	30.5	13.0	91	42	0.0	6.3	2.4	2.0
18	28.0	11.4	91	43	0.0	8.6	7.0	2.3
19	25.0	11.2	97	43	0.0	5.6	3.4	2.1
20	26.5	11.4	93	43	0.0	7.2	2.4	2.5
21	27.6	11.5	93	44	0.0	7.1	1.3	2.4
22	27.0	10.7	95	43	0.0	6.1	1.4	2.2
23	27.5	13.1	95	65	0.0	5.3	1.8	2.1
24	23.0	11.0	95	63	0.0	0.0	1.1	1.7
25	24.0	11.9	90	30	0.0	1.8	1.3	1.5
26	28.0	13.4	93	31	0.0	8.6	3.0	2.5
27	28.5	14.0	80	48	0.0	6.5	2.4	2.2
28	27.0	14.4	92	72	0.0	5.6	3.6	2.1
29	24.0	10.9	90	50	**29.2**	0.0	6.3	5.6
30	25.5	10.4	95	53	0.0	8.5	1.5	1.9
Total	**838.7**	**402.6**	**2705.0**	**1430.0**	**29.2**	**154.3**	**82.5**	**69.3**
Averg.	**28.0**	**13.4**	**90.2**	**47.7**	**–**	**5.1**	**2.8**	**2.3**
Prog.	**–**	**–**	**–**	**–**	**1216.8**	**–**	**–**	**–**

APPENDIX-V

Genotypes	Days to flowering		Days to maturity	
	Control	Heat Treatment	Control	Heat Treatment
Vandana	89	92	120	119
IET 28417	88	84	115	108
N-22	90	90	121	116
IET 28409	88	91	119	119
IET 27908	85	94	114	118



APPENDIX-VI-Important weather parameters recorded at Pantnagar during the crop growth period in Kharif-2019 season

VITA

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Thesis Title : **“MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL ASSESSMENT OF HEAT TOLERANCE IN VARIOUS RICE (*Oryza sativa* L.) GENOTYPES”.**

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ABSTRACT

Rice is a staple food crop in global food system fulfilling the energy requirement of major part of world population. It is very sensitive to environmental factors such as temperature, light, drought etc. during critical stages of growth, such as flowering and seed development. High temperature can irreversibly damage the rice grain quality, yield and plant processes. A research investigation was carried out to evaluate the effect of high temperature stress on morpho-physiological and biochemical parameters; and to study the yield attributes of different rice genotypes under heat stressin B1 block of N. E. Borlaug crop research center, Pantnagar during kharif season 2019. Heat treatment was given to different rice genotypes during flowering by making a polythene tunnel in one block which traps heat and other block kept open as control. Both the ends were open for sufficient ventilation. Among 30 genotypes only five genotypes, viz., Vandana, IET 28417, N-22, IET 28409 and IET 27908 were selected for the further research work on the basis of their sensitivity to high temperature and on yield attributes.

Parameters such as plant height, effective tiller number, total dry matter, leaf area index, chlorophyll content, chlorophyll fluorescence, stem weight, panicle weight, number of filled grains per panicle, number of spikelet, spikelet fertility, test weight, grain yield, harvest index, total carbohydrate and protein content of harvested seeds etc. were recorded. It was found that chlorophyll fluorescence, leaf weight, stem weight, panicle weight and TDM reduced after flowering. At maturity, there was a decrease in shoot weight, TDM, panicle weight, spikelet fertility, grain yield, harvest index andproteindue to high temperature. Physiological and biochemical analysis revealed that the carotenoid content and LAI were increased in all; whereas, carbohydrate, chlorophyll a, chlorophyll b content, test weight, spikelet number, grain number, panicle number, effective tillers and plant height were increased/decreased in some genotypes. The parameters which were positively correlated with grain yield were leaf weight, stem weight, panicle number, panicle weight, shoot weight, and TDM whereas test weight was negatively correlated. Genetic diversity was responsible for the stress effects and stress mitigation in the crop as different genotypes from diverse backgrounds showed varied results; since, out of five genotypes, IET28417 was found to be tolerant while IET 27908 and Vandana were sensitive to high temperature in the present investigation.

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सारांश

विश्व की आबादी के प्रमुख हिस्से की ऊर्जा आवश्यकता को पूरा करने वाली वैश्विक खाद्य प्रणाली में चावल एक मुख्य खाद्य पदार्थ है। यह विकास के महत्वपूर्ण चरणों, जैसे कि फूल और बीज विकास के दौरान पर्यावरणीय कारकों जैसे तापमान, प्रकाश, सूखा आदि के प्रति बहुत संवेदनशील है। उच्च तापमान अपरिवर्तनीय रूप से चावल की गुणवत्ता, उपज और पौधों की प्रक्रियाओं को नुकसान पहुंचा सकता है। खरीफ मौसम २०१६ के दौरान नॉर्मन् ई। बोरलॉग फसल अनुसंधान केंद्र, पंतनगर के बी–१ ब्लॉक् में विभिन्न चावल के जीनोटिपिक् रूपों के रूपात्मक–शारीरिक और जैव–रासायनिक मापदंडों पर तथा उपज–गुणों पर उच्च–तापक्रम प्रतिरोधक क्षमता के प्रभाव का निर्धारण करने हेतु एक शोध जांच की गई । एक ब्लॉक् में एक पॉलिथीन सुरंग बनाकर अलग–अलग चावल के जीनोटिपिक् रूपों के लिए हीट ट्रीटमेंट दिया गया था, जिसमें हीट ट्रॅप होती थी और दूसरा ब्लॉक् नियंत्रण के रूप में खुला रखा गया था। प्रवेश द्वार पर्याप्त वायू–संचालन के लिए खुले थे। ३० जीनोटिपिक् रूपों में केवल ५ जीनोटिपिक् रूप : – वंदना, आईईटी २८४१७, एन–२२, आईईटी २८४०६ और आईईटी २७६०८ को धान उपज और फसल सूचकांक के आधार पर आगे के शोध कार्य के लिए चुना गया।

पौधे की ऊँचाई, प्रभावी टिलर संख्या, टोटल ड्राई मैटर, पत्ती–क्षेत्र सूचकांक, हरितलवक सामग्री, हरितलवक प्रतिदीप्ति, तने का वजन, संयुक्त मंजरी वजन, प्रति संयुक्त मंजरी में भरे हुए दानों की संख्या, स्पाइकलेट संख्या, स्पाइकलेट जननक्षमता, हजार दानों का वजन, दानों की उपज, फसल सूचकांक, उत्पादित बीजों में कार्बोहाइड्रेट, प्रोटीन आदि को दर्ज किया गया। यह पाया गया कि, हरितलवक प्रतिदीप्ति, पत्ती का वजन, तने का वजन, संयुक्त मंजरी वजन और टीडीएम फूलधारण के उपरांत घट गया। परिपक्वता के समय, टहनी का वजन, टीडीएम, संयुक्त मंजरी वजन, प्रति संयुक्त मंजरी में भरे हुए दानों की संख्या, स्पाइकलेट जननक्षमता, दानों की पैदावार, फसल सूचकांक और प्रोटीन की मात्रा में कमी देखी गई। शारीरिक और जैव रासायनिक विश्लेषण से पता चला है कि सभी जीनोटिपिक् रूपों में कैरोटीनॉइड सामग्री और पत्ती–क्षेत्र सूचकांक में वृद्धि हुई थी; तथा, कुछ जीनोटिपिक् रूपों में कार्बोहाइड्रेट, हरितलवक–अ, हरितलवक–ब, हजार दानों का वजन, स्पाइकलेट संख्या, दानों की संख्या, संयुक्त मंजरी संख्या, प्रभावी टिलर और पौधे की ऊँचाई में वृद्धि अथवा कमी हुई थी। अनाज की पैदावार से सकारात्मक रूप से सहसंबद्ध मापदंडों में पत्ती का वजन, तने का वजन, संयुक्त मंजरी वजन, संयुक्त मंजरी संख्या, टहनी का वजन और टीडीएम थे; तथा, हजार दानों का वजन नकारात्मक रूप से सहसंबद्ध था। फसल में तनाव के प्रभावों और तनाव के शमन के लिए जीनोटिपिक् विविधता जिम्मेदार है क्योंकि विभिन्न पृष्ठभूमि के विभिन्न जीनोटिपिक् रूपों में विभिन्न परिणाम दिखाई दिए; ५ जीनोटिपिक् रूपों में से उच्च तापमान के प्रति आईईटी २८४१७ सहिष्णु तथा आईईटी २७६०८ और वंदना अतिसंवेदनशील थे।

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