RESEARCH ARTICLE

Impact of High Temperature Stress on Morpho-Physiological Traits and Yield of Rice (*Oryza sativa* L.) Genotypes

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Received : 23rd, April 2021
Revised : 30th, April 2021
Revised : 19th, May 2021
Accepted : 29th, May 2021

ABSTRACT

High temperature stress is a major environmental factor that affects crop growth, development and yield, it especially limits rice yield. Hence, an experiment was conducted to study the impact of high temperature on morpho-physiological parameters and yield of rice genotypes. Ten rice genotypes were used in this study *viz.,* N22, ADT 36, ADT 37, ADT 43, ADT 45, CO 51, ASD 16, MDU 6, TPS 5 and Anna (R) 4. The study was carried out at OTC (Open Top Chamber) with the treatments of ambient, ambient +2 °C and ambient +4 °C. Stress was imposed from anthesis to early grain filling period. Observations on plant height, the number of tillers, leaf area, SPAD (Chlorophyll index) and chlorophyll stability index (CSI) were done after the stress imposement and grain yield was calculated after harvest. Results revealed that, the significant changes were observed in morpho-physiological traits and grain yield of rice genotypes among the treatments and with the genotypes. N22 (10% and 19%) and Anna (R) 4 (12% and 22%) recorded less reduction of grain yield in ambient +2 °C and ambient +4 °C compared with ambient, due to less reduction of total chlorophyll content, SPAD values, leaf area and increased plant height. These parameters resulted in higher biomass which indirectly contributed to higher grain yield in N22 and Anna (R) 4 under high temperature.

Keywords: *Rice; High temperature; Leaf area; Chlorophyll index; Total chlorophyll content*

INTRODUCTION

Climate change is a current trend that has an adverse impact on agriculture. Among the abiotic stresses, high temperature is major stress which cruelly affects plant growth and productivity. The global temperature is predicted to rise by 2.5 to 4.3 °C by the end of the century 2100 (IPCC, 2007). The maximum and minimum daily temperatures, the number of hot days and warm nights in a year are estimated to increase (IPCC, 2013). Rice (*Oryza sativa* L.) is the most widely consumed staple food for half of the world's population. Worldwide, rice is grown in 114 countries on 116 million hectares (M ha) to produce more than 650 million tons (FAO, 2008). India being the top rice producer of 43.20 million hectares, faces shifting of growing seasons due to global warming, leads to fall in the production by 40% (Cago, 2017). Generally rice is adversely affected by high temperatures in the tropics and lower temperatures in the temperate regions (Dubey *et al.,* 2018).

All plant species have an optimum temperature range for efficient physiological functions such as growth, development and reproduction. Temperature above or below optimum has a negative impact on plant performance leading to loss in economic yield. High temperature affects morphological, physiological, and biochemical characters which serve as a base for yield reduction (Wang *et al.,* 2003). With the rising temperature, plant height, and the number of tillers increased in rice (Oh-e *et al.,* 2007). Leonard *et al.* (2021) revealed that the number of tillers were decreased under high-temperature stress. Leaf area is an important parameter; higher leaf area contributes to higher chlorophyll content and photosynthesis, also increase grain yield. High temperature reduced leaf area due to an early senescence (Anil Sebastian and Selvaraju, 2017).

Chlorophyll is the most critical photosynthetic pigment that plays a vital role in regulating crop yield. However, chlorophyll is quite delicate, not very stable and easily affected by abiotic stresses. These alterations in the amount of chlorophylls depend on edaphic and climatic factors (Gond *et al*., 2012). The reduction in chlorophyll content may occur

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due to the stress-induced impairment in pigment biosynthetic pathways or in pigment degradation, loss of the chloroplast membrane under stress conditions (Reddy *et al.,* 2004 and Sareetha, 2017). High temperature above the optimum has a drastic effect on chlorophyll content (Sunita *et al.,* 2017). SPAD (Soil Plant Analysis Development) values generally decreased under environmental stresses, and the temperature had the most potent effect on SPAD values. According to Celaleddin Barutcular *et al.* (2016) SPAD values were more strongly affected by location and heat stress than by drought stress. Lower SPAD values that contribute to reduced dry matter accumulation and yield (Kurniawan *et al.,* 2019 and Vinitha *et al*., 2020).

High-temperature exposure from seedling to panicle initiation stage resulted in mortality of tillers and fewer spikelets (Zacharias *et al.,* 2010). Rice is highly sensitive to high temperature particularly at the flowering and grain filling stage. Even 1 °C increase in daytime maximum/nighttime minimum severely affects rice yield by 10% (Dubey *et al*., 2018). Yield losses under high temperature were attributed to spikelet sterility and reduction of grain weight (Prasad *et al.,* 2006; Shi *et al.,* 2013). Heat stress can disturb carbohydrate metabolism, affecting plant growth and development, pollen viability, and ovule fertilization leading to spikelet sterility and loss of grain yield in rice (Islam *et al.,* 2018). High-temperatures at flowering and grain-filling phases reduce the yield by causing spikelet sterility and shortening the duration of grain-filling phase (Tian *et al.,* 2007 and Xie *et al.,* 2009). Dubey *et al.* (2018) confirmed that the high temperature during the ripening stage affected 1000 grain weight in rice. Therefore, it is essential to study the impact of high temperature stress on morpho-physiology and yield of rice genotypes to recommend farmers to grow tolerant genotypes to get a higher yield under high-temperature hotspot regions. With this background this experiment was conducted to study morpho-physiological characters and yield of rice genotypes under high-temperature stress.

MATERIALS AND METHODS

Ten short-duration rice genotypes namely N22, ADT 36, ADT 37, ADT 43, ADT 45, CO 51, ASD 16, MDU 6, TPS 5 and Anna (R) 4 were chosen for this study. Seeds were collected from various rice research stations of Tamil Nadu. This experiment was conducted from January to April 2019, using Open Top Chambers present in the Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore. OTC is made of polycarbonate sheet of 4m×4m×4m. Among the three chambers, one for control (ambient temperature) and others for exposing high temperature (+2 °C and +4 °C from ambient). By using infrared source, humidifiers and wireless signal transmission with SCADA integration facility, temperature and relative humidity (RH) were maintained inside the chambers. Two plants per pot were maintained with three replications. Stress was imposed from the anthesis stage to an early grain filling stage from morning 9 am to evening 5 pm. The maximum air temperature for ambient, ambient +2 °C and ambient +4 °C ranged from 36.79 °C – 40.88 °C, with high relative humidity (RH - 85.6%) was recorded at the ambient chamber (75.2%) (Figure 1). Observations were recorded after the stress imposition (90 DAS) and stress-imposed plants were compared with plants which grown under ambient condition.

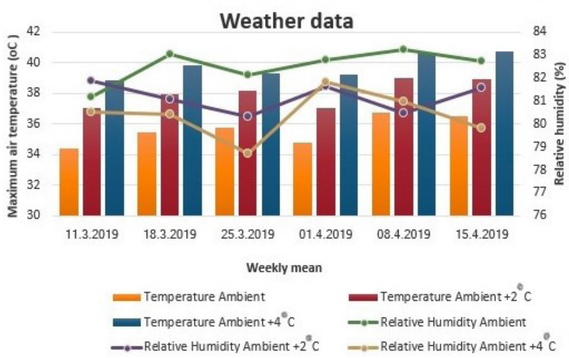

Figure 1. Weather data of maximum air temperature (°C) and relative humidity (%)

Plant height was measured from the base of the shoot to the tip of the growing point and the mean plant height was calculated and expressed in cm. Leaf area per plant was measured using a Leaf Area Meter (LICOR, Model LI 3000) and expressed as cm^2 $plant^{-1}$. Total chlorophyll content was estimated by the method suggested by Yoshida *et al.* (1971) and expressed as mg g^{-1} fresh weight. SPAD readings were recorded using chlorophyll meter (SPAD 502) designed by the Soil Plant Analytical Development (SPAD) section, Minolta, Japan, using the method described by Minolta (1989) and Monje and Bughree, (1992). Grain yield was calculated after harvest by five plants average and expressed in g $plant^{-1}$. For statistical analysis, the data collected from this experiment were statistically analyzed in a CRD (Completely Randomized Design) through SPSS software (Statistical Package for the Social Sciences) base software version11.5 (2001). The critical difference (CD) was computed at 0.05 probability level.

RESULTS AND DISCUSSION

Plant height (cm plant^{-1})

Plant height was increased under high-temperature conditions. Among the genotypes, N22 (113.7, 115.3 and 116.1 cm) recorded more plant height followed by Anna (R) 4 (110.3, 111.2 and 113.2 cm) in ambient, ambient +2 °C and ambient +4 °C, respectively (Table 1.) Plant height is an important trait for growth since increased plant height would allow greater biomass production and yield potential in crops (Zhang *et al.,* 2004). Sandeep *et al.* (2020), reported that the high temperature causes an increment in plant height, and it acts as an important factor for genetic differentiation in rice genotypes. Vinitha *et al.* (2020) suggested that the heat stress generally causes an increment in plant height; this might be an adaptive nature of the rice plants to escape heat. They try to quicken their phenophases, hence irrespective of heat tolerant ability plant height generally increases. Therefore, the plant height can be considered one of the important traits for determining tolerance under stress conditions. Leonard Bonilha Piveta *et al.* (2021) suggested that, the heat stress also negatively affects plant height, however, genotype WR-RN increased its height in heat stress conditions. The above results were supported to this present study.

Table 1. Effect of high-temperature stress on plant height (cm) and leaf area of rice genotypes

Genotypes	Ambient	Ambient +2 °C	Ambient +4 °C
N22	113.7	115.3	116.1
ADT 36	95.1	96.8	97.7
ADT 36	95.7	97.3	97.8
ADT 36	98.1	99.9	99.5
ADT 36	93.2	92.6	95.2
CO 51	96.6	97.6	98.8
ASD 16	107.2	109.3	108.6
MDU 6	101.1	102.5	103.9
TPS 5	93.8	94.2	95.3
Anna (R) 4	110.3	111.2	113.2
Mean	100.48	101.67	102.61
	G	T	G*T
SEd	2.194	1.202	3.800
CD (0.05)	4.366	NS	7.562

Number of tillers

Active tiller number is very much crucial for grain yield of rice, generally, stress affects tiller number of rice. No significant variation was observed among the genotypes. Plants maintained same number of tillers in ambient, ambient +2 °C and ambient + 4 °C treatments, because stress was imposed after the completion of active tillering phase. So, there is no such variation in the tiller numbers, under stress treatments. CO 51 (14, 13 and 14) recorded more tiller numbers followed by Anna (R) 4 (13, 14 and 13) in ambient, ambient +2 °C and ambient +4 °C respectively (Table 2). Leonard *et al.* (2021) reported that, almost all genotypes had reduced tiller numbers under heat stress. The panicle number is a yield component dependent on the tiller number. Hence, the number of tillers is an essential trait to study under stress conditions, which indirectly contribute to grain yield of rice genotypes.

Table 2. Effect of high-temperature stress on the number of tillers in rice genotypes

Genotypes	Ambient	Ambient +2 °C	Ambient +4 °C
N22	11	12	12
ADT 36	11	12	12
ADT 37	12	12	13
ADT 43	11	12	13
ADT 45	13	12	13
CO 51	14	13	14
ASD 16	13	13	12
MDU 6	11	12	11
TPS 5	12	12	11
Anna (R) 4	13	14	13
Mean	12.1	12.9	12.4
	G	T	G*T
SEd	0.236	0.129	0.408
CD (0.05)	0.469	0.258	0.813

Leaf area (cm^2 $plant^{-1}$)

The time trend of leaf area revealed a gradual increase from vegetative to grain filling stage. Decreased leaf area was observed under high-temperature conditions in rice varieties. Irrespective of the genotypes there was a decrease in the leaf area during ambient +2 °C and ambient +4 °C compared to control. Higher leaf area reduction was observed in ADT 36, ADT 37 and CO 51 in ambient +2 °C (19%, 15% and 15%) and CO 51, ADT 36 and ADT 37 (35%, 33% and 25%) in ambient +4 °C (Figure 2). According to Anil Sebastian and Selvaraju, 2017, high-temperature stress reduced leaf area due to an early senescence. This might be the reason for decreasing leaf area under heat stress. Leaf area is a fundamental determinant of the total photosynthesis of a plant. Leaf area always shows a positive relationship with net photosynthetic activity, because leaf enlargement is attributed to an increase in number and width of grana and also high degree of stacking of grana (Fortun *et al.,* 1985). Gupta and Guhey (2011) reported a significant reduction in leaf area in susceptible genotypes than tolerant genotypes under high-temperature stress, similar result was observed in this study. Thus, an optimum leaf area of 0.33 cm^2 to 0.89 cm^2

is required to maintain photosynthesis and grain yield under heat stress (Sabine Stuerz and Folkard Asch, 2019).

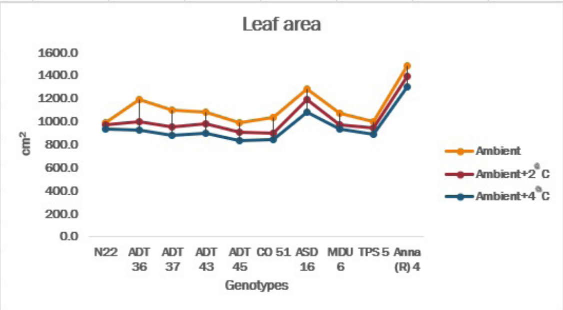

Figure 2. Effect of high-temperature stress on Leaf area (cm^2) of rice genotypes

Total chlorophyll content

Chlorophyll synthesis is sensitive to heat stress and is a good indicator of heat stress injury. Heat stress has significant negative effect on the leaf chlorophyll content at ambient +2 °C and ambient +4 °C in all the genotypes. Anna (R) 4, N22 and ADT 45 recorded less reduction of chlorophyll content (8%, 12% and 13%) under ambient +2 °C. Anna (R) 4, N22 and ASD 16 (23%, 24% and 28%) recorded a less reduction of chlorophyll content under ambient +4 °C. ADT 36 recorded 30% and 62% reduction under ambient +2 °C and ambient +4 °C (Figure 3). Reduction in total chlorophyll content is related to photosynthesis reduction due to reduced antenna size and thus less light-harvesting during heat stress (Shanmugam *et al.,* 2013). Gosavi *et al.* (2014) reported that under heat stress susceptible genotypes showed higher reduction in chlorophyll content than the tolerant genotypes. High-temperature stress causes photosynthesis reduction through disruptions in the structure and function of chloroplasts and reductions in chlorophyll content in wheat leaves (Brestic *et al.,* 2016; Sunita *et al.,* 2018). Reduction in chlorophyll content during grain filling under heat stress in field conditions was reported to be associated with reduced yield (Ram *et al.,* 2017 and Sunita *et al.,* 2018), which is also reported during this study.

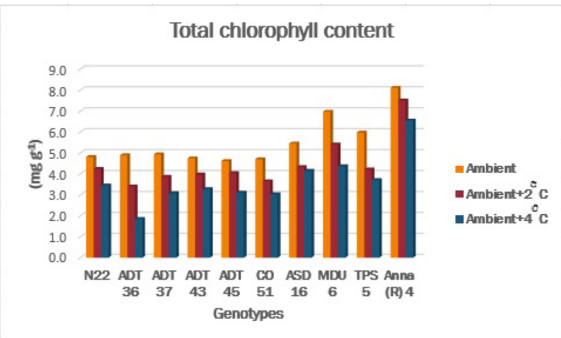

Figure 3. Effect of high-temperature stress on total chlorophyll content of rice genotypes

SPAD (Chlorophyll Index)

SPAD chlorophyll value is expressed as chlorophyll index. In all the stress treatments, all the genotypes recorded less chlorophyll index than ambient. Compared to all the treatments ambient +4 °C had a higher SPAD chlorophyll reduction percentage in all the genotypes. Among the genotypes, ADT 36, ADT 37 and CO 51 (21%, 18.8% and 18%) had the higher reduction percentage in ambient +4 °C. Figure 4, shows N22, ASD 16 and Anna (R) 4 (6.8%, 6.1%, and 6.4%) had the lesser reduction percentage in ambient+4 °C. SPAD measurements are widely used to assess the absolute chlorophyll content per leaf area in research settings and agricultural systems. Lower reduction in chlorophyll content under heat is a good indicator of tolerance, which has been proved in rice varieties. The decline in chlorophyll content is associated with chloroplast damage caused by reactive oxygen species (ROS) which produced under various environmental stresses (Ashraf and Harris, 2013). Nirmal Kumar *et al.* (2018) reported that decreased chlorophyll content was observed in rice under high-temperature conditions. According to Tafesse *et al.* (2020), chlorophyll index was reduced upto 14.67% at high temperature over control. These results were confirmed with this present study.

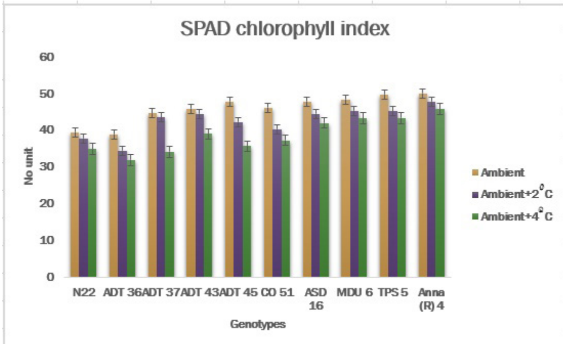

Figure 4. Effect of high-temperature stress on SPAD chlorophyll index of rice genotypes

Grain weight

Irrespective of the genotypes, the higher reduction in grain yield was observed under ambient +2 °C and ambient +4 °C, which showed a significant difference among the genotypes. Higher grain yield reduction was observed in ADT 43 followed by CO 51 and ADT 37 (53%, 46% and 44%) in ambient +2° C over control. CO 51 followed by ADT 37 and ADT 43 (78%, 71% and 69%) recorded a higher yield reduction under ambient +4 °C over control. Among the genotypes, N22 and Anna (R) 4 recorded less yield reduction (10% and 12%) in ambient +2 °C and (19% and 22%) in ambient +4 °C, respectively (Figure 5). The study conducted by (Ye *et al.* 2012) proved that N22 as a heat-tolerant cultivar. (Vivitha *et al.,* 2017), reported a less percent reduction of yield in N22 upto 6.94% under heat stress conditions. During ripening, the panicle is a highly sensitive organ to high-temperature stress (Morita *et al.,* 2004). According to Gaballah and Abu, (2019) high-temperature stress reduced panicle length and panicle weight of rice genotypes. These results were found similar to this present study.

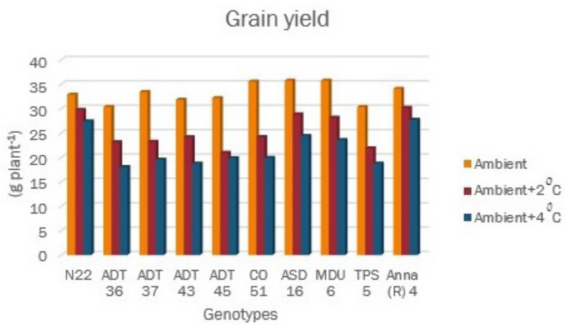

Figure 5. Effect of high-temperature stress on Grain yield (g plant^{-1}) of rice genotypes

CONCLUSION

The present study concluded that plant height, the number of tillers, leaf area, total chlorophyll content and SPAD values were essential for grain yield of rice genotypes under high-temperature conditions. N22 and Anna (R) 4 recorded high yield under high-temperature conditions. CO 51, ADT 37 and ADT 43 recorded the lesser yield under ambient +2 °C and ambient +4 °C than other genotypes. N22 and Anna (R) 4 showed less reduction in leaf area and SPAD chlorophyll values and increased plant height. Anna (4) and N22 showed less reduction of total chlorophyll content under stress conditions. CO 51 has highest tiller number, higher Leaf area and SPAD chlorophyll index than all genotypes under ambient condition, but higher reduction percent was observed in leaf area, SPAD chlorophyll index under ambient +2 °C and ambient +4 °C. Therefore, plant height, leaf area, total chlorophyll content and SPAD chlorophyll index are the important parameters which were combat with the high-temperature stress to attain higher grain yield in this study.

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