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Research Article

Morphological, Physiological and Yield Responses of Some Rice Varieties (*Oryza sativa* L.) as Exposed Under High Temperature in Indonesia

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Abstract

Background and Objective: Temperature increase caused by global warming can affect plants growth and production, including the rice plant. The purpose of this study was to determine the morphological, physiological and yield responses of some rice varieties exposed under high temperature. **Material and Methods:** The study was conducted in Cikarawang, Bogor from June, 2014 to February, 2015 and used Randomized Block Design (RBD) with 2 factors, difference temperature (T1: 28.3, 22.1 and 38.2°C, T2: 32.1, 22.8 and 47.9°C and T3: 33.1, 23.4 and 50.1°C) as average, minimum and maximum daily temperature, respectively and eight rice varieties. Rice plants were exposed under difference temperature treatment since 56 days after seeding until harvest time. **Results:** Results showed that high temperature inhibited exsertion of panicle all varieties. Leaf temperature increased 3-6°C at average temperature exposure 32.1 and 33.1°C. Silungonggo showed highest leaf temperature (34.7°C), whereas IR 64 showed the lowest (33.4°C). There was decreasing yield from 68.1-92.0% at average temperature of 32.1°C. **Conclusion:** Varieties which had better yield had well exsertion of panicle, low leaf temperature and high percentage of filled grain. The IR 64 had the lowest leaf temperature, Menthik Wangi and Jatiluhur had well exsertion of panicle but still have low percentage of filled grain.

Key words: High temperature stress, photosynthesis, rice growth, spikelet sterility, stomata

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Abiotic stresses, such as drought, salinity, extreme temperatures, chemical toxicity and oxidative stress are serious threats to agriculture. The plant had some adaptation mechanisms tolerant to maintain a growth and yield in stress condition[1]. *Sorghum* had tolerance mechanisms of adaptation to drought stress conditions, it had more accumulation of biochemical metabolites and higher grain yield[2].

Rice is one of the most important cereals grown in most parts of the world. In the tropical areas, rice grows optimally in temperature ranged between 25-32°C, with a threshold at 35°C[3]. The increase of global temperature, as a result of climate change has negatively affected plants growth. The average global temperature is predicted to reach 2-4°C in the 21st century[4]. Increasing the temperature causes evaporation of water on the earth's surface increases. This will change various climate elements such as humidity, water condensation and precipitation. Climate change can have an impact on changes in cropping patterns which means reducing food safety and an area gets drought stress. Rice plant requires a lot of water in the process of cultivation. Physiological processes such as photosynthesis was strongly influenced by the availability of water, the drought conditions inhibited vegetative growth[5].

A high temperature stress on rice showed different plant responses. Flowering and grain filling were stage sensitive to heat stress[6,7]. Prasad *et al.*[8] reported that high temperatures decreased pollen production. Fertility grain is an important component in the production of rice[9]. Temperature above 34°C during the flowering stage will affect flower sterility, decreased grain filling and reduced grain yield. However, high temperature did not significantly affected the number of spikelet per panicle and the weight of 1000 rice grains[7-10]. Increased temperatures could also cause rice grains chalkiness[11].

Increased temperatures caused damage to cells and cell organelles plants. Direct damage that occurs in plants was protein denaturation and aggregation. Damage indirectly was an inactivation in chloroplasts and mitochondria, inhibition of protein synthesis, protein degradation and loss of membrane integrity[12]. High temperatures inhibited the growth of the plant and decreased of yield up to 41%[13,14].

Rice productivity under heat stress correlates with the plant adaptation ability[15]. Cao *et al.*[16] reported that there were mechanisms of stress tolerance of plants to high temperatures, the plant has an antioxidant enzyme that issued the plant to avoid the stress of high temperatures. Antioxidant enzymes incurred by the plant was malondialdehyde, peroxidase, superoxide dismutase and catalase increased to inhibit the activity of Reactive Oxygen Species (ROS). Some rice varieties have tolerant strategies, which occurs by alter the metabolism of plant tissues. The panicle will be avoid heat injury by reducing its temperature. Matsui *et al.*[17] reported that panicles temperature could reach 6°C lower than the environment when the atmospheric temperature was higher. Furthermore, the plant had a mechanism of flowering formation and early anthesis before the maximum temperature occurs[6].

The use of rice varieties that are tolerant to high temperature stress is developed to adapt climate change in the future. Therefore, it is necessary to do research the response of some varieties under high temperature. Morphological and physiological differences in the characteristics of each variety, requires a deep understanding of the impact of high temperature on rice production. Research in Indonesia on plant responses to the increasing of air temperature due to global climate change has not been widely studied. Results from this study is expected to provide information on the response of some rice varieties to high temperatures and to be useful in the development of new varieties that have a high temperature tolerance.

MATERIALS AND METHODS

Experiment sites: This research was conducted in Cikarawang Field experiments, Bogor from June-December, 2014. Postharvest was conducted in the PostHarvest Laboratory, Bogor Agricultural University from December, 2014-February, 2015.

Experimental design and plot management: This experiment used Randomized Block Design (RBD) nested with 2 factors, difference temperature and rice varieties. Experimental unit used 3 replications that nested on the main factors. The temperature difference consists of 3 levels temperature treatment as the main plot, namely: (T1) The average daily air temperature in polyethylene house 28.3°C, (T2) The average daily air temperature in polyethylene house 32.1°C and (T3) The average daily air temperature in polyethylene house 33.1°C. Rice varieties used 8 namely Ciherang, Menthik Wangi, IR 64, IPB 3S, Silugonggo, Jatiluhur, Way Apo Buru and HIPA 14.

The seeding of each variety was grown in the seedling tray for 14 days. Rice was transplanted into polybag (35×40 cm) with 7 L of planting media per polybag. Each experimental unit consists of 6 plants placed in a planting container with size 2.0×1.8×0.3 m. Rice was planted with lowland system that kept the water level up to 2 cm above the soil surface. Maintenance included 3 times of fertilization application. The first fertilizer of 37.5 kg N ha^{-1}, 36 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}, applied 2 Weeks After Trasplanting (WAT). The second and third application were 37.5 kg N ha^{-1} at 5 WAT and 9 WAT. Pest and disease prevention were applied as the field conditions.

High temperature treatment: The research was conducted in plastic polyethylene house consists of 3 compartments with different temperature. The research design was to expose rice plant under high temperature that adjusted naturally by sun shine in the polyethylene house. High temperature treatment followed the ambient temperature inside a plastic house. In the first plastic house (T1), the roof was plastic polyethylene and the walls was shading net. The second (T2), 3/4 part of plastic house was polyethylene, while in the third (T3), the plastic house used at whole part polyethylene plastic and the surface soil was given black silver mulch with a silver color in upper part.

The air and soil temperature recorded using a thermo recorder (TR-71U, T and D, Japan) periodically with interval of 30 min to get more detail information on temperature changing during rice growth season. The average daily temperature was obtained from the average air temperature and soil temperature during the treatment period. The maximum temperature was obtained from the average daily highest temperature and minimum temperature was obtained from the average daily lowest temperature during the treatment period.

High temperature treatment was conducted at 56 days after seeding until harvest time. Growth stage of each variety could be seen on Table 1. When the high temperature treatment given, Menthik Wangi and Silungonggo were still at vegetative stage, while Way Apu Buru was at the end of vegetative stage, Ciherang, IPB 3S, HIPA 14 and Jatiluhur were at the iniatial of reproductive stage and IR 64 had entered the reproductive stage. Prasad *et al.*[8] observed that critical period of rice growth to high temperatures was at flowering stage but at this study high temperature treatment was given before the critical period of the plant.

Daily maximum air temperature during the research period reached over 35°C (Fig. 1a). At T2 and T3 treatment, the plant was on high temperature stress from 08:00 to 16:00, while at T1 the plant was on high temperature stress from 09:30 to 14:30. The maximum and average air temperature for T1 (38.2/28.3°C), T2 (47.9/32.1°C) and T3 (50.1/33.1°C) (Fig. 1a), with maximum air temperature increase of up to 9.9°C (T1-T2) and 11.9°C (T1-T3) (Table 2). The maximum and average soil temperature for T1 (29.3/27.3°C), T2 (30.9/29.2°C) and T3 (31.4/29.2°C) (Fig. 1b). The research condition was set with keeping water available during rice growing. It was keep the plant form drought stress.

Morphological character: Plant height (cm) measured from the soil surface to the top of longest leaves/panicle. Number of tillers measured every 2 weeks from 7-9 WAT and harvest. Shoot dry weight (g) measured by stem and leaves dry weight of plants at harvest. Panicle exertion was measured at harvest time by giving a score in accordance with the guidelines IRRI[18].

Phisiological character: Flowering (days) was observed after 50% heading and harvest time (days) was observed after 90% yellow rice. Greenness leaf was measured at 63 DAS by using a soil-plant analysis development (SPAD-502 plus; Konica Minolta, Japan) on the flag leaf main stem. Stomatal density (stomata/mm^{-2}) were observed at 63 DAS by nail polish

Table 1: Growth stage of rice plant when treated by high temperature at 56 days after sedding

Varieties	Stage
Menthik Wangi	Tillering
Silungonggo	Tillering
Way Apu Buru	Maximum tillering
Ciherang	Booting
IPB 3S	Booting
HIPA 14	Booting
Jatiluhur	Booting
IR 64	Panicle initiation

Table 2: Average daily maximum and minimum temperature

	Temperature (°C)					
	Soil			Air		
Levels	T1	T2	T3	T1	T2	T3
Maximum	29.3±0.8	30.9±0.5	31.4±0.7	38.2±0.4	47.9±0.7	50.1±2.1
Minimum	25.4±0.5	27.4±0.1	27.8±0.3	22.1±0.6	22.8±0.5	23.4±0.4
Average	27.3±0.7	29.2±0.4	29.2±0.5	28.3±0.4	32.1±0.1	33.1±0.9

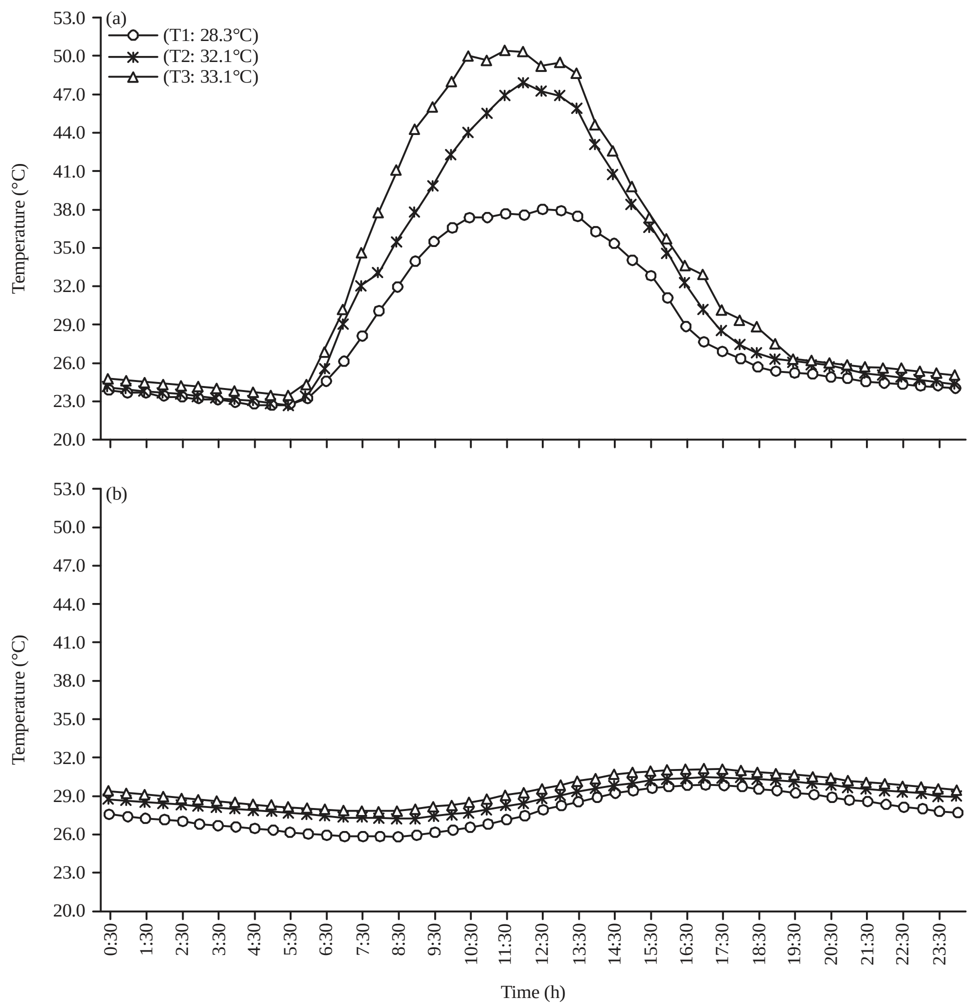

Fig. 1(a-b): (a) Daily average air temperature and (b) Daily average soil temperature

method on the flag leaf and were observed by magnificying 100 times under microscope Olympus CX23. Time observation was conducted at 10:00 am.

Leaf temperature (°C), transpiration (mol H_2O m^{-2} sec^{-1}) and photosynthetic rate (µmol CO_2 m^2 sec^{-1}) measured at 77 DAS (21 day after high temperature treatment), the photosynthetic rate of flag leaf was determined using Li-6400XT Portable Photosynthesis system (LI-COR Biosciences, Lincoln, NE, USA) from 10:00 to 11:30 am when the Photosynthetic Active Radiation (PAR) above the canopy was 980-1100 µmol m^{-2} sec^{-1} and CO_2 set at 380-410 ppm. Three leaves were measured for each treatment.

Yield component: Panicle length (cm) was measured from the base to the top of panicle. Number of panicles and the number of grains per panicle were observed by counting the number of panicles per hill. Each panicle was counted for the number of grains. Weight of 1000 grains (g) were observed from fill grain weight. Percentage of filled grain (%) was observed by using the formula:

$$\text{Percentage of filled grain} = \frac{\text{No. of filled grain}}{\text{No. of total grain}} \times 100\%$$

Statistical analysis: Data analysis was conducted using ANOVA at 5%. If the variance was significantly different then tested further by Least Significant Difference (LSD) at 5%. Data processing used SAS software 9.1.3.

RESULTS

Morphological responses: Results showed that high temperature increased of tiller number and shoot dry weight differ among rive varieties, reduced productive panicles number and to inhibited panicle exsertion among rice varieties. Data showing the effect of high temperature on

Table 3: Morphological character on varieties of high temperature

	Plant height (cm)			Tiller numbers			Productive panicles			Shoot dry weight (g per plant)			Panicle exertion		
Varieties	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
Menthik Wangi	120.6	120.8	120.0	39.0	52.7	58.3	18.0	4.3	0.0	43.9	56.6	91.2	1	1	5
Silungonggo	97.4	95.4	96.5	22.0	50.0	56.3	11.7	2.3	0.0	22.4	39.5	49.5	3	5	7
Way Apo Buru	102.5	104.9	105.2	25.3	57.3	62.0	13.0	2.3	0.0	31.6	47.7	60.2	1	5	7
Ciherang	105.4	108.2	105.8	35.0	48.0	60.3	14.0	1.7	0.0	33.9	60.6	79.1	1	5	7
IPB 3S	103.2	104.1	102.8	27.7	49.0	55.3	8.3	1.7	0.0	31.0	43.3	54.9	3	5	5
HIPA 14	130.3	128.4	129.5	30.7	58.3	64.3	15.7	1.3	0.0	41.3	68.4	77.0	1	5	7
Jatiluhur	149.5	143.7	143.8	23.3	62.7	72.7	11.3	1.3	0.0	34.7	71.2	79.2	1	1	5
IR 64	138.3	140.2	138.7	24.7	58.0	70.3	19.0	4.3	0.0	22.7	44.9	49.5	1	3	5
Heat treatment (HT)		NS			**			**			*			**	
Variety (Var)		**			**			**			*			**	
HT×Var		NS			**			**			**			**	

*Significant level at LSD α = 0.05, **Significant level at LSD α = 0.01, NS: Non significant differences. Scoring of panicle exertion: 1: Well exerted, 3: Moderately well exerted, 5: Just exerted, 7: Partly exerted, 9: Enclosed. Daily average temperature of T1: 28.3°C, T2: 32.1°C and T3: 33.1°C

morphological responses was presented in Table 3. Compared to growth stage on varieties of this research, high temperature treatment did not affect the growth of plant height. Jatiluhur had highest plant height, while Silungunggo had the lowest plant height (Table 3). Interaction of high temperature treatment and varieties significantly affected the tillers number. Tiller numbers increased with increasing temperatures on all varieties. Compared to the treatment, tiller number at 33.1°C daily average temperature was higher than at 28.3°C (Table 3).

Nevertheless, the number of productive panicles decreased significantly to the high temperature treatment in all varieties. At 32.1°C daily average temperature, there was 1-5 productive panicles, while at 33.1°C all panicles produced unfilled grain (Table 3). Interaction of high temperature treatment and varieties affected significantly of shoot dry weight. Temperature treatment increased shoot dry weight in all varieties (Table 3). The increase in shoot dry weight due to the increased number of tillers at high temperature treatment.

Panicle exertion was the panicle ability to get out of the leaf sheath. In this study, exposure to high temperatures were also able to inhibit panicle exertion. Menthik Wangi and Jatiluhur had better panicle exertion characters compared to the other varieties exposed to average daily temperature 32.1°C (Table 3).

Physiological responses: Results of analysis of variance parameters of physiological responses showed in Table 4 and 5. High temperature naturaly delayed time to flowering and time to harvest time, increased SPAD value, leaf temperature among rice varieties. High temperature treatment and varieties interaction significantly affected the days flowering and harvest time. At 32.1°C daily average temperature, flowering occurred faster, approximately 1-4 days. Exception for the Menthik Wangi and Silungonggo, flowering process which took 2-4 days, slower if compared 28.3°C daily average temperature. The daily average temperature 33.1°C resulted in slower flowering process, 1-11 days of treatment compared to daily average temperature of 32.1°C (Table 4). High temperature treatment delayed harvest time to 5-8 days at average daily temperature of 32.1°C for all varieties. At 33.1°C average daily temperature, there did not produce grain filled panicles and plants were destructive at the age of 130 DAS in all varieties (Table 4).

High temperatures increased SPAD value. The increasing of SPAD value was caused by delayed of grain filling phase at 32.1 and 33.1°C average daily temperature exposure. The interaction of temperature and rice variety had significant effect on leaf temperature, transpiration and photosynthesis rate. High temperature treatment increased leaf temperature approximately 3-6°C during the exposure at 32.1 and 33.1°C average daily temperature (Table 5). The highest leaf temperature was 34.7°C. At the time of observation, air temperature was between 36.1 and 48.3°C.

Increasing temperature treatment increased leaf transpiration and plant photosynthesis rate. Transpiration rate increased with temperature raise treatment in all varieties. The highest transpiration rate at average daily temperature of 32.1°C was IR 64 (12.46 mol H_2O m^{-2} sec^{-1}) and at 33.1°C average daily temperature was Jatiluhur (20.68 mol H_2O m^{-2} sec^{-1}). High temperature treatment increased the photosynthesis rate of Menthik Wangi, Jatiluhur and HIPA 14 (Table 5).

Yield responses: The effect of high temperature on different growth stage of rice dependent on rice varieties. Rice varieties showed also differ on spikelet number, reduced of filled grain percentage and weight fill grain, as well as weight of

Table 4: Physiological character on varieties of high temperature

	Days to flowering			Days to harvest time			SPAD value		
Varieties	T1	T2	T3	T1	T2	T3	T1	T2	T3
Menthik Wangi	102.7	104.3	105.3	121.0	128.0	#	38.7	39.5	43.1
Silungonggo	86.7	90.3	94.3	114.0	120.0	#	35.8	39.2	40.4
Way Apo Buru	80.3	78.3	84.3	109.0	116.0	#	35.7	38.4	40.0
Ciherang	77.7	74.0	81.7	114.0	121.0	#	36.6	42.7	40.7
IPB 3S	69.3	68.3	79.3	109.0	114.0	#	33.8	38.7	40.5
HIPA 14	72.3	68.7	76.7	109.0	114.0	#	36.8	38.9	42.0
Jatiluhur	69.7	68.3	79.0	109.0	114.0	#	37.5	38.8	38.6
IR 64	62.0	60.3	62.9	106.0	114.0	#	37.4	41.8	44.5
Heat treatment (HT)	**			**			**		
Variety (Var)	**			**			*		
HT×Var	**			**			NS		

*Significant level at LSD α = 0.05, **Significant level at LSD α = 0.01, NS: Non significant differences. #Harvest time at T3 was not statistically processed due to no productive panicles. Daily average temperature of T1: 28.3°C, T2: 32.1°C, T3: 33.1°C

Table 5: Physiological character on varieties of high temperature

	Leaf temperature (°C)			Transpiration rate (mol H_2O m^{-2} sec^{-1})			Photosynthesis rate (μmol CO_2 m^{-2} sec^{-1})			Stomatal density (stomata/mm^{-2})		
Varieties	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
Menthik Wangi	30.2	30.4	33.7	6.2	8.3	14.6	18.6	19.8	21.5	200.0	170.7	192.0
Silungonggo	29.8	30.8	34.7	7.9	7.0	18.0	26.0	18.6	23.6	192.0	189.3	197.3
Way Apo Buru	29.8	31.7	34.0	8.2	9.7	19.3	18.7	19.9	18.3	173.3	184.0	176.0
Ciherang	29.7	30.2	33.8	8.3	11.1	12.9	23.6	22.7	22.0	213.3	213.3	234.7
IPB 3S	29.7	31.1	34.4	6.5	8.6	18.1	22.4	19.0	19.8	157.3	173.3	154.7
HIPA 14	30.5	31.2	34.3	4.9	10.4	21.5	15.9	18.1	23.7	165.3	176.0	192.0
Jatiluhur	30.3	31.3	34.2	7.9	10.9	20.7	19.1	21.7	23.2	160.0	202.7	178.7
IR 64	29.4	30.1	33.4	9.4	12.5	14.8	25.5	28.7	18.8	162.7	162.7	189.3
Heat treatment (HT)	*			**			*			NS		
Variety (Var)	**			**			**			*		
HT×Var	*			**			**			NS		

*Significant level at LSD α = 0.05, **Significant level at LSD α = 0.01, NS: Non significant differences. Daily average temperature of T1: 28.3°C, T2: 32.1°C, T3: 33.1°C

Table 6: Yield component character on varieties of high temperature

	Spikelet number per panicles			Percentage of fill grain (%)			Fill grain weight (g per plant)			Weight of 1000 grains (g)		
Varieties	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
Menthik Wangi	306.6	297.2	376.6	72.1	10.4	0.0	37.7	10.8	0.0	17.9	16.0	0.0
Silungonggo	200.3	193.7	210.9	66.5	4.5	0.0	20.3	4.1	0.0	23.0	20.4	0.0
Way Apo Buru	139.6	273.3	254.7	64.7	3.1	0.0	29.1	5.9	0.0	26.2	24.0	0.0
Ciherang	262.1	247.4	237.2	68.8	8.4	0.0	41.9	4.7	0.0	25.3	23.0	0.0
IPB 3S	403.9	464.7	485.4	64.3	1.6	0.0	38.2	4.9	0.0	27.3	24.2	0.0
HIPA 14	355.6	292.8	310.6	59.3	0.2	0.0	42.3	3.6	0.0	23.9	19.3	0.0
Jatiluhur	449.7	482.1	440.4	64.5	2.7	0.0	34.3	2.7	0.0	23.6	22.3	0.0
IR 64	172.8	200.4	212.9	75.4	7.5	0.0	26.5	8.4	0.0	25.0	23.0	0.0
Heat treatment (HT)	**			**			**			*		
Variety (Var)	**			**			*			**		
HT×Var	**			**			*			*		

*Significant level at LSD α = 0.05, **Significant level at LSD α = 0.01, NS: Non significant differences. Daily average temperature of T1: 28.3°C, T2: 32.1°C, T3: 33.1°C

1000 grains as response to increase of temperature. At 32.1°C daily average temperature treatment, spikelet number per panicle of Ciherang, Mentik Wangi and Hipa 14 decreased whereas it increased at IPB 3S, IR 64, Jatiluhur and Way Apo Buru compared to 28.3°C daily average temperature treatment. At 33.1°C daily average temperature treatment, number spikelet of Ciherang and Hipa 14 decreased whereas it increased for Menthik Wangi, IPB 3S, IR 64 and Way Apo Buru compared the 28.3°C treatment (Table 6).

Percentage of filled grain on Menthik Wangi declined 85.6% and HIPA 14 declined up to 99.6% at 32.1°C daily average temperature treatment. High temperature treatment decreased fill grain weight and weight of 1000 rice grains in all varieties. At the exposure average daily temperature of 33.1°C, all varieties produced unfilled grain. Weight of 1000 rice grains reduced 19.6% on HIPA 14 and 8.4% on IR 64 and Way Apo Buru (Table 6).

DISCUSSION

Reproductive phase was sensitive to high temperature stress. In the flowering phase, high temperature stress caused pollen production decreased resulting in decreased amount of pollen that was received by the stigma[8]. In this study percentage filled grain characteristic declining during high temperature treatment showed high grain sterility. This indicated a failure in the pollination process during anthesis. Temperature increase above 5°C from ambient temperature could increase the number of unfilled spikelets[19]. Another study reported that exposure to a temperature of 40°C decreased the spikelet filling rate and reduced yield[16].

High temperature treatment decreased filled grain weight and the weight of 1000 grains in all varieties. Ma *et al.*[20] reported that high temperatures caused to decrease in grain yield due to grain filling process inhibition. Zakria *et al.*[21] reported that high temperature stress caused faster grain filling rate which grain was not all filled. The increase average temperature by 1°C slowed grain filling phase for 4-5 days[22] and reduced grain yield 10%[23]. Increasing average temperature 2°C decreased filled grain 21.3-40.2%[24]. In this research grain yield decreased from 68.1-92.0% with increasing average temperature 3.8-4.8°C. High temperature treatment at weight of 1000 grains decreased from 8.4-19.6%. It agree with research Cao *et al.*[16] reported that high temperature stress on grain filling stage reduced duration of grain filling, weight of 1000 grains and loss of assimilate remobilization and sink activity.

Exposure to high temperatures could inhibit the flowering phase, mainly anthesis. During the flowering phase, mostly could not reach pollination so that fertility declined[25]. The IRRI[26] reported that high temperature treatment at 41°C for 4 h during the flowering phase caused damage and unfilled rice grain. Rice plants in this research received exposure to temperatures above 41°C in treatment T2 for 5 h and treatment T3 for 2-7 h at the temperature of 50°C.

Low leaf temperatures reduced transpiration rate and maintain the physiological function of the leaf. This indicated that plants have the ability to reduce leaf temperatures. Cao *et al.*[16] stated that one of the tolerant rice genotype characteristic was the leaf ability to maintain lower leaves temperature. Increased temperature affected leaf transpiration and plant photosynthesis rate. Plant transpiration increased with temperature raise treatment in all varieties.

High temperature stress increased shoot dry weight and SPAD value. Increasing caused delays during grain filling phase at the 32.1 and 33.1°C average temperature exposure. The SPAD value positively correlated with the N concentration and chlorophyll content in leaves[27]. This showed that assimilated the treatment of average temperature 32.1 and 33.1°C was accumulated in leaves. Another research also found physiological response of plants exposed to high temperatures increase biomass and leaf area decreased while increasing chlorophyll content[28].

Panicle exertion became important characters that could affect grain yield at high temperature stress[29]. Das *et al.*[30] reported that exposure to high temperatures above 40°C would inhibit panicle exertion. In this study, exposure to high temperatures were also affected to inhibit panicle exertion. Menthik Wangi and Jatiluhur had better panicle exertion characters compared to the other varieties exposed to average daily temperature of 32.1°C (Table 3).

High temperature treatment increased the number of tillers but decreased the number of productive panicles. It was suspected tiller numbers increasing was caused by the photosynthesis inhibition which assimilates distributed from source to sink. Number of productive panicles decreased because the panicles did not produce filled grains. The rate of grain filling was inhibited by exposure to high temperatures which resulted in unfilled grains.

CONCLUSION

High temperature treatment at different growth stage reduced grain yield in all varieties. The maximum and average temperature treatment 47.9/32.1°C decreased yield from 68.1-92.0%. The low percentage of filled grain caused high percentage of unfilled grain. The interaction between temperature and rice varieties affected significantly the number of tillers, number of productive panicles, flowering, harvest time, leaf temperature, transpiration rate, photosynthesis rate, spikelet per panicle, percentage of filled grain, fill grain weight and weight of 1000 grains. Varieties which had better yield had well exsertion of panicle, low leaf temperature and high percentage of filled grain. The IR 64 had the lowest leaf temperature, Menthik Wangi and Jatiluhur had well exsertion of panicle but still have low percentage of filled grain.

SIGNIFICANT STATEMENTS

Rice varieties have different responses to high temperature, indicating possibilities to explore benefits of genotypes adaptable to high temperature. Varieties which has better ability to high temperatures had well exsertion of panicle, lower leaf temperature and high percentage of filled grain.

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REFERENCES

1. Wang, W., B. Vinocur and A. Altman, 2003. Plant responses to drought, salinity and extreme temperatures: Towards genetic engineering for stress tolerance. Planta, 218: 1-14.
2. Getnet, Z., A. Husen, M. Fetene and G. Yemata, 2015. Growth, water status, physiological, biochemical and yield response of stay green sorghum (*Sorghum bicolor* (L.) Moench) varieties-a field trial under drought-prone area in Amhara Regional State, Ethiopia. J. Agron., 14: 188-202.
3. Yoshida, S., 1978. Tropical climate and its influence on rice. IRRI Research Paper Series No. 20, July 1978, Philippines, pp: 1-25. http://pdf.usaid.gov/pdf_docs/PNAAG711.pdf
4. IPCC., 2007. Climate Change and its Impacts in the Near and Long Term Under Different Scenarios. In: Climate Change 2007: Synthesis Report, Pachauri, R.K. and A. Reisinger (Eds.). IPCC., Geneva, Switzerland, pp: 43-54.
5. Husen, A., M. Iqbal and I.M. Aref, 2014. Growth, water status and leaf characteristics of *Brassica carinata* under drought and rehydration conditions. Braz. J. Bot., 37: 217-227.
6. Jagadish, S.V.K., P.Q. Craufurd and T.R. Wheeler, 2007. High temperature stress and spikelet fertility in rice (*Oryza sativa* L.). J. Exp. Bot., 58: 1627-1635.
7. Tao, L.X., H.J. Tan, X. Wang, L.Y. Cao, J. Song and S.H. Cheng, 2008. Effects of high-temperature stress on flowering and grain-setting characteristics of guodao 6. Acta Agron. Sin., 34: 609-674.
8. Prasad, P.V.V., K.J. Boote, L.H. Allen Jr., J.E. Sheehy and J.M.G. Thomas, 2006. Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. Field Crops Res., 95: 398-411.
9. Matsui, T., O.S. Namuco, L.H. Ziska and T. Horie, 1997. Effects of high temperature and CO_2 concentration on spikelet sterility in indica rice. Field Crops Res., 51: 213-219.
10. Tian, X., T. Matsui, S. Li, M. Yoshimoto, K. Kobayasi and T. Hasegawa, 2010. Heat-induced floret sterility of hybrid rice (*Oryza sativa* L.) cultivars under humid and low wind conditionsin the field of Jianghan Basin, China. Plant Prod. Sci., 13: 243-251.
11. Tsukaguchi, T. and Y. Iida, 2008. Effects of assimilate supply and high temperature during grain-filling period on the occurrence of various types of chalky kernels in rice plants (*Oryza sativa* L.). Plant Prod. Sci., 11: 203-210.
12. Taiz, L. and E. Zeiger, 2006. Plant Physiology. 4th Edn., Sinauer Associates Inc., New York, USA.
13. Ceccarelli, S., S. Grando, M. Maatougui, M. Michael and M. Slash *et al*., 2010. Plant breeding and climate changes. J. Agric. Sci., 148: 627-637.
14. Krishnan, R., B. Ramakrishnan, K.R. Reddy and V.R. Reddy, 2011. High-temperature effects on rice growth, yield and grain quality. Adv. Agron., 111: 87-206.
15. Tanaka, K., R. Onishi, M. Miyazaki, Y. Ishibashi, T. Yuasa and M. Waya-Inoue, 2009. Changes in NMR relaxation of rice grains, kernel quality and physicochemical properties in response to a high temperature after flowering in heat-tolerant and heat-sensitive rice cultivars. Plant Prod. Sci., 12: 185-192.
16. Cao, Y.Y., H. Duan, L.N. Yang, Z.Q. Wang, L.J. Liu and J.C. Yang, 2009. Effect of high temperature during heading and early filling on grain yield and physiological characteristics in *Indica* rice. Acta Agron. Sin., 35: 512-521.
17. Matsui, T. and K. Omasa, 2002. Rice (*Oryza sativa* L.) cultivars tolerant to high temperature at flowering: Anther characteristics. Ann. Bot., 89: 683-687.
18. IRRI., 1988. Standard Evaluation System. 3rd Edn., International Rice Research Institute, Philippines, Pages: 54.
19. Mohammed, A.R. and L. Tarpley, 2010. Effects of high night temperature and spikelet position on yield-related parameters of rice (*Oryza sativa* L.) plants. Eur. J. Agron., 33: 117-123.
20. Ma, Q.L., Y.S. Li, X.H. Tian, S.Z. Yan, W.C. Lei and N. Noboru, 2009. Influence of high temperature stress on composition and accumulation configuration of storage protein in rice. Sci. Agric. Sin., 42: 714-718.
21. Zakria, S., T. Matsuda, S. Tajima and Y. Nitta, 2002. Effect of high temperature at ripening stage on the reserve accumulation in seed in some rice cultivars. Plant Prod. Sci., 5: 160-168.
22. Nakagawa, H., W. Takahashi, T. Hasegawa, T. Watanabe and T. Horie, 2001. Development of a three-dimensional simulator for rice growth and development II. Accuracy of a rice phenology model to simulate heading stage and plant age in leaf number. Jap. J. Crop Sci., 70: 125-126.
23. Peng, S., J. Huang, J.E. Sheehy, R.C. Laza and R.M. Visperas *et al*., 2004. Rice yields decline with higher night temperature from global warming. Proc. Natl. Acad. Sci., 101: 9971-9975.

24. Shah, F., L. Nie, K. Cui, T. Shah and W. Wu *et al.*, 2014. Rice grain yield and component responses to near 2°C of warming. Field Crops Res., 157: 98-110.
25. Nitten, N.K., X. Gui, J.M. Reneeliza, N.B. Rajeev and Q. Cherryl *et al.*, 2014. Agronomic and physiological responses to high temperature, drought and elevated CO_2 interactions in cereals. Adv. Agron., 127: 111-156.
26. IRRI., 1982. Rice Research Strategies for The Future. International Rice Research Institute, Philippine, ISBN: 9789711040611.
27. Lin, F.F., L.F. Qiu, J.S. Deng, Y.Y. Shi, L.S. Chen and K. Wang, 2010. Investigation of SPAD meter-based indices for estimating rice nitrogen status. Comput. Electron. Agric., 71: S60-S65.
28. Tahir, I.S.A., N. Nakata, T. Yamaguchi, J. Nakano and A.M. Ali, 2009. Physiological response of three wheat cultivars to high shoot and root temperatures during early growth stages. Plant Prod. Sci., 12: 409-419.
29. Rang, Z.W., S.V. Jagadish, Q.M. Zhou, P.Q. Craufurd and S. Heuer, 2011. Effect of high temperature and water stress on pollen germination and spikelet fertility in rice. Environ. Exp. Bot., 70: 58-65.
30. Das, S., P. Krishnan, M. Nayak and B. Ramakrishnan, 2014. High temperature stress effects on pollens of rice (*Oryza sativa* L.) genotypes. Environ. Exp. Bot., 101: 36-46.