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RESEARCH PAPER

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Contribution of genetic x temperature interaction to performance and variance of rice yield in Indonesia

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Abstract

Efforts to maintain rice productivity grown under global temperature changing is growing high temperature tolerant varieties. Rice varieties available today are sensitive to high temperature so that the development of varieties for adaptation to high temperature is required. Rice was grown at two temperature conditions, first at the natural temperature (in the open ground) and the second at the high temperature conditions (in the green house). The experiment was arranged in a randomized complete block design with three replications. The results showed that there were significant differences among the varieties evaluated for all traits observed. The results also showed that plant height, time to heading, time to flowering, and panicle lenght were not affected by temperature conditions. Some traits were affected by genotypes x temperature conditions. Based on this study, the varieties that could maintain their yield under high temperature conditions were Situ Patenggang, Mekongga, Kalimutu, and IPB 6R. The varieties could be used as genetic material in breeding program for adaptation to high temperature conditions.

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Introduction

Rice is the main food crop in Indonesia. Rice consumption continue to increase along with the increase of population. Indonesia has made great efforts to increase national rice production. Currently, one of the challenges in increasing national rice production is the threat of global warming which could result in an increase in the temperature of the earth's surface. Increasing temperature of the earth's surface is expected to be one of the causes of the decline in agricultural productivity.

IPCC (2007) has reported that at the end of 21th century the average temperature of the earth's surface will rise between 2-4°C. The climate in Indonesia has become warmer during the 20th century. The average annual temperature has increased by around 0.3°C since 1900 which temperatures in the 1990^{s} was the warmest period in this century. According to the National Institute of Aeronautics and Space (2011) in 1961 to 1990 there was an increase in daily temperatures nearly 1^{o}C above average temperature occurring in all seasons. The Indonesian Agency for Meteorological, Climatological, and Geophysics (2011) reported that the average temperature in Indonesia has increased at 0.036-1.383°C in the period of 1983-2003.

Indonesia is a tropical country which rice is grown in regions where current temperatures are already close to the optimum temperatures for rice production. Therefore, any further increases in the mean temperatures or of short period of high temperatures during the crop growing season could reduce grain yield. Increased air temperature exceeds the optimum temperature for crop growing lead to high temperature stress for crops. High temperature stress is one of the factors that cause impaired growth and development of plants (Shrivastava, *et al.*, 2012; Prasanth, 2012).

High temperature stress causes an increase in the rate of transpiration so that more water is needed. Plants that are facing high temperature stress on seedling growth period decreased weight and lenght of shoots and roots (Gupta *et al.*, 2013). The flowering to seed filling period is the most sensitive period to high temperature stress (Macckill, 2010; Rang, 2011) because it causes a decrease in yield and harvest index (Matsui and Omasa, 2002; Rahman *et al.* 2009, Islam 2011; Jana *et al.*, 2012). Yield decrease under high temperature stress is caused by increasing pollen sterility and decreasing grain filling periode (period between flowering to harvesting).

One mechanism to reduce the rate of transpiration of plants is by reducing stomatal conductance, but low rate of transpiration result in reduced CO2 absorbed by the plants which will leads to reduce rate of photosynthesis. The reduction in the rate of photosynthesis in plants resulting in yield reduction. Efforts to mitigate the increase in temperature to maintain rice productivity is by growing high temperature tolerant varieties. According to Mackill *et al.* (2010), rice varieties available today are sensitive to high temperature, therefore there is a need for the development of varieties for adaptation to high temperature.

The information about growth and development of rice under high temperature in tropical conditions of Indonesia is still very limited. The purpose of this study was to obtain information about the contribution of genetic x temperature interactions to performance and variance of agronomic traits of rice.

Materials and methods

Place and time of study

The research was conducted at the Cikabayan experiment field, University Farm of the Bogor Agricultural University and the Rice Research Station, Muara, Bogor, Indonesia from April to August 2013.

Genetic materials

The genetic materials used in this study were 10 national rice varieties namely Mekongga, IR-64, Inpari-13, Situ Patenggang, Kalimutu, IPB 3S, IPB 4S, IPB 5R, IPB 6R, and IPB 7R.

Experimental design

The experiment was conducted in a randomized complete block design (RCBD) with three replications. The treatments used were temperature conditions and genotype. Temperature conditions were natural temperature which is crop grown at opening ground outside of greenhouse, while the second temperature conditions was the high temperatures, which is crop grown in the greenhouse. The average temperature in opening ground was 22°C/38°C, while in green house is 23°C/42°C, respectively for minimum and maximum dayli temperature. Genotypes used consisted of 10 national varieties so that experiment contained 60 experimental units.

Working proceedures

Fourteen days after sowing (DAS), the seedlings were transplanted into pot culture containing a mixture of soil and manure in the ratio 2:1. Crop management was optimal in terms of fertilization, irrigation, and weed and pest control. Watering is done by an intermittent system until 10 days before harvesting. Traits observed were total tiller number, panicle number, days to heading, flowering, and harvesting, panicle length, filled grain number/plant, unfilled grain number/plant, total grain number/plant, percentage of unfilled grain, seed weight, and 1000-seed weight.

Data analysis

Analysis of variance was carried out according to the procedure for the randomized complete block design to determine the significance of variation between temperature conditions a well as among the different genotypes. The software used was Minitab 12. Mean separation was done by t test and Duncan's multiple range test for $P \leq 0.05$. Broad sense heritability was calculated based variance partition of the expected mean square of the randomized complete block design (Table 1).

Genetic variance (σ^2_g) = (M3-M2)/rs

G x E Interaction Variance (σ^2_{gs}) = (M2-M1)/r

Environmental variance (σ^2_e) = M1

Phenotipic variance (σ^2_p) = σ^2_g + (σ^2_{gs})/s + (σ^2_e)/rs

Broad sense heritability h^2_{bs} = (σ^2_g/σ^2_p) x 100%.

Results and discussion

Rice performance under two difference temperature conditions

In this study, genetic materials were grown at natural temperature conditions (22°C/38°C) to 50 days after transplanting and then the plants that were exposed to high temperature stress moved to the greenhouse, while for natural temperature treatment the plants remain outside of the greenhouse. Plants that were exposed to high temperatures untill harvesting. Natural temperature conditions is the temperature in the opening ground and high temperature conditions was temperature inside greenhouse. The results of temperature measurement for natural conditions are 22°C and 38°C, while for the condition of high temperature is 23°C and 42°C, respectively for the minimum and maximum temperatures. The optimum temperature of rice growing is ranged from 20 to 35 °C (DOA of Srilanka, 2014).

Table 1. Analysis of variance combined using a random model

Source of variance	Degre of freedom	Mean square	Expected mean square
Temperature conditions (s)	s-1	MS5	σ^2 e + g (σ^2 r/s) + gr (σ^2 s)
Replication/(s)	s(r-1)	MS4	σ^2 e + g (σ^2 r/s)
Genotypes (g)	g-1	MS3	σ^2 e + r (σ^2 gs) + rs (σ^2 g)
g x s	(s-1)(g-1)	MS2	σ^2 e + r (σ^2 gs)
Error	s(r-1)(g-1)	MS1	σ^2 e

The variance analysis showed that temperature had a significant effect on total tiller number, panicle number, days to harvesting, unfilled grain number, filled grain number, total grain number, percentage of unfilled grain number, seed weight, and 1000 seed weight. The variance analysis also showed that genotype significantly affected all traits observed. Interaction between genotype and temperature significantly affected plant height, panicle number days to flowering and harvesting, filled grain number, total grain number, seed weight, and 1000 seed weight. The effect of temperature condition of low land rice is presented in Table 2 and the effect of genotype on agronomic characters of various genotypes observed is presented in Table 3 and Table 4.

Table 2. Agronomic traits of rice grown under natural temperature and high temperature conditions.

Traits observed	Mean under natural temperature	Mean under high temperature
Tiller number	21.9a	17.5b
Panicle number	19.6a	17.1b
Plant height	124.4	124.2
Days to heading (DAS)	73.9	73.8
Days to flowering (DAS)	77.9	77.8
Days to harvesting (DAS)	111.9a	109.9b
Panicle lenght (cm)	27.1	26.9
Unfilled grain number	1625.3a	1049.9b
Filled grain number	1808.9 a	1541.3b
Total grain number	3434.2a	2591.2b
Percentage of unfilled grain	46.5a	40.2b
1000-seed weight (g)	25.9a	23.0b
Seed weight (g)	47.4a	35.8b

Values having common letter(s) in a line do not differ significantly at 5% level as per t test.

The growth and development of paddy rice at natural temperature conditions were better than at high temperature conditions in the greenhouse (Table 2). Among the genotypes evaluated, Mekongga, and IPB 3S have higher yield potential and significantly different from IR 64, Situ Patenggang, and Kalimutu (Table 3 and Table 4). Mekongga, IR64, IPB 6R, IPB 7R, Situ Patenggang, and Kalimutu had shorter days to harvesting at high temperature conditions (Table 5). All of the varieties evaluated had lower total grain number due to high temperature stress, but only significantly different for Inpari 13, IPB 4S, IPB 5R, and IPB 7R. Inpari 13, IPB 4S, and IPB 5R is strongly influenced by high temperature stress because these varieties had significantly lower filled grain number due to high temperature stress (Table 5 and Table 6). The Inpari 13, IPB 3S, IPB 4S, IPB 5R, and IPB 7R varieties had lower grain weight and 1000 grain weight due to high temperature stress. Varieties IR 64 and Situ Patenggang were able to sustain the grain weight under high temperature stress, but has a lower grain weight than other varieties. Varieties that were not affected by temperature stress and have a high grain weight were Mekongga and IPB 6R. Inpari 13, IPB 3S, IPB 4S, IPB 5R, and IPB 7R were considered as sensitive varieties to high temperature stress.

Table 3. Mean of tiller number, days to heading, days to flowering, days to harvesting, and plant height of rice genotypes evaluated for adaptation to high temperature stress

	Karakter					
Varieties	Tiller number	Panicle number	Days to heading (DAS)	Days to flowering (HSS)	Days to harvesting (HSS)	Plant height (cm)
Mekongga	29.1^{a}	26.3^{a}	76.9^{a}	80.9^{a}	112.3^{ab}	111.3^{d}
IR64	30.2^{a}	27.8^{a}	73.8^{b}	77.8^{b}	110.2^{de}	109.1^{d}
Inpari13	23.0^{b}	22.7^{b}	73.4^{b}	77.4^{b}	113.5^{a}	112.0^{d}
IPB 3S	14.1^{c}	13.5^{cd}	74.4^{b}	78.4^{b}	113.2^{a}	141.3^{a}
IPB 4S	12.7^{cd}	11.8^{de}	73.5^{b}	77.5^{b}	108.8^{e}	132.9^{b}
IPB 5R	14.6^{c}	13.5^{cd}	74.7^{b}	78.7^{b}	113.0^{ab}	138.3^{a}
IPB 6R	15.1^{c}	15.7^{c}	77.1^{a}	81.1^{a}	111.7^{bc}	131.8^{bc}
IPB 7R	14.9^{c}	14.0^{cd}	76.6^{a}	80.6^{a}	112.8^{ab}	132.6^{b}
Situ Patenggang	9.7^{d}	9.3^{e}	65.1^{c}	69.1^{c}	103.0^{f}	128.7^{c}
Kalimutu	29.5^{a}	28.5^{a}	73.2^{b}	77.2^{b}	110.5^{cd}	104.8^{e}

Values having common letter(s) in a column do not differ significantly at 5% level as per DMRT.

Table 4. Mean of panicle lenght, unfilled grain number, filled grain number, total grain number, percentage of unfilled grain number, seed weight, and 1000-seed weight of rice genotypes evaluated for adaptation to high temperature stress.

Varieties	Traits observed						
	Panicle lenght (cm)	Unfilled grain number	Filled grain number	Total grain number	% unfilled grain	Seed weight (g)	1000 seed weight (g)
Mekongga	23.4^{d}	1178.8^{cd}	2010.3^{a}	3189.2^{abc}	36.7^{e}	49.8^{a}	24.9^{b}
IR64	24.1^{cd}	1312.7^{bcd}	1444.5^{bc}	2757.3^{bc}	47.3^{abc}	36.1^{cd}	25.6^{ab}
Inpari13	25.7^{b}	1621.5^{ab}	1787.0^{ab}	3408.5^{ab}	46.7^{abcd}	41.8^{abcd}	23.1^{c}
IPB 3S	29.7^{a}	1214.8^{cd}	1781.0^{ab}	2996.0^{abc}	40.4^{bcde}	48.8^{ab}	26.1^{ab}
IPB 4S	29.1^{a}	1162.2^{d}	1697.5^{abc}	2859.5^{bc}	40.1^{cde}	46.2^{abc}	26.8^{a}
IPB 5R	30.4^{a}	1837.2^{a}	1591.0^{abc}	3428.2^{ab}	53.3^{a}	37.9^{bcd}	22.5^{c}
IPB 6R	29.6^{a}	1760.2^{a}	1917.3^{a}	3677.5^{a}	47.6^{ab}	42.7^{abcd}	22.4^{c}
IPB 7R	29.1^{a}	1573.8^{abc}	1594.8^{abc}	3168.5^{abc}	48.4^{a}	34.9^{d}	21.9^{c}
Situ Patenggang	24.4^{bcd}	696.3^{e}	1303.0^{c}	2643.3^{d}	34.7^{e}	34.0^{d}	25.7^{ab}
Kalimutu	25.2^{bc}	1018.7^{de}	1624.7^{abc}	2643.3^{cd}	39.7^{de}	43.7^{abcd}	25.6^{ab}

Values having common letter(s) in a column do not differ significantly at 5% level as per DMRT.

This study showed that among the genotypes evaluated, there were some genotypes that had decreased grain weight when grown under high temperature stress, but there were also genotypes that were able to maintain grain weight under high temperatures stress. IPB 6 R and Mekongga were two varieties that were able to maintain high yield potential when grown under high temperature conditions so that the two varieties is thought to possess tolerance to temperature stress. The varieties IR 64 and Situ Patenggang were also able to retain yield potential, but the grain weight was lower compared to other varieties.

Table 5. Days to heading, days to flowering, days to harvesting of each genotype grown under natural and high temperature conditions.

Varieties	Days to heading (DAS)		Days to flowering (HSS)		Days to harvesting (HSS)	
	NT	HT	NT	HT	NT	HT
Mekongga	76.3^{abcd}	77.7^{a}	80.0^{abcd}	81.7^{a}	113.7^{ab}	111.0^{cde}
IR64	75.1^{bcdef}	72.4^{g}	79.3^{bcde}	76.3^{fg}	112.3^{abc}	108.0^{f}
Inpari13	74.3^{defg}	72.5^{f}	78.3^{bdefg}	76.7^{fg}	114.3^{a}	112.7^{abc}
IPB 3S	74.7^{cdefg}	74.1^{defg}	78.7^{bcdef}	78.3^{bdefg}	113.7^{ab}	112.7^{abc}
IPB 4S	73.7^{fg}	73.3^{fg}	77.7^{defg}	77.3^{efg}	109.7^{def}	108.0^{f}
IPB 5R	73.9^{efg}	75.4^{abcdef}	78.0^{cdefg}	79.3^{abcde}	113.3^{ab}	112.7^{abc}
IPB 6R	76.9^{abc}	77.3^{ab}	80.7^{ab}	81.7^{a}	114.0^{a}	109.3^{ef}
IPB 7R	76.2^{abcde}	77.0^{ab}	80.3^{abc}	81.0^{a}	114.0^{a}	111.7^{bcd}
Situ Patenggang	64.3^{h}	65.8^{h}	68.3^{h}	69.7^{h}	104.0^{h}	102.0^{g}
Kalimutu	74.1^{defg}	72.3^{g}	78.0^{cdefg}	76.0^{g}	111.7^{bcd}	109.3^{ef}

Values having common letter(s) in a trait observed do not differ significantly at 5% level as per DMRT.

High temperature stress affect growth, development, production and quality of crops (Matsui, *et al.*, 2005; Oh-e, I., Saitoh, Kuroda. 2007; Tsukaguchi and Iida, 2008; Nagai and Makino, 2009; Shrivastava, *et al.*, 2012). Yield reduction due to a disruption in the vegetative phase of growth, such as impaired formation of chlorophyll so that the leaves undergo faster senescence (Prasanth *et al.*, 2012). Disorders of the generative stage of rice, such as an increase in pollen sterility due to high temperature stress have also been reported (Matsui and Omasa, 2002; Islam, 2011; Rang *et al.*, 2011; Wei-hui, Da-wei, and Guo-ping, 2012; Tenorio *et al.*, 2013). Rahman, *et al.* (2009) reported that high temperature stress experienced by the plant causes a decrease in the number of days required for the growth of plants so harvested more quickly and causes a decrease in yield. According to Islam (2011), high temperature stress causes a decrease in seed weight per plant and harvest index in rice.

This research indicated that the increase in temperature is an abiotic stress that could cause yield loss in rice. According Mackill *et al.* (2010), most of the rice varieties available today are sensitive to high temperatures.

Table 6. Mean of total grain number, filled grain number, seed weight, and 1000-seed weight of each genotype grown under natural and high temperature conditions.

Varieties	Total grain number		Filled grain number		Seed weight (g)		1000-seed weight (g)	
	NT	HT	NT	HT	NT	HT	NT	HT
Mekongga	3232^{bcd}	3146^{bcde}	1882^{abcd}	2138^{a}	49.1^{abcde}	50.6^{abcd}	25.9^{bcd}	23.8^{e}
IR64	2846^{cfgh}	2668^{defg}	1289^{cd}	1600^{abcd}	34.9^{defg}	37.3^{cdefg}	27.7^{ab}	23.5^{e}
Inpari13	4164^{ab}	2652^{def}	2149^{a}	1424^{bcd}	53.1^{abc}	30.6^{fg}	24.8^{cde}	21.4^{f}
IPB 3S	3419^{cde}	2572^{efg}	2032^{ab}	1529^{abcd}	59.9^{a}	37.7^{cdefg}	27.8^{ab}	24.5^{cde}
IPB 4S	3523^{ab}	2195^{fgh}	2026^{ab}	1368^{cd}	59.1^{ab}	33.4^{efg}	29.3^{a}	24.4^{cde}
IPB 5R	4439^{a}	2417^{efg}	1951^{abc}	1231^{d}	50.2^{abcd}	25.7^{g}	24.5^{cde}	20.5^{f}
IPB 6R	3775^{abc}	3579^{bcd}	1839^{abcd}	1995^{ab}	43.8^{bcdef}	41.8^{cdefg}	24.1^{de}	20.9^{f}
IPB 7R	3837^{ab}	2500^{def}	1771^{abcd}	1418^{bcd}	41.4^{cde}	28.5^{fg}	23.5^{e}	20.4^{f}
Situ Patenggang	2092^{gh}	1906^{h}	1327^{cd}	1278^{d}	34.5^{defg}	33.6^{efg}	25.4^{cde}	26.1^{bcd}
Kalimutu	3012^{efg}	2274^{fgh}	1820^{abcd}	1428^{bcd}	48.4^{abcde}	38.9^{cdefg}	26.4^{bc}	24.9^{cde}

Values having common letter(s) in a trait observed do not differ significantly at 5% level as per DMRT
NT = natural temperature; HT = high temperature.

Genetic parameter of rice under two difference temperature conditions

The results of this study also showed that the variation of agronomic traits observed caused by temperature conditions, genotype, and the interaction between genotype and temperature conditions. Contribution of each factor to variation of traits observed can be calculated by separation mean expected square so that heritability for each character were obtained. Table 7 showed that all the characters observed had high heritability, except for filled grain number, total grain number, and seed weight.

Table 7. Variance component and heritability of agronomic traits of rice genotypes.

Traits	Genetic variance	Phenotypic variance	Broad sense heritability (%)
Tiller number	59.70	62.42	95.64
Panicle number	46.83	51.82	90.38
Days to heading	11.35	12.04	94.30
Days to flowering	11.37	12.02	94.55
Days to harvesting	9.11	10.01	91.07
Plant height	172.53	178.84	96.47
Panicle lenght	7.23	7.48	96.69
Unfilled grain number	95516.68	127683.70	74.81
Filled grain number	3634.65	44776.71	8.12
Total grain number	114537.11	230994.26	49.58
Percentage of unfilled grain	28.24	33.49	84.33
1000-seed weight	0.01	32.61	0.04
Seed weight	2.62	3.27	79.91

The results showed that variance due to interaction between genotype and temperature conditions and environmental factors had a greater efffect on the variation of filled grain number, total grain number, and seed weight. This resulted in all three characters had lower heritability values than the other characters.

The same results have been reported by other researchers. Das *et al.* (2011) reported that the interaction of genotype and environment influence on rice yield. Ishak (2012) also suggested that variance due to interaction of genotype and environment affects filled grain number causing heritability of this trait to be low.

Grain weight is a quantitative character of crops that has a high economic value. Yield improvement through plant breeding would be difficult if the environment is very large influence. Among the observed characters, plant height, panicle number, unfilled grain number, and percentage of unfilled grain, and 1000 seed weight had a high heritability so that the five characters can be used as selection criteria to improve grain weight in a breeding program. Bui *et al.* (2013) reported that the percentage of unfilled grains can be used for the improvement of seed weight because the character determine tolerance to high temperature stress. Tesfamichael *et al.* (2014) suggested using a weight of 100 seeds for breeding program to improve yield potential.

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