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Variability of upland rice genotypes response to low light intensity

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Abstract. *Hairmansis A, Yullianida, Supartopo, Jamil A, Suwarno. 2017. Variability of upland rice genotypes response to low light intensity. Biodiversitas 18: 1122-1129.* Plantation areas have a great potential to be utilized for upland rice production through intercropping. One of major constraints in the cultivation of upland rice as intercropping is low light intensity caused by shading. Improvement of rice varieties for shading tolerance is therefore important to increase rice production in upland areas. The objective of this study was to investigate the variability of upland rice genotypes responses to shading and identify the best genotypes for intercropping rice cultivation. Thirty-eight upland rice breeding lines, the shading tolerant rice variety Jatiluhur, and the shading susceptible rice variety IR64 were evaluated for their response to low light intensity in the greenhouse and the field. Greenhouse screening was conducted to determine their shading tolerance in vegetative stage while evaluation in the field was performed to evaluate their agronomic performance under 55% shading and normal conditions. Variation in upland rice genotypes on low light stress was revealed both in greenhouse and field trials. In the greenhouse trial, 12 genotypes showed higher survival rate compared to tolerant rice variety Jatiluhur. Field evaluation demonstrated that 55% shading increased plant height, reduced productive tiller number, delayed flowering time, increased spikelet sterility and reduced grain yield. Upland rice breeding line B11908F-TB-3-WN-1 showed high yield relative in shading condition compared to normal condition and had high-stress tolerance index (STI) which indicated the genotype was tolerant to shading.

Keywords: *Oryza sativa,* shading, upland, intercropping

INTRODUCTION

Rice is the staple food for more than half world population. Its demand is continuously increasing with the increase of the population. About 75% of rice production in the world is produced in irrigated areas, and the rest is supplied from rainfed areas including rainfed lowland and upland areas. Rice cultivation in upland areas worldwide accounts for about 15 million hectares and contributes about 4% of the total rice production in the world (GRiSP 2013). While the large portion of rice production comes from irrigated areas, the areas tend to decrease because of rapid land conversion. Therefore, the role of rainfed areas such as upland for extensification of rice production become more important in the future.

In tropical countries, such as Indonesia, upland rice has significant contribution in supplying staple food for people living in marginal dryland areas (Suwarno et al. 2001). In Indonesia, upland rice is cultivated in about 1.1 million hectares, contributes around 5% of the total rice production in the country (MOA 2013). It is cultivated in a diverse area as monoculture and intercropping with other crops (Toha et al. 2009, Sopandie and Trikoesoemaningtyas 2011). Palm oil, coconut, rubber and teak plantation area, which were distributed throughout the country have enormous potential to be utilized for intercropping with upland rice. It was estimated about 2 million ha of such areas are available every year for upland rice cultivation (Toha et al. 2009). In contrast to the intensive rice system in irrigated areas, the rice productivity in upland area is low due to an adverse environmental condition such as drought, soil acidity, and low soil fertility (Suwarno et al. 2001). In addition to such complex problems, rice production system as intercropping is constrained by low light intensity due to shading (Sopandie et al. 2003; Toha et al. 2009).

Rice plants require optimum solar radiation for their growth and development. Reduction in light intensity interrupt photosynthetic activities, decrease plant growth and biomass which ultimately affect grain yield (Sopandie et al. 2003, Liu et al. 2014; Wang et al. 2015). Variation in rice genotypes response against low irradiation has been shown in several studies (Demao and Xia 2003; Sopandie et al. 2003; Wang et al. 2015; Wang et al. 2016). Reduction in photosynthetic rate caused by shading has been shown lower in tolerant genotypes compared to sensitive genotypes (Demao and Xia 2003; Wang et al. 2015). The response was associated with the activity of ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBPCO) in which the reduction of the RuBPCO activities in tolerant cultivar was smaller than sensitive cultivar (Demao and Xia 2003). The chlorophyll a and ratio of chlorophyll a/b in tolerant genotype was also shown higher in shading tolerant rice genotype compared to sensitive genotype under low radiation (Sopandie et al. 2003). Wang et al. (2015) suggested the increase in chlorophyll content of tolerant genotype as adaptive capacity respond to low light intensity to improve plant ability in light harvest and to increase their photosynthetic rate. This adaptive mechanism allowed rice plant to increase grain filling under shading condition (Wang et al. 2015; Wang et al. 2016).

The establishment of a consortium of upland rice with other crops in Indonesian arable areas is a major strategy to increase rice production and population access to that staple food (Sumarno and Hidayat 2007). Until recently the number of shading tolerant rice varieties available for farmers remains limited. Therefore, improvement of rice varieties for this trait is important. Identification on tolerant genotypes is important to select best genotypes which can be deployed in target areas. The objective of this study was to investigate the variability of thirty-eight upland rice genotypes responses to shading and to identify the best genotypes for intercropping rice cultivation.

MATERIALS AND METHODS

Plant materials

Thirty-eight upland rice breeding lines derived from different crosses were selected for the experiments (Table 1). Upland rice variety Jatiluhur and popular lowland rice variety IR64 were used as a check for shading tolerant and shading susceptible rice varieties, respectively.

Shading experiment in the greenhouse

Complete shading treatment was performed in the upland rice seedling stage in the screen house. The protocol was modified from Sahardi (2000). Rice seeds were germinated in petri dish for 48 hours. Healthy and germinated rice seeds were then transferred in a plastic pot (35 cm × 25 cm × 10 cm) filled with soil collected from paddy field of Muara experimental station in Bogor. Soil moisture was maintained in the field capacity level. In each pot, eight lines and two check varieties were grown. Three replications were used in this trial. Rice plants were maintained in normal light condition for 10 days before complete shade treatment was applied for 10 days by placing the pots in a containment covered by a black fabric sheet. After 10 days grown under complete shading, the plants were moved to normal condition and their survival rate was calculated. Classification of rice tolerance to complete shading was determined using the method proposed by Sasmita (2008). Based on the survival rate, the genotypes were classified as tolerant (more than 60%), moderate (40% to 60%) and susceptible (less than 40%).

Shading experiment in the field

Field trials were conducted in Muara experimental station, Bogor district of West Java province, Indonesia during the wet season 2014-2015. The experiments consisted of two different light intensity, in normal condition (without shading) and 55% shade condition. The 55% shading treatment was chosen to increase the low light stress on rice as in the previous studies tolerant rice genotypes have been identified using 50% shading treatment (Soepandi et al. 2003; Sasmita 2008). Shading was imposed from seedling until harvesting by placing 55% shade net 2 m above the ground. The experiments were designed in a randomized complete block design with three replications. Each genotype was grown in 2 m × 5 m plot. Management practices for rice growing in both conditions were similar. In brief, the rice seeds were directly seeded in soil and were arranged in rows with a plant spacing of 15 cm within a row and 30 cm between rows. Fertilizers were applied three times, at 10 days after sowing using 200 kg NPK (15:15:15) per ha, at 35 days after sowing using 100 kg NPK (15:15:15) per ha and at the booting stage using 100 kg urea per ha. Data were collected for plant height, number of productive tiller, days to heading, days to harvest, number of filled grains per panicle, grain weight, and grain yield (moisture content of 14%) by following the standard evaluation procedure for rice (IRRI 2014). Shading tolerance genotypes were determined based on 1) their yield relative in stress condition compared to normal condition and 2) stress tolerance index (STI) (Fernandez 1992) which was calculated using the formula:

Stress tolerance index (STI)= (Yield in normal) × (Yield in shading) / (Average yield in normal)^2

RESULTS AND DISCUSSION

Response of upland rice genotypes to complete shading in the seedling stage

Rapid and efficient screening method is important in a breeding program to assess genetic variation of rice genotypes response against environmental stresses such as low light intensity. The method had been shown effectively differentiated between tolerant and susceptible genotypes (Sasmita 2008; Mara et al. 2015). In the present study 40 upland rice genotypes were evaluated for their response to complete shading for short periods of 10 days in vegetative stage. Variability in response to complete shading was demonstrated by the upland rice genotypes. Based on their survival rate, the rice genotypes were ranged from susceptible (less than 40%) to tolerant (more than 60%) to complete shading. Rice variety Jatiluhur which was used as tolerant check showed higher survival rate (90%) compared to susceptible check IR64 (59%) (Figure 1). The survival rates of 38 upland rice breeding lines ranged from the lowest of 37% in genotype G7 to the highest of 100% in genotype G34 (Figure 1). There were 12 genotypes which had survival rate comparable or higher than tolerant check Jatiluhur including G13, G14, G16, G17, G18, G19, G33, G34, G35, G36, G37 and G38 (Figure 1). The higher survival rate in tolerant genotypes was suggested to be related to their ability to store their energy and to minimize respiration rate during the complete shading (Sasmita 2008).

Response of upland rice genotypes to 55% shading in the field

Plant height, number of tiller and maturity characters

There was variation in the plant height of upland rice genotype in response to low light intensity (Figure 2A). Most of the upland rice genotypes showed increased plant height in shading condition, which was similar to the observation by Singh (2005) and Sopandie et al. (2003). However, G2, G16 and G38 genotypes showed lower plant height in shading condition including shading tolerant variety Jatiluhur.

Table 1. Upland rice genotypes and their parentage

Code	Genotypes	Parentage
G1	B14202F-MR-BLK	SMD9C-13/Situpatenggang
G2	B14231F-MR-BLK	(II YOU936/Batutegi)-3//Situpatenggang
G3	B14178F-MR-2	Limboto/Situpatenggang
G4	B14217F-MR-BLK	Terong/B10580E-KN-28-1-1
G5	B14176F-MR-BLK	Krowal-2/Situpatenggang
G6	B14144F-MR-3	Ciapus/Fatmawati*5//Situpatenggang
G7	B14083D-TB-21	B11492F-TB-12/IR60080-23
G8	B12480D-MR-7-1-1	Batutegi/CNA2903//IR60080-23/Cimelati
G9	B11592F-MR-23-2	IR60080-23/BP303
G10	B14086D-TB-70	TB409B-TB-14-3/B11178G-TB-29
G11	B13642E-TB-71	TB409B-TB-14-3/Bardaugol
G12	TB155J-TB-3-1-1	Way Rarem/Ketan Tuban
G13	B13638E-TB-12-2-WN-1	Danau Gaung/B11598C-TB-2-1-B-7
G14	B11908F-TB-3-WN-1	Gajah Mungkur/Cabacu
G15	B13636G-TB-8-WN-1	TB409B-TB-14-3/Ketan Rangeun
G16	B12168D-MR-38-1-6-TB-1	Cirata/IR60080-23
G17	B11579E-MR-7-1-1	TB154E/IRAT144//IRAT379
G18	B12154D-MR-10	IR60080-23/IRAT13
G19	B12498E-MR-1-9	IR68886/BP68*10//Selegreng///Maninjau/Asahan
G20	B12492C-MR-21-2-1	Rantai Emas//Guarani/Asahan
G21	B12056F-TB-29-1	Selegreng/Simacan
G22	B12159D-MR-40-1	Limboto/IRAT13
G23	B11592F-MR-16-1-5-1	IR60080-23/BP303
G24	B12056F-TB-1-64-6	Selegreng/Simacan
G25	B11923F-MR-33-1	IR60080-23/Guarani
G26	B11604E-MR-2-4	IR60080-23//IRBL8/IRBL23
G27	B10580E-KN-28-1-1	TB154E-TB-1/Kapuas
G28	B13655E-TB-13	Jatiluhur/TB409B-TB-14-3
G29	B11579E-MR-7-1-1-1	TB154E/IRAT144//IRAT379
G30	B11930F-TB-2	IRAT144/Guarani
G31	B12828E-TB-2-3-1	Selegreng/Ciherang//Kencana Bali
G32	B12498F-MR-1-9-3-TB-1	IR68886/BP68*10//Selegreng///Maninjau/Asahan
G33	B12492C-MR-21-1-13-4-TB-1	Rantai Emas//Guarani/Asahan
G34	TB356B-TB-12-2-2-1-2-1-1	Limboto/Atomita 4
G35	B12056F-TB-1-5-4-1	Selegreng/Simacan
G36	B12498F-MR-1-3	IR68886/BP68*10//Selegreng///Maninjau/Asahan
G37	B12825E-TB-2-4	BP342B-MR-1-3-KN-1-2-1-MR-2-1/Dendang//IR69502-6-SKN-UBN-1-B-1-3
G38	B12476E-MR-11	Limboto/IRAT13//Sayap Putih/Asahan
JTL	Jatiluhur	Improved variety
IR64	IR64	Improved variety

A number of productive tiller of upland rice genotypes were also affected by shading (Figure 2B). All genotypes showed decreased tiller number in shading condition compared to normal condition. The reduction of tiller number of upland rice ranged from 26% to 73%. Some of the upland rice genotypes showed a small reduction in their tiller number in response to low light including G17, G22, and G33. Sasmita (2008) indicated tolerant genotypes had a lower reduction in their tiller number compared to susceptible genotypes. However, it was shown that shading tolerant rice Jatiluhur had similar tiller number reduction trend as susceptible variety IR64 of about 50%. The tolerance response showed by Jatiluhur might be caused the genotype was able to compensate its leaf area even though their tiller number decreased as indicated by Soepandi et al. (2003).

The result from this study also indicated low light intensity delayed flowering time of upland rice genotypes (Figure 2C) which agreed to the result from the previous study (Cai 2011). Shading tolerant rice variety Jatiluhur also showed prolonged days to flowering in shading condition compared to normal condition. However, some genotypes showed earlier flowering time in shading condition compared to normal condition in response to low light intensity such as G8, G18, G20, G21, G22, and G24.

Furthermore, harvesting time of upland rice genotypes was also considered affected by shading (Figure 2D). Shading has prolonged maturity time of most upland rice genotypes. Similar to flowering time, some genotype showed a different response in their harvest time. The genotypes G18, G22 and G24 which had earlier flowering time in shading condition were also showed earlier harvest time in shading condition compared to normal condition.

Yield component and grain yield

The 55% shading decreased a number of filled grain per panicle of almost all upland rice genotypes except for G10, G22, G35 and Jatiluhur (Figure 3A). The reduction ranged from 6% (G10) to 57% (G18) with an average reduction in a number of filled grain was 36%. Reduction in the number of filled grain in tolerant check variety Jatiluhur was lower compared to susceptible check variety IR64. Other upland rice genotypes which showed a small reduction in number of filled grain were G10 and G22. Shading directly reduced photosynthetic rate in plants resulted in significant reduction in grain filling (Wang et al. 2015; Pan et al. 2016). Wang et al. (2015) observed shading tolerant rice variety had smaller reduction in their grain filling compared to susceptible variety due to improvement in their light use efficiency.

The result from this study also showed that 55% shading increased the number of empty grain per panicle of upland rice, even though the variation in the number of empty grain in each genotype were remarkably large (Figure 3B). Moreover, the shading reduced spikelet fertility of all rice genotypes (Figure 3C). The reduction in spikelet fertility ranged from 7% to 40%. Shading tolerant check variety Jatiluhur showed a smaller reduction in spikelet fertility compared to susceptible check IR64. Some genotypes showed a smaller reduction in the spikelet fertility including G5, G8, G22, and G27.

Grain weight of rice is also one of the traits affected by shading during the reproductive stage (Wang et al. 2015). The result from this study also indicated that shading reduced the grain weight of upland rice genotypes (Figure 3D).

In the present study grain yield of upland rice genotypes in normal condition ranged from 2.33 t/ha (G2) to 4.35 t/ha (G9) (Table 2). The yield seriously affected by 55% shading with the range of rice yield in this stress condition were 0.45 (G34) to 1.55 (G14). The shading tolerant rice check Jatiluhur yielded 3.83 t/ha in normal condition and 1.44 t/ha in shading condition, while susceptible variety IR64 yielded 3.36 t/ha in normal condition and 0.74 t/ha in shading condition. The effect of shading on grain yield have been reported in rice and other crops (Singh 2005; Liu et al. 2014; Wang et al, 2015; Pan et al. 2016; Cai 2011, Li et al. 2010).

We then determined the level of shading tolerance of rice genotypes through their yield relative in shading condition compared to normal condition and based on stress tolerance index (STI) proposed by Fernandez (1992). Based on the yield relative, the tolerant rice variety Jatiluhur showed yield relative of 38% while susceptible check IR64 had yield relative of 22% (Table 2). There were several upland rice lines which had higher yield relative than Jatiluhur, such as G11 (44%), G14 (44%), and G22 (40%) indicated those lines are having better shading tolerant than Jatiluhur. The yield relative is used to determine genotype which performed well in stress condition. Furthermore, based on the stress tolerance index, the highest score was shown by shading tolerant variety Jatiluhur (0.51) (Table 2). Other genotypes with high STI were G14 (0.50), G9 (0.48), G12 (0.44) and G6 (0.42) (Table 2). Using this index, rice genotypes which had high yield potential both in normal and stress condition could be identified (Fernandez 1992).

Correlation analysis was performed to study relationship between survival rate of upland rice genotypes grown under complete shading in seedling stage and their relative yield under shading compared to normal condition (Figure 4). While several studies had used shading treatment in seedling stage to determine shading tolerant of rice varieties (Sahardi 2005, Sasmita 2008; Mara et al. 2015), result from this study indicated there was a weak relationship between these two measurements (Figure 4). As grain yield is the main target in the selection of shading tolerant rice, the selection of superior genotypes under shading condition from vegetative to reproductive stage is, therefore, more appropriate for further studies.

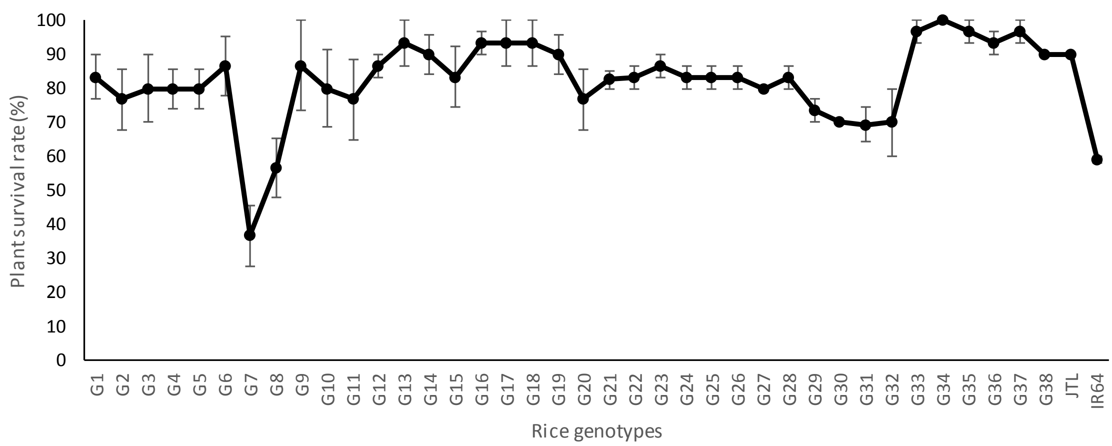

Figure 1. Survival rate of 40 upland rice genotypes under complete shading for 10 days in vegetative stage

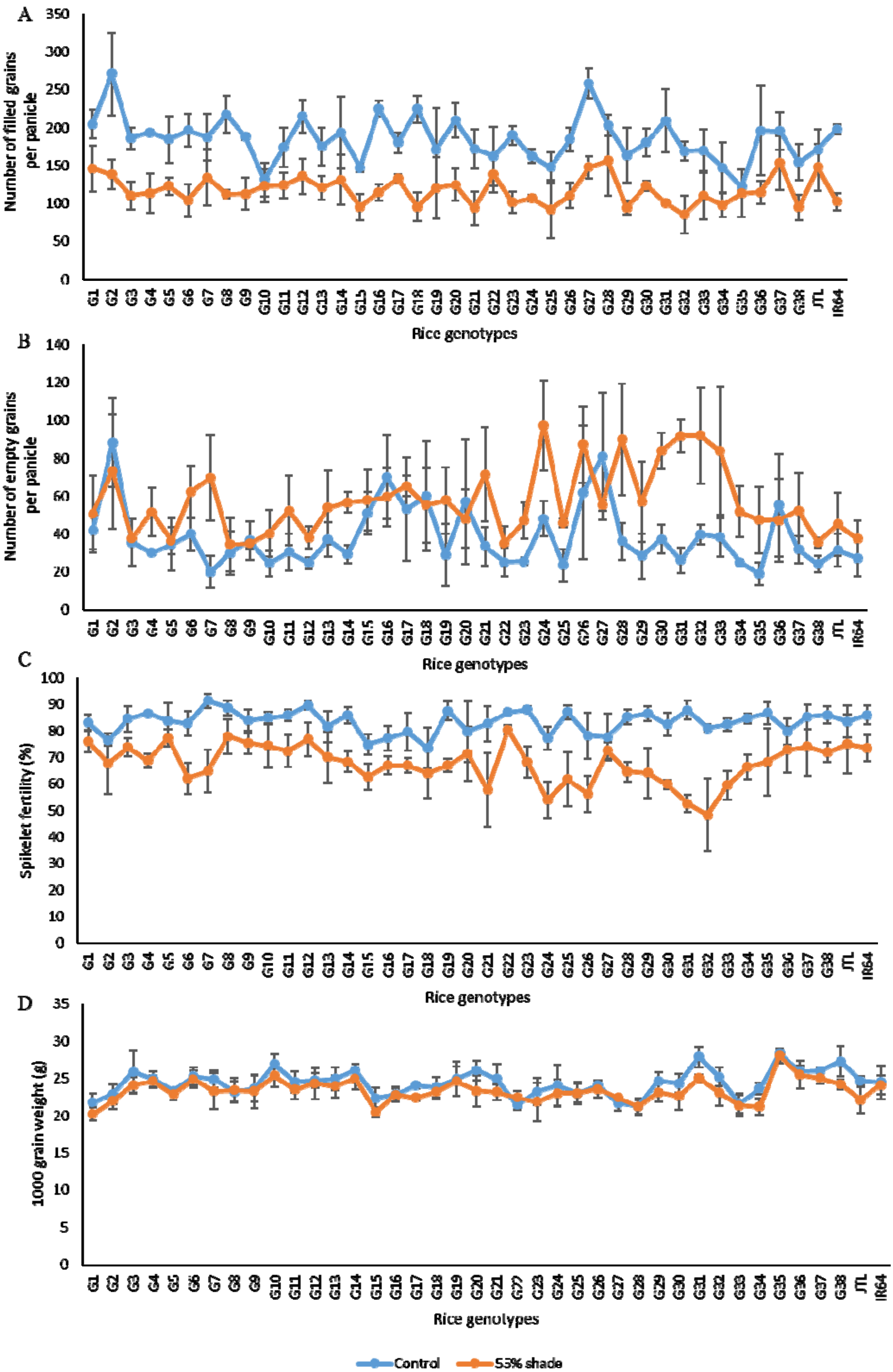

Figure 2. Plant height, productive tiller number, days to flowering and days to harvest of 40 upland rice genotypes under control and 55% shade conditions

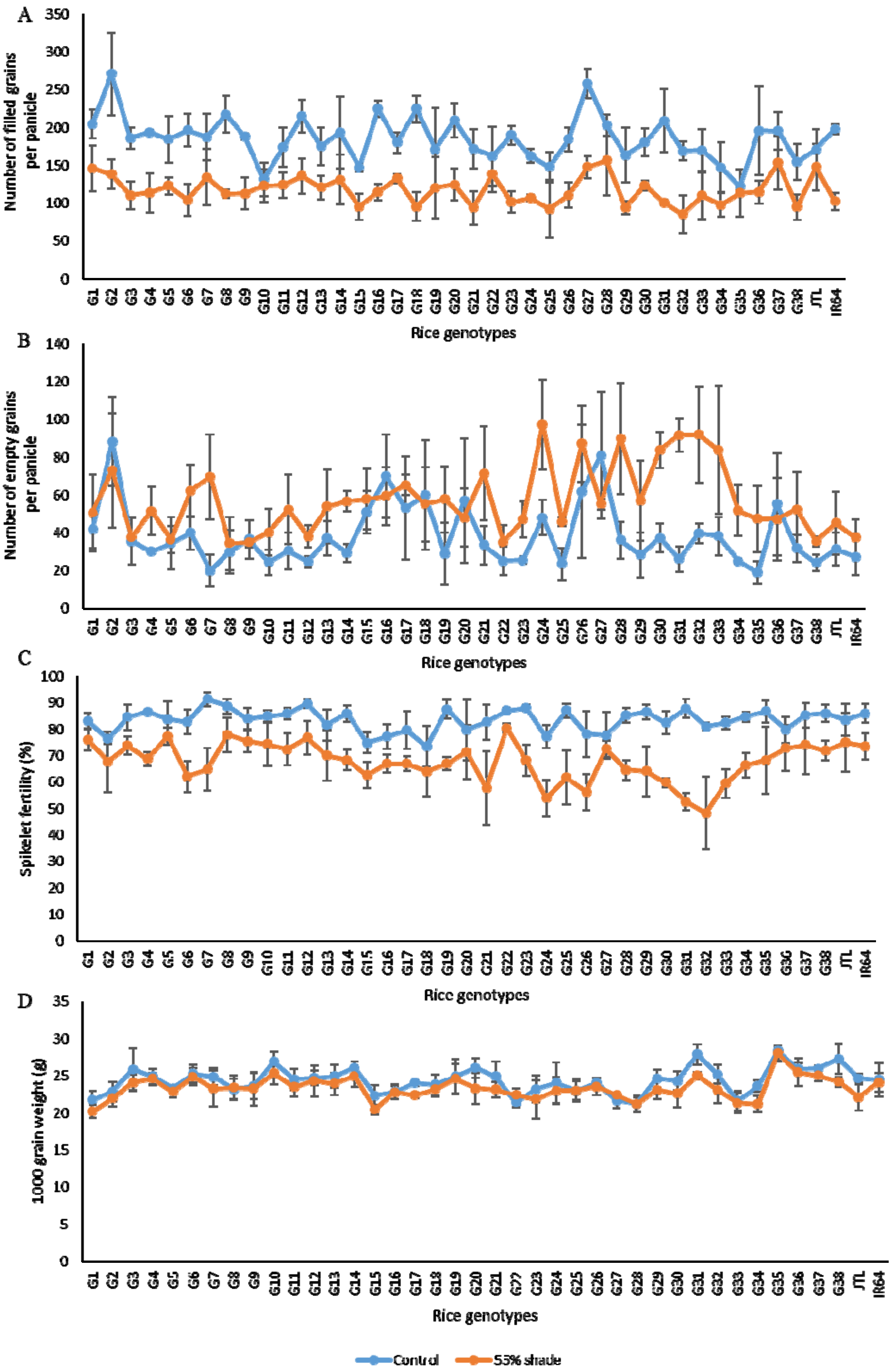

Figure 3. Yield component of 40 upland rice genotypes under control and 55% shade conditions

Table 2. Grain yield, relative yield reduction under 55% shade and control condition and stress tolerance index of 40 upland rice genotypes

Code	Genotypes	Grain yield ± SE (t/ha)		Relative yield in 55% shade and control	Stress tolerance index (STI)
		Control	55% shade		
G1	B14202F	3.35±0.5	0.93±0.3	0.28	0.29
G2	B14231F	2.33±0.7	0.54±0.2	0.23	0.12
G3	B14178F-MR-2	3.89±0.5	0.92±0.3	0.24	0.33
G4	B14217F	3.52±0.4	0.76±0.1	0.22	0.25
G5	B14176F	3.87±0.6	0.85±0.3	0.22	0.30
G6	B14144F-MR-3	3.54±0.2	1.29±0.4	0.36	0.42
G7	B14083D-TB-21	3.28±0.5	0.93±0.3	0.28	0.28
G8	B12480D-MR-7-1-1	3.23±1.3	0.78±0.2	0.24	0.23
G9	B11592F-MR-23-2	4.35±0.9	1.21±0.4	0.28	0.48
G10	B14086D-TB-70	2.86±0.5	1.06±0.3	0.37	0.28
G11	B13642E-TB-71	3.02±0.7	1.32±0.3	0.44	0.37
G12	TB155J-TB-3-1-1	4.02±1.0	1.18±0.2	0.29	0.44
G13	B13638E-TB-12-2-WN-1	4.00±0.9	0.99±0.3	0.25	0.36
G14	B11908F-TB-3-WN-1	3.53±0.2	1.55±0.6	0.44	0.50
G15	B13636G-TB-8-WN-1	3.22±0.5	0.76±0.3	0.24	0.23
G16	B12168D-MR-38-1-6-TB-1	2.89±0.3	0.83±0.2	0.29	0.22
G17	B11579E-MR-7-1-1	3.41±0.5	0.92±0.2	0.27	0.29
G18	B12154D-MR-10	2.99±0.4	1.04±0.2	0.35	0.29
G19	B12498E-MR-1-9	3.67±0.4	0.77±0.1	0.21	0.26
G20	B12492C-MR-21-2-1	3.09±0.5	1.07±0.2	0.35	0.30
G21	B12056F-TB-1-29-1	2.52±0.5	0.92±0.1	0.36	0.21
G22	B12159D-MR-40-1	3.26±0.9	1.29±0.1	0.40	0.39
G23	B11592F-MR-16-1-5-1	3.03±0.3	0.79±0.2	0.26	0.22
G24	B12056F-TB-1-64-6	3.42±0.3	0.84±0.3	0.24	0.26
G25	B11923F-MR-33-1	4.05±0.5	0.73±0.2	0.18	0.27
G26	B11604E-MR-2-4	3.09±0.2	1.11±0.3	0.36	0.32
G27	B10580E-KN-28-1-1	3.54±0.5	1.15±0.1	0.33	0.37
G28	B13655E-TB-13	3.19±0.9	0.65±0.3	0.20	0.19
G29	B11579E-MR-7-1-1-1	2.43±0.4	0.8±0	0.33	0.18
G30	B11930F-TB-2	3.14±0.3	0.93±0.3	0.30	0.27
G31	B12828E-TB-2-3-1	3.05±0.5	0.54±0.2	0.18	0.15
G32	B12498F-MR-1-9-3-TB-1	3.45±0.9	0.69±0.4	0.20	0.22
G33	B12492C-MR-21-1-13-4-TB-1	3.64±0.5	0.88±0.4	0.24	0.29
G34	TB356B-TB-12-2-2-1-2-1-1	3.14±0.3	0.45±0.2	0.14	0.13
G35	B12056F-TB-1-5-4-1	2.37±0.1	0.92±0.4	0.39	0.20
G36	B12498F-MR-1-3	2.61±0.6	0.91±0.3	0.35	0.22
G37	B12825E-TB-2-4	3.64±0.5	1.08±0.1	0.30	0.36
G38	B12476E-MR-11	3.26±0.9	1.01±0.3	0.31	0.30
JTL	Jatiluhur	3.83±0.8	1.44±0.6	0.38	0.51
IR64	IR64	3.36±0.4	0.74±0.2	0.22	0.23

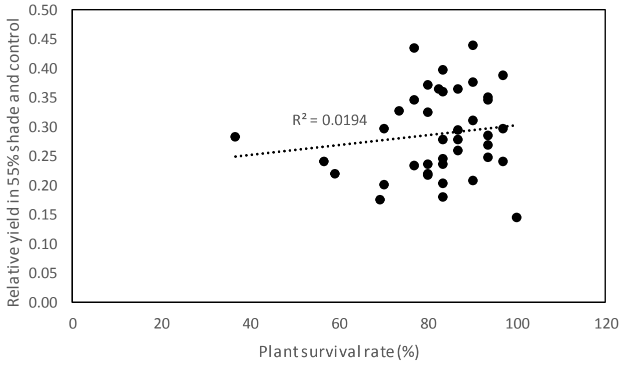

Figure 4. Relationship between upland rice survival rate under complete shading in vegetative stage and relative yield under 55% shade and control.

In conclusion, we found a variation of upland rice genotypes in response to low light intensity. Low light intensity stress in rice increased plant height, reduced productive tiller number, delayed flowering time, reduced grain filling, increased spikelet sterility, and reduced grain yield. We identified promising rice breeding lines which were tolerant to shading. The lines have potential to be further evaluated for their performance in upland rice areas under plantation. The tolerant genotypes developed through this study would be useful for the establishment of consortium of upland rice with other crops in Indonesia

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