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Genotype-Environment Interaction and Yield Stability of Upland Rice in Intercropping Cultivation

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ABSTRACT

Rice cultivation as intercropping in plantations is a potential approach to increase land resource efficiency. Implementation of rice intercropping would require genotypes adapted to shaded environments. This study aimed to clarify the interaction of genotype and environment on agronomic characteristics of upland rice grown under intercropping system and to identify suitable genotypes for this particular cropping system. Multi-location trials evaluated twelve upland rice lines and two check varieties in eight upland sites during the wet season (WS) 2015-2016. Rice was grown as intercropping in six sites and as monoculture in two sites. Rice as intercrop was cultivated in between plantations of tall coconut, rambutan, teak, albizia, and natural rubber. The result of this study revealed that the interaction between genotype and environment was significant for all agronomic characteristics. The genotype B12056F-TB-1-29-1 was the best performer when grown as intercropping in Subang and Indramayu, with shading intensities of 65% and 44%, respectively. The genotype B11908F-TB-3-WN-1 was the best yielder in Cianjur and Lampung Tengah, which had 37% and 54% shading intensity, respectively. The genotype B12825E-TB-2-4 was the best performer in Lampung Timur with shading intensity of 45%, while Jatiluhur was the best genotype in Banyumas with shading intensity of 82%. The yield of rice genotypes grown as monocultures was higher than as intercropping. Among the genotypes, B12056F-TB-1-29-1 showed the highest yield across sites. Stable and high-yield genotypes identified from this study are expected to be adopted by farmers for intercropping rice cultivation.

1. Introduction

Rice is the primary food for almost half the world's population (Muthayya *et al.* 2014). It is produced in many ecosystems, including irrigated, flood-prone, and upland areas, covering temperate, sub-tropic, and tropical areas (Khush 1997). Most rice worldwide is produced under the irrigated system, while only about 8% of rice is produced in the upland (Saito *et al.* 2018). In some countries, upland rice is grown as intercrop in between trees, implementing the agroforestry concept (Ghauhan *et al.* 1994; Hondrade *et al.* 2017; Singh *et al.* 1997; Rodenburg *et al.* 2022; Wangpakapattanawong *et al.* 2017). Intercropping rice in plantations is a common cropping practice aimed at increasing the efficiency in using available land resources and labor (Wangpakapattanawong *et al.* 2017). For instance, in Southern Thailand, rice was grown between rubber, which covered about 34% of the farming system in the area (Simien and Penot 2011). In Indonesia, rice was often used as intercrop in teak plantations (Perdana *et al.* 2012; Roshetko *et al.* 2013).

Various abiotic constraints hamper rice cultivation in upland areas. Major abiotic constraints in upland rice cultivation include drought, soil acidity, and low soil fertility (Bernier *et al.* 2008; Haefele *et al.* 2014; Saito *et al.* 2018). Low light intensity becomes an additional problem, particularly for upland rice grown as an intercrop (Rodenburg *et al.* 2022). Shading from the plantation canopy in the intercropping system reduces light intensity which is essential for the growth and development of rice plants (Vandenbussche *et al.* 2005; Wang *et al.* 2015). The low light intensity stress caused by shading

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disrupted photosynthetic activities, decreased plant growth and biomass, and affected rice grain yield (Liu *et al.* 2014; Wang *et al.* 2015). The development of rice varieties that specifically adapted to the environmental condition of intercropping system would be beneficial to increase rice productivity in such an ecosystem (Brooker *et al.* 2015; Ghauhan *et al.* 1994).

Several studies have indicated that rice genotypes varied in response to low light intensity (Demao and Xia 2001; Hairmansis *et al.* 2017; Wang *et al.* 2015, 2016). Tolerant genotypes maintained a higher photosynthetic rate under low light intensity than sensitive genotypes (Demao and Xia 2001; Wang *et al.* 2015). It was suggested that tolerant genotypes adapted to low light intensity by increasing their chlorophyll content to increase the photosynthetic rate, which allowed rice to improve grain filling under this stress condition (Wang *et al.* 2015, 2016).

Limiting upland areas in plantations as intercropping would need a genotype adapted to this specific environment. Evaluation of rice breeding materials in multiple environments representing different intercropping systems would allow the identification of stable genotypes suitable for such specific cropping systems (Balestre *et al.* 2010; Braun *et al.* 2010; Kumar *et al.* 2012; Mandal *et al.* 2010). This study aimed to clarify the interaction of genotype and environment on grain yield and its associated characteristics of upland rice grown under intercropping system and to identify suitable genotypes for this particular cropping system.

2. Materials and Methods

2.1. Experimental Sites and Plant Materials

Multi-location trials were conducted in eight upland sites during the wet season (WS) 2015-2016 (Table 1). Rice was grown as intercropping in six sites and as monoculture in two sites. Rice as intercrop was cultivated in between trees of tall coconut (*Cocos nucifera*) in Cianjur, rambutan (*Nephelium lappaceum*) in Subang, teak (*Tectona grandis*) in Indramayu, albizia (*Albizia chinensis*) in Banyumas, and natural rubber (*Hevea brasiliensis*) in Lampung Timur and Lampung Tengah (Table 1). The shading intensity in intercropping sites was estimated by measuring light intensity in open spaces and between plantations using a digital lux meter (Smart Sensor® AR823). The shading intensity was the light intensity ratio under the plantation canopy and open space outside the plantation. It ranged from the highest of 82% under albizia plantation to the lowest of 37% in between coconut plantations (Table 1). Rice as monoculture (without shading) was grown in Kebumen and Purworejo.

Twelve upland rice breeding lines and two released varieties were evaluated at each site. The upland rice lines were developed by Indonesian Center for Rice Research (ICRR) namely B12480D-MR-7-1-1, B14086D-TB-70, B13642E-TB-71, B11908F-TB-3-WN-1, B12168D-MR-38-1-6-TB-1, B12056F-TB-1-29-1, B12159D-MR-40-1, B12056F-TB-1-64-6, B11604E-MR-2-4, B13655E-TB-13, B12056F-TB-1-5-4-1, and B12825E-TB-2-4. Two commercially released upland rice varieties, Inpago 5 and Jatiluhur, were used as checks.

2.2. Management of Experiments

The experiment was arranged in a randomized complete block design in each location with four replications. Crop establishment was done using direct seeding by dibbling rice seeds in the soil at 30 cm × 15 cm spacing in 14 rows of 4.5 m length, with the total plot size for each genotype being 18.9 m^2. Inorganic NPK (15:15:15) fertilizer at the rate of 200 kg ha^{-1} was applied 10 days after sowing and 100 kg ha^{-1} 35 days after sowing. Urea at the rate of 100 kg ha^{-1} was applied at the booting stage. Agronomic characteristics of rice were recorded in all sites, including the number of productive tillers (NPT), days to flowering (DTF), number of grains per panicle (NGP), percentage of fertile grains per panicle (FGP), 1000-grain weight (GW), and grain yield (moisture content of 14%) (GY).

Table 1. Site characteristics of multi-location yield trial of upland rice

Sites	Rice cultivation	Soil type	Elevation (m asl)	Shading intensity (%)	Plantation
Cianjur, Jawa Barat	Intercropping	Alluvial	115	37	Tall coconut
Subang, Jawa Barat	Intercropping	Latosol	94	65	Rambutan
Indramayu, Jawa Barat	Intercropping	Regosol	99	44	Teak
Banyumas, Jawa Tengah	Intercropping	Regosol	236	82	Albizi
Lampung Timur, Lampung	Intercropping	Podzolic	49	45	Natural rubber
Lampung Tengah, Lampung	Intercropping	Podzolic	71	54	Natural rubber
Kebumen, Jawa Tengah	Monoculture	Alluvial	21	0	-
Purworejo, Jawa Tengah	Monoculture	Alluvial	82	0	-

2.3. Statistical Analysis

Analysis of variance (ANOVA) was performed for data from each location. Combined ANOVA was done for data across eight locations to analyze the interaction of genotype and environment. Stability analysis was performed using the regression method (Finlay and Wilkinson 1963). Analysis was carried out using the statistical software Crop Stat 7.2 developed by International Rice Research Institute.

3. Results

3.1. Performance of Upland Rice as Intercropping and Monoculture Crops

Environment and genotype significantly affected the grain yield, number of productive tillers, crop duration, and yield components of upland rice (Table 2). The interaction between genotype and environment was also significant for all characteristics, including grain yield (Table 2); therefore, the cultivar's yield ranking was different across environments (Table 3). The yield of rice genotypes grown as monoculture was higher than as intercropping. There was a negative and significant correlation between shading intensity and grain yield ($r = -0.92$) (Figure 1A). The highest environment yield of 6.18 t ha^{-1} was achieved in Kebumen, where rice was grown without shading stress. A high environment yield of 5.55 t ha^{-1} was also attained in rice cultivation as monoculture in Purworejo. The site Cianjur, where rice was grown under tall coconut with an estimated shading intensity of 37%, showed an environment yield of 4.44 t ha^{-1}. Other sites where rice was grown as intercropping showed lower environmental yield. The lowest environment yield was shown in Banyumas, where rice was grown under an albizia plantation with a shading intensity of 82%. In this site, the upland rice showed an average yield of 2.55 t ha^{-1}.

The genotype B12056F-TB-1-29-1 showed the highest yield (4.62 t ha^{-1}) (Table 3). This genotype was the best performer when grown as

Table 2. Combined ANOVA for grain yield and yield component across eight sites of multi-location trials of upland rice

Source of variation	Degree of freedom	GY		NPT		DTF		NGP		FGP		GW	
		MS	F Pr	MS	F Pr	MS	F Pr	MS	F Pr	MS	F Pr	MS	F Pr
Environment	7	88.4	<.0001	812.7	<.0001	1536.0	<.0001	75035.4	<.0001	0.557	<.0001	138.1	<.0001
Replication within environment	24	0.4	0.0588	17.0	<.0001	7.1	0.0568	2739.7	<.0001	0.044	<.0001	1.6	0.0346
Genotype	13	4.3	<.0001	31.4	<.0001	84.8	<.0001	4500.4	<.0001	0.065	<.0001	143.9	<.0001
Genotype × environment	91	2.1	<.0001	6.0	<.0001	25.5	<.0001	1274.7	<.0002	0.014	<.0001	13.7	<.0001
Error	312	0.3		3.3		4.6						0.8	

GY = grain yield (t ha^{-1}), NPT = number of productive tiller, DTF = days to 50% flowering, NGP = number of grains per panicle, FGP = percentage of fertile grains per panicle, GW = 1,000-grain weight (g)

Table 3. Grain yield ± SD (t ha^{-1}) of upland rice genotypes in eight sites with different shading intensities

Genotype	Sites (shading intensity)								Mean
	Cianjur (37%)	Subang (65%)	Indramayu (44%)	Banyumas (82%)	Kebumen (0%)	Purworejo (0%)	Lampung Timur (45%)	Lampung Tengah (54%)	
B12480D-MR-7-1-1	4.09±0.57	4.02±0.54	3.94±0.27	2.20±0.29	7.39±0.08	5.24±0.33	2.39±0.48	4.34±0.15	4.20±1.63
B14086D-TB-70	4.58±1.01	3.17±0.24	3.60±0.44	2.77±0.12	6.71±0.19	4.63±0.28	3.64±0.23	3.31±0.65	4.05±1.25
B13642E-TB-71	4.53±0.46	2.36±0.47	1.14±0.09	3.27±0.28	5.65±0.24	4.93±0.25	2.90±0.79	4.03±0.48	3.60±1.47
B11908F-TB-3-WN-1	6.81±0.84	2.69±0.57	2.64±0.33	2.47±0.33	4.80±0.60	6.13±0.96	3.15±0.72	4.37±0.54	4.13±1.68
B12168D-MR-38-1-6-TB-1	4.84±0.35	3.50±0.43	3.43±0.41	2.33±0.07	5.57±0.49	6.09±0.73	3.27±0.57	3.84±0.40	4.11±1.27
B12056F-TB-1-29-1	5.12±0.35	4.74±0.41	4.65±0.39	2.41±0.26	6.07±0.53	6.97±1.87	3.20±0.23	3.81±0.11	4.62±1.49
B12159D-MR-40-1	3.75±0.63	2.84±0.22	2.78±0.26	2.80±0.23	6.93±0.63	5.53±1.02	2.69±0.39	4.18±0.27	3.94±1.56
B12056F-TB-1-64-6	4.09±0.63	2.52±0.24	2.47±0.24	2.29±0.30	5.07±0.44	5.28±0.67	3.07±0.23	3.06±0.61	3.48±1.19
B11604E-MR-2-4	3.08±0.32	2.61±0.65	1.88±0.33	2.96±0.08	5.53±1.05	4.09±0.57	3.04±0.29	3.01±0.26	3.27±1.10
B13655E-TB-13	2.67±0.42	2.98±0.34	2.91±0.18	2.51±0.22	6.05±0.81	6.55±0.18	3.42±0.35	2.95±0.49	3.75±1.60
B12056F-TB-1-5-4-1	4.97±0.64	3.44±0.48	2.63±0.44	2.59±0.16	7.65±1.26	6.02±1.12	3.42±0.26	4.33±0.59	4.38±1.76
B12825E-TB-2-4	4.51±0.26	4.18±0.15	4.09±0.70	2.04±0.04	6.78±0.36	5.10±0.57	3.70±0.42	4.02±0.55	4.30±1.33
Inpago 5	3.21±0.81	3.74±0.54	4.42±0.15	1.92±0.26	6.50±0.94	5.67±0.82	3.04±0.54	3.52±0.45	4.00±1.48
Jatiluhur	4.60±0.37	3.90±0.75	3.57±0.75	3.61±1.03	6.07±0.32	4.21±0.95	3.09±0.09	3.77±0.53	4.10±0.91
Mean	4.44	3.25	3.01	2.55	6.18	5.55	3.16	3.77	3.99
LSD (5%)	0.88	0.68	0.58	0.49	0.92	1.14	0.64	0.66	0.27

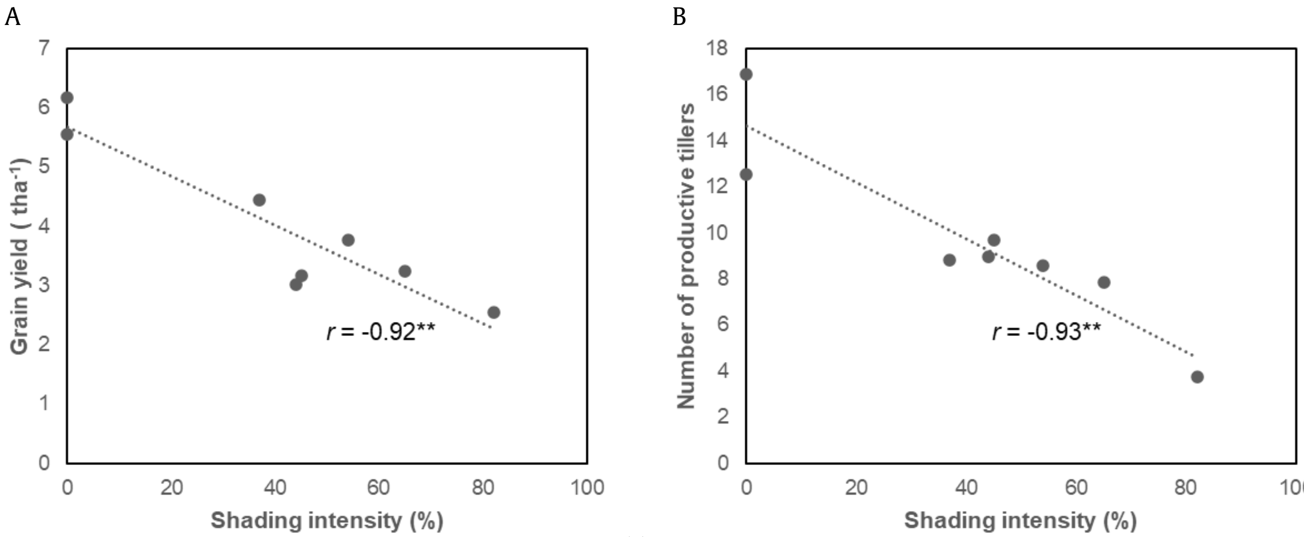

Figure 1. Relationship of shading intensity with (A) grain yield and (B) number of reproductive tillers of upland rice genotypes

intercropping in Subang and Indramayu, as well as monoculture in Purworejo. The genotype B11908F-TB-3-WN-1 was the best yielder in Cianjur and Lampung Tengah, which had 37% and 54% shading intensity, respectively. The genotype B12825E-TB-2-4 was the best performer in Lampung Timur, where rice was grown under natural rubber with a shading intensity of 45%. In Banyumas, the site with the highest shading intensity, rice variety Jatiluhur yielded 3.61 t ha^{-1} and was the best genotype in this site.

While genotype × environment interaction was significant for days to 50% flowering (DTF) characteristic (Table 2), the correlation between shading intensity and DTF was not significant ($p>0.05$). The environment means for DTF in Banyumas, the site with the highest shading intensity, was 90 d, comparable to the environment mean in monoculture sites Kebumen and Purworejo (Table 4). On average, the upland rice genotypes across the eight sites had a DTF of 82 to 87 d.

The number of productive tillers (NPT) was likely the most sensitive to shading. The correlation between shading intensity and NPT was negative and significant ($r = -0.93$) (Figure 1B). In monoculture sites Kebumen and Purworejo, the environment mean for NPT was 16.90 and 12.54 tillers per hill, respectively (Table 5). The number of productive tillers of upland rice sharply decreased in intercropping sites. The lowest environmental index for NPT was shown in Banyumas, which had the strongest light stress.

Shading stress affected the grain yield component, which was indicated by the variation in the number of grains per panicle (NGP) and the percentage of fertile grains per panicle (FGP) in different sites (Table 6). The highest NGP was shown in the monoculture site Purworejo, while the lowest NGP was in Subang, with 65% shading intensity. The lowest FGP was found in Banyumas, with a shading intensity of 82% (Table 6). In other sites where rice was cultivated as intercropping, the environmental index for FGP ranged from 60% to 77% and was comparable to the monoculture site.

The correlation between shading intensity and 1,000-grain weight (GW) was not significant ($p>0.05$). In shading conditions, the environment index of GW varied from 26.65 g (Lampung Timur) to 30.36 g (Indramayu) (Table 7). The 1000-grain weight of upland rice in the monoculture sites of Kebumen and Purworejo was also within the range. Among the upland rice lines, line B12480D-MR-7-1-1 showed the highest value of GW across the eight sites.

The relationship between agronomic traits with grain yield of rice genotype under different light intensities was clarified by correlation analysis (Table 8). Significant correlations were observed

Table 4. Days to flowering ± SD of upland rice genotypes across eight sites with different shading intensities

Genotype	Sites (shading intensity)								Mean
	Cianjur (37%)	Subang (65%)	Indramayu (44%)	Banyumas (82%)	Kebumen (0%)	Purworejo (0%)	Lampung Timur (45%)	Lampung Tengah (54%)	
B12480D-MR-7-1-1	89±1.3	89±1.9	78±4.5	94±1.7	91±1.0	83±4.0	84±0.5	83±0.8	86±5.2
B14086D-TB-70	89±0.0	86±1.0	75±3.0	92±3.2	91±1.9	83±1.9	81±2.2	79±1.0	84±6.1
B13642E-TB-71	88±4.0	88±3.1	80±2.9	87±1.3	84±0.5	83±5.3	83±0.5	81±5.2	84±3.0
B11908F-TB-3-WN-1	85±2.5	88±1.0	74±1.2	87±1.8	91±3.9	80±0.0	82±1.3	79±0.5	83±5.6
B12168D-MR-38-1-6-TB-1	88±3.0	87±0.8	71±1.5	89±1.0	91±5.0	80±0.0	84±2.1	82±0.8	84±6.4
B12056F-TB-1-29-1	90±1.0	86±0.8	76±2.5	90±0.8	93±2.2	81±1.4	78±0.0	79±0.6	84±6.4
B12159D-MR-40-1	91±2.8	89±2.2	73±4.2	92±3.7	93±3.9	84±1.0	89±0.0	86±0.8	87±6.4
B12056F-TB-1-64-6	85±2.5	87±1.0	74±1.4	84±1.5	86±1.5	80±0.0	82±1.0	81±0.8	82±4.2
B11604E-MR-2-4	91±2.8	88±2.1	73±2.4	90±1.7	92±1.7	80±2.9	83±0.5	84±1.0	85±6.2
B13655E-TB-13	96±0.6	88±3.5	82±2.4	94±0.8	86±1.3	77±1.3	92±4.2	86±0.0	87±6.3
B12056F-TB-1-5-4-1	89±0.0	87±0.5	74±4.5	89±0.8	91±2.2	81±1.9	80±0.5	77±1.0	84±6.3
B12825E-TB-2-4	91±1.0	88±1.3	72±1.5	89±1.0	86±1.7	85±1.3	81±1.5	77±0.5	83±6.3
Inpago 5	94±3.0	86±1.0	78±1.5	97±1.8	89±3.9	84±0.8	88±0.6	82±0.5	87±6.0
Jatiluhur	91±1.0	87±2.2	77±4.5	90±1.4	87±1.9	81±4.9	83±0.8	79±1.0	84±5.0
Mean	90	87	75	90	89	81	83	81	85
LSD	3	2	4	3	4	3	2	2	1

Table 5. Number of productive tiller ± SD of upland rice genotypes across eight sites with different shading intensities during

Genotype	Sites (shading intensity)								Mean
	Cianjur (37%)	Subang (65%)	Indramayu (44%)	Banyumas (82%)	Kebumen (0%)	Purworejo (0%)	Lampung Timur (45%)	Lampung Tengah (54%)	
B12480D-MR-7-1-1	6.92±1.91	7.75±2.41	8.50±2.27	3.58±1.52	18.05±2.73	10.15±0.47	9.25±1.44	7.55±0.66	8.97±4.16
B14086D-TB-70	7.75±1.26	5.50±1.91	7.50±1.58	3.67±0.00	18.30±2.56	10.60±1.32	9.40±1.63	8.70±1.15	8.93±4.37
B13642E-TB-71	7.42±1.23	3.83±2.40	9.88±1.70	5.17±2.59	15.85±2.79	12.10±0.93	9.15±1.02	7.45±1.33	8.86±3.84
B11908F-TB-3-WN-1	6.58±1.03	7.67±1.78	7.50±1.47	3.25±0.32	11.95±1.81	11.30±1.57	8.95±1.72	7.30±0.81	8.06±2.75
B12168D-MR-38-1-6-TB-1	9.25±1.45	7.58±2.22	11.88±2.10	3.75±0.74	16.55±2.94	11.45±2.13	11.20±1.90	7.95±0.89	9.95±3.77
B12056F-TB-1-29-1	6.67±1.05	9.08±4.46	9.25±2.60	3.21±0.92	15.85±1.71	12.00±1.23	10.60±1.70	8.45±0.66	9.39±3.71
B12159D-MR-40-1	9.58±1.66	7.17±5.10	9.00±2.08	4.33±1.19	18.30±0.87	14.15±2.50	9.60±1.07	10.15±1.95	10.29±4.26
B12056F-TB-1-64-6	7.92±0.50	6.58±2.17	8.38±0.75	3.75±2.64	14.90±1.23	12.05±1.59	9.35±1.53	7.50±0.74	8.80±3.40
B11604E-MR-2-4	7.83±2.19	7.33±2.87	8.63±1.25	2.92±0.96	15.80±1.10	12.70±2.54	8.85±1.97	7.40±1.74	8.93±3.85
B13655E-TB-13	13.42±0.74	11.25±4.88	10.63±1.25	3.33±1.05	19.60±4.79	14.80±1.07	10.00±0.82	10.50±1.29	11.69±4.64
B12056F-TB-1-5-4-1	9.92±2.46	7.50±2.62	7.88±1.31	3.08±0.57	17.45±0.68	15.25±1.80	10.45±2.14	9.30±1.52	10.10±4.51
B12825E-TB-2-4	8.67±1.12	7.83±4.15	8.63±1.44	3.83±1.45	18.75±3.60	12.45±0.57	9.10±1.67	8.95±0.81	9.78±4.32
Inpago 5	9.25±1.26	8.08±3.19	9.00±1.68	3.42±1.13	17.15±0.84	13.05±0.57	10.50±1.39	9.40±1.34	9.98±4.06
Jatiluhur	12.25±5.36	12.75±5.95	9.00±1.29	4.92±2.27	18.15±2.77	13.45±1.34	9.60±1.57	9.25±1.23	11.17±3.92
Mean	8.82	7.85	8.98	3.73	16.90	12.54	9.71	8.56	9.64
LSD	2.94	3.44	2.47	2.07	3.54	1.97	1.95	1.57	0.89

between NPT, NGP, FGP, and GW with grain yield. The highest correlation was found between NPT and grain yield (r = 0.63).

3.2. Yield Stability of Upland Rice

The stability of upland rice yield was determined by using a regression approach. The grain yield of the upland rice genotype was regressed against the environmental yield index (Figure 2A). Genotype which had regression coefficient approaching the slope for the overall regression (b = 1) is considered as stable genotype such as B12056F-TB-1-29-1, Inpago 5, B11908F-TB-3-WN-1, B12168D-MR-38-1-6-TB-1, B12825E-TB-2-4, and B13642E-TB-71 (Figure 2B). The stable genotype had a higher yield than the mean yield (3.99 t ha^{-1}) such as B12056F-

Table 6. Number of grains per panicle ± SD and percentage of fertile grains per panicle ± SD of upland rice genotypes across eight sites with different shading intensities

Genotype	Sites (shading intensity)								Mean
	Cianjur (37%)	Subang (65%)	Indramayu (44%)	Banyumas (82%)	Kebumen (0%)	Purworejo (0%)	Lampung Timur (45%)	Lampung Tengah (54%)	
Number of grains per panicle									
B12480D-MR-7-1-1	135.25±11.95	120.19±17.68	164.05±15.87	136.29±38.41	121.40±38.73	176.81±31.98	140.33±24.76	165.80±10.24	145.02±21.29
B14086D-TB-70	120.33±52.48	138.42±13.26	176.51±18.03	86.16±15.58	132.98±32.47	186.00±33.40	178.53±14.79	157.20±7.51	147.02±34.17
B13642E-TB-71	133.58±16.97	51.21±11.24	151.63±29.34	106.04±52.46	130.15±14.66	221.43±11.49	161.76±22.45	189.81±18.73	143.20±51.84
B11908F-TB-3-WN-1	151.25±56.72	113.66±34.35	139.31±11.06	127.67±14.58	131.70±12.07	188.50±14.84	176.93±30.12	168.20±21.39	149.65±26.21
B12168D-MR-38-1-6-TB-1	130.08±37.86	113.50±48.93	166.06±17.89	103.00±16.84	127.76±9.47	223.13±22.76	175.58±22.75	174.23±20.44	151.67±40.10
B12056F-TB-1-29-1	144.75±16.52	127.05±13.34	132.31±9.74	115.34±62.23	118.21±16.86	187.98±19.88	151.46±16.71	125.03±6.63	137.77±23.75
B12159D-MR-40-1	132.50±26.01	50.11±23.02	147.03±9.00	109.88±22.02	102.56±23.31	222.53±38.57	169.30±44.88	180.00±28.34	139.24±53.13
B12056F-TB-1-64-6	157.58±57.16	101.67±37.21	170.28±22.32	129.75±18.13	144.21±43.83	251.95±36.78	166.58±9.14	213.66±26.50	166.96±47.31
B11604E-MR-2-4	131.00±41.83	86.21±30.33	157.58±33.66	93.88±61.77	98.26±21.76	204.06±16.93	167.13±53.45	170.26±19.38	138.55±42.91
B13655E-TB-13	104.34±54.23	89.57±29.98	156.88±17.12	95.33±53.61	98.56±30.97	194.23±12.49	141.15±17.61	152.08±5.23	129.02±37.67
B12056F-TB-1-5-4-1	114.09±30.22	61.27±7.99	129.95±23.93	95.29±40.70	116.06±32.12	178.28±13.21	137.11±11.58	121.38±7.38	119.18±33.58
B12825E-TB-2-4	144.41±21.55	87.78±23.68	176.63±26.53	129.75±33.52	95.48±28.90	234.01±62.43	166.68±43.60	163.33±39.84	149.76±47.07
Inpago 5	123.16±23.27	98.46±38.74	168.80±12.66	96.46±26.44	121.58±15.36	214.56±22.99	122.28±28.29	170.23±16.91	139.44±41.16
Jatiluhur	135.00±34.61	51.29±6.42	162.66±12.07	120.55±20.32	100.38±14.22	218.43±41.84	141.01±39.29	128.88±14.62	132.28±48.04
Mean	132.67	92.17	157.12	110.39	117.09	207.28	156.85	162.86	142.05
LSD	38.76	37.56	31.16	49.24	38.35	41.11	39.55	29.31	13.26
Percentage of fertile grains per panicle									
B12480D-MR-7-1-1	77.39±17.87	83.67±6.53	66.14±4.32	36.35±23.90	83.28±4.71	79.20±4.45	63.76±10.79	74.85±3.57	70.58±15.63
B14086D-TB-70	77.98±13.91	82.84±5.83	64.49±11.71	61.90±20.33	86.29±4.45	77.66±5.71	81.38±3.95	82.16±7.10	76.84±8.88

Table 6. Continued

Genotype	Sites (shading intensity)								Mean
	Cianjur (37%)	Subang (65%)	Indramayu (44%)	Banyumas (82%)	Kebumen (0%)	Purworejo (0%)	Lampung Timur (45%)	Lampung Tengah (54%)	
B13642E-TB-71	77.35±6.44	69.65±5.54	56.95±7.17	51.67±7.96	67.19±2.18	60.72±5.87	62.77±7.84	71.75±7.43	64.76±8.37
B11908F-TB-3-WN-1	76.03±9.02	82.77±7.57	65.38±9.34	57.57±15.55	80.64±5.09	84.40±4.22	68.01±9.02	83.12±2.46	74.74±9.94
B12168D-MR-38-1-6-TB-1	73.61±3.15	67.62±4.04	69.69±6.18	52.99±24.85	73.64±6.97	75.04±9.82	77.94±5.78	81.79±5.23	71.54±8.70
B12056F-TB-1-29-1	86.07±2.02	73.11±5.08	64.00±9.69	43.50±22.43	74.26±4.58	80.58±6.12	70.37±5.07	86.70±2.69	72.32±14.00
B12159D-MR-40-1	80.13±8.38	70.72±6.84	59.40±9.00	51.61±24.46	82.37±3.26	70.17±9.42	81.51±8.95	76.00±4.05	71.49±11.07
B12056F-TB-1-64-6	69.33±5.35	74.43±8.75	44.15±11.51	27.17±27.99	65.45±5.24	67.61±3.56	61.47±5.08	64.49±5.21	59.26±15.72
B11604E-MR-2-4	78.18±10.73	75.98±7.91	58.28±3.99	47.54±12.69	76.16±8.79	78.89±3.24	55.20±12.69	68.21±2.52	67.30±12.10
B13655E-TB-13	69.89±12.88	85.82±5.79	63.97±5.06	47.99±16.38	80.24±3.21	87.03±3.27	72.87±6.54	83.40±2.43	73.90±13.27
B12056F-TB-1-5-4-1	75.97±5.51	71.91±7.84	53.10±6.96	42.54±24.02	84.16±3.31	72.53±7.47	76.86±2.83	83.50±1.60	70.07±14.71
B12825E-TB-2-4	67.74±20.88	76.65±8.68	61.25±5.04	54.01±16.50	68.11±11.45	73.30±5.91	65.83±3.85	77.24±6.10	68.02±7.88
Inpago 5	75.98±12.73	84.47±9.29	56.58±7.66	33.22±21.28	79.74±2.80	76.22±7.40	65.30±4.29	68.94±5.29	67.56±16.42
Jatiluhur	74.01±6.14	66.93±8.26	60.02±6.23	57.55±15.48	75.76±8.31	66.92±9.71	70.41±4.96	82.17±8.51	69.22±8.16
Mean	75.69	76.18	60.24	47.54	76.95	75.02	69.55	77.45	69.83
LSD	14.11	10.24	10.82	21.8	8.63	9.35	9.73	6.73	4.21

Table 7. One thousand grain weight ± SD (g) of upland rice genotypes across eight sites with different shading intensities

Genotype	Sites (shading intensity)								Mean
	Cianjur (37%)	Subang (65%)	Indramayu (44%)	Banyumas (82%)	Kebumen (0%)	Purworejo (0%)	Lampung Timur (45%)	Lampung Tengah (54%)	
B12480D-MR-7-1-1	33.63±0.43	33.15±0.83	33.43±0.39	28.75±0.11	32.83±0.25	32.35±1.94	28.25±0.42	28.68±0.54	31.38±2.37
B14086D-TB-70	32.23±0.26	27.68±4.39	33.10±0.18	29.16±0.07	33.48±0.46	30.41±2.53	25.90±0.26	25.75±0.84	29.71±3.10
B13642E-TB-71	30.33±0.10	30.25±0.50	30.50±0.36	29.69±0.46	29.30±0.44	30.84±0.83	26.25±0.53	26.55±0.44	29.21±1.80
B11908F-TB-3-WN-1	30.03±0.17	30.35±0.31	30.43±0.38	30.66±0.43	30.00±0.37	29.52±0.75	27.35±0.44	27.50±0.42	29.48±1.31
B12168D-MR-38-1-6-TB-1	29.53±0.29	28.33±0.21	27.30±0.73	22.34±0.31	26.53±0.43	26.47±0.89	26.10±0.68	26.15±0.30	26.59±2.09
B12056F-TB-1-29-1	28.25±0.26	32.13±0.35	30.35±0.06	26.29±0.08	20.69±0.51	29.72±2.92	27.08±0.51	27.00±0.16	27.69±3.44
B12159D-MR-40-1	25.03±0.05	21.83±0.21	28.68±0.46	25.45±0.37	23.53±0.35	23.64±1.20	27.18±0.62	27.45±0.44	25.35±2.32
B12056F-TB-1-64-6	28.85±0.06	29.83±0.63	32.43±0.50	26.26±0.22	29.90±0.65	29.22±2.00	26.80±0.28	27.05±0.25	28.79±2.04
B11604E-MR-2-4	29.13±0.26	23.68±0.28	26.48±0.53	23.25±0.13	26.38±0.35	24.48±0.70	26.40±0.57	26.25±0.34	25.76±1.90
B13655E-TB-13	25.63±0.26	27.43±0.40	28.40±0.64	26.35±0.30	27.60±0.48	26.30±0.93	26.15±0.25	26.10±0.66	26.75±0.95
B12056F-TB-1-5-4-1	33.05±0.13	31.23±0.39	32.83±0.59	29.53±0.31	33.65±0.42	29.94±0.57	26.35±0.66	26.53±0.41	30.39±2.84
B12825E-TB-2-4	30.00±0.14	26.65±0.47	32.48±0.41	26.98±4.99	32.70±0.57	29.43±2.66	26.45±0.25	26.78±0.33	28.93±2.62
Inpago 5	30.10±0.08	28.23±0.21	32.28±0.28	28.25±0.51	28.23±0.22	29.14±0.43	26.28±0.49	26.38±0.35	28.61±1.96
Jatiluhur	27.63±0.42	24.35±0.21	26.30±0.77	22.18±0.30	25.40±0.39	24.75±0.60	26.50±0.26	26.35±0.55	25.43±1.68
Mean	29.53	28.22	30.36	26.80	28.59	28.30	26.65	26.75	28.15
LSD	0.34	1.72	0.66	1.97	0.50	2.24	0.65	0.63	0.44

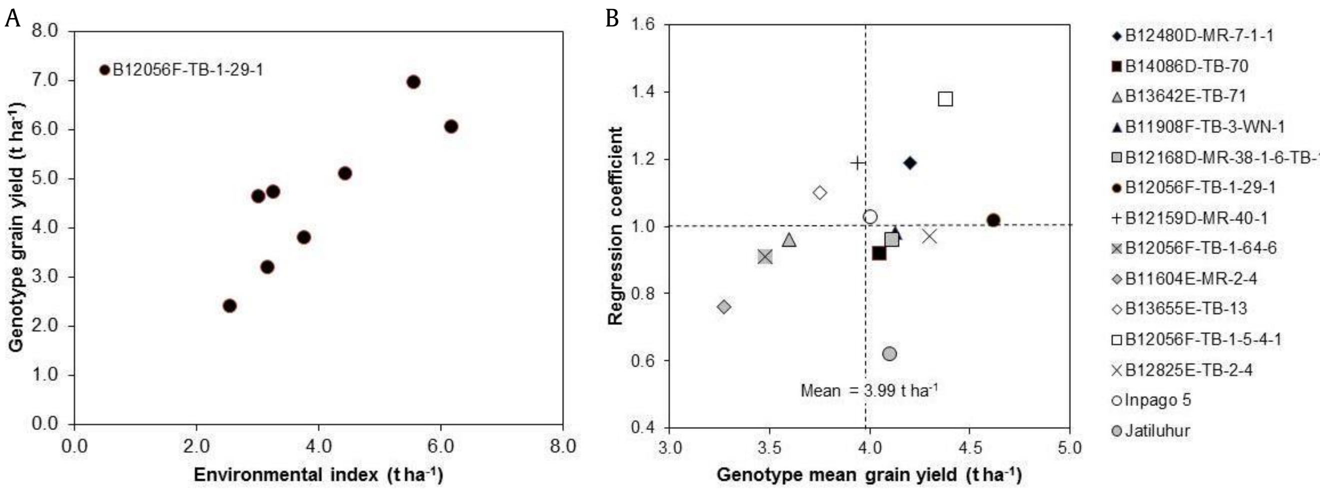

Figure 2. Yield stability of upland rice across eight environments. (A) Yield response of rice genotype B12056-TB-29-1 versus the environmental index in eight locations (B) A scattered regression coefficient plot versus upland rice genotype mean grain yield (t ha^{-1})

Table 8. Correlation of grain yield and agronomic characteristics of upland rice genotypes grown under different shading intensity

	NPT	DTF	NGP	FGP	GW	GY
NPT	1					
DTF	-0.021	1				
NGP	0.140**	-0.425**	1			
FGP	0.383**	-0.001	0.028	1		
GW	0.081	-0.078	0.022	0.041	1	
GY	0.630**	0.045	0.149**	0.401**	0.239**	1

NPT = number of productive tillers, DTF = Days to flowering, NGP = number of grains per panicle, FGP = percentage of fertile grains per panicle, GW = One thousand grain weight, GY = Grain yield, ** = P<0.01

TB-1-29-1, B12825E-TB-2-4, B11908F-TB-3-WN-1, and B12168D-MR-38-1-6-TB-1, were considered as genotypes which were well adapted to all environments. In contrast, the stable genotype with lower yield compared to mean yield, such as B13642E-TB-71, was poorly adapted to all environments.

Upland rice variety Jatiluhur showed a regression coefficient of 0.62 and was significantly different from the average slope (b = 1), which indicated that this genotype specifically adapted to an unfavorable environment such as in Banyumas, which had the highest shading intensity. In contrast, the regression coefficient of the genotype B12056F-TB-1-5-4-1 is significantly higher than 1, indicating that this genotype only adapted to a favorable environment, such as in Kebumen.

4. Discussion

The present study indicated the potential implementation of intercropping rice system in the different plantations commonly found in the tropical upland ecosystem, including tall coconut, rambutan, teak, albizia, and natural rubber (Wangpakapattanawong *et al.* 2017). The study showed significant genotype and environment interaction effects and suggested the opportunity to identify rice genotypes that specifically adapted to the intercropping system. Several studies indicated that intercropping systems needed specific cultivars for optimum utilization (Brooker *et al.* 2015; Ghauhan *et al.* 1994; Hondrade *et al.* 2017). While the yield environmental index of rice cultivation in intercropping was lower than in monoculture, there were potential genotypes well adapted to low-light-stress environments.

The low grain yield of rice in the intercrop system was suggested to be associated with the reduction in important yield components such as the number of productive tillers, number of grains per panicle, number of fertile grains per panicle, and grain weight, as indicated by a significant correlation between grain yield and these characteristics. The number of the productive tiller (NPT) is one of the important components determining grain yield (Li *et al.* 2003). The effect of light intensity on tiller number has been reported in previous studies (Hairmansis *et al.* 2017; Lafarge *et al.* 2010; Liu *et al.* 2014). Admittedly, in addition to the light intensity, many environmental factors might influence the genotype and environment interaction, including altitude and soil type (Cairns *et al.* 2011; Shrestha *et al.* 2013). Rice grown at high altitudes could be affected by low-temperature stress (Shrestha *et al.* 2013). The present multi-environmental yield trials were conducted in low to mid-altitude areas where most tropical upland rice varieties adapted, thus avoiding the effect of altitude on the genotype and environment interaction. In addition, different soil types among the experimental sites can potentially be confounding variables in this study's genotype and environment interaction. However, the association between environmental yield index and soil type was insignificant based on the Spearman correlation test ($p>0.05$, data not shown).

The breeding program aimed to develop stable and high-yielding rice genotypes in various environments. In this study, several genotypes showed stable and high yields, such as B12056F-TB-1-29-1, B12825E-TB-2-4, B11908F-TB-3-WN-1, and B12168D-MR-38-1-6-TB-1. However, narrow adaptability might be helpful for a specific purpose. For instance, genotype Jatiluhur which had a regression coefficient significantly lower than 1, would be beneficial for rice cultivation in plantation areas with high shading intensity. In contrast, a genotype with a regression coefficient significantly higher than 1, such as B12056F-TB-1-5-4-1, would be helpful for rice cultivation in favorable areas as a monoculture. Genotype with $b < 1$, like Jatiluhur, is called a "work horses" genotype, while a genotype with $b > 1$, like B12056F-TB-1-5-4-1, is called a "race horses" genotype (Tollenaar and Lee 2002). Fertile irrigated rice cultivation areas were predicted to significantly decrease as the impact of climate change (Bouman *et al.* 2005; Tuong and Bouman 2003). The situation strived for the utilization of unfavorable dryland areas. Upland areas in between plantations are potential land resources for rice cultivation. Identification of rice genotypes adapted to the intercropping system in this study presented an opportunity to increase rice production in such an ecosystem. Recently, the stable and high-yielding rice line revealed from this study, B12056F-TB-1-29-1, was released as a new upland rice variety in Indonesia named "Rindang 1 Agritan". In addition to its adaptability to a shading environment, this rice line has other desirable characteristics for upland ecosystems, including resistance to rice blast disease, moderately tolerant to drought, and tolerance to aluminum toxicity (Sastro *et al.* 2021). The variety is expected to be adopted by farmers for intercropping rice cultivation. The sustainable rice production landscape integrated with agroforestry (Wangpakapattanawong *et al.* 2017) should be implemented to cultivate such improved rice variety as intercropping.

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