Improved Rice Varieties Developed for High-Altitude Tropical Upland Areas of Indonesia

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Abstract— **Sustainability of rice (*Oryza sativa* L.) production in high-altitude tropical upland is challenged by various abiotic and biotic problems. The main problems include low temperatures and blast disease. Farmers in high-altitude tropical uplands of Indonesia are still growing traditional rice varieties due to the absence of improved adaptive varieties. Development of improved varieties which are adapted to the high-altitude upland environment is therefore needed to increase productivity. This study aimed to investigate the interaction of genotype and environment of upland rice varieties across ten high-altitude upland locations in Indonesia and to determine their adaptability in the target areas. In addition, screening on blast disease and grain quality analysis was performed to characterize the genotypes. Significant interaction effects between genotype and the environment were observed for all agronomic characters. Genotype adaptability was determined based on the regression coefficient of grain yield and the environmental index. Genotypes such as B14168E-MR-10 adapted well in locations with low environmental indexes. In contrast, genotypes such as B11592F-MR-23-2-2 adapted well in locations with high environmental indexes. Screening using ten rice blast races showed that upland rice genotypes had a broad spectrum of resistance. Most of the genotypes had intermediate amylose content in the grains. Recently, the lines B14168E-MR-10 and B11592F-MR-23-2-2 have been approved to be released as new, improved rice varieties for high-altitude upland in Indonesia, namely Luhur 1 and Luhur 2, respectively. Both varieties are expected to be adopted by farmers in high-altitude upland to increase rice productivity in this environment.**

Keywords— **Upland rice; high altitude; low-temperature stress; blast disease.**

I. INTRODUCTION

Rice is the staple food for almost half of the world population [1]. Rice production must be continuously increased to meet the growing demand of the world population. Upland rice cultivation, which covered about 15 million hectares worldwide, contributes to achieving global rice production sustainability [2]. In Indonesia, upland rice is cultivated in about 1.1 million hectares and is the largest among Southeast Asian countries [3]. Upland rice areas are distributed from low to high-altitude and scattered throughout the islands of the country.

Rice production in upland is constrained by various biotic and abiotic stresses resulting in lower yield than lowland rice cultivation. Blast disease is considered major biotic stress, while drought, aluminum toxicity, and nutrient deficiency are among major abiotic constraints in tropical upland rice areas [3]. In the high-altitude upland area, cold stress become an additional problem in rice production [4]. Farmers in Indonesia's high-altitude upland area are growing low-yielding traditional rice varieties with good adaptability to environmental stresses due to no improved varieties adapted to this harsh environment. The development of improved varieties that are tolerant to environmental stresses in high-

altitude upland is important to increase rice productivity in this specific ecosystem.

Low-temperature stress severely affected rice production in a temperate region and high-altitude of tropical areas [4]–[7]. Rice is seriously affected by low-temperature stress during germination, seedling, and reproductive stages [5]. Cold stress inhibited rice germination and slowed rice's early development [8]. Cold stress delayed growth during the vegetative stage and caused severe stunting in susceptible varieties [9]. In the reproductive stage, rice panicle's stress-induced sterility thus significantly reduced grain yield [10].

Genetic variation in the tolerance to low temperature has been intensively studied in rice germplasm [9]–[11]. Several traditional varieties from high-altitude areas have been used as a donor for the improvement of cold tolerance, such as Silewah [11] and Sigambiri Putih [12] from Indonesia, and Chhomrong Dhan from Nepal [13]. In Indonesia, a number of cold-tolerant rice varieties have been introduced to the farmers in high-altitude regions for irrigated ecosystems [14], [15] but not for upland. The effect of low temperature on rice cultivated in upland was suggested to be more serious than irrigated in which the water layer functioned as a thermal buffer [4]. Many potential rice lines for high altitude upland have been identified through conventional breeding combined with the participatory approach [16].

To further develop rice varieties adapted to high-altitude upland, it is needed to evaluate rice breeding lines' adaptability in multi-environments. Through multi-environments test, the interaction of genotype and environment can be clarified. Therefore, breeders would determine rice varieties that will be introduced for adoption by farmers in specific environments [17], [18]. This study's objective was to study the interaction of genotype and environment of upland rice genotypes in multi-environment trial in high-altitude upland areas. In addition, screening on blast disease under artificial condition and grain quality analysis were performed to be used as references in selecting rice varieties which will be introduced to farmers in the tropical high-altitude upland of Indonesia.

II. MATERIALS AND METHOD

A. Plant Materials

Twelve advanced upland rice breeding lines were used in this study, including B13650E-TB-80-2, B11592F-MR-23-2-2, B12165D-MR-8-1-1-2, B11910D-MR-22-2, B14217F-MR-1, B14168E-MR-5, B14168E-MR-6, B14168E-MR-10, B14168E-MR-11, B14168E-MR-12, B14168E-MR-13, and B14168E-MR-20. Indonesian Center for Rice Research developed the materials. Improved upland rice variety Limboto and traditional rice variety Sigambiri Putih were used as check varieties. Additionally, blast susceptible check variety, Kencana Bali, was used in the experiment for blast disease screening.

B. Multi-location Yield Trials

Multi-location yield trials were conducted in ten sites representing high-altitude tropical upland areas in three provinces of Indonesia, including North Sumatra, West Java, and Central Java provinces (Table 1). The altitude ranged from the lowest of 707 meters above sea level (masl) in

Temanggung (Central Java) to the highest of 1059 masl in Wonosobo (Central Java). The trials were performed during wet season (WS), which were started around September to November 2015. In each site, the experiment was arranged in a randomized completed block design with four replications. Upland rice establishment was carried out by direct seeding with plant spacing of 30 cm × 15 cm. Fertilizers were applied to the experimental plot in the rate of 200 kg ha^{-1} urea, 100 kg ha^{-1} SP36 and 100 kg ha^{-1} KCl. Number of productive tillers, plant height, flowering time, maturity, number of grains per panicle, 1000 grain weight and grain yield were recorded in all experimental sites. Combined analysis of variance (ANOVA) was performed to determine the interaction of genotype and environment. Stability analysis was carried out using regression coefficient of yield and environmental index [19]. Statistical analysis was performed using CropStat.

TABLE I
SITES FOR MULTILOCATION YIELD TRIAL OF HIGH-ALTITUDE UPLAND RICE GENOTYPES DURING WS 2015-2016

Sites	Elevation (m asl)	Average temperature (°C)*	Sowing date
Majanggut I, Pakpak Bharat, North Sumatra	809	22.3	02-09-2015
Sukarame, Tanah Karo, North Sumatra	1053	21.1	04-09-2015
Siempat Nempuh, Dairi, North Sumatra	813	-	03-09-2015
Karang Kobar, Banjarnegara, Central Java	851	21.0	14-11-2015
Bulu, Temanggung, Central Java	707	22.3	08-11-2015
Kepil, Wonosobo, Central Java	1059	23.6	12-11-2015
Kaliangkrik, Magelang, Central Java	900	21.7	09-11-2015
Cibadak, Cianjur, West Java	900	21.5	25-11-2015
Pasirjambu, Bandung, West Java	923	21.1	23-11-2015
Pasirwangi, Garut, West Java	995	20.1	24-11-2015

*Data source: https://en.climate-data.org/

C. Evaluation of Blast Disease Resistance

The resistance of rice genotypes against rice blast disease was analyzed during a seedling stage in a greenhouse. Ten rice blast races were used in this study to determine the reaction pattern of rice genotype in a wide range of blast isolates. The rice blast races were race 001, race 013, race 041, race 033, race 073, race 133, race 173, race 023, race 101, and race 051. Preparation of rice blast inoculum, rice growth condition, rice blast infection, and scoring of the symptoms were performed following the protocol described in the previous study [20].

D. Evaluation of Grain Quality

Analysis on grain quality was performed to determine the amylose content and the texture of rice genotypes. For each genotype, a total of 100 mg of rice powder (sieve mesh size 80) was used as the sample for amylose content analysis. The

analysis was performed following the protocol described by [21]. Based on the amylose content, the texture of rice genotype were classified as waxy (0-2%), very low (3-9%), low (10-19%), intermediate (20-25%) and high (>25%) [22].

The texture of cooked rice was determined using an organoleptic test by 20 panelists. A total of 200 g of rice samples were cooked using 300 ml water using the electric rice cooker. Cooked rice, which was cooled down, was then placed on a small plate and distributed to the panelists. Each panelist scored the rice texture as very soft (1), soft (2), medium (3), and hard (4). Classification of rice texture was based on the average score of all panelists and classified as very soft (1-1.5), soft (1.6-2.4), medium (2.5-3.4), and hard (3.5-4.0).

III. RESULTS AND DISCUSSION

A. Genotype by Environment Interaction of Agronomic Characters

Combined ANOVA was performed to clarify the interaction of genotype and environment on important agronomic characters of upland rice grown across ten locations. The effect of genotype (G), environment (E), and G×E interaction were significant for all traits, including plant height, number of tillers, flowering time, maturity, number of filled grain per panicle, number of empty grains per panicle, the total number of grains per panicle, the weight of 1000 grains, and grain yield (Table 2). The presence of G×E interaction indicated that the genotype ranking varied in different sites and determined the general and specific adaptation of rice genotypes to different sites [17], [23].

TABLE II
MEAN SQUARE OF AGRONOMIC CHARACTERS OF RICE IN COMBINED ANOVA ACROSS TEN SITES OF MULTI-LOCATION TRIALS OF UPLAND RICE IN HIGH ALTITUDE AREAS DURING WS 2015-2016

Source of variation	Degree of freedom	PH	NPT	DF	DM	FG	EG	TG	GW	GY
Environment	9	18134.5**	631.9**	1618.9**	2568.5**	37490.7**	8449.8**	39237.6**	226.4**	71.4**
Replication within Environment	30	358.3**	28.2**	17.9**	10.0**	3642.1**	569.4**	3619.2**	7.2**	0.1ns
Genotype	13	7050.9**	68.9**	315.3**	342.7**	1835.3**	1954.2**	4719.5**	193.3**	10.7**
Genotype × Environment	117	269.6**	18.5**	44.1**	31.3**	1356.2**	1028.2**	1194.3**	8.7**	4.0**
Error	390	120.1	10.8	3.7	1.9	501.0	239.9	659.7	3.0	0.2

PH= plant height (cm), NPT= number of productive tillers, DF= days to 50% flowering, DM= days to maturity, FG= number of filled grain per panicle, EG= number of empty grains per panicle, TG= total number of grains per panicle, GW= weight of 1000 grains (g), GY= grain yield (t ha^{-1})

Wide variation in agronomic characters were observed among the upland rice genotypes and across the environments (Table 3). Average data from ten sites showed the plant height of upland rice genotypes ranged from 97.74 to 153.43 cm. The rice breeding lines had higher plant architecture than check variety Limboto but lower than traditional check variety Sigambiri Putih. Comparing the average plant height of improved variety Limboto in the present study and the result from multi-location trial in low altitude [20] indicated that rice's plant height decreased in high-altitude. Several studies also reported that plant height increased by the increase of temperature [24].

TABLE III
AGRONOMIC CHARACTERS OF UPLAND RICE BREEDING LINES AND CHECK VARIETIES ACROSS TEN SITES OF MULTILOCATION YIELD TRIALS DURING WS 2015-2016 IN HIGH ALTITUDE AREAS

Genotypes	PH	NPT	DF	DM	FG	EG	TG	GW
B13650E-TB-80-2	123.85	13.13	95.73	123.20	118.44	55.37	173.80	22.99
B11592F-MR-23-2-2 (Luhur 2)	110.56	13.74	97.35	123.00	110.58	36.99	147.57	24.55
B12165D-MR-8-1-1-2	131.47	10.70	105.48	131.53	117.24	58.07	175.32	26.78
B11910D-MR-22-2	118.70	12.31	103.45	128.55	103.88	46.30	150.17	25.76
B14217F-MR-1	111.92	12.27	100.30	125.28	107.70	37.69	145.39	26.67
B14168E-MR-5	112.17	14.42	100.05	125.03	110.15	46.55	156.69	25.68
B14168E-MR-6	110.76	14.83	99.78	124.55	107.48	44.34	151.82	25.02
B14168E-MR-10 (Luhur 1)	120.20	14.18	100.08	124.40	117.79	42.49	160.28	26.38
B14168E-MR-11	112.82	14.62	100.55	124.70	117.18	45.65	162.83	25.71
B14168E-MR-12	109.07	14.67	99.33	124.53	111.73	41.92	153.65	27.18
B14168E-MR-13	111.56	12.95	98.33	124.08	101.67	55.65	157.32	24.69
B14168E-MR-20	107.53	13.94	100.08	124.80	97.96	41.05	139.01	23.73
Limboto	97.74	12.07	95.93	121.83	100.91	47.47	148.37	26.29
Sigambiri Putih	153.43	11.83	103.78	131.35	105.44	35.74	141.18	32.40
Mean	116.55	13.29	99.99	125.48	109.15	45.38	154.53	25.98
LSD (5%)	4.82	1.44	0.85	0.61	9.84	6.81	11.29	0.77

PH= plant height (cm), NPT= number of productive tillers, DF= days to flowering, DM= days to maturity, FG= number of filled grains per panicle, EG= number of empty grains per panicle, TG= number of total grains per panicle, GW= weight of 1000 grains (g)

The number of productive tillers (NPT) of upland rice genotype ranged from 10.70 to 14.83 (Table 3). The NPT of breeding lines were mostly higher than traditional variety Sigambiri Putih except for B12165D-MR-8-1-1-2.

Improvement in number of productive tillers is one of breeding target to increase yield [25].

Average flowering time of upland rice in high altitudes ranged from 95.73 to 105.48 days, while the maturity from 121.83 to 131.53 days (Table 3). Almost all upland rice breeding lines had earlier maturity compared to traditional check variety Sigambiri Putih except B12165D-MR-8-1-1-2. The maturity period of rice in high-altitude was longer compared to in low-altitude [26]. Improved variety Limboto showed an average of maturity of 111 days when grown in low-altitude [20], about 10 days earlier compared to maturity in this study. The differences in the growth period between high altitude and low altitude might be related to air temperature differences [24].

The number of filled grains per panicle of upland rice genotypes across ten environments ranged from 97.96 to 118.44 (Table 3). Among the rice genotypes, the line B14168E-MR-10 had the highest number of filled grains per panicle. The number of empty grains per panicle ranged from 35.74 to 58.07, and the total number of grains per panicle ranged from 139.01 to 175.32. The grain weight of upland rice genotypes varied from 22.99 to 32.40 g (Table 3). Grain filling characters were highly affected by low-temperature

stress [5], [6], [10]. Cold tolerant rice variety exhibited high rate of seed set under low temperature stress [6].

B. Grain Yield and Stability Analysis

The ranking of grain yield of upland rice varied among sites (Table 4). In Pakpak Bharat (809 masl), the best-yielding genotype was B14168E-MR-12 (5.93 t ha^{-1}). In the higher location Tanah Karo (1053 masl), the highest yield was achieved by traditional check variety Sigambiri Putih (5.66 t ha^{-1}). Four breeding lines produced grain yield more than 3 t ha^{-1} in Tanah Karo, namely B14168E-MR-10, B14168E-MR-11, B14168E-MR-12, and B14168E-MR-13. The line B14168E-MR-10 was also the highest-yielding genotype in Dairi (813 masl) and Bandung (923 masl), producing a grain yield of 4.78 t ha^{-1} and 4.66 t ha^{-1}, respectively. Among the sites, Cianjur (900 masl) had the highest environmental mean for grain yield (6.68 t ha^{-1}). In this site, two lines showed grain yield more than 8 t ha^{-1} (B14217F-MR-1 and B14168E-MR-5). In Garut (995 masl) and Banjarnegara (851 masl), the line B11592F-MR-23-2-2 showed the best performance genotype yielded 4.93 t ha^{-1} and 5.67 t ha^{-1}, respectively. In the location with the lowest altitude, Temanggung, the highest yield was achieved by Limboto (6.21 t ha^{-1}), the variety which was developed for low altitude upland areas.

TABLE IV
GRAIN YIELD OF UPLAND RICE VARIETIES IN MULTILOCATION YIELD TRIALS DURING WS 2015-2016 IN TEN SITES OF HIGH ALTITUDE UPLAND AREAS

Genotypes	Grain yield (t ha^{-1}) in each site (altitude - masl)										Genotype Mean (t ha^{-1})
	Pakpak Bharat (809)	Tanah Karo (1053)	Dairi (813)	Cianjur (900)	Bandung (923)	Garut (995)	Banjarnegara (851)	Temanggung (707)	Magelang (900)	Wonosobo (1059)	
B13650E-TB-80-2	2.90	2.90	1.82	7.30	3.32	4.47	3.66	4.36	3.05	4.32	3.81
B11592F-MR-23-2-2 (Luhur 2)	4.93	2.76	2.30	6.82	2.68	4.93	5.67	5.26	6.86	3.33	4.55
B12165D-MR-8-1-1-2	2.98	2.48	2.61	5.93	3.22	3.12	3.95	4.42	5.50	4.26	3.85
B11910D-MR-22-2	3.88	2.30	0.20	6.61	3.58	3.43	4.28	5.10	7.08	3.83	4.03
B14217F-MR-1	5.75	2.78	3.16	8.64	3.62	3.83	4.54	5.38	5.01	3.17	4.59
B14168E-MR-5	5.15	2.82	4.61	8.62	3.58	3.33	3.79	3.88	5.31	5.29	4.64
B14168E-MR-6	3.20	2.77	2.43	6.10	2.83	3.40	4.38	4.81	5.27	3.64	3.88
B14168E-MR-10 (Luhur 1)	5.77	3.47	4.78	6.41	4.66	4.10	3.83	5.04	5.84	4.23	4.81
B14168E-MR-11	5.25	3.34	4.20	5.32	4.37	4.10	4.45	4.67	6.67	5.03	4.74
B14168E-MR-12	5.93	3.67	4.38	6.55	4.11	3.65	3.48	5.53	6.40	3.87	4.76
B14168E-MR-13	3.68	3.14	0.78	5.91	3.51	4.00	3.33	4.67	4.85	5.15	3.90
B14168E-MR-20	1.02	1.99	2.39	5.97	3.48	3.80	3.85	5.33	5.32	5.84	3.90
Limboto	2.43	2.18	1.73	5.65	3.24	3.69	2.96	6.21	2.23	2.12	3.24
Sigambiri Putih	3.68	5.66	3.01	7.05	2.06	2.44	3.30	3.31	1.45	2.46	3.44
Environmental Mean (t ha^{-1})	4.20	2.87	2.81	6.68	3.58	3.85	4.10	4.87	5.60	4.33	4.29
Coefficient of variation (%)	10.88	11.02	11.53	10.07	11.48	15.01	10.58	12.88	10.14	11.26	11.49
Least significant difference (5%)	0.63	0.48	0.45	0.96	0.57	0.8	0.6	0.89	0.73	0.65	0.68

Across ten locations, the grain yield of upland rice genotypes ranged from 3.24 to 4.81 t ha^{-1}. The best genotype across ten locations was B14168E-MR-10 which had a higher mean of yield than both check varieties Limboto and Sigambiri Putih (Table 4). Stability analysis was performed by using regression of yield to the environmental yield index [19]. The coefficient of regression of upland rice variety varied, indicating that specific adaptation of rice genotypes to different environments. Several genotypes showed a coefficient of regression less than 1.0, namely B14168E-MR-

10, B14168E-MR-11, B14168E-MR-12, and Sigambiri Putih (Fig. 1).

These genotypes adapted to poor environments, such as in Tanah Karo and Dairi (Table 4). In contrast, genotype had a coefficient of regression more than 1.0 (B11592F-MR-23-2-2, B11910D-MR-22-2, B14217F-MR-1) adapted to the environment with high yield indexes such as in Cianjur and Magelang. Information on the adaptability of rice genotypes in a specific environment is important to determine the target area of adoption [18], [27], [28].
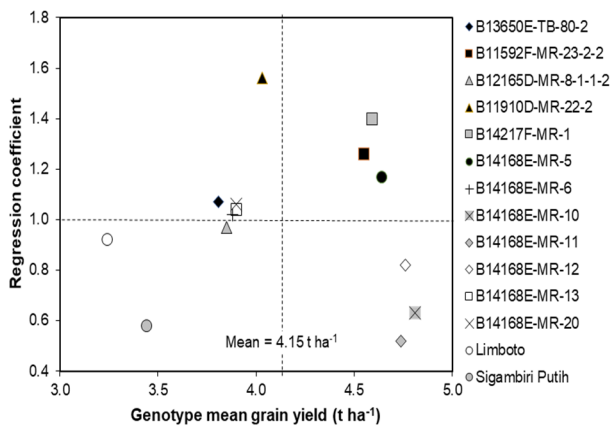
Fig. 1. Biplot of genotype mean grain yield and regression coefficient (*bi*) of grain yield to upland rice's environmental yield index in multi-location yield trials during WS 2015-2016 in high-altitude upland areas.

C. Response to Rice Blast Disease

Upland rice genotypes showed varying responses against ten races of *P. grisea* (Table 5). Susceptible rice check variety Kencana Bali showed a susceptible response to all blast races indicating that all blast isolates used were virulence. Upland rice breeding lines showed resistant or moderate resistant responses to five or more blast races indicating the wide spectrum response of blast resistance of the lines. Cultivation of rice varieties having broad-spectrum resistance in upland is important to minimize yield losses due to blast infection [29]. Two genotypes showed resistant or moderately resistant responses to all blast races viz. B14168E-MR-12 and check variety Limboto. Five genotypes, namely B13650E-TB-80-2, B11592F-MR-23-2-2, B14168E-MR-6, B14168E-MR-11, and traditional variety Sigambiri Putih, showed resistant or moderately resistant response against nine of blast races and were susceptible to only one of the blast races. Such variation in rice genotypes' blast resistance would benefit from being utilized in rice blast management in the upland area through cultivar mixture [30].

D. Rice Grain Quality

Amylose content of upland rice genotypes ranged from the lowest of 20.23% (Sigambiri Putih) to the highest of 24.78% (Limboto) (Table 6). Hence, they were classified as intermediate (20-25%) [22]. Rice with intermediate amylose content is preferred by most Indonesian consumers, particularly in Java island [31]. The cooked rice texture of upland rice genotypes was mostly classified as medium rice, except for B14168E-MR-10 and Sigambiri Putih, which had a soft texture (Table 6).

TABLE V
LEAF BLAST RESISTANCE OF UPLAND RICE GENOTYPES ARTIFICIALLY INOCULATED BY TEN RACES OF *P. GRISEA* DURING SEEDLING STAGE IN GREENHOUSE

Genotypes	Reaction to *P. grisea* races									
	Race 001	Race 013	Race 041	Race 033	Race 073	Race 133	Race 173	Race 023	Race 101	Race 051
B13650E-TB-80-2	R	R	R	MR	R	R	R	S	R	MR
B11592F-MR-23-2-2 (Luhur 2)	MR	MR	S	MR	R	MR	MR	R	MR	MR
B12165D-MR-8-1-1-2	MR	MR	S	MR	R	MR	R	S	MR	S
B11910D-MR-22-2	MR	MR	S	MR	R	MR	R	R	MR	R
B14217F-MR-1	MR	MR	R	R	MR	MR	R	MR	S	S
B14168E-MR-5	MR	R	MR	MR	MR	S	S	MR	S	S
B14168E-MR-6	R	R	R	R	MR	R	S	R	MR	R
B14168E-MR-10 (Luhur 1)	S	R	MR	MR	MR	S	S	MR	R	S
B14168E-MR-11	R	MR	R	MR	R	MR	MR	R	MR	S
B14168E-MR-12	R	MR	R	R	R	MR	R	R	MR	MR
B14168E-MR-13	S	MR	MR	S	MR	S	MR	MR	MR	S
B14168E-MR-20	S	R	MR	S	S	S	R	MR	MR	S
Limboto	R	R	R	R	R	MR	MR	R	R	MR
Sigambiri Putih	MR	R	MR	MR	R	R	MR	R	R	S
Kencana Bali (susceptible check)	S	S	S	S	S	S	S	S	S	S

*R= Resistant, MR= Moderately resistant, S= Susceptible

TABLE VI
AMYLOSE CONTENT AND COOKED RICE TEXTURE OF HIGH-ALTITUDE
UPLAND RICE GENOTYPES

Genotype	Amylose content (%)	Rice texture
B13650E-TB-80-2	23.31	Medium
B11592F-MR-23-2-2 (Luhur 2)	24.28	Medium
B1216D-MR-8-1-1-2	24.13	Medium
B11901D-MR-22-2	24.12	Medium
B14217F-MR-1	24.22	Medium
B14168E-MR-5	22.16	Medium
B14168E-MR-6	24.32	Medium
B14168E-MR-10 (Luhur 1)	21.03	Soft
B14168E-MR-11	23.44	Medium
B14168E-MR-12	22.21	Medium
B14168E-MR-13	23.15	Medium
B14168E-MR-20	23.22	Medium
Limboto	24.78	Medium
Sigambiri putih	20.23	Soft

E. Registration of the new rice varieties

Farmers in high altitude upland of Indonesia until now is still growing traditional rice varieties such as Sigambiri Putih [32]. The absence of improved upland rice varieties which adapted to the areas is one of the reasons. Knowledge of the adaptability of sweetened upland rice in different environments in this study is important in determining the varieties' target adoption. In addition, information on their resistance to blast disease observed through this study could be used as the basis in varietal recommendation. More importantly, the rice varieties' grain quality could be aligned to the preference of the consumer in the target areas. Two breeding lines evaluated in this study, B14168E-MR-10 and B11592F-MR-23-2-2, were recently released as new varieties for Indonesia's high-altitude upland environment Luhur 1 and Luhur 2, respectively. These two varieties were among high-

yielding lines, and they had contrast adaptability to a different environment. Both varieties had wide spectrum of blast resistance and showed acceptable cooked rice texture. It is expected that the farmers will rapidly adopt these two varieties in high-altitude upland areas of Indonesia.

IV. Conclusion

The interaction between genotype and environment significantly affected rice agronomic performance in high altitude upland areas. The rice genotypes varied in their adaptability in different environments. Genotypes such as B14168E-MR-10 adapted well in locations with low environmental indexes, while genotypes such as B11592F-MR-23-2-2 adapted well in high environmental indexes. The upland rice genotypes had a broad spectrum of resistance to rice blast disease. Most of the genotypes had intermediate amylose content in the grains. Improved rice varieties identified through this study have the potential to be adopted by farmers in high altitude areas to increase rice productivity.

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