Yield Stability of Aromatic Upland Rice with High Yielding Ability in Indonesia

Totok Agung Dwi Haryanto, S. Suwarto & Tomohiko Yoshida

Yield Stability of Aromatic Upland Rice with High Yielding Ability in Indonesia

Totok Agung Dwi Haryanto[1], Suwarto[1] and Tomohiko Yoshida[2]

(*[1]Faculty of Agriculture, Jenderal Soedirman University, Purwokerto 53123, Indonesia;*
[2]Faculty of Agriculture, Utsunomiya University, Utsunomiya 321-8505, Japan)

Abstract : Aromatic rice variety, Mentikwangi, was crossed with high-yielding upland rice variety, Poso, and the pedigree was selected to obtain lines with high yielding and aromatic characters. The objectives of the research were to study the yield stability of aromatic upland genotypes across different locations and to select aromatic upland rice genotypes having wide adaptability, and or specific location adaptability. Yield stability of genotypes was estimated by using regression lines proposed by Finlay and Wilkinson. Some genotypes showed high yield stability and wide adaptability in different locations, and others showed good adaptability to a specific location. The lines having high yield stability and wide adaptability were G10 (405 g m^{-2}), G19 (400 g m^{-2}), G39 (418 g m^{-2}), and G136 (411 g m^{-2}), which may be considered as candidates of new aromatic upland rice cultivars. Situpatenggang had specific adaptability at the fertile locations; and Poso and G13 at the infertile locations. Genotype x location interactions for the yield and its components performance were observed.

Key words : Adaptability, Aromatic upland rice, Yield stability.

Rice is one of the most important food crops in the world and the second largest cereal crop. Rice is the staple food of nearly one-half of the world's population. It contributes over 20% of the total calorie intake of the human population (Chaudhary and Tran, 2001). In general, rice is boiled and eaten as a main dish; however, with the development of the processing industry and increased prosperity, it is processed to create a variety of rice products, as well as forming a constituent of a wide range of snack foods, baked products and beverages. Different kinds of preparation of rice demand different grain qualities; both physical and chemical. There are rice varieties which produce grain of a different kind in terms of physical appearance, chemical composition or aroma. A number of aromatic rice varieties are known in various countries. In India, Pakistan, Thailand, Bangladesh, Nepal, Iran, Afghanistan, Myanmar, and also Indonesia these rice varieties are the most prized.

There are many studies on aromatic rice in Asia. Breeding, production and future prospects of aromatic rice have been studied in China (Tang and Wang, 2001), India (Bentur and Krishnaiah, 2001; Modgal and Gupta, 2001; Rani and Krishnaiah, 2001; Singh et al., 2001), Cambodia (Sarom, 2001), Myanmar (Nwe et al., 2001), Pakistan (Mann and Ashraf, 2001), Thailand (Narula and Chaudhary, 2001) and Viet Nam (Nghia et al., 2001a, b).

In Indonesia, aromatic rice which have a perfumed, nutty flavour, aroma, and have a light, fluffy texture when cooked was already cultivated for a long time.

Farmers are usually growing local aromatic rice cultivars in an irrigated land, such as Pandanwangi, and Rojolele. However, the local cultivars are late maturity (more than 120 days) and sensitive to pest and disease. Several new aromatic rice cultivars were already released in recent years such as Bengawan Solo (1993), Sintanur (2001) and Batang Gadis (2002) which have high yielding, early maturing, and tolerant to pest and disease relatively.

Kato et al. (2006a) mentioned that developing of new water-saving rice production systems, besides enhancing and stabilizing of current rainfed rice production systems, was one of the major options for the increase of rice production using the limited water resource. Studies on the cultivar x environment interactions for yield of upland rice (Lafitte and Courtois, 2002), dry matter production of upland rice (Kato et al., 2006a), and grain yield of upland rice (Kato et al., 2006b) have been reported. However, information about aromatic rice specifically for cultivation in the upland is still limited. An upland aromatic rice cultivar, Situppatenggang, was already released in 2002.

In Indonesia, development of aromatic upland rice is of importance to improve upland rice quality and upland productivity. The upland area in Indonesia is around 11.6 million ha, and is not used for crop production optimally yet. The area for upland rice production is only 1.2 million ha, and it produces 2.6 million tons per year with productivity of 2.27 t ha^{-1} (Central Bureau of Statistic, 2004).

Table 1. Plant height (cm) in each genotype at eight locations.

Genotypes	Pwj	Bms	Kds	Tgl	Btg	Kbm	Crb	Bjn	Avg.
G9	121 de	133 ce	107 bd	135 de	116 bc	143 eg	111 cd	109 de	122
G10	117 cd	123 c	112 bf	125 cd	95 ab	136 de	111 cd	101 cd	115
G12	132 f	127 cd	116 df	144 e	105 b	148 g	125 ef	121 f	127
G13	132 f	133 de	117 ef	143 e	111 bc	146 fg	116 de	111 de	126
G19	113 bc	111 b	104 b	122 bd	83 ab	127 bc	103 bc	95 bc	107
G34	108 b	125 cd	104 b	125 cd	99 ab	136 de	109 cd	106 de	114
G35	136 f	128 cd	116 df	125 cd	100 ab	156 h	127 f	109 de	125
G39	116 cd	127 cd	120 f	126 d	115 bc	139 ef	117 de	112 e	121
G136	121 de	138 e	109 be	108 b	92 ab	124 bc	110 cd	104 ce	113
Ps	121 de	128 cd	114 cf	133 de	106 b	146 fg	121 ef	121 f	124
Mw	124 e	127 cd	106 bc	121 bd	139 c	130 cd	111 cd	106 de	121
Slg	85 a	83 a	79 a	85 a	67 a	90 a	81 a	69 a	80
Stp	111 bc	104 b	107 bd	109 bc	97 ab	121 b	97 b	89 b	104

Values with the same letter in a column do not differ significantly at p=0.05.
(Pwj, Bms, Kds, Tgl, Btg, Kbm, Crb, Bjn were Regency of Purworejo, Banyumas, Kudus, Tegal, Batang, Kebumen, Cirebon, Banjarnegara, respectively).

We have studied the development of the aromatic upland rice in Indonesia. It started with crossing upland rice tolerant to drought with lowland aromatic rice. Poso cultivar (high-yielding upland rice, tolerant to drought, Indica type) and Mentikwangi (low-land aromatic rice, Javanica type) has been conducted in 2001. Genetic studies and the maternal effect of aromatic character have been reported (Totok et al., 2005). The pedigree has been selected from the F2 to F5 generation for aromatic upland rice lines (Totok, 2004). In 2004, 50 selected lines of F5 were examined for their growth and yield performance. Among them, 25 lines were aromatic, and among those 25 aromatic lines, 19 lines were high yielding in terms of grain yield per plant. Preliminary yield trial was conducted for 19 lines, and 9 lines were selected as aromatic and high yielding upland lines (Totok and Utari, 2005).

It is necessary to examine the yield stability of the aromatic upland rice, and to obtain lines having high yield stability across different locations and/or having specific locational adaptability. The yield stability across different locations varies with the genotype (Fehr, 1987). Finlay and Wilkinson (1963) used regression analysis for estimating the stability. Relationship between the yield at each location and the location index was expressed to a straight line (regression line) for each genotype and for mean yield of all genotypes. Then, the regression lines for the yield of each genotype were compared with that for the mean yield of all genotypes over all locations to estimate the yield stability of each genotype.

Yield and yield components of a crop are influenced by genotype (G), environment (E), and their (GxE) interaction. Every factor of the environment has a potential to cause differential performance, associated with GxE interaction (Fehr, 1987). GxE interaction was measured by the analysis of variance.

Materials and Methods

1. Materials

Nine rice lines obtained by crossing between Poso (Ps) cultivar (high yielding upland rice, tolerant to drought, Indica type) and Mentikwangi (Mw) cultivar (lowland aromatic rice, Javanica type) were used in this experiment. Four other rice cultivars, namely Ps and Mw (as parents), Silugonggo (Slg), and Situ Patenggang (Stp) were also used as reference genotypes. Slg and Stp were upland rice cultivars released in 2002 by Ministry of Agriculture, Indonesia. Thus, 13 genotypes in total were used in this field experiment.

2. Methods and design

The 13 genotypes were planted in the upland at eight different locations in Java, Indonesia in January 2006 and harvested in May 2006. The locations were Purworejo (Pwj), Banyumas (Bms), Kudus (Kds), Tegal (Tgl), Batang (Btg), Kebumen (Kbm), Cirebon (Crb) and Banjarnegara (Bjn). At each location, seeds of each genotype were sown directly in a 5×2.5 m plot in the rate of 3–4 seeds per hole. Seedlings were thinned to 2 seedlings per genotype. Planting distance was 25 cm between rows and between plants. No irrigation was applied. Water supply was depended on the rainfall. The experiment was a randomized complete block design with three replications. Fertilizer rate was 200 kg ha^{-1} N, 100 kg ha^{-1} P$_2$O$_5$ and 100 kg ha^{-1} K$_2$O.

Data for plant height (cm), the number of productive tillers per hill, panicle length (cm), the number of grains per panicles, 1000-grain weight (g),

Table 2.   The number of productive tillers per hill in each genotype at eight locations.

Genotypes	Pwj	Bms	Kds	Tgl	Btg	Kbm	Crb	Bjn	Avg.
G9	21.2 de	18.5 a	16.5 ac	16.0 be	21.9 cd	19.1 bc	18.1 bd	15.1 bc	18.3
G10	23.3 e	17.8 a	22.6 de	19.3 de	15.8 ab	20.3 c	19.5 cd	13.6 ac	19.0
G12	18.0 bc	12.9 bd	22.2 ce	12.9 ab	15.0 ab	19.7 bc	17.5 bd	13.7 ac	16.5
G13	17.9 bc	12.0 cd	20.5 bd	13.0 ab	17.6 bc	19.8 bc	18.7 bd	11.8 ac	16.4
G19	20.3 ce	15.7 ac	19.5 bd	15.0 bd	11.8 a	21.2 c	15.2 ab	10.7 ac	16.2
G34	20.4 c	15.2 ac	12.3 a	15.9 be	13.3 ab	20.4 c	15.4 ab	10.9 ac	15.5
G35	23.1 e	14.3 ac	16.3 ab	13.9 bc	12.0 a	20.3 c	20.7 de	11.2 ac	16.5
G39	19.5 bd	11.9 cd	19.5 bd	16.3 be	21.9 d	16.0 ab	16.7 ac	10.0 ab	16.9
G136	18.7 bd	14.7 ac	21.4 be	15.3 bd	11.7 a	19.5 bc	20.2 cd	12.2 ac	16.7
Ps	16.4 b	13.9 ac	20.3 bd	18.0 ce	14.4 ab	18.3 ac	15.5 ab	13.4 ac	16.3
Mw	19.7 cd	15.9 ac	20.8 be	16.9 be	17.7 bc	22.0 c	23.9 ef	12.3 ac	18.7
Slg	19.5 bd	16.9 ab	26.4 e	20.3 e	24.5 d	22.2 c	25.9 f	16.9 c	21.6
Stp	13.3 a	89 d	17.7 ad	9.2 a	11.4 a	14.9 a	13.1 a	7.9 a	12.1

Values with the same letter in a column do not differ significantly at p=0.05.
(For Pwj, Bms, Kds, Tgl, Btg, Kbm, Crb and Bjn see Table 1).

Table 3.   Panicle length (cm) in each genotype at eight locations.

Genotypes	Pwj	Bms	Kds	Tgl	Btg	Kbm	Crb	Bjn	Avg.
G9	23.2 d	25.0 ac	24.9 bc	24.4 ac	23.8 bc	29.3 g	24.9 ce	22.3 bc	24.7
G10	23.6 d	25.3 ab	25.0 bc	25.8 be	23.2 bc	27.8 df	24.1 bd	23.6 bd	24.8
G12	23.8 d	24.3 ac	24.7 bc	26.3 ce	28.0 d	29.0 fg	25.4 de	24.6 bd	25.8
G13	23.8 d	23.4 be	25.7 bc	27.1 de	24.1 d	28.4 fg	23.2 ac	24.2 bd	25.0
G19	21.8 b	23.0 ce	24.8 bc	24.1 ac	18.9 a	26.7 cd	22.8 ab	23.0 bd	23.1
G34	22.0 bc	22.6 e	22.7 a	24.8 ad	23.7 bc	26.2 bc	23.4 ad	23.5 bd	23.6
G35	25.5 e	22.5 e	25.1 bc	27.5 e	22.8 bc	28.7 fg	25.0 ce	23.9 bd	25.1
G39	23.5 d	24.9 ad	26.3 c	25.3 be	22.2 bc	28.2 eg	26.2 e	23.5 bd	25.0
G136	23.0 cd	25.7 a	23.9 ab	25.1 be	23.2 bc	27.0 ce	23.9 bd	24.8 cd	24.6
Ps	23.5 d	24.1 ae	26.1 c	26.0 ce	22.0 bc	28.1 eg	23.9 bd	25.5 d	24.9
Mw	21.6 b	22.9 de	24.1 ab	25.0 be	21.6 b	27.2 ce	23.2 ac	22.7 bc	23.6
Slg	19.9 a	20.7 f	22.3 a	22.3 a	17.7 a	22.6 a	21.7 a	17.7 a	20.6
Stp	21.2 b	24.6 ad	25.0 bc	23.3 ab	21.7 b	25.4 b	22.4 ab	22.0 b	23.2

Values with the same letter in a column do not differ significantly at p=0.05.
(For Pwj, Bms, Kds, Tgl, Btg, Kbm, Crb and Bjn see Table 1).

and grain weight (g) per hill were collected from 5 randomly chosen plants from each plot. Yield (g) was measured from 5 m^2 effective plots. Data were analyzed combined with variance. Means were separated by Duncan's Multiple Range Test (DMRT) when the variance analysis revealed significant differences (Steel and Torrie, 1980).

Regression linear analysis proposed by Finlay and Wilkinson (1963) was used to analyze the yield stability of genotype, as follows.

$$Yij = \mu + gi\, Ij + \sigma\, ij$$

where:
  Yij: yield mean of a genotype i at the j location,

  μ : Population mean,
  gi : Regression coefficient of the i genotype,
  Ij : Environmental index of the j location,
  σ ij : Regression deviation of the i genotype at the j location.

The genotype having the regression line above that for mean yield of all genotypes over all locations is considered to have high yield stability and capable of adapting to all the locations. Such genotype would increase the yield as the productivity of the location improves. The genotype having a regression line crossing that for the mean yield of all genotypes over all locations is considered to have adapted well to a specific location. The genotype having a regression

Table 4. The number of grains per panicle in each genotype at eight locations.

Genotypes	Pwj	Bms	Kds	Tgl	Btg	Kbm	Crb	Bjn	Avg.
G9	114 a	100 bd	100 a	104 a	99 bc	161 bd	105 a	82 b	108
G10	121 ab	113 bd	122 ac	115 ab	160 de	149 bc	120 ac	84 b	123
G12	147 de	127 b	145 c	152 cd	201 e	233 e	149 cd	119 cd	159
G13	141 ce	116 bc	137 bc	146 c	143 cd	185 d	148 cd	103 bc	140
G19	135 be	107 bd	174 de	136 bc	80 a	187 d	132 ad	114 cd	133
G34	130 ad	116 bc	115 ab	140 bc	157 cd	165 bd	135 ad	122 cd	134
G35	140 ce	112 bd	115 ab	128 ac	117 bc	139 ab	126 ac	112 cd	124
G39	149 ef	124 b	182 e	137 bc	107 bc	243 ef	184 e	134 de	158
G136	127 ac	111 bd	137 bc	141 bc	111 bd	175 cd	138 bd	125 cd	133
Ps	141 ce	123 b	151 cd	138 bc	112 bc	175 cd	144 cd	147 e	141
Mw	122 ab	91 cd	124 ac	130 ac	136 bd	164 bd	126 ac	104 bc	125
Slg	121 ab	83 d	110 ab	101 a	73 a	117 a	111 ab	56 a	96
Stp	165 f	184.9 a	175 de	176 d	152 de	265 f	163 de	115 cd	175

Values with the same letter in a column do not differ significantly at p=0.05.
(For Pwj, Bms, Kds, Tgl, Btg, Kbm, Crb and Bjn see Table 1).

Table 5. One-thousand-grain weight (g) in each genotype at eight locations.

Genotypes	Pwj	Bms	Kds	Tgl	Btg	Kbm	Crb	Bjn	Avg.
G9	25.4 bc	27.1 bd	20.9 ab	23.2 ab	24.4 d	25.4 bc	22.7 ab	23.4 ab	24.1
G10	29.7 g	29.1 a	24.2 e	29.2 e	27.1 g	27.7 d	25.4 cd	29.2 ef	27.7
G12	27.6 e	26.8 bd	20.3 a	25.9 be	26.0 g	26.3 bd	22.3 a	26.5 cd	25.2
G13	29.9 g	27.7 ac	23.7 de	27.2 ce	26.7 g	27.6 d	24.4 bd	29.6 f	27.1
G19	26.9 d	26.9 bd	21.2 ab	28.6 de	19.2 a	25.4 bc	24.0 ad	23.6 ab	24.5
G34	25.5 bc	25.8 ce	20.0 a	22.7 ab	25.9 fg	25.1 b	23.8 ad	23.2 ab	24.0
G35	25.6 c	26.9 bd	21.5 ac	23.2 ab	24.3 d	23.3 a	23.8 ad	21.6 a	23.8
G39	27.4 de	25.2 de	21.3 ab	24.9 bd	24.9 ef	25.7 bc	23.5 ac	24.9 bc	24.7
G136	24.9 b	24.8 e	20.6 ab	19.7 a	22.3 b	26.8 cd	22.8 ab	24.7 bc	23.3
Ps	28.3 f	26.9 bd	22.2 bd	24.0 bc	24.8 de	26.0 bd	24.3 bd	25.1 bc	25.2
Mw	28.2 f	27.9 ab	23.1 ce	25.3 be	22.8 bc	26.3 bd	25.2 cd	27.2 de	25.8
Slg	23.0 a	21.1 f	19.7 a	21.9 ab	22.1 b	23.5 a	22.9 ab	23.3 ab	22.2
Stp	27.3 de	24.7 e	20.9 ab	23.6 ac	23.6 cd	25.6 bc	25.6 d	23.9 b	24.4

Values with the same letter in a column do not differ significantly at p=0.05.
(For Pwj, Bms, Kds, Tgl, Btg, Kbm, Crb and Bjn see Table 1).

line below that for the mean yield of all genotypes over all locations is considered to have low yield adaptability across locations (Finlay and Wilkinson, 1963).

Results and Discussion

All of the nine upland rice lines and four reference cultivars sown at eight different locations grew well. Plants headed between 59 and 92 days after planting (DAP). The grains were harvested between 94 and 115 DAP.

Analysis of variance showed a significant effect of location, genotype and their interaction on yield and all yield components (data not shown). Table 1 shows the plant height of each genotype at each location.

Plant height varied significantly with the genotype of each location. The lowest plant was Slg in Batang (67 cm) and the highest was G35 in Kebumen (156 cm). They also had the lowest and the highest mean values as the average at all locations.

Tables 2∼7 show the number of productive tillers per hill, panicle length, the number of grains per panicle, 1,000-grain weight, grain weight per hill, and yield, respectively, of each genotype at each location. These values significantly varied with the genotype at each location in plant height, indicating the genetic variability. This is because the genotypes used in this study originated from F_2 population of Mw x Ps crossing.

Table 6.　Grain weight per hill (g) in each genotype at eight locations.

Genotypes	Pwj	Bms	Kds	Tgl	Btg	Kbm	Crb	Bjn	Avg.
G9	24.9 a	22.7 ab	17.1 a	17.2 a	30.8	25.2 a	23.9 ab	18.2 ac	22.5
G10	25.3 a	21.1 ab	34.0 bc	27.5 ab	42.3	27.7 ab	23.7 ab	16.9 ac	27.3
G12	29.9 bc	14.0 bc	27.7 ac	18.1 ab	37.9	26.6 ab	23.1 a	23.6 ac	25.1
G13	30.8 ce	19.2 ab	32.4 bc	21.7 ab	26.7	25.2 a	26.0 ab	18.0 ac	25.0
G19	33.2 df	23.4 ab	32.4 bc	27.4 ab	12.9	36.4 d	26.2 ab	17.8 ac	26.2
G34	26.3 ab	22.7 ab	19.1 a	27.3 ab	16.3	27.4 ab	25.6 ab	18.7 ac	22.9
G35	27.7 ac	25.8 a	18.3 a	19.2 ab	20.8	25.0 a	24.4 ab	13.4 a	21.8
G39	31.6 ce	20.9 ab	37.9 c	23.7 ab	30.4	36.0 d	33.2 c	20.3 ac	29.3
G136	35.9 f	18.9 ab	36.3 c	18.9 ab	31.9	33.5 bd	26.4 ab	26.6 bc	28.6
Ps	29.8 be	26.5 a	38.1 c	29.0 b	22.1	27.3 ab	24.3 ab	29.6 c	28.3
Mw	28.7 ac	22.8 ab	31.3 bc	28.0 ab	32.9	28.2 ac	29.5 bc	20.9 ac	27.8
Slg	29.0 ad	18.9 c	22.8 ab	22.1 ab	11.7	27.2 ab	25.3 ab	14.0 ab	20.1
Stp	33.5 ef	20.8 ab	27.7 ac	16.9 a	30.2	34.5 cd	28.0 ac	10.8 a	25.3

Values with the same letter in a column do not differ significantly at p=0.05.
(For Pwj, Bms, Kds, Tgl, Btg, Kbm, Crb and Bjn see Table 1).

Table 7.　Yield (g m^{-2}) in each genotype at eight locations.

Genotypes	Pwj	Bms	Kds	Tgl	Btg	Kbm	Crb	Bjn	Avg.
G9	375.4 a	324.0 bd	113.4 a	197.4 a	493.2 ef	372.0 ab	401.8 ac	109.0 ac	325.4
G10	381.4 a	344.8 bd	190.0 cd	440.0 de	666.6 g	434.8 bd	379.0 ab	101.2 ac	405.2
G12	466.6 bc	401.8 cd	156.6 ac	245.4 ab	606.6 fg	360.0 ab	370.2 a	141.6 ac	372.4
G13	492.6 cf	293.0 bc	230.0 de	296.6 ad	426.6 de	317.6 a	416.4 ab	108.0 ac	353.4
G19	524.0 fg	400.2 cd	186.6 cd	463.0 e	206.6 ab	575.2 f	445.6 bc	107.0 ac	400.2
G34	426.0 b	326.6 bd	106.6 a	401.0 ce	260.0 ac	467.2 cd	436.2 ac	112.0 ac	346.2
G35	431.4 bc	366.4 bd	126.6 ab	253.2 ac	333.2 bd	315.8 a	389.8 ac	80.2 a	316.6
G39	479.4 de	281.8 b	273.4 e	387.0 be	486.6 ef	486.4 de	531.6 d	121.6 ac	418.0
G136	546.6 g	308.6 bd	243.4 e	284.0 ac	510.0 ef	560.4 f	421.8 ac	159.6 bc	410.6
Ps	494.0 ef	275.6 b	180.0 bd	389.8 be	353.2 cd	418.4 bd	389.4 ac	177.6 c	357.2
Mw	442.6 bd	407.0 d	183.4 cd	356.4 be	526.6 ef	393.6 bc	458.0 c	125.2 ac	395.4
Slg	470.6 ce	148.8 a	233.4 de	293.8 ac	186.6 a	396.6 bc	404.2 ac	84.2 ab	304.8
Stp	535.4 fg	349.6 bd	186.6 cd	258.6 ac	483.2 e	549.0 ef	448.6 bc	65.0 a	401.6

Values with the same letter in a column do not differ significantly at p=0.05.
(For Pwj, Bms, Kds, Tgl, Btg, Kbm, Crb and Bjn see Table 1).

The results indicated that each line responded differently to the location conditions, showing that the genotype's ranking differed with the sowing location. Different responses of upland rice cultivars to water conditions have been reported (Kato et al., 2006b). These results suggested that yield and yield components were influenced by genotype x location interaction as shown in our experiment. Lafitte and Courtois (2002) also reported that the anthesis date, leaf fresh weight, root pressure, leaf area and rooting depth of upland rice were changed by cultivar x environmental interaction,

The number of productive tillers per hill significantly varied with the genotype at each location.

The number of productive tillers per hill was lowest in Stp (8 tillers) at Bjn and highest in Slg at Kds (26 tillers). It was not different among G10, G12, G136 and Mw at Kds. Stp and Slg had the smallest and the largest number of productive tillers per hill, 12 and 22 tillers, respectively, on the average.

Panicle length was significantly different among genotypes at each location. Slg at Bjn had the shortest panicle (18 cm), which was not different from that at Btg. G9 at Kbm had the longest panicle (29 cm), which was not different from that of G12, G13, G35, G39 and Ps. Slg had the shortest panicle as the average at all locations, 21 cm. On the other hand, G12 had the longest panicle as the average at all locations (26 cm).

The number of grains per panicle was significantly different among genotypes at each location. The lowest number of grains per panicle was observed in Slg at Bjn and the highest in Stp at Kbm (265), which was not different from that in G39. Slg and Stp had the smallest (96) and largest (175) mean number of grains per panicle as the average at all locations.

The 1,000-grain weight was significantly different among genotypes at each location. Slg at Kds had the lightest 1,000-grain weight (20 g) and G13 at Pwj the heaviest (30 g), which was not different from that in G10. Slg and G10 also had the lightest and the heaviest mean 1,000-grain weight as the average at all locations, 22 and 28 g, respectively. Lafitte and Courtois (2002) reported that the mean 1,000-grain weight of 48 upland rice cultivars grown under nine different environments varied from 16.4 to 24.7 g. However, Fukushima et al. (2006) showed that the yearly variation of 1,000-grain weight was from 20.3 to 22.5 g in Akisayaka and from 22.0 to 22.9 g in Yumehikari.

Grain weight per hill was significantly different among genotypes at each location. Slg at Btg had the lightest (12 g) and G13 at Pwj the heaviest (31 g) grains. Slg and G10 had the lightest and the heaviest grain weight per hill as the average at all locations, 22 and 28 g, respectively.

Yield (g m^{-2}) at each location was significantly different among genotypes. The yield was lowest in Stp at Bjn (65.0 g m^{-2}) and highest in G10 at Btg (666.6 g m^{-2}) which was not different from that in G12 at Bjn. Slg and G39 were genotypes having the lowest and the highest yield as the average at all locations, 304.8 and 418.0 g m^{-2}, respectively (Table 7).

The lines having higher mean values of yield components than the reference cultivars had a higher yield than the reference cultivars. For instance, G10 had larger number of tillers per hill than Ps, Mw and Stp; longer panicle than Mw, Slg and Stp; heavier 1,000-grain weight than any other cultivar, resulting in high average yield (405 g m^{-2}). G19 had a larger grain number per panicle than either Mw or Slg, heavier 1,000-grain weight than either Stp or Slg, heavier grain weight per hill than any other cultivar, resulting in a high average yield (400 g m^{-2}). G39 had a larger number of tillers per hill than Ps and Stp, longer panicles than any other cultivar, higher grain number per panicle than Ps, Mw and Slg, heavier 1,000-grain weight than Stp and Slg; and heavier grain weight per hill than any other cultivar, resulting in a high average yield (418 g m^{-2}). G136 had a larger number of tillers per hill than either Ps or Stp; longer panicle than Mw, Slg and Stp; a larger number of grains perpanicle than either Mw or Slg; and heavier grain weight per hill than any other cultivar, resulting in high average yield (411 g m^{-2}). Thus, G10, G19, G39 and G136 had higher yield components than the others. On the other hand, Fukushima et al. (2006) indicated that a larger
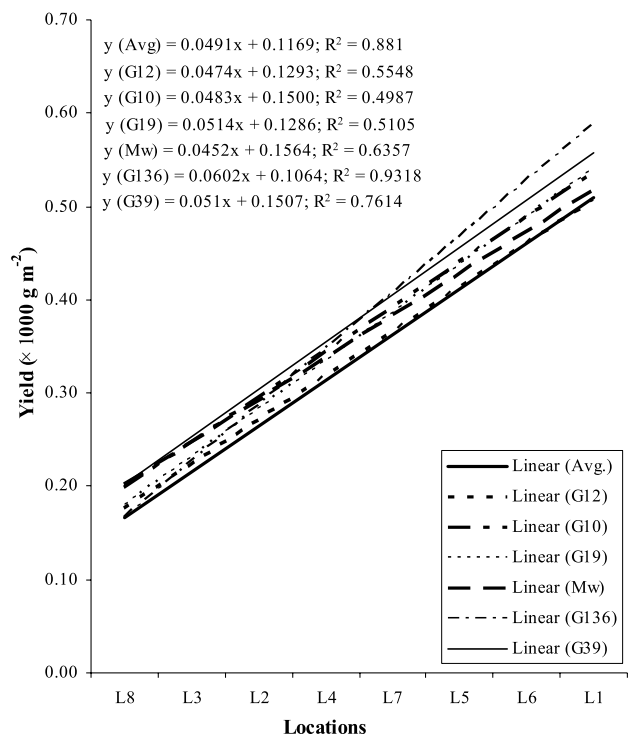

Fig. 1 Regression lines for genotypes above that for the mean yield (g m^{-2}) of all genotypes at different locations. (L1–L8 were: Pwj, Bms, Kds, Tgl, Btg, Kbm, Crb and Bjn, respectively).

number of spikelets per unit area and having sink and source abilities during the late ripening stage were the two characters required for high yielding ability of Akisayaka rice cultivar. Our results confirmed the high yield component on the average contributed to high yielding ability.

Table 7 shows that yield of G39 was higher than or not significantly different from that of at least 3 reference cultivars at all locations. Yields of G136 and G19 were higher than those of 3 reference cultivars at all locations, except for G136 at Tgl and G19 at Btg. However, the yield of G10 was higher than that of reference cultivars, at 5 locations; Kbm, Btg, Tgl, Kds and Bms. Our study suggested that G10, G19, G39 and G136 are aromatic rice lines having high yielding ability across different locations. The yield of G10, G19, G39, and G136 are 405 g m^{-2}, 400 g m^{-2}, 418 g m^{-2}, and 411 g m^{-2}, respectively.

The genotype having the regression line above that for the mean yield of all genotypes over all locations is estimated to have high yield stability. Our study showed that G10, G12, G19, G39, G136 and Mw had regression lines above that for the mean yield of all genotypes over all locations. It shows that these genotypes may have high stability and good adaptability across 8 locations (Fig. 1).

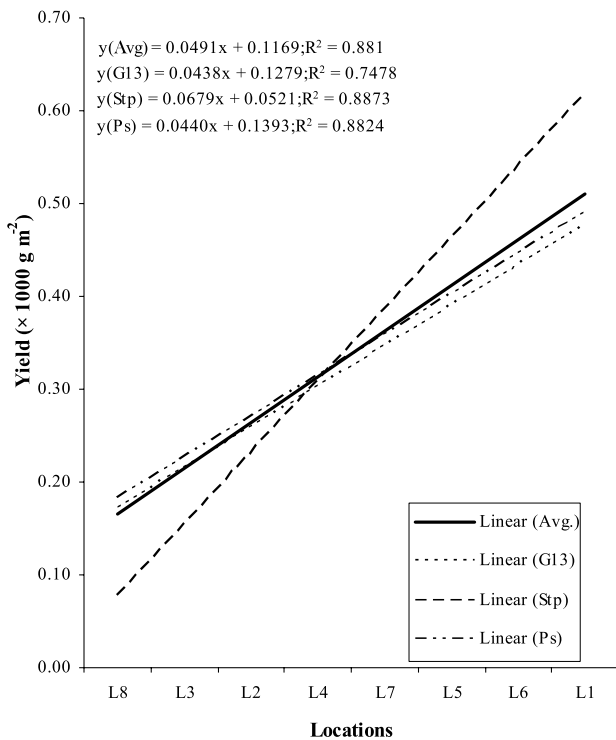The genotype having the regression line crossing that for the mean yield of all genotypes is estimated

Fig. 2. Regression lines for genotypes above that for the mean yield (g m^{-2}) of all genotypes at different locations. (For L1 - L8 see Fig. 1).
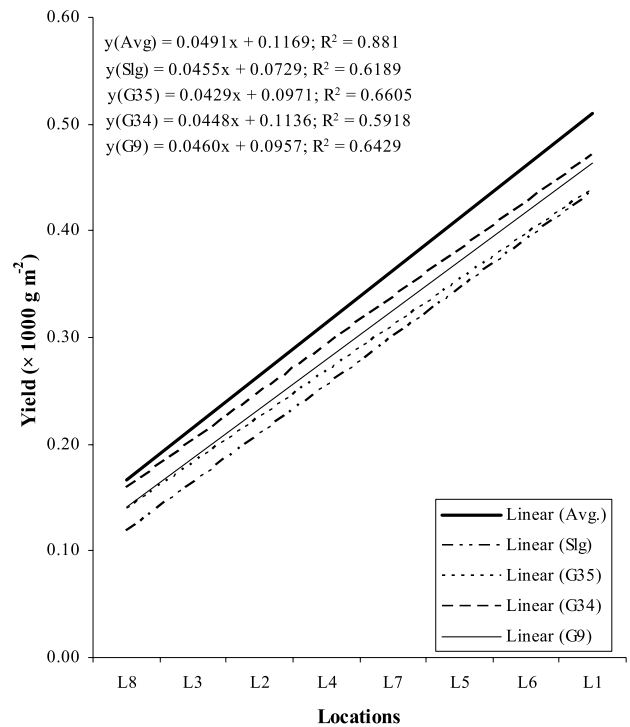

Fig. 3. Regression lines for genotypes below that for the mean yield (g m^{-2}) of all genotypes at different locations. (For L1 - L8 see Fig. 1).

to have specific adaptability. In this study, Stp is considered to have specific adaptability to the fertile (high productive) locations, whereas Ps and G13 have specific adaptability to the infertile (low productive) location (Fig. 2).

The regression lines crossing each other revealed the genotype x location interaction. The locational difference in yield of the genotype relative to that of other genotypes shows the locational change of the ranking of the genotype.

The genotype having the regression line below that for the mean yield of all genotypes over all locatioins is estimated to have low yield stability. G9, G34, G35 and Slg are considered to have low stability (Fig. 3).

Based on the high yielding (Table 7), high yield components (Tables 2∼6) and high yield stability (Fig. 1), G136, G39, G19 and G10 are considered as prospective aromatic upland rice lines having high yielding ability, high yield stability and wide adaptability.

In conclusion, yield stability across different locations varied with the genotype. Some genotypes had high yield stability and wide adaptability to all locations, and some others had high adaptability to specific location. The lines having high yield stability and wide adaptability were G10 (405 g m^{-2}), G19 (400 g m^{-2}), G39 (418 g m^{-2}), and G136 (411 g m^{-2}), which are considered as candidates for new aromatic upland rice cultivars. The genotypes having specific adaptability

were Stp at the fertile locations, and Ps and G13 at the infertile locations. Genotype x location interaction for the yield and its components were observed. Yield components contributing to higher yielding ability was confirmed.

Acknowledgements

References

Bentur, J.S. and Krishnaiah, K. 2001. Insect pest of Basmati and other quality rice and their management in India. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 89-100.

Central Bureau of Statistic, 2004. Indonesian statistic. Indonesian Central Bureau of Statistic, Jakarta. 35.

Chaudhary, R.C. and Tran, D.V. 2001. Speciality rice of the world : a prologue. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 3-14.

Fehr, W.R. 1987. Principles of Cultivar Development. Vol.1. Theory and Technique. Collier Macmillan Publishers,

London. 249-259.

Finlay, K.W. and Wilkinson, G.N. 1963. The analysis of adaptation in a plant breeding programme. Aust. J. Agron. Res. 114 : 742-754.

Fukushima, A., Kusuda, O., Nakano, H. and Morita, S. 2006. Analysis of high yielding ability in a rice cultivar Akisayaka. Plant Prod. Sci. 9 : 369-372.

Kato, Y., Kamoshita, A., Yamagishi, J. and Abe, J. 2006a. Growth of three rice (*Oryza sativa* L.) cultivars under upland conditions with different levels of water supply. 1. Nitrogen content and dry matter production. Plant Prod. Sci. 4 : 422-434.

Kato, Y., Kamoshita, A. and Yamagishi, J. 2006b. Growth of three rice (*Oryza sativa* L.) cultivars under upland conditions with different levels of water supply. 2. Grain yield. Plant Prod. Sci. 9 : 435-445.

Lafitte, H.R. and Courtois, B. 2002. Interpreting cultivar x environment interactions for yield in upland rice : assigning value to drought-adaptive traits. Crop Sci.42 : 1409-1420.

Mann, R.A. and Ashraf, M. 2001. Improvement of Basmati and its production practices in Pakistan. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 129-148.

Modgal, S.C. and Gupta, P.C. 2001. Package of practices to cultivate Basmati type aromatic rices in Uttar Pradesh, India. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 101-110.

Narula, A. and Chaudhary, R.C. 2001. Current status and future of the famous aromatic rice variety Khao Dawk Mali in Thailand. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 163-174.

Nghia, N.H., Buu, B.C., Trinh, L.N. and Thao, L.V. 2001a. Speciality rice in Viet Nam : breeding, production and marketing. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 175-190.

Nghia, N.H., Buu, B.C., Trinh, L.N. and Thao, L.V. 2001b. Improvement of aromatic rice in Viet Nam. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world.

Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 191-200.

Nwe, K.T., Myint, T.T. and Garcia, A.G. 2001. Breeding and cultivation of superior quality rices in Myanmar. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK.115-128.

Rani, N.S. and Krishnaiah, K. 2001. Current status and future prospects for improvement of aromatic rices in India. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 49-78.

Sarom, M. 2001. Current status of aromatic and glutinous rice varietas in Cambodia : their breeding, production and future. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 19-34.

Singh, R.K., Sahai, V.N., Sharma, R.N., Singh, U.S., Singh, S. and Singh, O.N. 2001. Current status and future prospects for improving traditional aromatic rices varieties in India. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 79-88.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and Procedures of Statistic. A Biometrical Approach. 2nd ed., McGrow-Hill, New York. 401-437.

Tang, S. and Wang, Z. 2001. Breeding for superior quality aromatic rice varieties in China. In R. Duffy, R.C. Chaudhary and D.V. Tran eds., Speciality rices of the world. Breeding, production and marketing. FAO of the UN Rome. Science Publishers, Inc. Plymouth, UK. 35-44.

Totok, A.D.H. 2004. Growth, yield and rice quality of F5 genotypes from crossing of Mentikwangi X Poso for developing of aromatic upland rice. J. of Rur. Dev. Jend Soedirman Univ. 2 : 122-128.

Totok, A.D.H., Suwarto, Daryanto and Soesanto, L. 2005. Constructing of high yielding and aromatic upland rice variety for improving of its production and economic value. J. Agroland. Fac. Agric. Tadulako Univ. 3 : 93-99.

Totok, A.D.H. and Utari, R.S. 2005. Yield trial of F6 pure lines from crossing of Mentikwangi x Poso in comparison with their parents. Res. Report. Fac. of Agric. Jend. Soedirman Univ. 22-30.