Genetic Parameters of Some Characters and Their Correlation with Rice Grain Yield in Relation to the Plant Adaptability to Semi-Deep Stagnant Flooding Condition

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ABSTRAK. Parameter Genetik Beberapa Karakter dan Korelasinya dengan Hasil Gabah Dalam Kaitannya dengan Adaptasi Tanaman Padi terhadap Kondisi Rendaman Stagnan. Banjir stagnan (stagnant flooding, SF) merupakan masalah utama pada ekosistem padi di daerah rawan banjir; air dapat merendam tanaman setinggi 20-50 cm sepanjang musim tanam. Di Indonesia, cekaman semacam ini ditemukan di daerah Rawa Lebak. Penelitian dilakukan untuk mengetahui parameter genetik yang berperan terhadap adaptasi kondisi cekaman SF. Delapan belas genotipe padi, termasuk 6 near iso-genic lines (NILs) SUB1 dari varietas padi yang ditanam luas di Asia dan varietas cek, ditanam pada kondisi rendaman stagnan setinggi 50 cm pada musim hujan (MH) 2009 di Los Banos, Pilipina. Hasil penelitian menunjukkan bahwa sebagian besar genotipe memberikan respon morfologi dan agronomi berbeda pada kondisi normal dan SF. Sebagian besar galur NILs SUB1 memiliki hasil gabah lebih rendah daripada galur tetuanya SUB1, karena SUB1 dapat menekan pemanjangan batang dan menghambat kontak tajuk dengan udara. Galur SUB1 lainnya (PSBRc68 dan IR70181-32) memiliki hasil gabah tinggi pada kondisi SF. Bobot tajuk, bobot daun, luas indek daun, diameter batang, tinggi tanaman, dan jumlah anakan merupakan karakter yang paling efektif digunakan sebagai kriteria untuk seleksi tandem terhadap hasil gabah, karena variabilitas genetiknya luas, heritabilitasnya tinggi, dan korelasinya dengan hasil gabah kuat.

Kata kunci: Sub1, adaptasi, heritabilitas, variabilitas.

ABSTRACT. *Stagnant flooding (SF) is a major problem in flood-prone rice ecosystem where the depth of flood water ranging from 20-50 cm in the entire seasons. In Indonesia this kind of water stress can be found in swampy basin area or Rawa Lebak. A study was conducted to determine the genetic parameters related to rice plant adaptability to SF. Eighteen rice genotypes including the recently developed 6 pairs of SUB1 near isogenic lines (NILs) of widely planted varieties and checks were tested under 50 cm depth of SF in the 2009 wet season at Los Banos, Philippines. The results showed that most of genotypes showed different responses on morphological and agronomical characters under SF and normal conditions. Most of the SUB1 NILs had lower grain yields than their respective parents. This was because SUB1 suppressed shoot elongation and less restoring contact with the air. Some SUB1 lines such as PSBRc68 and IR70181-32, however, produced high grain yields under this condition. Under SF condition, rice genotypes required shoot elongation to allow restoring contact with the air, therefore the traits that related to growth attributes such as shoot weight, leaf weight, LAI, stem diameter, plant high, and tiller number were strongly correlated with the grain yields. These traits also had broad genetic variability, high heritability, and strong correlation with grain yields. Selection under real stress SF conditions was effective to obtain high yielding genotypes and also tolerant.*

Keywords: Sub1, adaptation, heritability, variability.

Flood is major abiotic stress in most rice ecosystem especially in rain-fed area and it has been characterized with great diversity of many factors, such as in amount and duration of rainfall, depth and duration of flooding, frequency and time of flooding, soil type, and topography (Douglash 2009). More than 20 million ha of rice lands in South and Southeast Asia undergo flooding and more than 100 million people live and make their living in the flood-prone ecosystem (Hossain and Abidin 2004). Meanwhile, the areas affected by flooding had increased due to rising of the earth atmosphere temperature (global warming) which induces heavy precipitation and tropical cyclone in most part of Asia (Easterling *et al*. 2007). In Indonesia, total damaged area and production lost nationally due to flood in rice field were estimated at about 268,823 hectares and it economic loss was estimated at about US$353.7 million per year (Manikmas 2008). Therefore, overcoming this problem can get much benefit to farmers and people who live in the flood prone environment.

There are two important types of flood affect the rainfed lowland rice ecosystem; they are temporary complete submergence and the stagnant flooding (Maurya *et al*. 1988; Lafitte *et al*. 2006; Ismail *et al.* 2008).Temporary complete submergence in various water levels within 1-2 weeks caused by high tide during monsoon or continuous heavy rain. However, in some area with poor drainage system flooding results water stagnation (20-50 cm) or stagnant flooding in entire life cycle of the crops. In Indonesia, stagnant flooding areas mostly occur in the poor drainage area such as basin swampy area (*rawa lebak*). Rice cultivation in this area is still limited and commonly found in Sumatera and Kalimantan Island around 500.000 ha and with low productivity (Alihamsyah dan Ar-Riza 2006). One of the limiting factors to increase productivity in this area is prolonged flood, especially during rainy season and some time it can be affected by moonson.

Under stagnant flooding or when the submergence extends to stagnant flooding, the submergence tolerance varieties differ in their response. Study to short stature type variety, Swarna-Sub1 did not perform well under stagnant flooding followed submergence treatment (Singh *et al*. 2009, Singh *et al*. 2011). During the early stage of rice plant, internal oxygen deprivation can be prevented by submergence tolerance. Meanwhile prolonged stagnation of water needs enhancement of shoot elongation, which allows plants to extend their leaves out of the water for restoring contact with the atmosphere (Voesenek *et al*. 2004). This makes possible reason of rice plant to have submergence tolerance as well as moderate stem elongation to become adapted under stagnant flooding.

Moreover, the IRRI breeding lines that derived from FR13A, *SUB1* donor, such as IR70213-9-CPA-12-UBN-2-1-3-1, IR70181-5-PMI-3-2-B-1 and PSBRc68 have both tolerant to submergence and to stagnant flooding. These lines are taller compared with the introgression of *SUB1* varieties (IRRI 2008, unpubl res). However, there are also some lines that do not possess *SUB1* but perform yield better under stagnant flooding such as, IR72862-27-3-2-3, IR78581-12-3-2-2 and IR67440-M-5-1-1 (Mackill *et al*. 2010). This indicates that the difference in genetic background of introduced *SUB1* lines could also make the difference in their adaptation to stagnant flooding.

In order to identify the characters that correlate to genetic adaptability of rice plants to flood conditions, it is necessary to characterize the floodwater environment and to investigate the physiological processes behind the plant response to environmental changes. Information regarding genetic parameters and their heritability under stagnant flooding is still limited, despite their usefulness for breeding. Since tolerance mechanisms seem to be controlled by various characters, it is necessary to find out the secondary characters that have strong correlation with grain yield. Many secondary characters are easier to measure than yield across representative stress environments, particularly if the character expressed easyly to be measured, measured in seedlings, or can be identified by using genetic markers. The challenge to selection for secondary characters as an aid to crop improvement for water logging environments is that the character itself must be strongly correlated with yield in the target environment. Genetic variability, phenotypic variability, heritability, and correlation of various characters to grain yield in stagnant flooding and normal conditions were studied in the 2009 wet season.

MATERIALS AND METHODS

Experimental Design and Management

The experiments was carried out at the experimental farm of the International Rice Research Institute (IRRI), Los Baños (14°11' N, 121°15' E, 21 m elev.) the Philippines during the wet season from July to November 2009. The soil was an Aquandic Epiaquoll with pH 6.0, 16.2 g organic C/kg, 1.50 g total N/kg, and 32.9 cmol/kg cation exchange capacities. A total eighteen rice genotypes consisted the sixth pair of mega variety with their near isogenic lines (NILs) of *SUB1 A-1* gene, five IRRI breeding materials which possess *SUB1 A1* gene, and one of the SF tolerant were used in this experiment. The genotypes were planted at two set field experiment with different flooding conditions, e.g.:

I. Normal shallow flood/irrigated conditions (2-5 cm water level)
II. Stagnant flooding from 21 DAT approximately 50 cm through flowering.

Crop management followed the standard rice cultural practices. Pre-germinated seeds for all genotypes were sown in the seedling bed 50 $g.m^{-1}$. At 21 d after sowing, the seedlings were uprooted and transplanted to the field pond with one seedling per hill. The rice genotypes were planted on each of plot using randomized completely block design with three replications at 9 rows x 20 plants per plot, total 7.5 m^2 and plant spacing 20 cm x 20 cm. Urea, SP-36, KCl and $ZnSO_4$ were applied at 90:30:30:5 $kg.ha^{-1}$ as basal fertilizers. 45 kg of Urea was applied at 40 DAT and 60 DAT as additional fertilizer. The stagnant flood (SF) treatment was given with starting water level was approximately 30 cm, then the water gradually increased ~40 cm and ~50 cm, at one (36 DAT) and two weeks (43 DAT) after initial flooding, respectively. The water level then was maintained ~50 cm until the harvest time.

Variance homogeneity was tested using Bartlett test as described by Gomez and Gomez (1984). All of experiment data were tabulated and computed using software computer. The data tabulation, scott-knott analysis, and analysis of covariance was performed by microsoft EXCEL 2007. While statistical analysis of variance used sofware SAS 9.0 PROC GLM (SAS 2002).

Assessment of Survival and Phenology

Plant survival percentage was percentage of number of survival plant per total number of plants before flooding. Day to maturity was counted when 80% of populations of the entry (genotype) reach its panicles to mature or yellowing. The shoot elongation was measured by subtraction of plant height at 21 DAT (before submergence) with the plant height at 36 DAT (after submergence or during 15 d SF). Plant height was measured from soil surface to tip of the tallest panicle (awns excluded) during the flowering stage are completed. The number fertile grain was counted and divided to total number of grain per main panicle from five plant samples. The grain were measurements in grams of 1000 well-developed whole grains, dried to 13% moisture content, weighed on a precision balance. Grain yield was total of all grain harvested from samples area are 6 rows x 0.2 m x 4 m = 4.8 m^2, which not include two border plants along side of plot. Grain yield per hectare will be counted at 14% moisture content.

Statistical Analysis

Analysis of variance (ANOVA) for combine enviroment analysis followed method described by Fehr (1987). The phenotypic variance (σ^2_f) was calculated based on mean basis from variance estimation that given from the ANOVA using the following formula;

$$\sigma^2_f = \sigma^2_e + \sigma^2_g + \sigma^2_{ge}$$

The standard deviation of variance genetics ($\sigma\sigma^2_g$) and variance ($\sigma\sigma^2_f$) were determined by method in Wahdah *et al.* (1996):

$$\sigma\sigma_g^{\ 2} = \sqrt{\frac{2}{r^2}\left[\frac{M_2^{\ 2}}{df_{\ genotypes}+2}\right]+\left[\frac{M_1^{\ 2}}{df_{\ error}+2}\right]}$$

$$\sigma\sigma_f^{\ 2} = \sqrt{\frac{2}{r^2}\left[\frac{M_1^{\ 2}}{df_{\ error}+2}\right]}$$

Genetics and phenotypic variability were determined by the ratio variance with their standard deviation. If $\sigma_g^{\ 2}/\sigma\sigma_g^{\ 2} > 2$ or $\sigma\sigma_f^{\ 2}/\sigma\sigma_f^{\ 2} > 2$, then the genetic and phenotypic variability considered as broad.

The estimations of heritabilities was the ratio of genetics variance (σ^2_g) with phenotypic variace (σ^2_f) which was obtained from analysis variance in the Table 2 and 3 as descibed by Fehr (1987) was used by following formula:

$$h^2 = \frac{\sigma^2{}_g}{\sigma^2{}_f}$$

The coefficient of genetics correlation (r_g) and phenotypic correlation (r_f) between two random variables*X* and *Y* with expected values were calculated based on analysis covariance as described by following formula:

$$r_g = \frac{Covg_{xy}}{\sqrt{\sigma^2_{gx}\sigma^2_{gy}}}$$

$$r_f = \frac{Covf_{xy}}{\sqrt{\sigma^2_{fx}\sigma^2_{fy}}}$$

where σ^2_{gx} and $\sigma^2_{gy}$was variance genetics of variable X and Y, σ^2_{fx} and σ^2_{fy} was variance phenotypic of variable X and Y and Cov_{gxy} and Cov_{gxy} was covariance genetics and phenotypic of variable X and Y. The significance test of r_g and r_f was performed using t test with $t_{value} > t_{table}$ (df = n-2), the coefficient of correlation is significant

The data tabulation, covariance analysis, genetics correlations, phenotypic correlation, genetics variability, phenotypic variability and heritabilty were performed by microsoft EXCEL 2007,while statistical analysis of variance used sofware SAS 9.0 PROC GLM (SAS 2002).

RESULTS AND DISCUSSION

Characteristics of Agronomy Traits

Constracting with normal conditions, under ~50 cm SF most genotypes resulted less survival (Table 1). This because during initial flooding treatment in the vegetatif stage some plant were not able to escape from submerged especially the short type genotypes. It could be seen in the short type varieties like IR64 Sub1, Swarna Sub1 and CR1009 Sub1. Different responses of genotypes were also found under ~50 cm SF, of which lines with SUB1were not always having high survival rate compared to it recurrent parent. The highest survival was PSBRc68 while the lowest was Swarna Sub1.

There was variation in plant height among rice genotypes under SF which ranged from 117 to 161cm. All of Sub1 lines showed shorter plant compared to its recurrent parent. Three of them were significant different such as IR64 Sub1 vs IR64 (117cm vs 123cm), Swarna Sub1vs Swarna (117cm vs 126 cm) and CR1009 Sub1 vs CR1009 (123 cm vs 126 cm). This was because of the effect of SUB1 gene which inhibited stem elongation following submergence stress (Setter and Laureless 1996). In temporary submergence or flash flooding the gene had beneficial effect because elongation was not necessary, therefore the remaining assimilate could be used to conserve energy for recovery during desubmerged. Meanwhile for prolonged SF the elongation was necessary for allowing the above plant part to get air and light for physiological proses.

In general, there was delayed in day to flowering among genotypes under SF condition (Tabel 1). Day to flowering of the SUB1 lines was similar compared to their respective parents under normal and SF. Delayed of day to flowering occurred during SF in all genotypes as it to took the surviving plants additional time recover and to resume normal vegetative growth, and to overcome damage caused by the stress.

Following ~50 cm SF conditions, the number of panicles of most genotypes reduced compared that of normal conditions (Table 2). IR49830-7, IR70181-32, IR67440-M and PSBRc68 produced high number of panicles under SF although under the normal condition they were not high producing panicle types. This means that high number panicle under normal conditions was not always expressed under prolonged flooding stress. The low number of panicles was also probably due to the compensation for increase of plant high. The limiteded more biomass productions under stressed condition, plant tended to choose whether to produce more tiller or to elongate the stem. Because the elongation was more important for survival the compensation was a sacrifice for producing tiller or panicle. Vergara and Ismail (2008) proposed that criteria for tolerance genotypes under SF conditions should include the ability to produce more panicles, as much as if they were grown in the normal conditions. Apparently, this was not the case for materials that were tested.

Prolonged ~50 cm SF showed that most of genotypes reduced their number of filled grain per panicle, increased unfilled grain and reduced the fertility. Decreasing the percentage the spikelet fertility under SF could be as higher 3 to 40% of which IR64 was the lowest and Sambha Mahsuri was the highest. Improper grain filling under SF conditions also was reported by Amante (1986). This because under prolonged flooding stress can reduced translocations of assimilates to the sink. Also, photosynthetic ability declined and respiratory rate decreased due to the reduction of area of some of photosynthetically active leaves remained under water, where they only receive diffused light. Furthermore, photosynthesis became weak under reduced light conditions, and translocation of assimilate as to develop grain also became weak.

Table 1. Survival, plant height and flowering of rice genotypes ~ 50 cm SF, and normal condition in the WS 2009.

Genotypes	SUB1[§]	Survival (%)		Plant height (cm)		Day to flowering (d)	
		SF	Normal	SF	Normal	SF	Normal
IR64 Sub1	+	59 b	100 a	117 e	98 d	93 d	85 f
IR64	-	76 a	100 a	123 d	98 d	91 d	89 e
Swarna Sub1	+	39 c	99 a	117 e	101 d	115 b	107 c
Swarna	-	44 c	100 a	126 d	100 d	116 b	108 c
S. Mahsuri Sub1	+	62 b	99 a	123 d	99 d	114 b	107 c
S. Mahsuri	-	61 b	99 a	126 d	96 d	114 b	108 c
BR11 Sub1	+	50 b	100 a	132 c	115 b	106 c	103 d
BR11	-	59 b	99 a	134 c	115 b	109 c	103 d
CR1009 Sub1	+	54 b	98 a	123 d	104 d	124 a	119 a
CR1009	-	57 b	99 a	128 c	103 d	123 a	120 a
TDK1 Sub1	+	78 a	99 a	135 c	116 b	114 b	108 c
TDK1	-	87 a	99 a	137 c	117 b	114 b	109 c
Inpara 3	+	87 a	99 a	144 b	115 b	109 c	102 d
PSBRc68	+	88 a	100 a	146 b	121 a	101 c	100 d
IR49830-7	+	80 a	99 a	135 c	115 b	115 b	112 b
IR70181-5	+	87 a	99 a	144 b	116 b	105 c	92 e
IR70181-32	+	87 a	99 a	127 d	108 c	87 e	81 f
IR67440-M	-	88 a	98 a	161 a	127 a	117 b	111 b
Means		67	99	132	110	109	104
$F_{Genotypes}$		4.6*	0.2	15.5*	15.0*	49.1*	118.4*
CV (%)		17.8	1.8	7.5	6.5	2.3	1.67

SF= ~ 50 cm stagnant flooding until maturity; small letter follows value in column was mean separation by Scott-Knott at 5% level.
* and ** which was F value significantly different at 5% and 1% respectively.
[§] (+) was the lines with SUB1 gene and (-) was the lines without SUB1 gene.

The Grain Yield and Its Components

Most of genotypes reduced their number of filled grains per panicle, increased the unfilled grain and reduced the fertility under SF conditions, but number filled and unfilled per panicle under submergence similar to those under normal conditions (Table 2). Sambha Mahsuri and its Near Isogenic Line (NIL) were not only had the highest number of filled grain under submergence (189 and 187 grains) but also had similar than did under normal conditions (184 and 189). Meanwhile, IR64 and its NILs had lower of unfilled grain resulted higher panicle fertility. Most of genotypes reduced their panicle fertility when exposed to flooding stress and was more severe when it was subjected to SF. Under this condition, the panicle fertility was ranged from 44 to 81%.

Most of genotypes reduced their number of filled grains per panicle, increase unfilled grain and reduced the fertility under ~50 cm SF. Improper grain filling under SF conditions also was reported (Amante 1986; Singh *et al*. 2008). This was because under prolonged partial submergence, the translocations of assimilates to sink was reduced.

Most of genotypes had lower grain yields under SF compared to those under normal condition (Table 3). Under the ~50 cm SF condition, most of the SUB1 lines had lower grain yield compared to the those of non SUB1 lines. But, certain SUB1 lines such as PSBRc68 and IR70181-32 had higher grain yield under this condition. Reduction in grain yield under SF conditions could be attributed to the degree of injury experienced by each genotype, which was, in turn, the ability to produce grains. The more they survived under stress conditions the more yield could be produced. Severely stressed plants normally lose their biomass, lose their leaves and tillers and took much longer to recover and started developing new organs, these would affect the production of assimilate that whould be translocated to the sink. Our result suggested that the introgression of SUB1 gene did not always give positive effect to the performance of grain yield when it was exposured to SF. Following SF most of genotypes depleted in above ground dry matter weight (AGDMW) in average two folds compared to that of the normal condition (Table 3). The depletion of AGDMW due to stressed conditions results lower of Harvest Index's (HI) in most of genotypes. This indicates that plant needs to produce more biomass (e.g plant hight, stem diameter) to survive from the flooding stress, this whould be sacrifice the development of grains and made lower HI.

Table 2. Panicle number, filled grains per panicle, and panicle fertility under ~ 50 cm SF and normal condition in the WS 2009.

Genotypes	SUB1[§]	Panicle number		Filled grains per panicle		Panicle fertility (%)	
		SF	Normal	SF	Normal	SF	Normal
IR64 Sub1	+	119 c	344 a	96 b	98 d	80 a	89 a
IR64	-	167 b	325 a	95 b	98 d	81 a	89 a
Swarna Sub1	+	75 d	327 a	91 b	140 b	45 d	83 a
Swarna	-	120 c	329 a	92 b	148 b	49 c	82 b
S. Mahsuri Sub1	+	142 c	309 a	116 a	184 a	48 c	81 b
S. Mahsuri	-	114 c	320 a	113 a	188 a	46 c	79 b
BR11 Sub1	+	124 c	276 b	59 c	147 b	37 e	77 b
BR11	-	174 b	325 a	62 c	147 b	41 d	74 c
CR1009 Sub1	+	122 c	318 a	85 c	130 b	46 c	67 d
CR1009	-	132 c	326 a	79 c	131 b	44 d	68 d
TDK1 Sub1	+	186 b	296 a	73 c	107 c	50 c	80 b
TDK1	-	239 a	307 a	81 c	110 c	61 b	78 b
Inpara 3	+	191 b	255 b	70 d	125 c	47 c	75 c
PSBRc68	+	218 a	272 b	102 a	129 b	71 b	75 c
IR49830-7	+	226 a	281 b	88 c	107 c	59 c	76 b
IR70181-5	+	150 b	258 b	88 c	122 c	62 b	74 c
IR70181-32	+	197 a	254 b	83 c	122 c	67 b	73 c
IR67440-M	-	238 a	329 a	107 a	132 b	58 c	74 c
Means		163	303	88	131	55	77
$F_{Genotypes}$		12.3**	3.1**	4.3**	13.6**	29.0*	8.3**
CV%		21.1	16.6	13.2	10.6	8.3	4.5

SF= ~ 50 cm stagnant flooding until maturity; Small letter follows value in column is mean separation by Scott-Knott at 5% level.
* and ** are F value significantly different at 5% and 1% respectively.
[§] (+) was the lines with SUB1 gene and (-) was the lines without SUB1 gene.

Table 3. Above ground dry matter, grain yield and harvest Indexs under ~ 50 cm SF and normal condition in the WS 2009.

Genotypes	SUB1[§]	Above ground dry matter (g.m^{-2})		Grain yield (t.ha^{-1})		Harvest index	
		SF	Normal	SF	Normal	SF	Normal
IR64 Sub1	+	415 c	946 c	2.87 b	4.62 a	0.32 a	0.33 b
IR64	-	563 b	907 c	3.44 a	4.85 a	0.33 a	0.35 b
Swarna Sub1	+	294 d	1068 b	0.89 e	5.45 a	0.23 d	0.34 a
Swarna	-	331 c	1050 b	1.20 d	5.36 a	0.27 b	0.34 a
S. Mahsuri Sub1	+	472 c	1015 c	1.32 d	4.36 b	0.22 c	0.30 b
S. Mahsuri	-	426 c	1052 b	1.44 d	4.36 b	0.25 c	0.29 c
BR11 Sub1	+	398 c	986 c	1.00 d	5.44 a	0.22 c	0.35 a
BR11	-	449 c	1064 b	1.43 d	5.39 a	0.25 c	0.34 b
CR1009 Sub1	+	413 c	1180 b	1.33 d	4.90 a	0.24 d	0.29 c
CR1009	-	311 d	1108 b	0.89 e	4.98 a	0.22 c	0.31 b
TDK1 Sub1	+	661 b	1326 a	2.13 c	4.86 a	0.25 c	0.27 c
TDK1	-	759 a	1252 a	2.86 b	4.84 a	0.25 c	0.28 c
Inpara 3	+	863 a	1371 a	2.22 c	4.11 b	0.20 d	0.23 c
PSBRc68	+	801 a	1335 a	3.47 a	5.51 a	0.28 b	0.29 c
IR49830-7	+	660 b	1226 a	2.56 b	4.92 a	0.28 b	0.28 c
IR70181-5	+	841 a	1362 a	2.82 b	5.04 a	0.25 c	0.27 c
IR70181-32	+	688 b	934 c	3.15 a	4.71 a	0.31 a	0.34 a
IR67440-M	-	807 a	1379 a	2.50 b	4.84 a	0.24 c	0.26 c
Means		564	1142	2.08	4.92	0.27	0.30
$F_{Genotypes}$		8.6**	1.5$^{n.s}$	23.7**	1.4^{ns}	7.7*	4.3*
CV(%)		18.2	8.4	16.3	11.8	13.0	9.5

SF= ~ 50 cm stagnant flooding until maturity; Small letter follows value in column was mean separation by Scott-Knott at 5% level.
* and ** which was F value significantly different at 5% and 1% respectively.
[§] (+) was the lines with SUB1 gene and (-) was the lines without SUB1 gene.

Genetic Variation, Heritability and Correlation with Grain Yield

All observed phenotypic characters showed broad variability, and their genetic variability varied among characters (Table 4). Under SF, plant height, shoot dry weight, leaves dry weight, LAI, number of panicle per area, 1000 seed weight, fertility, and upper internodes had broad genetic variability and high heritability. Moreover under SF, the growth characters, number of panicle per area, 1000-seed weight, fertility, upper internodes, and had broad genetic variability and high heritability.

Even though most of the reports indicated that grain yield was quantitative character which had low heritability, but in our finding under SF the heritability was high. This was probably caused that the flooding stress was an obvious discriminator between tolerance and sensitive genotypes resulting a consistent grain yield in a given environment hence the heritability also was high.

Under normal condition most of characters of plant growth attributes (shoot dry weight, CGR, leaves dry weight and LAI) had narrow variability and low to medium heritability (Table 4). However, the grain yield and its attributes such as filled grain fertility, 1000-seed weight, and panicle number had board genetic variability and high heritability.

In general, most of characters were correlated phenotypically with grain yield but less correlated genetically (Table 5). Survival and growth attributes were correlated with grain yield under submergence and SF conditions. Number of panicle per hill under submergence was correlated negatively, but when it was converted to number of panicle per area the correlation was positive. Under SF, plant height and upper internode length were correlated with grain yield. Moreover, growth duration had negative correlation with grain yield under submergence. Under SF, filled grain and high spikelet fertility had strong correlations with grain yield. Other character which showed significantly correlated with grain yield was HI.

All phenotypic variability of the characters were broad, but for the genetic variability varied among characters. This mean that the variations was greatly influenced by environment not only by genetics per se. Among the characters which were observed, only the important characters that can be used as tandem selection to important characters such as survival and grain yield. The characters to be used as tandem selections should have strong associations with survival

Table 4. Genetic and phenotypic variability of rice genotypes under ~50 cm stagnant flooding and normal condition in the WS 2009.

Characters	~50 cm stagnant flooding						Normal					
	$\sigma^2 f \pm \sigma\sigma^2 f$	criteria	$\sigma^2 g \pm \sigma\sigma^2 g$	criteria	h^2	criteria	$\sigma^2 f \pm \sigma\sigma^2 f$	criteria	$\sigma^2 g \pm \sigma\sigma^2 g$	criteria	h^2	criteria
Survival (%)	258.1±68.18	B	186.1±66.69	B	0.72	H	73.55±10.59	B	12.22±11.39	N	0.17	L
Shoot weight*(g.m^{-2})	5807.±1693.	B	4927.±1652.	B	0.85	H	1751.±381.0	B	886.2±377.6	B	0.51	H
CGR* (g.d^{-1}m^{-2})	24.53±4.755	B	9.720±4.778	B	0.40	M	1.459±0.314	B	0.723±0.311	B	0.50	M
Leaves weight* (g.m^{-2})	8414.±2240.	B	6150.±2190.	B	0.73	H	755.1±132.1	B	233.2±135.1	N	0.31	L
LAI *	0.820±0.239	B	0.697±0.233	B	0.85	H	0.251±0.054	B	0.124±0.053	N	0.50	M
Stem diameter (cm)	0.004±0.000	B	0.002±0.000	B	0.67	H	0.006±0.001	B	0.004±0.001	B	0.72	H
Internodes number	0.316±0.069	B	0.162±0.068	B	0.67	H	0.285±0.081	B	0.232±0.079	B	0.81	H
Internodes length (cm)	20.86±5.562	B	15.28±5.439	B	0.34	H	7.567±2.325	B	6.965±2.266	B	0.92	H
Plant Height (cm)	102.9±27.90	B	77.54±27.27	B	0.73	H	82.15±25.20	B	75.43±24.56	B	0.92	H
Day to flowering (d)	147.2±37.11	B	97.97±36.38	B	0.56	H	78.16±24.97	B	76.36±24.33	B	0.98	H
Day to maturity (d)	147.2±37.11	B	97.97±36.38	B	0.43	M	113.9±35.49	B	107.1±34.60	B	0.94	H
Panicle per hill	7.009±1.266	B	2.352±1.287	N	0.51	H	2190.±574.1	B	1559.±561.8	N	0.71	H
Panicle per .m^{-2}	7564.±2010.	B	5514.±1966.	B	0.73	H	319.8±61.67	B	125.2±62.02	N	0.39	H
Filled grain panicle^{-1}	2452.±633.6	B	1703.±620.3	B	0.75	H	0.017±0.003	B	0.005±0.003	B	0.33	H
Unfilled grain panicle^{-1}	415.1±107.3	B	288.6±105.0	B	0.69	H	29.43±9.317	B	28.36±9.082	B	0.96	H
Spikelet Fertility(%)	0.018±0.003	B	0.008±0.003	B	0.70	H	5.037±0.961	B	1.926±0.968	N	0.38	L
1000 seed weight (g)	24.03±7.588	B	23.06±7.396	B	0.44	M	0.002±0.000	B	0.000±0.000	B	0.39	L
Panicle length (cm)	3.622±0.829	B	2.025±0.818	B	0.96	H	0.077±0.006	B	0.00±0.009	N	0.09	L
Harvest index	0.003±0.000	B	0.000±0.000	N	0.24	M	0.081±0.013	B	0.019±0.013	N	0.24	L
Grain yield (ton.ha^{-1})	1.932±0.578	B	1.710±0.564	B	0.72	H	0.845±0.202	B	0.514±0.199	B	0.61	M

Abbreviation: $\sigma^2 f \pm \sigma\sigma^2 f$ is phenotypic variance and its standard deviation; $\sigma^2 g \pm \sigma\sigma^2 g$ is phenotypic variance and its standard deviation; h^2 is heritability; B = broad; N = Narrow; H = high; M = medium; L = low; *, measurement was done at 66 DAT; $^+$, measurement was done at 36 DAT

and grain yield, as well should have broad genetic variability and high heritability. However only few, among the characters observed met that requirement.

Under normal condition most of characters related to plant growth (shoot dry weight, CGR, leaves dry weight and LAI) had narrow variability and low to medium heritability. These were because under normal condition there were no significant variations among genotypes as a result their genetic variability which was narrow. Yield related characters and its component which directly contributed to grain yield such as filled grain, fertility, 1000-seed weight, tiller number had broad genetic variability as well as high heritability. Under submergence conditions, the dry matters of upper part of component such as shoot and leaves dry weight, CGR and LAI tiller number per area and starch concentration, had broad genetic variability and high heritability, as well as strong correlations with gain yield.

The objective of rice improvement under flood prone environment put attentions on the grain yield. Our research pointed out that the grain yield had broad genetic variability and high heritability only under flooding stress condition. This mean that it would be relatively easy to select high yield genotypes under flooding stress conditions, the environment variance less contribution than the genetics variance, but there was no high yielding genotypes under SF. In this situation selection could be done at early generations, using bulk segregation or pedigree method or by using successive backcross method.

Table 5. Genetic (r_g) and phenotypic (r_f) correlation of grain yield with various characters under Submergence, 50 cm SF until maturity, and normal in the DS 2009.

Characters	SF		Normal	
	r_f	r_g	r_f	r_g
Survival	0.92*	0.66*	0.03	0.00
Shoot dry weight	0.90*	0.77*	-0.10	-0.00
CGR	0.79*	0.31*	0.00	0.00
Leaf dry weight	0.89*	0.65*	-0.00	-0.00
LAI	0.89*	0.75*	0.48*	0.23
Stem diameter	0.94*	-0.10	0.42*	-0.00
internodes number	-0.10	0.00	0.53*	0.12
Upper internodes length	0.24	0.08	0.48*	0.24
Plant Height	0.47*	0.45*	0.06	0.06
Day to flowering	-0.30*	-0.20	0.58*	0.56*
Day to maturity	-0.30*	-0.20	0.59*	0.55*
Panicle number	0.88*	0.23	0.00	0.00
Panicle number per area	0.66*	0.06	0.01	0.00
Filled grains per panicle	0.30*	0.02	0.47*	0.33*
Unfilled grains per panicle	-0.10	-0.10	-0.50*	-0.20
Fertility	0.28*	0.12	0.47*	0.16
Harvest Index	0.41*	0.23	0.22	0.08

Remark: Sub, 15 d Submergence; SF, ~ 50 cm stagnant flooding until maturity; *, Significant at level 5%.

In this experiment the populations were advanced line which had different characteristic in tolerance to flooding stress. The consistency expression of *SUB1* gene resulting tolerant to flooding condition contributed to grain yield consistently. Many genetic studies related to *SUB1* gene from classical genetic study to sequencing of the gene, most of result pointed that it is a major gene and high heritable (Suprihatno and Coffman 1981; Mohanty and Khush 1985; Haque *et al*. 1989; Mishra *et al*. 1996).

The heritability of upper internodes length and plant height of rice genotypes under prolonged SF not only high but also it had strong association with elongation, survival and grain yield. These results indicate that there was a possible chance to select high yield genotypes under stagnant flood conditions. However, when the environments was under normal condition, the grain yield heritability became very low (0.10). Selection of high yield genotypes under various environment was more difficult, but relatively easy to select high yielding genotypes under certain flooding stress conditions, if there was one with high yield.

Interestingly since the shoot elongations had contradictive effect to survival and grain yield on the rice genotypes under submergence with that in SF condition, therefore it would be difficult to find rice genotypes that was able to adapt better under these two kind flood conditions. Effort to combine elongation ability and submergence tolerance was done by Ray *et al*. (1993). They concluded that submergence tolerance and stem elongation ability could be combined in the same genotype if strongly submergence tolerant genes are present in submergence tolerant parents. Combining stem elongation ability and submergence tolerance in semi-dwarf rice varieties, if possible, could widen the adaptability of such genotype to certain situations when the rice crop got submerged in flash floods and subsequently had to elongate in order to stay above the surface of gradually rising water and prolonged SF.

CONCLUSIONS

Based on the research concluded that:

1. The introgression of SUB1 gene did not always give positive effect to grain yield when it was exposured to SF.
2. PSBRc68 and IR70181-32 had higher grain yield compared to mega variety SUB NILs under SF conditions
3. The characters that related to growth attributes had broad genetic variability, high heritability and strong correlation with grain yield such as shoot weight, leaves weight, LAI, stem diameter, plant high, and tiller number
4. To obtain genotypes with high yield that suitable for prolonged flooding of SF, it was effective to select under real stressed SF conditions is suggested.

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