Rice Tolerance to Flooding Stress on Germination Stage and Early Seedling Growth under 5 cm Water Depth

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ABSTRACT

Flood is one of the major environmental constraints that may harm plant productivity which requires specific mechanism to cope with stress. Flood prone area where rice is major crop to be cultivated, transplanting method on cultivation system cost high labor with consequence on low seedling survival. Direct seeding may offer solution for this condition with additional improvement needed on seed tolerant to germinate on anaerobic environment. An experiment was conducted to evaluate 23 rice varieties of tolerance to flooding stress on germination stage under 5 cm water depth. The experiment design was Nested – Randomized Complete Block Design with two factor and three replications. Result showed that rice germination under anaerobic condition was varied with Lambur has highest survival rates among others. Tolerance level was characterized from higher survival ability followed by high biomass accumulation and length of the shoot and root.

Keywords: anaerobic germination, direct seeding

ABSTRAK

Banjir merupakan salah satu kendala lingkungan yang dapat mengganggu productivitas tanaman dan membutuhkan mekanisme khusus untuk mengatasinya. Daerah rawan banjir dimana padi adalah tanaman budidaya utama, metode transplanting membutuhkan biaya tenaga kerja besar dengan konsekuensi rendahnya tingkat keberhasilan pertumbuhan. Sistem tebar benih langsung menawarkan solusi untuk kondisi tersebut dengan perbaikan kualitas toleransi benih untuk berkecambah pada kondisi anaerob. Penelitian dilakukan untuk mengevaluasi tingkat toleransi 23 varietas padi pada cekaman rendaman dengan kedalaman 5 cm dan 10 cm. Hasil dari penelitian menunjukkan bahwa perkecambahan anaerob pada kedalaman 5 cm bervariasi dimana Lambur memiliki kemampuan untuk tumbuh paling tinggi diantara semua varietas yang diujikan. Tingkat toleransi dikarakterasi dari kemampuan untuk tetap tumbuh yang tinggi selama perkecambahan diikuti akumulasi biomass yang tinggi dan panjang tajuk serta akar.

Kata kunci: perkecambahan anaerob, tebar benih langsung

INTRODUCTION

One of the global warming effects is increasing flood case due to increasing of rain occurrences or enhance of sea water level. Flood defined as the occurrence or condition where the land is immersed as the effect of increasing water volume. Flood occurs when the presence of water in the soil in excess of field capacity (Greenway, Armstrong, & Colmer, 2006; Levitt, 1980). Excess water regime inhibits rice growth even only in the root zone (referred as waterlogging) and becomes dangerously severe when the water partially or completely submerged rice plant (Colmer

& Voesenek, 2009; Voesenek, Colmer, Pierik, Millenaar, & Peeters, 2006). Soon after the root zone flooded, oxygen deplete and plant start to converts its metabolism into anaerobic which consume higher energy and resulting lower energy. Thus, a plant which is exposed to flood stress usually reduces its growth and yield due to the requirements of energy to survive.

Rice growing areas in the excess water regimes categorized as irrigated, rain fed lowland, deep water and tidal wetlands (Khush, 1984). Rice is grown in water depths ranging from 5 to 20 in irrigated or rainfed paddy fields, to 0.5 to over 5 m in flood-prone areas, with floods lasting in weeks to months (Kirk, Greenway, Atwell, Ismail, & Colmer, 2014). Almost 53% of the world rice area is irrigated land which has an adequate water supply during growing season. Rainfed lowlands have a great diversity of growing conditions that vary by amount and duration of rainfall, depth and duration of standing water, flooding frequency, time of flooding, soil type and topography. Tidal wetlands are near seacoasts and island estuaries that are directly or indirectly influenced by tides (Khush, 1984).

On tidal wetlands area where the exposed of water relatively unpredictable, transplanting method was cost high labor. Thus, direct seeding proposed as advance solution with improvement of seed ability to growth on anaerobic condition. This research was aimed to determine Indonesian rice varieties tolerance responses to anaerobic germination and early seedling growth. The information of tolerant variety will be useful to study physiological and morphological characters in order to establish high yielding rice tolerant under anaerobic conditions. The success of this research will promote application of direct seeding on flooding prone area which benefiting in suppress labor cost.

MATERIALS AND METHOD

Anaerobic germination experiment was conducted from August to September 2014 in Cikarawang Field Laboratory, Darmaga, Bogor, West Java, Indonesia. Plant biomass was observed in Post Harvesting Laboratory, Department of Agronomy and Horticulture, Bogor Agricultural University.

Plant materials used in this research were 23 rice varieties from Indonesian Center for Rice Research (ICRR), they were IR42, IR64, Ciherang, Inpari30, Inpari29, Lambur, Kapuas, Lalan, Air Tenggulang, Punggur, Batanghari, Dendang, Tapus, Mahakam, Barito, Mendawak, Siak Raya, Banyuasin, Indragiri, Margasari, Inpara3, Martapura, and Inpara 1. IR42 used as susceptible control for anaerobic germination as its trait was previously reported sensitive toward anaerobic condition. Experiment was arranged in Nested – Randomized Complete Block Design replicated three times.

About 25 seeds were sow at 1 cm of soil depth followed by normal drainage and submerged with 5 cm water depth as treatment. During the treatment, water level was maintained 5 cm for 21 days for anaerobic conditions plot and normal irrigation was given to control plot.

Observation was conducted 21 days after the seeds grown to certain variables, i.e.: seedling survival (%), shoot length (cm), root length (cm), and plant biomass (g). The measurement of plant biomass was conducted after all observation has been done by separate shoot and root part the put in on dry oven for 72 hours under 60°C. Then, dry weight measured using digital scale.

Data were analyzed using analysis of variance (ANOVA). If results showed differences in the treatment, Least Significant Difference (LSD) test would be performed with α=5%. Correlation analysis also performed among variables observed. The SAS System for Windows 9.0 software was used for that analysis. IBM SPSS Statistics 19 software was used for cluster analysis.

RESULTS AND DISCUSSION

Survival of anaerobic germination

Seedling survival was the percentage of rice seedling that germinated and growth after 21 days following the treatment with the origin number of seeds that sowed. Reduction of seedling survival was the percentage of difference between percentage of seedling survival under optimum and flooding conditions (Table 1).

Table 1. Interaction between germination condition and rice varieties to plant survival (%)

Rice variety	Germination conditions		Δ
	Optimum	Flooding 5 cm	
	…………(%)…………..		
Ciherang	85.3 a-c	48.0 e-i	-43.7
IR42	93.3 ab	18.7 j-m	-80.0
IR64	94.7 a	26.7 i-m	-71.8
Inpari29	82.7 a-c	37.3 g-k	-54.8
Inpari30	90.7 ab	48.0 e-i	-47.1
Inpara1	90.7 ab	57.3 d-g	-36.8
Inpara3	88.0 a-c	28.0 i-m	-68.2
Air Tenggulang	93.3 ab	10.7 lm	-88.6
Banyuasin	92.0 ab	30.7 h-l	-66.7
Barito	92.0 ab	26.7 i-m	-71.0
Batanghari	92.0 ab	26.7 i-m	-71.0
Dendang	78.7 a-d	44.0 f-i	-44.1
Indragiri	97.3 a	42.7 g-i	-56.2
Kapuas	89.3 ab	38.7 g-j	-56.7
Lalan	92.0 ab	36.0 g-k	-60.9
Lambur	88.0 a-c	70.7 b-e	-19.7
Mahakam	93.3 ab	29.3 h-m	-68.6
Margasari	97.3 a	14.7 k-m	-84.9
Martapura	90.7 ab	6.7 m	-92.6
Mendawak	93.3 ab	52.0 e-h	-44.3
Punggur	97.3 a	66.7 c-f	-31.5
Siak Raya	84.0 a-c	52.0 e-h	-38.1
Tapus	93.3 ab	8.0 lm	-91.4
Average	90.8	35.9	-60.5
Variety			*
LSD Value			43.5

Remarks: Value which followed by the same alphabet showed no significant difference in the Least Significant Difference P<0.05; Δ: reduction percentage of seedling survival; *: significantly different at P<0.05; ns: not significant

Seedling survival with submergence condition during germination stage significantly lower than those under optimum condition. Reduction of plant survival germinated under flooding 5 cm varied (Table 1). Based on percentage of plant survival reduction in depth of 5 cm, cluster analysis was done to classify the rice varieties into several classifications due to dissimilarity (Figure 1). Cluster analysis technique associated with the concerned data to classify whether the data can be summarized meaningfully into a small part of cluster or object cluster or individual which similar to each other and which different with an individual of another cluster. Two individuals categorized as 'similar' when they had a lower distance of dissimilarity or higher distance of similarity. The dissimilarity between object can be measured using the distance of such as Euclidean distance, as short as the Euclidean distance between varieties indicated the similarity of each varieties (Everitt, Landau, Leese, & Stahl, 2011).

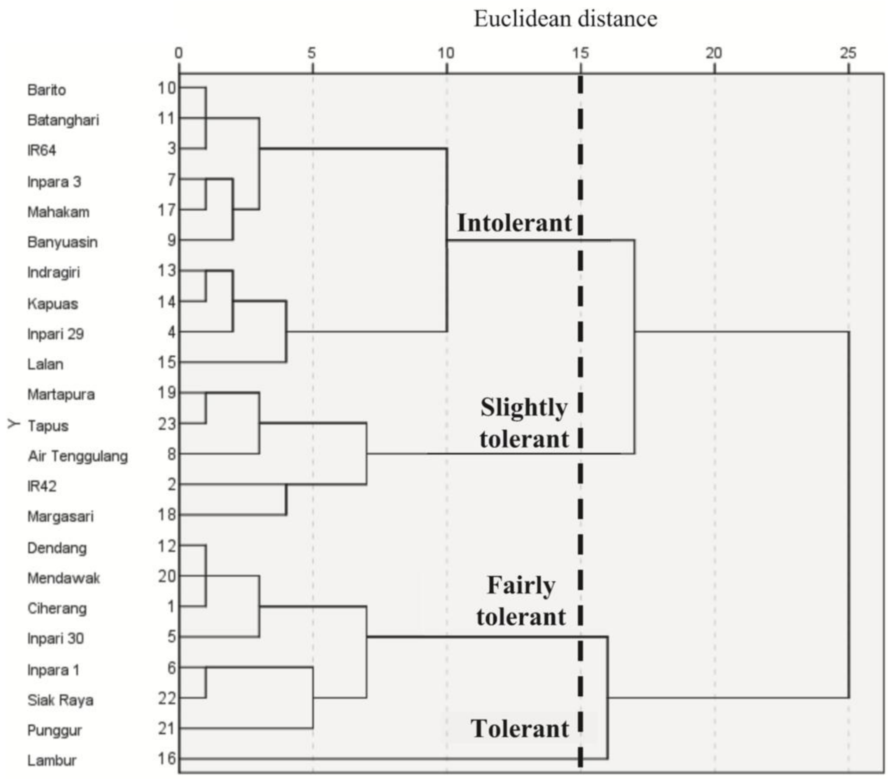

Figure 1. Classification of rice varieties tolerance level to flooding on germination stage based on reduction of plant survival

The higher and lower of dissimilarity is showed in dendrogram of Figure 1. Value between 0-25 shows the scale of Euclidean distance. The gathering of varieties directed inton0 indicated that the variety had higher similarity and lower dissimilarity. Cluster analysis was conducted on 23 rice varieties using the character of seedling survival. The value of dissimilarity (euclidean distance) on dendrogram is the scale from the original of euclidean distance. All rice varieties classified into four categories on dissimilarity value of 15 (euclidean distance). Barito, Batanghari, IR64, Inpara3, Mahakam, Banyuasin, Indragiri, Kapuas, Inpari29, and Lalan were classified into intolerant; Martapura, Tapus, Air Tenggulang, IR42, and Margasari were classified into slightly tolerant; Dendang, Mendawak, Ciherang, Inpari30, Inpara1, Siak Raya and Punggur were classified into fairly tolerant; and Lambur was classified into tolerant.

Germination and early seedling growth on submergence stress

Germination and seedling development start when seed dormancy has been broken and the seed absorbs adequate water then exposed to temperature ranging from 10-40°C. the physiological definition of germination is when the radicle or coleoptile (embryonic shoot) emerges from the ruptured seed coat (GRiSP, 2013). Seedling growth continues after germination with extension of the coleoptile and coleorhiza, then emergence the prophyll and radicle. During this growth stage, rice seedlings exhibit great morphological plasticity in response to changes in aeration, light, and temperature (Smith & Dilday, 2003).

In this experiment, submergence during germination stage inhibited plant growth than germination under optimum condition. Growth inhibition occurred to all variable that observed except for shoot-root length ratio which showed increasing ratio when germinated under anaerobic condition. Shoot length in optimum condition is higher than submergence under depth of 5 cm. Rice varieties behave differently when germinated under optimum and anaerobic condition. Under aerobic conditions, coleorhiza development is favored. The coleorhiza develops root hairs, followed by emergence of the seminal root (radicle). Within the coleoptile, the prophyll develops rapidly and emerges. Under anaerobic conditions of water seeding, the coleoptile is the first to emerge, and elongates without simultaneous development of other tissues. Emergence of the coleorhiza, seminal root, and prophyll are suspended until the coleoptile emerges from the floodwater surface and oxygen levels to the root are increased (GRiSP, 2013; Hoshikawa, 1989; Smith & Dilday, 2003). This explanation is able to answer the reason of shoot and root reduction when the seed germinated under submergence, and also suggested that coleoptile length should be measured during germination and early seedling growth to determine its elongation rate.

Root length in optimum condition was better than under anaerobic condition (Table 2). Reduction in root length when the rice germinated under submergence condition showed that root growth was inhibited. Miro & Ismail (2013) said that reduction in root growth is caused by the low oxygen and it also reduces the root function such as reducing nutrient and water uptake. Oxygenation and root development also can be promoted by draining flood waters (R. Helms & Slaton, 1994). Under anaerobic conditions, roots have been observed to develop few root hairs (Hoshikawa, 1989).

Growth inhibition showed also in shoot root elongation, fresh weight and dry weight accumulation. Shoot, root, and total fresh weight was significantly different between optimum and anaerobic condition. The growth inhibition caused by the plant difficulties to get oxygen supply during submergence. Oxygen is important to plant growth due its roles on metabolism process so that limited supply of oxygen inhibited plant growth (Jackson, Herman, & Goodenough, 1982).

Shoot-root length ratio in submergence condition is higher than optimum indicated that early seedling growth is directed to shoot elongation than root formation, even the shoot and root growth in optimum condition is higher than anaerobic (Table 2). Alpi & Beevers (1983) found that the final length of rice coleoptiles can exceed the length of aerobic coleoptiles while root fail to grow in anaerobic condition. This phenomenon is supposed to enhance the probability of coleoptile contact with water surface which allowing oxygen to diffuse internally to the root and support the seedling establishment (Magneschi & Perata, 2008).

Rice can germinate under hypoxic or anoxic conditions, but only tolerant genotypes have the ability of fast coleoptile elongation and root formation under anaerobic conditions in the field (Miro & Ismail, 2013). Coleoptile is the only organ of the embryo that can emerge from the seed on energy derived solely from anaerobic fermentation (Smith & Dilday, 2003). Coleoptile elongation is usually targeted for selection of tolerant rice genotypes germinating under submergence because it is easy to phenotype. Coleoptile length increases mainly through cell elongation. Cell division is active during the first 48 hours, and that is the period when oxygen is mostly required (Atwell, Waters, & Greenway, 1982). Since cellular expansion consumes less energy than cell division, the latter is the main process governing elongation under anoxia (Atwell et al., 1982; Magneschi & Perata, 2008).

Varieties which have the ability to germinate well in flooded soils would give advantage for direct-seeded systems in flood prone area and even for intensive irrigated systems where early flooding can suppress weeds (Ismail, Ella, Vergara, & Mackill, 2008). This will affect on huge savings in production cost compared than when rice is transplanted. It can also reduce the cost of weed control and labor use.

Table 2 The influence of germination environment to the observed variables

Variables	Germination Condition			
	Optimum		Flooded 5 cm	
Shoot length (cm)	24.6	a	20.5	b
Root length (cm)	13.0	a	11.6	b
Shoot fresh weight (g plant^{-1})	0.0908	a	0.0801	b
Root fresh weight (g plant^{-1})	0.0516	a	0.0344	b
Shoot dry weight (g plant^{-1})	0.0180	a	0.0160	a
Root dry weight (g plant^{-1})	0.0100	a	0.092	a

Remarks: Value which followed by the same alphabet in the same row for each experiment showed no significant difference in Least Significant Difference at $P < 0.05$

Correlation of each variable observed on germination

Plant survival was the most important variable to determine whether the variety is tolerant or intolerant on anaerobic germination. Plant survival on anaerobic germination significantly correlated with all variables observes except shoot dry weight and root dry weight (Table 3). This means that those variables had no correlation with plant survival, had no effect of environmental condition, and mainly affected by genetic diversity. Shoot dry weight and root length under anaerobic condition has no correlation with root fresh weight and total fresh weight, but correlated with shoot fresh weight. It means that root fresh weight and total fresh weight could not explain shoot dry weight and shoot length.

Table 3 Correlation of variable observed on anaerobic germination

Variable		Fresh weight ($g\ plant^{-1}$)		Dry weight ($g\ plant^{-1}$)		Length (cm)	
		Shoot	Root	Shoot	Root	Shoot	Root
Survival (%)		0.32**	0.32**	0.12 ns	0.15 ns	-0.35**	0.45**
Fresh weight	Shoot		0.60**	0.21*	0.30**	0.35**	0.54**
($g\ plant^{-1}$)	Root			0.07ns	0.21*	-0.02ns	0.39**
Dry weight	Shoot				0.80**	0.23**	0.26**
($g\ plant^{-1}$)	Root					0.28**	0.44**
Length (cm)	Shoot						0.30**

Remark: ns = no significant difference; ＝significantly difference at $P < 0.05$; **= significantly difference at $P < 0.01$

CONCLUSION

Among 23 Indonesian rice varieties tested under anaerobic conditions, only Lambur categorized as tolerant variety. Dendang, Mendawak, Ciherang, Inpari30, Inpara1, Siak Raya and Punggur were included in fairly tolerant. Tolerance level was characterized from higher survival ability followed by high biomass accumulation and length of the shoot and root.

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