Phenotypic Screening of Nigerian Rainfed Lowland Mega Rice Varieties for Submergence Tolerance

M. G. Akinwale, B. O. Akinyele, A. C. Odiyi, F. Nwilene, G. Gregorio, and O. E. Oyetunji

***Abstract*—The submergence tolerance of 20 rainfed lowland rice (*Oryza sativa* L.) cultivars consisting of six Nigerian rainfed lowland mega rice cultivars, five Asian submergence tolerant mega varieties, four landraces, two lowland NERICAs and three parents of Sub1 varieties were evaluated in a natural water pond that allows maintenance of flood water depth of 1.5m for a period of 14 days. The experiment was laid out in a randomized complete block design with three replicates. Seeds sown in the wet nursery were transplanted after 21 days to the puddled soil in the deep pond at 20cm x 20cm with two seedlings per hill in eight rows of 5m^2. Ten extra rows of susceptible varieties (IR42) were planted on one side of the pond to observe the extent of damage due to submergence. Thirty-day old seedlings were submerged for 14 days under 100cm of water followed by normal condition. Survival counts were taken visually 10 days after withdrawal of flood water. Data were also collected on plants for stem elongation, date at 50% flowering, plant height, number of tillers at maturity, number of panicles at maturity and grain weight. Plant survival recorded 10 days after de-submergence showed large cultivar differences. Percentage survival varied from 3.2 to 97.5%. All mega varieties with Sub1 gene had a significantly higher percentage survival and grain yield. Comparing the grain yields as influenced by submergence with grain yields obtained under normal lowland rainfed condition, FARO 57, a susceptible variety, was found to have the highest percentage yield reduction of 98.5%. Plant elongation during submergence was found to be negatively correlated with survival (r = -0.80), indicating the importance of reduced elongation growth during submergence.**

***Index Terms*—Lowland rice, mega varieties, stem elongation, submergence tolerance, Sub1 gene**

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I. Introduction

RICE is the most important food crop in the world. It is consumed by nearly 3 billion people almost daily. Rainfed lowland and deep water rice cultivars are cultivated on approximately 33% of global rice farmlands. This accounts for about 50 million hectares of the estimated 150 million hectares of rice fields worldwide (Huke and Huke 1997; Ito et al., 1999). According to Toojinda et al., (2003), flooding is a serious constraint to rice plant growth and survival in rainfed lowland and deepwater areas. This is because it results in partial or complete submergence of the plant. In Nigeria, approximately 70% rainfed lowland rice farms are prone to this seasonal flooding which is a major constraint to rice production in some major rice producing states, and each year, rice farmers in these parts of the country lose their entire crop to flooding. During any given year, yield losses in Nigeria resulting from flooding may range from 10 percent to total destruction. Recently, the extent of submergence stress has increased due to extreme weather events such as unpredicted heavy rains that have inundated wider areas across many states of the country. Among the most frequently and severely affected states in Nigeria are Kebbi, Niger, Kogi and Taraba states which together account for over 80% of lowland rice ecology in Nigeria (Erenstein et al., 2003). The experts say the situation may become worst as climate change progresses.

Submergence tolerance, which is partially a function of the character of flood water (Ram et al., 1999), is an important breeding objective intended to reduce, to the barest minimum, yield losses recorded in rainfed lowland and deep water rice areas (Kawano et al., 2009; Mackill, 1986; Mohanty and Chaudhary, 1986). Despite this recognition, there has been limited success in the various efforts to develop improved submergence tolerant varieties in Africa. One cause for intolerance to complete submergence in some rice cultivars is the desiccation of leaves after de-submergence (Setter et al., 2010). Systematic screening of rice germplasm in Asia has shown that there are excellent flood-tolerant rice types locally available. Among these are ‘FR13A’ and ‘FR43B’ of India, ‘Kurkaruppan’ of Sri Lanka and ‘Goda Heenati’ of Indonesia. It is from these locally available flood tolerant rice types that some submergence tolerant lines were developed through markers-assisted backcrossing. Some of these newly developed lines are Swarna+Sub1 or IR82810-

407, Sambha Mahsuri+Sub1 or IR84196-32, IR64+Sub1 or IR84194-139, TDK1+Sub1 (BC3F3) or IR85264-141 and BR11+Sub1 or IR85260-148. Not much of submergence screening has been done in Africa, most especially in Nigeria. The most relevant intervention to reduce vulnerability of lowland rice farms to submergence is to develop varieties that are submergence tolerant. Therefore, the present study was undertaken to screen lowland rice varieties in Nigeria for submergence tolerance.

II. Materials and Methods

The study was conducted at the experimental station of the International Institute of tropical Agriculture (IITA), Ibadan, Nigeria in the wet season of 2010. Twenty varieties of rice which consist of five Sub1 mega varieties from IRRI, four landraces, six lowland released varieties in Nigeria, two lowland NERICAs and three parents of Sub1 varieties were evaluated for submergence in a randomized complete block design with three replicates in a deep pond tank that allows maintenance of flood water depth of 1.5m for a period of 14 days of submergence. Seeds sown in the wet nursery were transplanted after 21 days to the puddled soil in the deep pond at 20cm x 20cm with 2 seedlings per hill in eight rows of $5m^2$. Ten extra rows of susceptible varieties (IR 42) were planted on one side of the pond to observe the extent of damage due to submergence. Nitrogenous fertilizer was applied at 30:30:30kg/ha as basal a day before transplanting. Gap-filling was done at 7 days after transplanting to ensure 100% plant establishment. The transplanted seedlings were allowed to grow for 30days before submergence. Number of plants was counted and height measured before submergence. The pond was filled with water to a depth of 1.5m to completely submerge the rice plants for a period of 14 days. The water depth was maintained for the period of 14 days by adding water regularly. Ten plants were randomly uprooted to monitor the extent of damage due to flooding. The submergence treatment was terminated at the 14^{th} day. The pond was left to drain for three days before putting water to a depth of 1-2cm and later to a depth of 5cm. Split application of fertilizer at the rate of 30kg/ha of nitrogen were applied at 10 days and another 30kg at 20 days after de-submergence.

To determine the percentage yield loss due to submergence stress, another experiment was conducted under normal rainfed lowland conditions. The 20 varieties were laid out in a randomized complete block design with three replicates. Seeds sown in the wet nursery were transplanted after 21 days to the puddled field. Two seedlings were transplanted per hill at a spacing of 20cm between rows and between hills in eight rows of $5m^2$. Inorganic fertilizer was applied in two split application, a basal of 200kg/ha before transplanting using NPK (15 15 15) and top dressed with Urea at the rate of 65kg/ha at the tillering stage and at the rate of 35kg/ha at booting stage. Approximately 5cm of standing water was maintained in the field until drainage before harvest. Weeds were controlled by application of post-emergence herbicide (Oritzoplus) 14 days after transplanting (DAT) and hand weeding.

III. Data Collection

Data were collected on plants for plant number and plant height before submergence, stem elongation, percentage survival after submergence, days to 50% flowering, number of tillers at maturity, number of panicles at maturity and grain weight.

IV. Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using general linear model (GLM) procedure for randomized complete block design in SAS (9.2). Correlation between different traits was determined using the proc corr procedures, also of SAS.

V. Results

The Results revealed significant variations among the cultivars in submergence tolerance and all other characters evaluated (Table 1).

A. Percentage Survival

Survival percentage varied from 3.19% to 25.66% for susceptible rice cultivars and 94.47% to 97.49% for tolerant cultivars. Kaura emerged the best surviving susceptible variety with percentage survival of 25.66 while FARO 57 recorded the lowest percentage survival (3.19%) and closely followed by FARO 52 with percentage survival of 3.54%. Among the tolerant varieties, the highest percentage survival (97.49%) was obtained from IR84196-32 (Sambha Mahsuri Sub1) and was found to be statistically the same with other submergence tolerant varieties. All varieties with submergence tolerant gene (sub1) had significant higher survival rate than other varieties evaluated.

B. Stem Elongation

Stem elongation due to submergence varied significantly among varieties (Table 1). Jan-Iri, FARO 57, FARO 52, and FARO 37 varieties were found to have recorded the highest shoot elongation of 39.00cm, 37.67cm, 35.00cm and 34.67cm respectively. The lowest shoot elongation of 17.33cm was recorded for IR 82810-407(Swarna Sub1) and closely followed by IR84196-32 (Sambha Mahsuri Sub1) that measured 19cm. Generally, elongation due to submergence stress was higher in the susceptible varieties than what obtained in the tolerant ones (Table 1).

C. Days to 50% Flowering

Duration to 50% flowering was significantly different among varieties at ($p<0.001$) with NERICA- L-34 taking the shortest time of 105 days to attained 50% flowering while Swarna took the longest time of 138 days.

D. Number of Tillers

The number of tillers ranged between 12.67 to 18.80 with variety IR84194 -139 recording the highest number of tillers of 18.80 while the lowest number of tillers (12.67) was recorded for variety FARO 36.

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E. *Number of Panicles per Plant*

The number of panicles per plant varied significantly across by varieties. It ranges from 10.33 in NERICA-L-19 to 19.43 in Sambha Mahsuri.

F. *Grain Yield*

The grain yield, observed to be largely affected by percentage survival, ranges from 0.11 to 1.18t/ha in the susceptible varieties and from 1.94 to 3.59t/ha in the tolerant varieties. IR85264-141 (TDK1 Sub1 (BC3F3)), a submergence tolerant variety, emerged the best yielder with average grain yield of 3.59t/ha followed by IR84194-139 (IR64 Sub1), another tolerant variety that gave grain yield of 3.30t/ha (Table 2).

G. *Percentage Yield Reduction Due to Submergence*

To determine yield reduction due to submergence stress, the tested varieties were evaluated under normal rainfed lowland condition. The results obtained showed that yield reduction due to submergence ranged between 98.47 and 66.40% in the susceptible varieties and between 16.36 and 40.74% in the tolerant varieties (Table 2). FARO 57, a released lowland variety in Nigeria recorded the highest yield loss of 98.47% due to submergence followed by FARO 52, another lowland released mega variety in Nigeria with yield reduction of 97.65%. The lowest grain yield reduction of 16.36% was recorded in IR84194-139 (IR64 Sub1), a tolerant mega variety from Asia.

VI. Correlation

The result of correlation analysis as shown by their coefficients of correlation (Table 3), revealed that percentage survival exhibited significantly positive correlation with 50% flowering ($r = 0.62^*$), number of tillers ($r = 0.48^*$), plant height ($r = 0.51^*$), grain yield ($r = 0.95^{***}$), but negatively correlated with stem elongation ($r = -0.80^{**}$). Stem elongation also correlated negatively with grain yield ($r = -0.80^{***}$).

VII. Discussion

The results obtained revealed that varieties with submergence tolerant gene (Sub1) exhibited significantly greater tolerance when compared with their original parents and other susceptible varieties, validating the effectiveness of Sub1 in conferring submergence tolerance. The result confirmed the observation that varieties with Sub1 gene have substantial level of tolerance to submergence stress (Sarkar et al., 2009; Septiningsih et al., 2009; Singh et al., 2009). This implies that introgression of Sub1 gene into African mega rice varieties will provide protection against crop loss due to submergence and increase crop security for lowland rice farmers. Rapid stem elongation during submergence competes with maintenance processes which require carbohydrates and energy, leaving less assimilates available to support maintenance required for survival during submergence (Voesenek et al., 2006; Ram et al., 2002; Setter and laurels 1996; Greenway and Setter 1996). Stem elongation due to submergence was found to be high in susceptible varieties than the tolerant varieties (Singh et al., 2001; Das et al., 2005), which implies that limited stem elongation growth is associated with variety's ability to survive submergence. This is probably due to the fact that the energy required for maintenance and survival processes is made readily available for the purpose and not released for stem elongation. Since stem elongation competes with maintenance processes for energy, it would reduce the chances of survival of the rice plants during submergence. This is corroborated by the findings of (Setter and Laureles, 1996; Sakar, 1998; Jackson and Ram, 2003).

Complete submergence at the vegetative stage considerably decreases number of panicles, number of grains per panicle, and grain-filling percentage and delayed flowering and maturity, thereby causing a dramatic decline in grain yield in intolerant varieties (Singh et al., 2009). Grain yield was found to be significantly higher in submergence tolerant varieties than the susceptible varieties (Singh et al., 2009; Sarkar et al., 2009). This can be attributed to higher survival rate, higher number of tillers and higher number of panicles observed in the tolerant varieties. The higher percentage yield reduction obtained in the susceptible varieties when compared with the yield obtained under normal rainfed lowland condition showed the level of yield loss that lowland rice farmers can suffer when their rice farms are completely submergenced. This confirms the report of Mackill et al., 1996, that yield losses resulting from flooding may range from 10 percent to total destruction. The lower yield reduction percentage obtained in Sub1 varieties raised hopes that this trait could be introduced into susceptible mega varieties in Nigeria to reduce the yield loss from flash flooding. Plant elongation during submergence has been found to be negatively correlated with percentage survival (Singh et al., 2001), emphasizing the importance of reduced stem elongation during submergence. The negative relationship ($r = -0.80^{***}$) between percentage survival and stem elongation support the observation that submergence tolerance and stem elongation rarely occur in the same genotype (Setter and laurels 1996.), suggesting difficulty in developing cultivars with both stem elongation ability and tolerance.

VIII. Conclusion

The results clearly showed that all the Nigerian lowland mega rice varieties evaluated are sensitive to submergence stress, indicating that submergence tolerant versions of these varieties are urgently needed. This will improve people's standard of living and stabilize household food supplies as the development of submergence varieties will ensure a more dependable food supply for poor farmers and their families. The negative correlation between stem elongation and percentage survival suggests that greater elongation during submergence has pronounced adverse effects on rice survival and that selection for minimal elongation as a trait should be part of breeding objectives in the development of submergence tolerant rice varieties, bearing in mind that submergence tolerance and elongation rarely occur in the same rice genotype.

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TABLE 1
MEAN PERFORMANCE OF 20 RICE VARIETIES SCREENED FOR SUBMERGENCE TOLERANCE

Designation	No submerged	No Survived	% Survival	Elongation (cm)	50%flowering (days)	No of tillers	No of panicles	Plant Ht (cm)	Yield (t/ha)
EX-CHINA	194.33	37.67	19.33cd	29.67	116.00	13.00	12.00	130.00	0.49de
FARO 35	195.67	37.67	19.25cd	30.67	110.33	16.00	14.20	99.08	1.11d
FARO 36	196.33	26.33	13.42e	33.67	109.00	12.67	12.00	125.33	0.59de
FARO 37	195.33	34.67	17.72cde	34.67	113.00	14.00	11.00	115.33	0.40de
FARO 44	199.33	28.67	14.39de	25.00	110.00	16.00	14.00	95.00	0.12e
FARO 57	198.67	6.33	3.19f	37.67	112.00	14.67	12.33	131.33	0.07e
IR 64	196.67	45.00	22.85bc	28.67	111.00	18.00	18.63	97.36	1.18d
IR82810-407	199.33	188.33	94.47a	17.33	123.67	18.22	15.93	92.83	2.64bc
IR84194-139	197.00	191.00	96.95a	20.67	117.33	18.80	18.63	91.29	3.30ab
IR85260-148	198.00	189.00	95.45a	26.12	132.00	17.67	16.87	110.17	1.94c
IR85264-141	194.00	188.67	97.26a	20.67	116.33	20.15	18.53	102.84	3.59a
JAN-IRI	193.33	25.33	13.17e	39.00	114.00	14.00	12.00	124.00	0.41de
KAURA	192.67	49.33	25.66b	27.67	117.00	14.00	12.33	115.33	0.82de
NERICA-L-19	198.33	25.00	12.61e	33.00	109.00	13.00	10.33	123.33	0.64de
NERICA-L-34	199.33	26.67	13.37e	26.33	105.00	14.00	12.00	102.67	0.44de
ODE-OMI	192.00	37.67	19.62cd	32.67	122.00	13.67	12.67	124.00	0.90de
R84196-32	199.00	194.00	97.49a	19.00	123.50	18.00	16.30	94.45	2.64bc
SAMBHA MAHSURI	195.00	30.67	15.70de	31.33	121.33	20.00	19.43	95.33	0.79de
SWARNA	194.00	34.67	17.85cde	23.33	138.33	19.00	18.83	91.75	1.03d
FARO 52	197.33	7.00	3.54f	35.00	117.00	16.00	14.23	106.42	0.11e
Means	**196.28**	**70.18**	**35.67**	**28.61**	**116.89**	16.04	14.61	**108.39**	**1.16**
CV %	**2.01**	**7.53**	**7.52**	**12.52**	**1.87**	**11.10**	**10.86**	**4.05**	**32.08**
R2	**0.64**	**0.99**	**0.99**	**0.84**	**0.99**	**0.88**	**0.74**	**0.94**	**0.91**
Pro	**ns**	***	***	***	***	***	***	***	***

* = significant at P<0.05; ** = significant at P<0.01; *** = significant at P<0.01; ns = non significant

TABLE 2
PERCENTAGE YIELD REDUCTION OF RICE CULTIVARS DUE TO SUBMERGENCE STRESS.

Designation	%Survival after 14-days submergence	Submerged Yld(t/ha)	Normal field Yld(t/ha)	% Yld Reduction
EX-CHINA	19.33	0.49	3.55	86.31
FARO 35 (ITA 212)	19.25	1.11	3.61	69.30
FARO 36	13.42	0.59	3.86	84.79
FARO 37	17.72	0.40	4.20	90.59
FARO 44	14.39	0.12	3.05	95.98
FARO 57	3.19	0.07	4.4	98.47
IR 64	22.85	1.18	3.5	66.40
IR82810-407	94.47	2.64	4.45	40.74
IR84194-139	96.95	3.30	3.95	16.36
IR85260-148	95.45	1.94	4.11	52.88
IR85264-141	97.26	3.59	4.46	19.51
JAN-IRI	13.17	0.41	2.98	86.14
KAURA	25.66	0.82	3.2	74.38
NERICA-L-19	12.61	0.64	4.88	86.95
NERICA-L-34	13.37	0.44	4.2	89.43
ODE-OMI	19.62	0.90	2.11	57.48
R84196-32	97.49	2.64	3.83	31.17
SAMBA MAHSURI	15.70	0.79	3.83	79.46
SWARNA	17.85	1.03	3.87	73.34
FARO 52	3.54	0.11	4.68	97.65

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TABLE 3
CORRELATION COEFFICIENT AMONG TRAITS

	% Survival	Elongation (cm)	50% flowering (days)	No of tillers	No of panicles	Plant Ht(cm)	Yield (t/ha)
%Survival	1						
Elongation(cm)	-0.8***	1					
50% flowering(days)	0.62**	0.57**	1				
No of tiller	0.48*	0.45*	0.71**	1			
No of panicle	0.31ns	0.01ns	0.34ns	0.21ns	1		
Plant Ht(cm)	0.51*	0.75***	0.70**	0.70**	0.34ns	1	
Yield(t/ha)	0.95***	-0.80***	0.63**	0.47*	0.17ns	0.55*	1

* = significant at P<0.05; ** = significant at P<0.01; *** = significant at P<0.01; ns = non significant

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