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Submergence tolerance and yield performance of rice varieties as affected by flash-flooding at different growth stages

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ABSTRACT

Rice varieties of different plant heights viz. Jagannath and Gayatri (semi-dwarf), Panidhan and Tulasi (semi-tall) and Amulya and Champaisali (tall) along with flood-tolerante local check FR13A (semi-tall) were evaluated for submergence tolerance and yield performance under flood-prone lowland conditions. Semi-dwarf varieties submerged for 10 days at active tillering and/or maximum tillering showed a greater tiller mortality (26.3%) and decrease in dry matter production (29.9%) compared with semi-tall types (13.9 and 22.8%), which were submerged partially. Flash-flooding at maximum tillering caused less damage than at early tillering. The semi-tall varieties, Panidhan and Tulasi produced maximum grain yield under natural submergence (2.84-3.33 t ha^{-1}) as well as flash-flooding at active tillering (2.17-2.56 t ha^{-1}) and maximum tillering (2.18-2.72 t ha^{-1}). The grain yield of improved tall selections, Amulya and Champaisali was low (1.93-2.04 t ha^{-1}) but stable (CV 4.8-5.1%) under flash-flooding The flood-resistant local check, FR13A showed a similar behaviour under flash-flooding as the tall types but produced lower grain yield (2.04-2.07 t ha^{-1}) than the improved semi-tall types.

Key words: *Dry matter accumulation, elongation, post-flood recovery, submergence tolerance, tiller mortality, grain yield, rice varieties, flood-prone lowlands*

Flash flooding occurs in the deltaic and coastal areas of eastern India results submergence rice crop. In most of these areas, the traditional tall, photosensitive rice varieties are predominantly grown which are well adapted to a wide range of flooding environments but they are low yielder (1.0-1.5 t ha^{-1}). Improved rice varieties with some degree of tolerance/avoidance to submergence have been developed to suit the water regime. Normally, the semi-dwarf submergence-tolerant types are recommended for shallow and intermediate lowlands (<50 cm water depth) but for greater flooding conditions, the tall elongating varieties are essential to avoid complete submergence (Sharma and Reddy, 1992). This study aims at evaluating the response of improved rice varieties of varying heights to flash-flooding at different growth stages when grown under naturally occurring intermediate lowland conditions.

MATERIALS AND METHODS

A field experiment was conducted during the wet seasons of 1994 and 1995 at the Central Rice Research Institute, Cuttack. The soil of the experimental site was alluvial sandy clay loam with pH 6.4, organic C 0.83%, total N 0.09%, available P 22 kg ha^{-1} and available K 128 kg ha^{-1}. Long-duration, photosensitive, popular rice varieties including two each from semi-dwarf type (Jagannath and Gayatri), semitall type (Panidhan and Tulasi) and tall type (Amulya and Champaisali), besides a traditional semi tall and best known flood tolerance local check (FR13A) were included in the study. These 7 varieties were grown in a field having naturally-occurring intermediate water depth. Brick walls were raised in the field up to a height of 1 m for imposing short term flash flooding and four such tanks were constructed, each of size 40 x 16 m. In each tank, the 7 varieties were sown @ 400 seeds m^{-2} at 20 cm row spacing, applying a common basal dose of 40 kg N ha^{-1} and 20 kg ha^{-1} each of P_2O_5 and K_2O in the plough furrow. For each variety, twenty rows of 4.0 m length were arranged in a plot size of 16 m^2. Three strips (blocks) each with 7 varieties were maintained in each tank to serve as three replications.

The crops raised in the tanks were subjected to simulated flash flooding at different growth stages *viz.* natural submergence, flash flooding at active tillering (60 days after sowing) and/or maximum tillering (80 days after sowing). There were 4 submergence levels in 1994 and 3 in 1995; thus making a total of 28 and 21 treatment combinations, respectively. The data were analysed as per the standard analysis of variance technique for a split plot design, keeping submergence levels in main plots and rice varieties in sub-plots. Observations were recorded on plant height, tiller number and dry matter accumulation – before as well as after the simulated flash-flooding. At crop maturity, the plant height from the tagged plants, total tillers and panicles from the fixed 1 m^2 area, weight of all these panicles, and yield of grain and straw from the central 12 rows of the plot were recorded.

RESULTS AND DISCUSSION

Flooding patterns and initial crop stand. There was a large variation in flooding patterns and initial establishment of rice in the two years (Figure 1). In 1994, the crop was sown at the optimum time with pre-monsoon showers and the plants grew well due to saturated soil conditions for about 35 days. Rapid increase in water depth from 36 days of growth up to 66 cm within 2 weeks caused complete submergence of semi-dwarf varieties, Gayatri and Jagannath for 10 days. However, the semi-tall varieties, Panidhan, Tulasi and FR13A and the tall types, Amulya and Champaisali were only partially submerged and their plants remained about 10-15 cm and 25-30 cm above the water level, respectively. The water receded to 30 cm at 60 days of growth and remained between 25 and 50 cm during the next 30 days. Simulated flash flooding at active tillering stage caused complete submergence of Jagannath, while the tips of leaves of Gayatri remained above the water level (2-9 cm). On the other hand, semi-tall and tall types were 12-24 and 25-32 cm above the water level, respectively. After the termination of flash-flooding at 70 days of growth, the water level receded to 30 cm. There was another natural flooding up to 80 cm in the beginning of September, just before the simulated flash-flooding at the maximum tillering stage. The water level started receding from last week of September (panicle initiation stage) and was zero in the end of November.

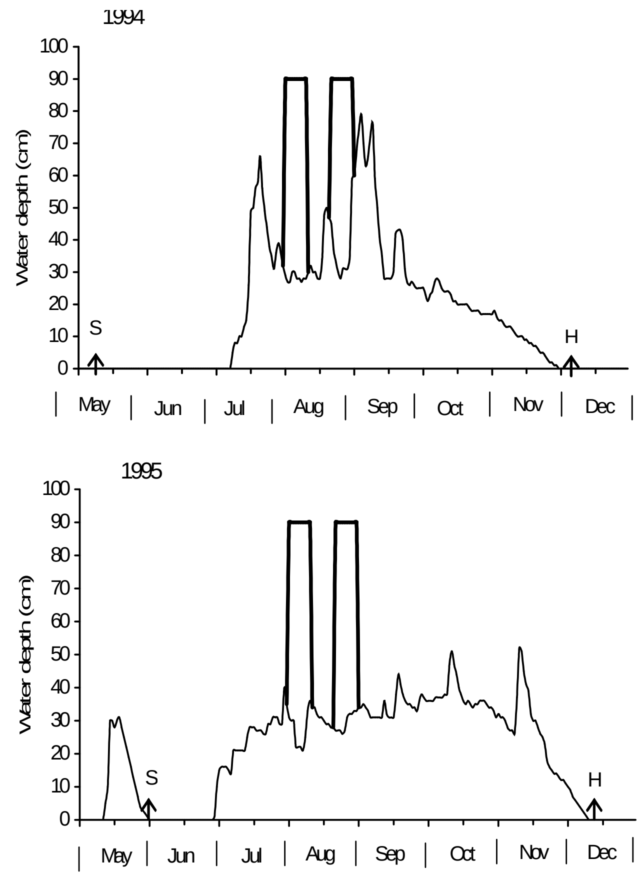

Fig. 1. Daily variations in flooding patterns during growth period of rice (______ natural submergence, ________ simulated flash-flooding). Arrows under S and H indicate dates of sowing and harvesting of rice varieties, except Panidhan which was harvested 10 days later than other varieties.

In 1995, unusually heavy rains (603 mm) in the third week of May resulted in an accumulation of water in the field up to 30 cm and made it practically impossible to sow the crop in dry soil. The water level receded by May end and sprouted seeds were sown on 1 June in saturated soil. This led to rapid germination but the seedlings were weak due to dense population. The water level accumulated gradually in the early stages up to 35 cm at 60 days of growth. Simulated flash-flooding at active or maximum tillering stages was imposed when the water level under natural submergence conditions was between 30 and 35 cm. The late monsoon rains in October and November caused flooding of greater depths (up to 50 cm), which coincided with pre-flowering and ripening stages, respectively. The water level remained unusually high in the later stages and receded completely by the second week of December.

Growth parameters. In 1994, growth parameters *viz.* plant height, tillers m^{-2} and dry matter accumulation were adversely affected due to submergence at active or maximum tillering stages. Plant height of all the rice varieties increased as a consequence of simulated flash-flooding, and remained marginally higher than non-flooded control. The plants of Jagannath were the dwarfest and thus submerged completely at active tillering and partially at maximum tillering. In all other varieties, the submergence at both the stages was partial, although a greater part of the dwarfer Gayatri and the semi-tall Panidhan, Tulasi and FR13A was under water than tall varieties, Amulya and Champaisali. The increase in height due to flash flooding was more in tall varieties, Amulya and Champaisali, and also in semi-tall FR13A, probably due to their greater elongation ability. The plant height remained comparatively lower under non-submerged conditions compared with that recorded after flash-flooding at both the stages. However, this trend was not observed at harvest when the non-flooded control recorded the tallest plants, which were significantly taller than those subjected to flash-flooding at both the stages (Table 1). This type of variable response was due to the poor recovering ability of the submerged plants compared with non-submerged conditions. The mean plant height was 16-21 cm less in 1995 than in 1994, which was attributed to poor plant growth in early stages due to wet seeding and early water accumulation. Further, the water depth also remained much lower during most of the crop growth period in 1995, which did not result in greater elongation of rice plants.

Number of tillers m^{-2} was higher in semi-tall and tall rice varieties than in semi-dwarf types. Tillering decreased as a consequence of simulated flash-flooding at both the stages but the decrease was greater due to flash-flooding at active tillering. Pande *et al.* (1979) also reported that submergence at early stages was more harmful because of plant mortality and reduction in tiller production. The tillers m^{-2} showed an increase under non-flooded control compared with that recorded before imposition of flash-flooding. The mortality of tillers due to flash-flooding at active tillering was comparatively higher in semi-dwarf varieties (26.2-26.4%) and tall varieties (25.4-28.7%) than in semi-tall varieties (13.6-14.1%), probably due to their varying degree of tolerance to submergence. The relatively smaller decrease in tillers m^{-2} due to flash-flooding at maximum tillering in all varieties 11.5-15.8% in semi-dwarf and tall varieties, and 8.5-9.2% in semi-tall varieties was due to lesser submergence of their plant parts and greater submergence tolerance due to advanced age of the crop. Older plants establish well in excess water, contained more dry matter and carbohydrates, and thus possessed greater submergence tolerance (Panda *et al*,. 1991, Chaturvedi *et al*., 1996, Sharma and Ghosh, 2001). The traditional rice variety, FR13A showed almost similar tiller mortality due to flash flooding at active tillering (15.7%) and maximum tillering (9.4%) as the improved semi-tall varieties.

Dry matter accumulation followed a trend similar to tillering. Semi-dwarf varieties produced lowest dry matter, which decreased further due to flash-flooding. The decrease in dry matter varied from 28.5-31.3, 20.3-25.3 and 30.8-32.6% due to flash-flooding at active tillering; and 15.3-20.5, 15.8-17.0 and 19.3-22.6% due to flash-flooding at maximum tillering in semi-dwarf, semi-tall and tall varieties, respectively. Amount of dry matter and carbohydrates in plant parts correlate positively with submergence tolerance (Reddy and Mittra,1985, Emes *et al.*, 1987). The relatively tolerant varieties, Panidhan and Tulasi had lower rate of reduction of dry matter during submergence and better recovery during the post-flood period, probably due to greater availability of substrate for regeneration of growth. The dry matter of FR13A at active tillering stage was equal to that of the semi-tall varieties but the former variety was distinctly superior at the maximum tillering stage. Further, the dry matter production under unsubmerged conditions was the highest in FR13A. Yamauchi *et al.* (1993) also observed very high seedling emergence and establishment of FR13A under flooded soil. The tall varieties showed a greater decrease in dry matter due to flash-flooding than the semi-tall varieties because they consumed the accumulated dry matter and carbohydrates for elongation with rising water to escape greater submergence but recovered poorly in the post-flooding period due to lodging.

Yield performance. Flash-flooding at active and/or maximum tillering stages decreased yield attributes of rice significantly (Table 1). The number of panicles m^{-2} decreased significantly due to flash flooding and the adverse effect was relatively more pronounced when flash flooding was imposed at active tillering than at

Table 1. Mean effect of flash-flooding at different growth stages on growth and yield performance of different rice varieties

Treatment	Plant height at maturity (cm)		Total tillers m^{-2}		Panicles m^{-2}		Panicle weight (g)		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995
Flash-flooding												
Natural submergence	155	134	126	115	102	94	2.28	2.76	2.45	2.65	8.14	7.60
Flash-flooding at active tillering	144	126	95	89	82	64	2.05	2.18	1.92	1.96	6.14	6.70
Flash-flooding at maximum tillering	149	133	113	93	91	70	2.11	2.36	2.03	2.11	7.92	8.10
Flash-flooding at active and maximum tillering	135	-	94	-	81	-	2.03	-	1.69	-	5.46	-
SEm± (6 D.F.)	3.2		4.3		2.9		0.051		0.060		0.27	
(4 D.F.)		2.8		4.7		2.6		0.082		0.071		0.406
CD (P=0.05)	11.1	10.9	14.9	18.4	10.0	10.2	0.176	0.322	0.208	0.279	0.934	1.594
Varieties												
Gayatri	122	96	104	119	88	85	2.17	2.68	1.85	2.29	3.87	6.64
Jagannath	116	102	88	110	82	74	1.99	2.30	1.64	1.81	2.19	5.47
Panidhan	154	136	117	106	111	90	2.58	2.74	2.71	2.93	9.46	9.20
Tulasi	146	124	120	114	97	80	2.15	2.18	2.29	2.46	7.02	7.21
Amulya	161	153	110	76	85	69	1.97	1.89	1.98	2.00	8.46	9.54
Champaisali	166	148	126	83	79	63	2.00	2.63	1.65	2.10	9.19	7.11
FR13A	155	6.9	84	85	81	71	1.97	2.59	2.04	2.07	8.23	7.05
SEm± (48 D.F.)	2.8		4.2		2.9		0.047		0.059		0.210	
(36 D.F.)		2.5		5.1		3.3		0.086		0.073		0.409
CD (P=0.05)	7.9	7.2	11.9	14.6	8.3	9.5	0.134	0.247	0.168	0.209	0.598	1.174

maximum tillering. Flash-flooding resulted in greater non-panicle bearing tillers in 1995 (24.7-28.1%) than in 1994 (13.7-19.5%). This was due to shorter plants in 1995, which were submerged to a greater extent causing greater tiller mortality and fewer panicles at maturity. Panicle weight was higher in 1995 than in 1994, due to fewer panicles in 1995. In earlier studies also, we observed opposite trends in the number and weight of panicles under excess water conditions (Sharma and Ghosh, 1998). The panicle weight also decreased significantly due to flash-flooding; and the decrease was comparatively greater when flash-flooding was imposed at early than at later stage (Reddy and Mittra, 1985). In 1994, flooding at both the stages did not cause a further decrease in panicle weight over flooding at one stage only.

In 1994, total tillers m^{-2} were less in semi-dwarf varieties but more in semi-tall and tall varieties compared with that in 1995. Interestingly, the semi-tall varieties produced the highest number of panicles in both years, followed by the semi-dwarf and the tall types. The semi-tall variety, Panidhan produced the maximum panicles m^{-2} with the heaviest weight in both years. The varieties, Jagannath and Tulasi were inferior in these attributes to Gayatri and Panidhan among the semi-dwarf and semi-tall types, respectively. This was due to the fact that Gayatri possessed some degree of submergence tolerance (Reddy *et al*., 1990), while Panidhan had relatively longer growth duration (+10 days) compared with other varieties. The improved tall variety Amulya did not show significant superiority over the local tall Champaisali in the number and weight of panicles. Similarly, the variety FR13A gave panicles m^{-2} lower than in the semi-tall types but its panicle weight was at par with other varieties, except Panidhan in 1994 (significantly higher), and Tulasi and Amulya in 1995 (significantly lower).

Mean grain yield of rice decreased due to flash-flooding, and the decrease was greater due to flash-flooding at active tillering (21.6-26.0%) than at maximum tillering (17.1-20.4%) compared with natural submergence conditions (Table 1). In 1994, flash-flooding at both the stages further decreased the yield significantly (31.0%) compared with that at active or maximum tillering only. Among the varieties, the semi-tall types outyielded others, with Panidhan being the best, followed by Tulasi in both the years. Interaction between submergence levels and rice varieties was also significant on grain yield (Table 2). In 1994, flash-flooding at maximum tillering had a lesser adverse effect on the yield of all rice varieties, except Jagannath and Amulya, which showed equal yield as that obtained when flash-flooding was imposed at active tillering. However, when flash-flooding was imposed at active and maximum tillering stages, there was a significant reduction in yield of Jagannath, Gayatri, Champaisali and FR13A compared with flash-flooding at maximum tillering only. The other improved varieties, Panidhan, Tulasi and Amulya did not show any decrease in yield when submerged consequitively at active and maximum tillering compared with that at either of the stages. This suggested that these varieties may be suitable for growing in recurrent flooding conditions. Although the tall varieties and semi-tall FR13A produced lower grain yield (1.65-198 t ha^{-1}) than improved semi-tall types (2.29-2.71 t ha^{-1}), the former types remained more stable (CV 4.76-5.11%) than the latter types (8.03-21.03%) and did not show any significant yield reduction due to flash-flooding at active or maximum tillering stages. On the other hand in 1995, flash-flooding at active or maximum tillering decreased the yield conspicuously in all the varieties, except Tulasi which remained unaffected. The yield of local types, FR13A and Champaisali was also not affected adversely due to flash-flooding at maximum tillering compared with natural submergence conditions. The semi-tall improved varieties performed better than others under natural submergence as well as flash-flooding conditions. The better performance of Panidhan and Tulasi in both the years was due to greater number and weight of panicles. These varieties showed greater tolerance to submergence as revealed from lesser adverse effect

Table 2. Interaction between flash-flooding and varieties on grain yield (t ha^{-1}) of rice

Varieties	Flash-flooding			
	Natural submergence	Flash-flooding at active tillering	Flash-flooding at maximum tillering	Flash-flooding at active and maximum tillering
		1994		
Gayatri	2.52	1.59	1.85	1.46
Jagannath	2.17	1.68	1.67	1.06
Panidhan	3.11	2.57	2.74	2.41
Tulasi	3.03	1.93	2.02	2.16
Amulya	2.22	2.01	2.01	1.69
Champaisali	1.85	1.67	1.76	1.34
FR13A	2.26	2.00	2.18	1.71
		1995		
Gayatri	2.77	2.08	2.02	-
Jagannath	2.47	1.43	1.53	-
Panidhan	3.55	2.55	2.70	-
Tulasi	2.65	2.40	2.33	-
Amulya	2.42	1.63	1.96	-
Champaisali	2.40	1.80	2.11	-
FR13A	2.27	1.82	2.11	-

	SEm±		CD (P=0.05)	
	1994 (48 D.F.)	1995 (36 D.F.)	1994	1995
Varieties at the same flash-flooding	0.119	0.126	0.339	0.362
Flash-flooding at the same or different varieties	0.126	0.137	0.359	0.393

on their growth parameters due to flash-flooding.

The results of this study suggest that intermediate statured rice varieties like Panidhan and Tulasi are most suitable for flood-prone lowland areas due to their ability to tolerate as well as avoid complete submergence and good post-flood recovery. The semi-dwarf types suffered a drastic reduction in yield due to flash-flooding, while the tall types yielded less despite their stable performance under variable flooding regimes.

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