



***SUB1* varieties increased rice (*Oryza sativa*) yield in flood-prone rainfed lowlands of coastal regions**

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Received: 15 January 2019; Accepted: 16 March 2020

ABSTRACT

Submergence of lowland rice (*Oryza sativa* L.) fields during the wet season in coastal regions adversely affects survival and productivity of rice. A field experiment was conducted for two consecutive wet seasons in 2016 and 2017 at ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal to evaluate the performance of six varieties carrying the *SUB1* gene (BR11-Sub1, Ciherang-Sub1, CR1009-Sub1, IR64-Sub1, Samba-Sub1, and Swarna-Sub1) along with two checks (DRR Dhan39 and Sabita) under stagnant and flash flooding situations. Sabita produced the highest grain yield (3.45 t/ha) followed by CR1009-Sub1 (3.27 t/ha) under stagnant flooding. Sabita is the local check under stagnant flooding. Under flash flooding, CR1009-Sub1 produced the highest grain yield of 4.11 t/ha, followed by Swarna-Sub1 (3.11 t/ha) and BR11-Sub1 (2.78 t/ha). Participatory varietal selection (PVS) was conducted during both the years to assess the preferences of farming communities for these varieties. Under stagnant flooding, the highest preference score was recorded for Sabita (0.62) followed by BR11-Sub1 (0.32) and CR1009-Sub1 (0.31). The lowest preference score was observed for IR64-Sub1 (-0.56), Samba-Sub1 (-0.31), and Ciherang-Sub1 (-0.26). Under flash flooding, the highest preference score was recorded for CR1009-Sub1 (0.63) followed by BR11-Sub1 (0.38) and Swarna-Sub1 (0.20). The lowest preference score was observed for IR64-Sub1 (-0.62), Samba-Sub1 (-0.34), Ciherang-Sub1 (-0.29), and DRR Dhan39 (-0.27). Based on the results of field experiments and farmers' preferences, CR1009-Sub1, BR11-Sub1, and Swarna-Sub1 could be recommended for cultivation in areas affected by flash floods in coastal areas of India.

Key words: Coastal ecosystem, Flash floods, Participatory selection, Rice, *SUB1*, Submergence

The International Rice Research Institute (IRRI) has identified rice (*Oryza sativa* L.) environments typically affected by “excess” water stress during the rice-growing period as (1) frequent flash floods/temporary floods

(submergence), for periods longer than 10 days and up to 18 days; (2) longer-term flooding of 20–60 cm (partial, stagnant or semi-deep); (3) deep water of 50–100 cm (deep water rice) for a duration ranging from a few weeks to months; and (4) very deep water or floating rice with water depth of 3–5 m for most of the season (Maclean *et al.* 2002, Ismail *et al.* 2008). In the coastal region of West Bengal, two main types of flooding (flash and stagnant floods) affect rice in rainfed lowlands during the *khari* (wet) season. Flash floods occur for a short period either due to heavy rain or due to the ingress of river water, and stagnant flooding (SF) is common in the saucer-shaped lowlands with high rainfall (>1800 mm annually) for more than a month.

Most rice cultivars die within a week of complete submergence – a major constraint to rice production in the South and Southeast Asia that causes annual losses of over US\$1 billion, mainly affecting the poorest farmers. As a coping strategy, farmers in flood-prone areas traditionally use landraces that can tolerate 10 days or more of complete submergence and resume growth upon de-submergence (Catling 1992). One such example is the *indica* cultivar FR13A, a pure line selection from the landrace *Dhalaputia*

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from Odisha. FR13A reaches 50% flowering at about 125 days after sowing, and was released by Orissa University of Agriculture and Technology in 1988 (Das 2012). It is highly tolerant of submergence and can survive over two weeks of complete submergence owing to a major quantitative trait locus (QTL) designated as *Submergence 1* (*SUB1*), on the short arm of chromosome 9. This cultivar was frequently used as the donor of *SUB1* QTL for a number of improved submergence tolerant rice genotypes commercialized in Asia (Xu *et al.* 2006; Mackill *et al.* 2012; Ismail *et al.* 2013). Earlier, 10-day-old seedlings of FR13A were reported to survive over 10 days of complete submergence (Vergara and Mazaredo 1975, HilleRislambers and Vergara 1982). Grains of this cultivar are deep reddish, bold, with distinct awn, all of which are considered undesirable traits in commercial rice varieties. Moreover, it lacks other agronomically important traits such as being photoperiod sensitive, tall, with poor grain quality and low yields of less than 2 t/ha, compared with modern, semi-dwarf varieties that can produce over 6 t/ha (Bailey-Serres *et al.* 2010). A milestone in breeding of rice for abiotic stress-prone ecosystems was the successful transfer of *SUB1* gene into eight Asian rice mega varieties, viz. Swarna, Samba Mahsuri, IR64, BR11, CR1009, Ciherang, TDK1, and PSBRc18 using marker-assisted backcrossing (Ismail *et al.* 2013). Most of these varieties are now widely adopted in flood-prone areas of South and Southeast Asia.

The success of the varieties containing the *SUB1* gene owned to their ability to survive prolonged submergence by assuming a quiescence strategy to conserve their energy reserves when underwater, and resume growth after the flood recedes (Bailly-Serres *et al.* 2010). These varieties perform better than the traditional landraces, in having higher yields and better grain quality, besides being tolerant of submergence. However, in coastal areas such as the Sundarbans delta where both flash-floods and stagnant floods are experienced, sometimes within the same season, these *SUB1* varieties have not been rigorously evaluated. The present studies were conducted to evaluate some of these *SUB1* varieties and popular local varieties, both under stagnant and flash flood situations typical of coastal zones of South Asia, to assess their performance and evaluate farmers' preferences of these varieties. The outcomes of the study will inform current and future breeding programs about the critical traits that need to be present in varieties suitable for coastal tropics.

MATERIALS AND METHODS

A field experiment was conducted twice, during the wet seasons (*kharif*) of 2016 and 2017 at the research farm of ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town (ICAR-CSSRI, RRS; 22° 15' N, 88° 40' E; 3.0 m above MSL), West Bengal, under either stagnant or flash flooding situations as main-plots. Six *SUB1* rice genotypes; Ciherang-Sub1 (Bina Dhan11), CR1009-Sub1 (Savitri-Sub1), IR64-Sub1, BR11-Sub1 (BRRI Dhan52), Samba-Sub1 (Samba Mahsuri-Sub1) and

Swarna-Sub1; together with two checks (DRR Dhan39 and Sabita) were used as sub-plots. The experiment was conducted in a split-plot design with three replications. The nursery was sown on June 28 and 29 and transplanted on August 08 and 09, respectively, during 2016 and 2017. Seedlings were transplanted and then subject to either (1) partial stagnant flooding with standing water of more than 40 cm during most of the growing season and (2) flash flooding situation, where the crop was completely submerged during periods of high rainfall with field water level surpassing 50 cm for less than two weeks, then the flood-water recedes with decrease in rainfall.

The soil in both experiments was silty clay, with 43% clay, 47% silt, and 10% sand. The pH of the topsoil was 6.9, the average bulk density of 1.44, and organic carbon concentration was 0.45%. The climate of the site is tropical monsoon with an average annual rainfall of 1802 mm, 90% of which occurs in the *kharif* season (June-November). During 2016, total rainfall was 2020.2 mm in 86 rainy days, of which 619.0 mm was recorded in the month of August, but the maximum rainy days (22) were in July. In 2017, total annual rainfall was 1944.5 mm, occurred in 82 rainy days. A maximum of 567.4 mm rainfall was in July, but the maximum rainy days (18) were during August. The field water depth was measured by installing measuring sticks in three areas in each experiment.

Seedlings were transplanted at a spacing of 15 cm × 15 cm and all plots in the field were similarly managed, with chemical fertilizers applied at a rate of 75-20-10 kg N-P₂O₅-K₂O/ha. Total P and K were applied as basal before transplanting, whereas N in the form of urea (neem coated) was applied in three equal splits at 7 days after transplanting (DAT), at maximum tillering (35 to 45 DAT), and at flowering (60 to 80 DAT). Plant height and leaf area were measured at the flowering stage, and leaf area was determined from 10 hills in each plot using a CI-202 portable leaf area meter (CID Biosciences), then leaf area index (LAI) calculated as leaf area relative to land area. Days to 50% flowering were determined by recording the number of days taken from sowing until 50% of the plants in a plot had flowered. At maturity, 12 representative hills were collected for measurement of panicle number/m², grains/panicle, fertility percentage [(number of fertile grains per panicle/total number of spikelets per panicle) × 100] and 1000 grain weight. Grain yield was recorded from 9 m² area at the center of each plot and expressed as t/ha. Chlorophyll concentration (mg/g fresh weight) was determined using 1 g of finely cut flag leaf sample ground in 20 ml of 80% acetone and centrifuged at 5000 rpm for 5 min. Total chlorophyll concentration was measured spectrophotometrically and calculated based on Porra (2002).

The entries underwent preference analysis (PA) when the lines were at least 80% mature (Manzanilla *et al.* 2014). This field evaluation process allowed male and female farmers of the Sundarbans region and scientists of ICAR institutes to vote on the performance of these varieties and report on their criteria for selecting the most and

least preferred varieties. The data gathered from PA were transformed using a “preference score” computed using the formula: Preference Score (PS) = (Number of positive votes – Number of negative votes)/Total number of positive and negative vote casts.

Data were subjected to analysis of variance (ANOVA) using the software Statistical Technique for Agricultural Research (STAR) developed by the International Rice Research Institute (<http://bbi.irri.org>). Since the interaction between genotype and year was not significant, the data means over the two years were presented. Treatment means were compared using critical difference (CD) values at a 5% level of significance wherever the F-test was significant (Panse and Sukhatme 1978). Associations between farmers’ preference scores and different parameters, as well as grain yield with yield attributes, were assessed through Pearson’s correlation coefficients using the STAR software.

RESULTS AND DISCUSSION

Flooding stress

Flooding stress was experienced during both years of study. During 2016, the field water depth under stagnant flooding (SF) was about 40 cm or more from 22 August to 13 October, and for flash flooding, water depth was over 50 cm from 22 August to 1 September. The stagnant flooding in 2017 experiment was from 15 August to 17 October, where the field water depth was more than 40 cm. Flash flooding completely submerged the crop from 14 to 23 August in 2017 with water depth exceeding 50 cm (Fig 1), then floodwater receded to less than 30 cm for the rest of the season. Under SF, the water depth was above 30 cm for most of the season

Growth and development

Sabita was the tallest and IR64-Sub1 was the shortest variety under both submergence and SF (Table 1). Due to its height (184 cm), Sabita tolerated SF more than the other genotypes; however, it did not tolerate flash floods exceeding 60-70 cm, which completely submerged the plants. Therefore, the height of Sabita was reduced significantly under flash flood situation (172 cm). Fast shoot expansion under flooding is a flood adaptive strategy that occurred in some varieties when subjected to SF (Kuanar *et al.* 2017; Singh *et al.* 2011). In response to stagnant flooding, genotypes showed varying degrees of

elongation, demonstrating considerable phenotype plasticity in this trait (Vergera *et al.* 2014). There was a significant interaction between flooding stress and genotype with respect to plant height (Table 1). Plant height significantly decreased under flash flooding in BR11-Sub1, DRR Dhan 39, and Sabita, with no significant effects on other varieties. Duration to 50% flowering (126–128 days) was also longer in Sabita, and significantly longer over all other genotypes. The shortest duration was observed for IR64-Sub1 (flowering in 84–89 days).

Plant height was shorter and flowering was delayed under flash flooding compared to stagnant flooding. Iftikharuddaula *et al.* (2015) reported that flowering of Sub1 varieties like BRRI Dhan 52 (BR11-Sub1) was delayed by up to 15 days due to flash floods. Significant delays in flowering and maturity of rice varieties subjected to submergence has been reported before, irrespective of the presence or absence of *SUB1* (Singh *et al.* 2009; 2011). LAI was the greatest in CR1009-Sub1 under SF (5.05) as well as flash flooding (4.78), followed by Sabita (4.61) and Swarna-Sub1 (4.27) under stagnant and flash flooding, respectively. The flooding stress and genotype interaction

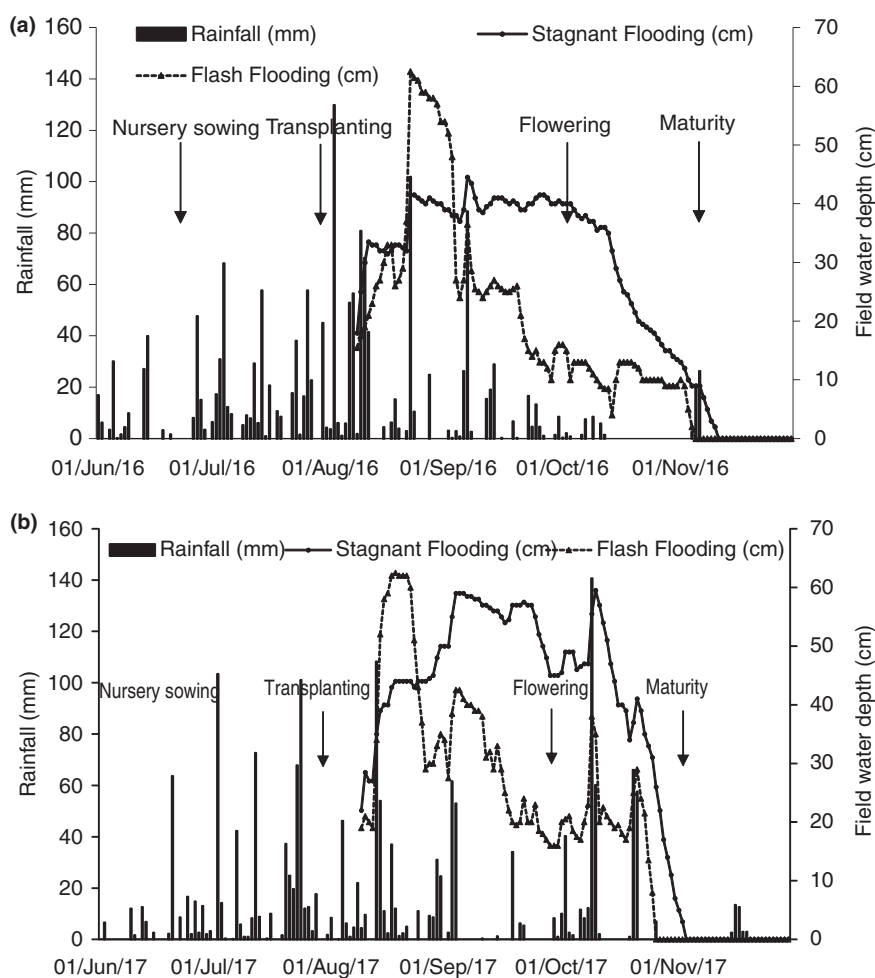


Fig 1 Rainfall (mm) and field water depth (cm) under flash flooding and stagnant flooding experiments at the research farm of the ICAR-Central Soil Salinity Research Institute, RRS, Canning Town during (a) 2016 and (b) 2017.

Table 1 Plant height, days to 50% flowering, leaf area index (LAI) and total chlorophyll concentration of *SUB1* varieties and checks under stagnant and flash flooding situations. Data are means of the wet seasons of 2016 and 2017

Genotype	Plant height (cm)			Days to 50% flowering			Leaf area index			Total chlorophyll (mg/g fresh wt.)		
	SF*	FF**	Mean	SF	FF	Mean	SF	FF	Mean	SF	FF	Mean
BR11-Sub1	114.2	98.8	106.5	102	108	105	3.65	3.96	3.80	2.77	3.05	2.91
Ciherang-Sub1	112.7	107.6	110.1	99	102	101	3.29	3.87	3.58	2.65	3.12	2.88
CR1009-Sub1	121.9	115.6	118.7	118	120	119	5.05	4.78	4.92	3.37	3.37	3.37
IR64-Sub1	81.9	79.6	80.7	84	89	87	2.89	3.19	3.04	2.49	2.74	2.62
Samba-Sub1	98.7	96.6	97.6	103	109	106	3.47	3.46	3.47	3.12	3.05	3.08
Swarna-Sub1	93.6	95.3	94.6	105	110	108	3.85	4.27	4.06	3.23	3.43	3.33
DRR Dhan39	122.7	110.8	116.8	103	105	104	3.56	3.25	3.41	2.54	2.56	2.55
Sabita	184.0	171.7	177.9	126	128	127	4.61	3.38	3.78	3.11	2.48	2.79
Mean	116.2	109.9	112.9	105	109	107	3.79	3.77	3.78	2.91	2.97	2.94
<i>CD (P≤0.05)</i>												
Flooding stress (F)		6.3			1.2			ns			ns	
Genotypes (G)		3.5			2.5			0.14			0.07	
F×G		5.5			ns			0.18			0.11	

*SF: Stagnant flooding, **FF: Flash flooding, ns: non-significant.

were significant for LAI, reflecting differential responses of the different genotypes to these two different types of flooding. LAI significantly decreased from 3.56 and 4.61 under SF to 3.25 and 3.38 (flash flooding) in DRR Dhan 39 and Sabita, respectively.

Total chlorophyll concentration was at par for CR1009-Sub1 (3.37 mg/g fresh weight) and Swarna-Sub1 (3.23–3.43 mg/g fresh weight) under both flooding types, which was significantly higher than in other genotypes, and Swarna-Sub1, Samba-Sub1, and Sabita are at par for total chlorophyll concentration under SF. Ciherang-Sub1, Samba-Sub1, and BR11-Sub1 were at par in total chlorophyll concentration

(3.05 – 3.12 mg/g fresh wt.) under flash flooding. Overall, total chlorophyll concentration decreased from 3.11 mg/g fresh weight under SF to 2.48 mg/g fresh weight under flash flooding in Sabita, unlike in other varieties. Retention of chlorophyll in leaves during submergence is important to maintain under-water photosynthesis, which improves survival by enhancing carbohydrate reserves (Ismail *et al.* 2013).

Yield components

Flooding stress, genotypes, and their interactions were significant for panicle density (Table 2). Panicle density was

Table 2 Yield contributing characters of *SUB1* varieties and checks under stagnant flooding and flash flooding conditions. Data are means of the wet seasons of 2016 and 2017

Genotype	Panicles/m ²			Grains/panicle			Fertility (%)			1000 grain wt. (g)		
	SF*	FF**	Mean	SF	FF	Mean	SF	FF	Mean	SF	FF	Mean
BR11-Sub1	185	211	198	188	174	181	69.92	75.39	72.65	23.59	21.35	22.47
Ciherang-Sub1	178	200	189	91	104	97	91.85	89.90	90.88	24.63	22.97	23.80
CR1009-Sub1	238	319	279	200	183	191	86.52	88.57	87.55	24.43	22.88	23.66
IR64-Sub1	152	238	195	80	73	76	83.61	77.43	80.52	22.32	19.11	20.71
Samba-Sub1	188	254	221	214	158	186	88.91	90.77	89.84	17.85	17.36	17.60
Swarna-Sub1	203	192	198	225	199	212	83.78	77.42	80.60	19.84	20.59	20.21
DRR Dhan39	165	188	176	163	153	158	87.74	78.00	82.87	24.34	24.54	24.44
Sabita	238	206	222	138	146	142	83.03	79.24	81.13	31.92	28.70	30.31
Mean	193	226	210	162	149	155	84.42	82.09	83.25	23.61	22.19	22.90
<i>CD (P≤0.05)</i>												
Flooding stress (F)		15.7			ns			ns			1.16	
Genotypes (G)		26.7			17.3			4.16			0.76	
F×G		36.1			24.2			5.68			1.15	

*SF: Stagnant flooding, **FF: Flash flooding, ns: non-significant.

significantly lower under stagnant flooding (193 panicles m^{-2}) compared to flash flooding (226 panicles m^{-2}), and was similar for Sabita and CR1009-Sub1 under SF, but significantly higher in CR1009-Sub1 over Sabita under flash flooding, leading to the higher yield of CR1009-Sub1 under flash flooding (Table 2). Mean number of grains per panicle was not significantly affected by flooding stress, but was higher in Sub1 gene introgressed genotypes like BR11-Sub1 (188), CR1009-Sub1 (200), Samba-Sub1 (214) and Swarna-Sub1 (225) under SF, and remained at par between these genotypes. Under flash flooding, the highest number of grains per panicle was observed in Swarna-Sub1 (199), which was at par with CR1009-Sub1 (183), BR11-Sub1 (174) and Samba-Sub1 (158). The mean spikelet fertility (%) varied from 82.1 – 84.4% under both flooding situations and the variation was non-significant. Ciherang-Sub1 showed the highest fertility of 91.9%, but it had lowest grains per panicle (91) after IR64-Sub1 (80) under stagnant flooding. Under flash flooding fertility was more than 80% in Samba-Sub1, Ciherang-Sub1 and CR1009-Sub1 (Table 2). Mean 1000-grain weight decreased significantly, from 23.6 g under SF to 22.2 g under flash flooding. Sabita (30.3 g) had the highest grain weight and Samba-Sub1 (17.6 g) had the lowest compared with other genotypes under both flooding treatments.

Yield and farmers' preference

The variation in mean grain yield (2.3 – 2.5 t/ha, averaged over genotypes) under the two flood conditions was not significant (Table 3). There was a significant effect of genotype and interaction with flooding stress. Averaged over flooding treatments, the highest grain yield (3.69 t/ha) was recorded for CR1009-Sub1, followed by Sabita (2.80

t/ha), BR11-Sub1 (2.72 t/ha) and Swarna-Sub1 (2.68 t/ha). Sabita, BR11-Sub1, and Swarna-Sub1 were at par with respect to grain yield. Under stagnant flooding, none of the *SUB1* varieties performed better than Sabita, the local check (3.45 t/ha) (Table 3). Among the Sub1 varieties, the highest grain yield of 3.27 t/ha was produced by CR1009-Sub1 (at par with Sabita) followed by BR11-Sub1 (2.65 t/ha). The poor performance of the Sub1 varieties, under stagnant flooding is because of their short stature, which become even shorter when flooded, compared with the tall variety Sabita that also elongate faster when partially flooded. Growth, phenology, and yield responses to stagnant flooding in rice depend on plant height and ability to elongate and tiller when partially flooded, and are independent of the presence of the *SUB1* gene (Singh *et al.* 2011). Genotypes like IR64-Sub1, Swarna-Sub1, and Samba-Sub1 are quite short, and if water depth remains at or above the canopy level for longer than 2 weeks, the plants may not be able to elongate and continue growth, due to the *SUB1* mediated suppression of elongation. Therefore, the *SUB1* gene should be introgressed into taller plant types for these coastal flood-prone areas, where stagnant flooding stress occurs frequently (Septiningsih *et al.* 2009). However, under flash flooding, both CR1009-Sub1 and Swarna-Sub1 produced higher yields than the check varieties Sabita and DRR Dhan39 with grain yields of 4.11 and 3.11 t/ha, respectively. Under flash flood conditions that leads to complete submergence, the *SUB1* varieties elongate at much slower rate underwater, thereby conserving energy for maintenance metabolism during recovery (Singh *et al.* 2014). The farmers' preference score was positive for Sabita, BR11-Sub1, and CR1009-Sub1 under stagnant flooding and for CR1009-Sub1, BR11-Sub1, Swarna-Sub1, and Sabita under flash flooding.

Correlation analysis between farmers' preference scores and important traits associated with growth and yield reveal that yield, plant height and duration to maturity ($r > 0.8^{**}$) are important characters for selection of a genotype for stagnant flooding situation, whereas yield, maturity duration, grains per panicle and LAI ($r > 0.6^{**}$) are important for flash flooding tolerance (Table 4). The Pearson's correlation (r) was highest for the association between grain yield and panicle density ($r = 0.69^{**}$) under stagnant flooding, and for grain yield with grains per panicle ($r = 0.72^{**}$) under flash flooding (Table 5). In a previous study, grain yield correlated significantly with panicle number ($r = 0.94^{**}$) and spikelets per panicle ($r = 0.91^{**}$) under SF (Kato *et al.* 2019). Panicle density, grains per panicle, and 1000 grain weight are the most important yield contributing factors under SF, whereas grains per panicle and panicle density are the two significant attributes contributing to higher yield under flash flooding (Table 5). Even though grain yield is the most important character, it is not the sole criteria for farmers' preference for a particular variety, and characters such as duration to maturity, plant height, resistances of diseases and pests play important role in determining the most preferred genotype in flood-prone areas (Manzanilla *et al.* 2011). Under stagnant flooding, tall genotypes like

Table 3 Yield and farmers' preference scores of *SUB1* varieties and checks under stagnant and flash flood conditions. Data are means of wet seasons of 2016 and 2017

Genotype	Grain yield (t/ha)			Preference score		
	SF*	FF**	Mean	SF	FF	Mean
BR11-Sub1	2.65	2.78	2.72	0.32	0.38	0.35
Ciherang-Sub1	1.53	2.64	2.08	-0.26	-0.29	-0.27
CR1009-Sub1	3.27	4.11	3.69	0.31	0.63	0.47
IR64-Sub1	0.79	1.55	1.17	-0.56	-0.62	-0.59
Samba-Sub1	1.95	2.10	2.03	-0.31	-0.34	-0.33
Swarna-Sub1	2.26	3.11	2.68	-0.26	0.20	-0.03
DRR Dhan39	2.17	1.85	2.01	-0.06	-0.27	-0.17
Sabita	3.45	2.14	2.80	0.62	0.15	0.39
Mean	2.26	2.53	2.40	-	-	-
CD ($P \leq 0.05$)						
Flooding stress (F)	ns			-		
Genotypes (G)	0.35					
F×G	0.52					

*SF: Stagnant flooding, **FF: Flash flooding, ns: non-significant

Table 4 Correlation coefficients for the associations between agronomic traits of rice genotypes and farmer's preference score under stagnant and flash flooding situation

Trait	Preference score under stagnant flooding		Preference score under flash flooding	
	Pearson's correlation (r)	Significance level (p value)	Pearson's correlation (r)	Significance level (p value)
Grain yield	0.85	<0.0001	0.66	0.0053
Plant height	0.80	0.0002	0.36	0.1739
Days to 50% flowering	0.81	0.0002	0.65	0.0064
Panicle density	0.61	0.0121	0.26	0.3295
Grains/panicle	0.23	0.3895	0.67	0.0046
Spikelet fertility %	0.23	0.3864	0.04	0.8883
1000 grain weight	0.69	0.0029	0.35	0.1892
LAI	0.77	0.0004	0.77	0.0005
Total chlorophyll conc.	0.41	0.1171	0.41	0.1179

Table 5 Pearson's correlation (r) between grain yield and yield attributes of rice genotypes under stagnant and flash flooding situation.

Trait	Grain yield	Panicle density	Grains/panicle	Spikelet fertility%	1000 grain weight
<i>Stagnant flooding</i>					
Grain yield		0.69***	0.49***	-0.20ns	0.46**
Panicle density			0.37*	-0.08ns	0.38*
Grains/panicle				-0.18ns	-0.36*
Spikelet fertility%					-0.12ns
<i>Flash flooding</i>					
Grain yield		0.56***	0.72***	0.13ns	0.15ns
Panicle density			0.29*	0.15ns	0.01ns
Grains/panicle				-0.06ns	0.17ns
Spikelet fertility%					-0.15ns
1000 grain weight					

*, **, *** indicate significance at $P < 0.05$, 0.01 and 0.001 , respectively; ns = non-significant.

Amal-Mana scored better for plant height than short-statured genotypes like Pankaj and Pratikshya, but still farmers are growing the latter varieties because they are relatively better in some other traits, such as resistance to lodging and biotic stresses (Sarangi *et al.* 2016). For stagnant flood-affected areas, varieties should mature relatively late compared with those required for flash flood-affected areas as the floodwater remains for a longer duration under the former (Fig 1). The field water depth increases fast in flash flood affected areas due to unusual high-intensity rain or ingress of river water in coastal areas, and completely submerge the plants for a relatively shorter period before receding. Therefore, genotypes with comparatively shorter duration are suitable for such situations. The introgression of the

SUB1 gene into these popular varieties did not have any negative impact on their performance under control (without submergence) conditions but considerably enhanced their yield and grain quality following short-term submergence (Mackill *et al.* 2012; Ismail *et al.* 2013; Singh *et al.* 2009).

Occurrences of flash floods of greater depths in deltaic regions will be more frequent in the future due to unusual high-intensity rains and sea level rise, which is worsening with climate change. The submergence of lowland rice fields due to floods during the wet season in coastal regions adversely affects the productivity of transplanted rice. Rice is the sole choice for the farming community in these areas because of flooding and excess wetting, besides other social considerations. *SUB1* gene, which imparts tolerance to submergence in rice is an effective adaptive strategy enabling resource-poor farmers in coastal regions to cope with this situation. Based on the results of these field experiments and farmers' preferences, CR1009-Sub1, BR11-Sub1, and Swarna-Sub1 can be recommended for areas affected by flash floods in coastal areas of India. For areas affected by both stagnant and flash-floods, taller genotypes should be introgressed with the *SUB1* gene to develop high-yielding varieties better adapted to this coastal ecosystem.

ACKNOWLEDGEMENTS

The authors thankfully acknowledge the financial and technical support of the Indian Council of Agricultural Research and the International Rice Research Institute for conducting this study. The authors are also thankful to the farming community of the Sundarbans region for their active participation in preference analysis of the rice genotypes.

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