values for different reaches from different approaches, the following threshold values can be provided from the new braiding index (B) for a broad range of classification: highly braided: $B > 30$; moderately braided: $5 < B < 30$; and low braided: $B < 5$. On the basis of this classification, braiding pattern of different reaches of Brahmaputra in Assam during 1973 and 2014 can be summarized as shown in Table 8.

The reaches which were only low and moderately braided in 1973, became moderately braided and highly braided during the 40 years (1973–2014). Braiding value increased by more than 50% in reach nos 2, 5, 6, 8, 10, 11, 12, 13, 14 and 15 during 1973–2014. More than 100% increase in braiding was observed in reach nos 5, 12 and 14 (Figure 5). This increase was due to development of more sandbars and distributaries resulting in increased mid-channel lengths and sandbar lengths. Area of Brahmaputra River in Assam has increased from 4906 km^2 in 1973 to 6258 km^2 in 2014. Widening of the river resulted in loss of huge land area by bank erosion in many locations. But, the increased area of Brahmaputra in Assam is not linked solely to river bank erosion. Increase in area (28%) of Brahmaputra during 1973–2014 was also due to bifurcation of streams without loss of land in addition to river bank erosion.

This paper has introduced a new braiding index for a large alluvial and braided river like the Brahmaputra using the number of mid-channel bars/river islands, which is a determining parameter of braiding. The suggested braiding index shows result comparable with other established approaches. One utility of the new index is that it has shown better correlation with sinuosity. River or reach with more fraction of area by bars has more braiding value. The number of mid-channel bars influences braiding value in case of same fraction of area by bars. Rivers or reaches with same fraction of area by bars and the same number of mid-channel bars will differ in braiding value by maximum width.

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Screening and enhancement of anaerobic germination of rice genotypes by pre-sowing seed treatments

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In the present study, 243 lowland rice genotypes were screened for anaerobic germination (AG) under 10 cm of flooding in plastic trays. Forty three genotypes showed anaerobic germination. Pre-sowing seed treatments of the genotypes by soaking, priming with water, 1% KCl and 5% PEG each for 24 h revealed enhanced AG and other seed germination parameters under flooding compared to control. Priming could

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induce AG in the genotypes that failed to germinate under submerged condition. Hydro-priming and 1% KCl priming found to be the best treatments showing the usefulness of pre-sowing seed treatments. Jalashree, Jalkuwari and Ranjit Sub1-C-376, having submergence tolerance, were identified as potential genotypes for AG and hence can be used in breeding programmes.

Keywords: Anaerobic germination, pre-sowing seed treatment, priming, submergence tolerant.

RICE (*Oryza sativa* L.) is the most important staple food crop of India ranking first in area and second in production in the world. The world rice production must increase approximately by 1% to meet the food demand of an ever growing population[1]. Therefore concerted effort is needed for increasing production per unit area rather than increasing the ever shrinking land area.

Agriculture in India is dependent on the monsoon. This is evident from the fact that the net irrigated area of the country is 60.9 M ha out of a total net sown area of 140.3 M ha. In Assam, rice occupies about two-thirds of the total cropped area of the state, and submergence is of common occurrence in winter rice (Sali rice) which coincides with heavy pre-monsoon and monsoon rains.

Seeds of the vast majority of higher plant species fail to germinate under anaerobic conditions, but rice being a semi-aquatic crop is able to germinate in a wide range of hydrologies, from aerobic soils in upland to anaerobic soils in waterlogged lowlands, in particular, with low (hypoxia) or no oxygen (anoxia), experienced during direct sowing in the paddy field as a consequence of soil flooding. Indeed, when germinated without oxygen, the rice coleoptile length can exceed the length of aerobic coleoptiles whilst root and primary leaf fails to grow[2]. Hypoxia is a condition in which O_2 concentration limits ATP production in the mitochondria and anoxia is the condition in which O_2 concentration is so low that almost no ATP is produced. Many scientists attributed the ability of rice seed to germinate in anaerobic condition on α-amylase, which can be produced even under anoxia and considered to be responsible for degradation of starch in the anoxic rice endosperm, thus ensuring continuous supply of energy to the germinating embryo in anaerobic condition[3].

Rice crop can be established by direct sowing as wet seeding, where pre-germinated seeds are sown in saturated puddled soils or as dry seeding on unsaturated soils; or by transplanting. Direct seeding involves low labour cost and time compared to transplanting, reduced water use and early harvest. Nevertheless, poor germination, uneven stand establishment and high weed infestation, especially in flood-prone rainfed areas constrain its productivity. Early flooding reduces weed infestation, but hampers seed germination and reduces seedling establishment. In such flooded condition, AG-tolerant rice genotypes only show seed germination and seedling emergence above the water surface[4,5].

Improvement of rice tolerance to flooding during germination and seedling growth is also important for direct seeding in lowland rice ecosystems. Good crop stand in adverse soil and atmospheric condition can be achieved by improving seed germination performance through the use of pre-sowing treatments. Seed priming is one such treatment. Priming[6] is a pre-sowing seed treatment where soaking followed by partial dehydration triggers the germination processes, but prevents the radicle emergence. It ensures rapid and uniform seed germination in various cereals[7–9]. Hence, the present study was an attempt to screen rice genotypes for AG and to evaluate the effectiveness of pre-sowing seed treatments on rice seedling establishment under flooded condition.

Altogether 243 rice genotypes belonging to shallow lowland, semi-deep water (Asra), deep water (Bao) and submergence tolerant genotypes maintained at Assam Agricultural University (Jorhat, Assam) were evaluated in the present investigation.

Before screening of genotypes for AG, a laboratory germination test was conducted for all the collected genotypes as per ISTA procedure[10], replicated twice to test viability and dormancy, if present. Thereafter, the rice genotypes for anaerobic germination were screened by sowing 20 seeds of each genotype in a tray of 20 cm height with two replications. The trays were initially filled with 5 cm layer of paddy soil. Seeds were sown 2 cm below the soil surface and immediately after sowing, the trays were filled with 10 cm deep water. The genotypes which showed germination and emergence of leaf tips above the water surface after 20 days of submergence were considered as having AG potential.

Observations were recorded after 20 days of submergence for AG percentage, seed vigour index (SVI) computed by multiplying the seedling length and AG percentage, seedling length, coleoptile length and number of adventitious roots. The α-amylase activity was analysed using 3-day-old seedlings[11].

Seeds of three genotypes showing high AG and SVI (Jalashree, Jalkuwari, Ranjit Sub1-C-376), three genotypes showing low AG and SVI (Kach Badal, Bagdar, Nail Uri) and three genotypes showing no AG during the first experiment but very popular in Assam (Ranjit, Bahadur, Swarna) were subjected to pre-sowing seed treatments for 24 h by (i) soaking in plain water at room temperature without drying back, (ii) hydropriming, (iii) priming with 1% potassium chloride and (iv) 5% PEG 6000. For (ii) to (iv) seeds were soaked in the respective solution at 15°C in a seed germinator. After 24 h seeds were taken out from the solution and dried back to their original moisture content by forced air under shade. One set was kept as control without any treatment. The seeds

Table 1. Seed parameters of the 43 genotypes showing anaerobic germination

Sl. no.	Genotype	Anaerobic germination (%)	Seedling vigour index	Seedling length (cm)	Coleoptile length (cm)	No. of adventitious roots	α-amylase activity (μg/mg)
V_1	Sali Badal	30.0	769.5	25.7	3.4	6.0	0.620
V_2	Laki Badal	22.5	623.3	27.7	3.1	6.0	0.520
V_3	Bagdar	20.0	416.0	20.8	2.5	5.0	0.630
V_4	Sunamukhi	17.5	452.4	25.9	2.6	6.0	0.580
V_5	Dud Laki	27.5	628.4	22.9	3.0	6.0	0.550
V_6	Kach Badal (2)	20.0	479.0	24.0	3.1	6.0	0.665
V_7	Nail Uri(2)	22.5	576.0	25.6	2.5	6.0	0.640
V_8	Chitri Kochu (1)	30.0	775.5	25.9	3.2	5.0	0.635
V_9	Karkati	20.0	586.0	29.3	3.0	6.0	0.650
V_{10}	Baga Amon (1)	22.5	693.0	30.8	3.3	6.0	0.655
V_{11}	Shona Biran	27.5	649.0	23.6	4.2	6.0	0.575
V_{12}	Lal Badal (1)	30.0	760.5	25.4	3.0	6.0	0.425
V_{13}	Lal Badal (2)	30.0	822.0	27.4	2.8	6.0	0.515
V_{14}	Asra	22.5	446.6	19.9	2.9	6.0	0.590
V_{15}	Badal	22.5	574.9	25.6	3.0	6.0	0.510
V_{16}	Gutak	20.0	665.0	33.3	4.6	5.0	0.635
V_{17}	Takur Bhog	20.0	493.0	24.7	4.0	6.0	0.465
V_{18}	Kala Birain (1)	50.0	1465.0	29.3	2.6	6.0	0.585
V_{19}	Lal Bus	45.0	1098.0	24.4	2.4	6.0	0.555
V_{20}	Koloingiri	22.5	455.6	20.3	3.0	6.0	0.435
V_{21}	Basjok Boa	32.5	991.3	30.5	3.3	6.0	0.450
V_{22}	Kharma	27.5	794.8	28.9	2.9	5.0	0.640
V_{23}	Jaisirya	20.0	446.0	22.3	4.2	6.0	0.515
V_{24}	Swarna Sub 1	20.0	432.0	21.6	3.4	6.0	0.525
V_{25}	Suagmoni	27.5	617.4	22.5	4.2	5.0	0.420
V_{26}	Ranjit Sub1-Z-1	32.5	724.8	22.3	3.7	6.0	0.435
V_{27}	Ranjit Sub1-Y-374	62.5	1271.9	20.4	2.8	6.0	0.465
V_{28}	Ranjit Sub1-A-193	50.0	1422.5	28.5	6.5	6.0	0.470
V_{29}	Ranjit Sub1-D-160	35.0	903.0	25.8	4.0	5.0	0.480
V_{30}	Ranjit Sub1-L-3	25.0	701.3	28.1	2.6	6.0	0.435
V_{31}	Ranjit Sub1-C-367	50.0	1800.0	36.0	3.4	5.0	0.465
V_{32}	Ranjit Sub1-Y-350	35.0	530.3	15.2	3.0	6.0	0.430
V_{33}	Ranjit Sub1-C-376	77.5	1933.6	25.0	3.1	6.0	0.435
V_{34}	Bahadur Sub1-1398-1	27.5	816.8	29.7	3.3	6.0	0.440
V_{35}	Bahadur Sub1-1324-1	25.0	701.3	28.1	2.5	6.0	0.425
V_{36}	Jalashree	85.0	2941.0	34.6	6.0	5.0	0.425
V_{37}	Jalkuwari	90.0	3442.5	38.3	6.9	6.0	0.620
V_{38}	PHY-5	60.0	714.0	14.4	4.3	6.0	0.515
V_{39}	PHY-8	20.0	577.0	28.9	3.6	6.0	0.535
V_{40}	IET-23335	30.0	730.5	24.4	3.8	5.0	0.515
V_{41}	IET-24672	20.0	399.0	20.0	4.2	6.0	0.605
V_{42}	Luit	20.0	339.0	17.0	3.0	6.0	0.635
V_{43}	Lakhimi	20.0	665.0	33.3	3.8	6.0	0.650
	Mean ± SE(m)	32.9 ± 8.6	871.4 ± 138.5	25.7 ± 3.5	3.6 ± 0.4	5.8 ± 0.5	0.530 ± 0.030
	Range	17.5–90.0	339.0–3442.5	14.4–38.3	2.4–6.9	5.0–6.0	0.420–0.670
	CD, 5%	24.4	395.6	10.1	1.3	NS	0.079

were used for AG test as described in the first experiment. Observations were taken for AG percentage, SVI, coleoptile length (cm), number of adventitious roots, shoot and seminal root length (cm), seedling fresh and dry weight (mg) after twenty days of submergence. Germination Index (GI) was recorded by germinating seeds in a petriplate.

The germination test conducted in the petri plate revealed variable germination capability of 243 rice genotypes ranging from 65% in Hash Badal and Jora Badal to 100% in 81 genotypes, with an average of 90.8%, indicating high viability and absence of dormancy.

Only 43 genotypes out of 243 rice genotypes showed germination under anaerobic condition and were found to be variable among themselves for AG, SVI, seedling length, coleoptile length and α-amylase activity but not for number of adventitious roots (Table 1).

Jalkuwari (90%) and Jalashree (85%) recorded AG above the standard germination percentage required for seed certification (80%). Ranjit Sub1-C-376 (77.5%) was at par with them. Other genotypes had AG potential with

Table 2. Pearson's correlation coefficients among the seed parameters of the 43 rice genotypes

Parameter	Anaerobic germination (%) (AG)	Seedling vigour index (SVI)	Coleoptile length (Col-L)	Seedling length (SL)	No. of adventitious roots (AR)	α-amylase activity (α-AA)
AG	1	**0.911**	**0.504**	0.265	–0.093	–0.284
SVI	**0.911**	1	**0.589**	**0.585**	–0.168	–0.174
Col-L	**0.504**	**0.589**	1	0.344	–0.177	–0.077
SL	0.265	**0.585**	0.344	1	–0.226	0.103
AR	–0.093	–0.168	–0.177	–0.226	1	–0.027
α-AA	–0.284	–0.174	–0.077	0.103	–0.027	1

Bold figures are significant at $P \geq 0.05$.

Table 3. Effect of seed treatments on seed quality parameters

Parameter	Seed treatment					CD, 5%
	Pre-soaking	Hydro-priming	1% KCl	5% PEG	Control	
Anaerobic germination (%)	52.78	52.77	53.15	52.59	32.70	3.34
Germination index	7.23	8.41	7.19	7.15	3.77	0.49
Seed vigour index	1160.0	2108.9	1602.0	1458.9	633.7	155.1
Shoot length (cm)	18.00	25.39	20.94	19.41	17.17	1.33
Seminal root length (cm)	3.59	8.54	6.54	5.16	2.95	0.50
No. of adventitious roots	5.15	10.41	7.02	6.70	4.19	0.53
Coleoptile length (cm)	1.61	3.61	3.15	2.89	1.18	0.27
Seedling fresh weight (mg)	98.48	548.93	586.89	120.67	57.66	28.86
Seedling dry weight (mg)	14.35	70.27	72.54	15.54	10.07	5.11

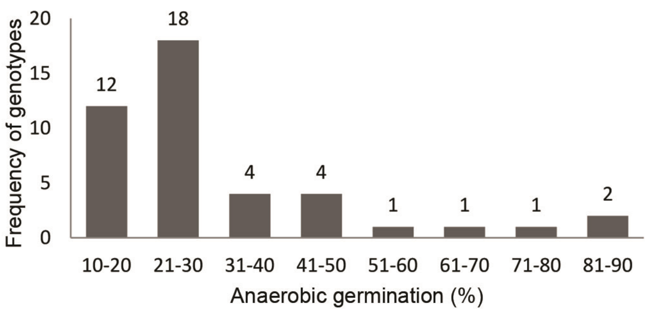

Figure 1. Frequency distribution of genotypes showing anaerobic germination.

variable frequency (Figure 1) ranging from 17.5% to 62.5%. SVI was highest for Jalkuwari followed by Jalashree, while lowest for Luit, a short duration variety. Moderately high SVI was observed in Ranjit Sub1-C-376, Ranjit Sub1-C-367, Kala Birain-1 and Ranjit Sub1-A-193. The longest coleoptile (6.9 cm) and seedling (38.3 cm) was produced by Jalkuwari which was at par with Ranjit Sub1-A-193 and Jalashree for coleoptile length and with twelve other genotypes for seedling length. Though the highest α-amylase activity (0.66 μg mg^{-1}) was observed in Kach Badal, it was at par with thirteen other genotypes.

The correlation coefficients (Table 2) revealed significant positive correlation among AG, SVI and coleoptile length; and between seedling length, SVI and coleoptile length though there was lack of association of α-amylase activity with any of the traits.

Genotypes varied significantly with respect to their response to different pre-sowing seed treatments for all the seed germination parameters, viz. AG, SVI, GI, coleoptile length, shoot and seminal root length, seedling fresh and dry weight and number of adventitious roots (Table 3). All the pre-sowing treatments enhanced AG over control. Hydropriming resulted in highest GI, SVI, shoot and root length, number of adventitious roots and coleoptile length. KCl priming was found best for enhancing seedling fresh and dry weight, though hydropriming was at par for dry weight. But pre-soaking failed to enhance shoot length and dry weight over control.

The genotypic response over all seed treatments (Table 4) indicated Jalkuwari and Jalashree to be the best performing genotypes under the anaerobic condition, as these two genotypes showed high AG, SVI, shoot and seminal root length, coleoptile length, number of adventitious roots, seedling fresh and dry weight. Another genotype Ranjit Sub1-C-376 was not far behind. After treatments, Kach Badal, Bagdar and Nail Uri showed marked increase in AG than before treatment. Ranjit, Bahadur, Swarna with no AG potential were not only able to germinate anaerobically after treatment, but also showed satisfactory shoot and root length, fresh and dry weight. GI for Kach Badal and Bahadur was higher than Jalkuwari and Jalashree indicating high vigour.

The most accepted index of seed quality is its ability to germinate. The purpose of laboratory testing of seed germination is to assess seed viability and to predict

Table 4. Genotypic responses to seed treatments for seed quality parameters

Genotype	AG (%)	GI	SVI	SL (cm)	SRL (cm)	AR	CL (cm)	SFW (mg)	SDW (mg)
Jalashree	76.0	7.83	2701.1	32.04	7.08	8.67	3.71	431.9	52.55
Jalkuwari	83.3	6.33	2876.1	30.30	7.23	10.46	3.25	485.3	58.19
Ranjit Sub1-C-376	66.7	6.55	1760.3	23.62	6.07	6.80	2.95	333.7	47.45
Kach Badal	47.8	8.06	991.0	15.33	4.81	5.76	2.00	196.1	24.81
Bagdar	44.0	6.59	995.6	18.00	4.36	6.28	2.31	228.2	26.58
Nail Uri	41.1	5.92	906.6	14.23	4.16	4.69	1.85	188.9	27.37
Ranjit	31.0	4.88	1182.2	21.66	6.15	7.86	2.53	343.9	50.55
Bahadur	24.3	8.02	569.4	11.72	5.00	5.71	2.21	252.4	32.33
Swarna	25.0	6.57	652.8	13.89	4.74	5.28	2.27	208.9	28.29
CD, 5%	4.4	0.66	208.1	1.78	0.67	0.72	0.36	38.7	6.85

SL, Shoot length; SRL, Seminal root length; AR, No. of adventitious roots; CL, Coleoptile length; SFW, Seedling fresh weight; SDW, Seedling dry weight.

performance of the seed in the field. In our study all the 243 collected genotypes showed high viability and absence of dormancy in laboratory test, but only 43 genotypes showed AG potential and varied significantly for all the traits. Earlier studies also reported variation in rice genotypes for their ability to establish under flooded soils[12,13]. Jalashree and Jalkuwari had high AG, SVI, coleoptile length and seedling length. Both are submergence tolerant genotypes, i.e. tolerant to submergence at vegetative stage[14], which carry submergence tolerance genes from FR13A. Ranjit Sub1-C-376, another submergence tolerant genotype also showed high AG and SVI. Other submergence tolerant genotypes like Swarna Sub1, Ranjit Sub1-L-3, Bahadur Sub1-1324-1 and Bahadur Sub1-1398-1 performed poorly; Ranjit Sub1-Y-374, Ranjit Sub1-C-367 and Ranjit Sub1-A-193 performed moderately under AG conditions indicating varying degrees of AG potential among submergence tolerant genotypes. Sunamukhi, Kach Badal (2), Luit, Bagdar, Takur Bhog and many others showed poor AG which may be due to their intolerance to submergence. Genotypes with low AG like Ranjit Sub1-C-367, Basjok Boa, Baga Amon (1), Karkati and Lakhimi produced seedling length at par with Jalkuwari having highest length, indicating scope for improvement in ability to germinate anaerobically. Jalkuwari along with Jalashree and Ranjit Sub1-A-193 also produced longer coleoptile, which is another reason for AG potentiality, as many studies[15–17] gave credit for AG in rice to its ability for coleoptile extension.

α-amylase activity which is found in germinating seeds, plays an important role in hydrolysing the endosperm starch into sugars that provides the energy for the growth of roots and shoots[18]. Many studies indicated positive relation of α-amylase activity with AG[3,7] but in our study, Kach Badal with low AG exhibited high α-amylase activity indicating that the ability of rice grains to degrade starch by α-amylase even in the absence of oxygen is one of the many factors allowing rice seeds for AG[19]. This further warrants the role of other enzymes needed for starch degradation present in the anoxic rice grain[3]. An inverse relationship[20] was also registered between α-amylase activity and growth of the 3- and 6-day-old seedlings in *indica* rice, as the correlation between α-amylase activity and fresh shoot and root weight was found to be insignificant. However, their mean values were higher in *indicas* than in *japonicas* and *javanicas*. The high amylase activity in some *indicas* may be due to the sensitivity of amylase activity mechanism to high temperature resulting in a large amount of amylase release prior to seedling growth[21]. Further, a relation between coleoptile elongation and α-amylase activity that was positive in embryos was negative in endosperm[22]. Once the amylase activation starts, the starch breakdown in rice becomes independent of seedling growth; thus α-amylase activity is one of the many factors that influences seedling growth[20].

Pre-sowing seed treatments especially seed priming lead to more uniform and faster germination even in abiotic stress condition[6,8]. These treatments not only enhanced the survival of genotypes in flooding, but also the other seedling establishment parameters compared to control[7,9]. The increased germination by seed priming techniques is known to have been caused by germination related processes such as water imbibitions before seed sowing. In the present study, pre-sowing treatments were found effective in enhancing AG specially hydropriming which enhanced GI, SVI, shoot and root length, number of adventitious roots and coleoptile length the most. There had been a report of improvement in AG of rice by 40% due to hydropriming[23]. But soaking failed to enhance shoot length and dry weight over control indicating that prolonged soaking may have some adverse effect. Enhanced anaerobic germination and related parameters due to priming may be attributed to increased membrane repair, enzymatic and metabolic activities[7].

Jalkuwari, Jalashree and Ranjit Sub1-C-376 performed better than other genotypes though AG was found to be lower than the first experiment, since treatments were done after four months of the first experiment, due to which some natural deterioration may have set in seeds. As these varieties were also submergence tolerant, they have the ability to metabolize carbohydrate through various mechanisms that help to mobilize and use stored energy[4], and seed priming further enhances this ability[7]. Genotypes showing low (Kach Badal, Bagdar, Nail Uri) or no AG (Ranjit, Bahadur, Swarna) before treatments showed marked increase in AG after treatments, indicating that AG could be induced in genotypes with no AG potential by treating them with various pre-sowing seed treatments.

It is concluded that genotypes Jalkuwari, Jalashree and Ranjit Sub1-C-376 with high AG can be utilized for direct seeding in flooded condition. Along with the local varieties like Kach Badal, Bagdar and Nail Uri, these genotypes can be used as parents in breeding programmes for incorporation of AG ability. Pre-sowing treatments especially hydropriming and 1% KCl priming for 24 h are effective in enhancing AG and its related traits in both AG-tolerant and intolerant genotypes. This testified the usefulness of seed priming techniques for rice seed germination and good crop establishment in submerged condition. Genotypes with the ability of AG and high seed vigour would improve and stabilize rice production even in flooded soil.

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