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Breeding for high yielding rice (*Oryza sativa* L.) varieties and hybrids adapted to aerobic (non-flooded, irrigated) conditions — II. Evaluation of released varieties

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Abstract

During wet season 2003, two hundred rice (*Oryza sativa* L.) varieties released for cultivation under various ecologies were screened in a puddled field (clay soil) under non-flooded, irrigated (aerobic) conditions, with Rasi and Vandana as check varieties. The checks known for their adaptation to water stress were planted at regular intervals (after every ten entries) to serve as controls. Twenty seven varieties showed yield advantage over the check Rasi. The popular varieties grown under irrigated conditions such as Jaya, IR 8, IR 64 etc. were found unsuitable. Most of the varieties with high yield potential and adaptation to aerobic conditions were found among rainfed shallow lowland and hill rice upland varieties, while the frequency of such varieties was very low among rainfed upland group varieties. Most of the selected irrigated varieties showed better performance under favourable moisture conditions with a few exceptions like Vikas which combined high yield and adaptation to aerobic environments. However, the semi deep water and deep water varieties were found unsuitable under aerobic conditions. Planting of checks at regular intervals as grids was very useful not only in detecting varying levels of stress across length and breadth of the field, but also in identifying suitable cultures for varying levels of stress.

Key words: Released varieties, non-flooded irrigated, aerobic condition, days to heading, grain yield

Introduction

Rice is the staple food for nearly half of the world's population, most of whom live in developing nations, particularly in Asia, where 92% of the world's rice is produced and consumed. Nearly 79% of the total worlds rice supply comes from only 75 million hectares of irrigated land in Asia. Therefore, the food security in this region largely depends on these 75 m ha, which is irrigated. Water is becoming increasingly scarce [1, 2] and most of the Asian nations including India are expected to face absolute water scarcity in the next 10-15 years, thus, threatening the sustainability of irrigated rice production in Asia. Besides, rice unlike other cereal crops *viz.*, wheat, maize, sorghum etc., requires more water per unit production of grain or for every 1000 calories of energy produced [3]. Therefore, in order to sustain and to increase the rice production to meet the future demands with limited water supplies, there is a need to genetically alter the basic water requirements of rice. Under this changing scenario water saving technologies that were investigated in the early 1970's such as saturated soil culture, and Alternate Wetting and Drying (AWD) are receiving renewed attention from researchers. Generally, the water saving irrigation practices shift away from continuous anaerobic conditions to alternate anaerobic-aerobic and, continuous aerobic conditions. Recently, Bouman [4] has summarized the key characteristics of various rice production systems by water management strategies. In China various forms of AWD and reduced flood water depths have been developed and massively adopted by farmers [5]. Aerobic rice is a new concept to further decrease water requirements in rice production. Aerobic rice cultivation has been a successful market integrated system in Brazil and it is also being grown in northern China with yield levels reported to be close to irrigated levels. Meanwhile, the shift from anaerobic to aerobic systems will have major consequences in respect of weeds, nutrients, disease and insect pest management.

The rainfed upland varieties are specifically suited to water limited environments, where drought occurs frequently during the crop growth, while the aerobic rice varieties are expected to withstand water stress and respond to high external inputs such as irrigation water and nutrients. Most of the varieties that are reported to perform well under aerobic conditions have been bred under upland conditions, but their yield potential is generally low [6]. However, there are not many studies on the comparative performance of lowland varieties under aerobic environments, but available reports suggest that lowland cultivars are not well suited for this kind of system and there is a tremendous genetic variation for adaptation to these environments [7]. In this context, the present study was taken up to examine the suitability of released varieties of various ecologies for their direct utility as varieties for cultivation under aerobic systems and to understand the ecological relationship, if any between the varieties and aerobic environments.

Materials and methods

Two hundred varieties released for various ecologies ranging from deep water to rainfed uplands were evaluated in field under limited water conditions during Wet Season 2003. The list of varieties evaluated is given in Table 1 and information related to parentage etc., are described in Prasada Rao *et al.*, [8]. The seeds were sown on 30th June, 2003 and seedlings transplanted in mainfield on 4th August, 2003 under puddled conditions. Each entry was represented by a single row of 3.5 m length with 20 cm spacing between rows and 15 cm between plants. After every ten entries, standard check varieties, Rasi and Vandana known for their adaptation to water stress were planted. The fertilizer application was similar to that recommended for irrigated lowland varieties. The field lay out depicting arrangement of screening material and check varieties at regular intervals is given in our earlier paper [9].

After planting, the experimental plot was maintained as rainfed. Water accumulated due to few rains was completely drained on 23rd August, 2003 and the field was allowed to dry for about 20 days. On September 12th a flush irrigation was given followed by top dressing with urea. Subsequently, the crop was not given any irrigation till its maturity. The amount of rain received during the crop growth *i.e.*, from planting to maturity is described earlier [9]. Days to heading was recorded for each of the entries, while at maturity, five plants from each entry including checks were chosen at random for recording grain yield data.

In order to identify desirable genotypes a method analogous to Gardners stratification technique was employed, wherein, a strip was divided into several grids each containing ten test entries and two check varieties on both sides. The grain yield of test entries was standardized against the mean yield of check variety in each grid and expressed as percentage over check variety's performance. The details on the methodology and its effectiveness have been discussed earlier [9]. Eleven entries (2-Deep Water; 2-Hill Rice Irrigated; 7-Semi Deep Water) were excluded from analysis, because of their poor phenotype combined with late flowering, tall plant type and lodging habit.

Results and discussion

The performance of released varieties under aerobic condition in terms of mean grain yield (g/5 plants) and the range for yield is presented in Table 2. Highest number of varieties tested (44%) were from irrigated system including different duration cultivars followed by rainfed upland cultivars (17%) and rainfed shallow lowland cultivars (15%). Highest average yield of 114 g was recorded by hill rice varieties suited for uplands with a minimum grain yield of 82 g. Of the four Hill Rice Upland (HRUP) varieties, two recorded an yield of about 82 g. It was intriguing to see that the minimum yield recorded by HRUP varieties was higher than the average yield of all other group of varieties. Therefore, we examined for the number of entries with similar performance in other groups as well. The rainfed shallow lowland varieties (31) were second in order with an average of 59 g and with wide variation ranging from 19.8 g to 127g. There were five entries which exceeded the minimum yield of HRUP varieties. On the contrary, the average yield of irrigated varieties tested (88) was 50 g with a range from 2.5 g to 103 g. The lowest grain yield of 2.5 g/5 pl was recorded in this group due to very high sterility. Eleven out of 88 entries tested recorded more than the minimum yield of HRUP varieties. While the average yield of rainfed upland varieties (34) was 49 g with a range of 12.2 g to 102 g. which means that the lowest yield recorded by any upland variety was higher than that of the irrigated variety and the highest yield recorded was close to that of the irrigated variety. However, only one entry *i.e.*, Kalarata recorded more than 80 g of yield. It is to be noted that none of the Semi Deep Water (SDW)/Deep Water (DW)/Scented Rice (SCR)/Irrigated Saline Alkaline (IRSA) varieties recorded the minimum yield of HRUP varieties. From the foregoing it was clear that the entries with high yield potential are rare in RUP group, where only one of 34 entries recorded higher yield. Similar observations have been made by earlier workers [6]. While the frequency of such lines was fairly high among RSL group followed by IR' group of varieties. Though only four HRUP varieties were tested, all of them recorded relatively higher yields, which suggests that it is worth examining this group of varieties for their performance in plains under non-flooded, irrigated conditions. One of the reasons for their better performance under aerobic conditions is that because of the frequent rains, the uplands in hills are more or less similar to the non-flooded irrigated condition for which they are well adapted. The SDW varieties (16) also recorded an average yield of 51 g with relatively higher values for the minimum yields. On the contrary, the variation observed in DW varieties was very narrow. It is interesting to note that there are contrasting differences between the performance of Hill Rice Irrigated (HRIR) and HRUP varieties, which suggests that the varieties suited for HRUP situations

Table 1. List of released rice varieties evaluated under aerobic (non-flooded, irrigated) conditions

SN		SN		SN		SN	
	IR	52	MTU 1001		**IRSA**	153	MDU 5
1	Abhaya	53	MTU 1010	103	CSR 4	154	Nagarjuna
2	Ajaya	54	Mugad Sugandha	104	CSR 6	155	Nagavali
3	Ambica	55	Mukti	105	CST 7-1	156	Nandi
4	ASD 16	56	Narmada	106	Luni Shree	157	Paiyur 1
5	ASD 17	57	Nidhi	107	Narendra Usar 2	158	Pankaj
6	ASD 18	58	Pant Dhan 6	108	Panvel 1	159	Phalguna
7	ASD 19	59	Pavizham		**RUP**	160	Puduvai Ponni
8	ASD 20	60	PKV HMT Seln.	109	Aditya	161	Radha
9	Bhadra	61	Pothana	110	Anjali	162	Safri 17
10	Bharathidasan	62	PR 114	111	Annada	163	Salivahana
11	Bhavani	63	Prabhat	112	Birsa Gora 102	164	Samba Mahsuri
12	Birsadhan 107	64	Prakash	113	Birsadhan 101	165	Savithri
13	Birsadhan 202	65	Prasad	114	Birsadhan 103	166	Shakuntala
14	CO 44	66	Pushkala	115	Birsadhan 104	167	Shyamala
15	CO 47	67	Pushpa	116	Birsadhan 105	168	Srikaklum Sannalu
16	Deepti	68	Rajendradhan 202	117	Birsadhan 106	169	Swarna
17	Dhanya Lakshmi	69	Ratna	118	Birsadhan 201	170	SYE-75
18	Gautham	70	Remya	119	Dular	171	TPS 1
19	GR 101	71	Sasyasree	120	GR 3	172	Vajram
20	GR 102	72	Shakti	121	GR 5	173	Vasundhara
21	GR 103	73	Shanthi	122	Harsha		**SDW**
22	GR 11	74	Sita	123	Heera	174	Amulya
23	GR 6	75	SR 3-9	124	IR 30864	175	Barh Avarodhi
24	Gurjari	76	Sughanda	125	JR 3-45	176	Golak
25	IET 8116	77	Suraksha	126	JR 353	177	Hemavati
26	IR 20	78	SYE-5	127	JR 75	178	Jal Lahari
27	IR 24	79	SYE-ER1	128	Kalarata	179	Jalmagna
28	IR 28	80	Tellahamsa	129	Kalinga III	180	Jogen
29	IR 36	81	TPS 2	130	MTU 9993	181	KHRS 26
30	IR 46	82	Triguna	131	N 22	182	Madhukar
31	IR 50	83	Vamshi	132	Narendra 1	183	Mandira
32	IR 54	84	Vasumati	133	Narendra 80	184	Matangini
33	IR 64	85	Vibhava	134	Poornima	185	Nalini
34	IR 66	86	Vikas	135	Poorva	186	Pani Dhan
35	IR 72	87	Vikramarya	136	Prasanna	187	Purnendu
36	IR 8	88	Yamini	137	Ravi	188	Saraswati
37	Jaya		**HRIR**	138	Sathi 34-36	189	Sudhir
38	Karthika	89	Himalaya 1	139	Tulasi		**DW**
39	KHP 2	90	Himalaya 2	140	Vagad Dhan	190	Chakia 59
40	Krishna Hamsa	91	Himalaya 2216	141	Varalu	191	Dinesh
41	Lakshmi	92	Himalaya 741	142	WGL-14377	192	Dubraj
42	Latha	93	Himalaya 799		**RSL**	193	Jal Prabha
43	Vladhuri	94	Nagardhan	143	CO 43	194	Jitendra
44	Mahamaya	95	RP 2421	144	CO 45		**SCR**
45	Mahaveera	96	RP 732	145	CO 46	195	Ambika
46	Mangala	97	T 23	146	Dharitri	196	Kasturi
47	vlanhar	98	VL Dhan 61	147	Gayathri	197	Pusa Basmati
48	MDU 2		**HRUP**	148	Jaisree	198	Taraori Basmati
49	MDU 3	99	China 988	149	Kanak	199	Rasi (C)
50	MDU 4	100	VL Dahn 163	150	Mahsuri	200	Vandana (C)
51	MO 5	101	VL Dhan 16	151	Manasarovar		
		102	VL Dhan 206	152	Vlandya Vijaya		

IR = Irrigated; **HRIR** = Hill Rice Irrigated; **HRUP** = Hill Rice Upland; **IRSA** = Irrigated Saline Alkaline; **RUP** = Rainfed Upland; **RSL** = Rainfed Shallow Lowland; **SOW** = Semi Deep Water; **DW** = Deep Water; **SCR** = Scented Rice; **C** = Check

Table 2. Mean yield (g/5pl) of released varieties belonging to different ecologies tested under aerobic (non-flooded, irrigated) conditions.

S.No.	Ecology	No. of entries	Grain yield/ 5pl		Entries with more than 80g/ 5pl of grain yield	
			Mean	Range	No.	%
1.	IR	88	50.4	2.5-103	11	12.50
2.	RUP	34	48.9	12.2-101.9	1	2.94
3.	RSL	31	58.7	19.8-127.3	5	16.13
4.	HRIR	10	47.5	13-101.1	1	10.00
5.	HRUP	4	114.1	82.2-140.5	4	100.00
6.	SCR	4	45.2	13.3-76.1	0	0.00
7.	SOW	16	51.6	39-79.6	0	0.00
8.	DW	5	47.6	46-49.2	0	0.00
9.	IRSA	6	44.3	28.1-58.0	0	0.00

IR = Irrigated; RUP = Rainfed Upland; RSL = Rainfed Shallow Lowland; HRIR = Hill Rice Irrigated; HRUR = Hill Rice Upland; SCR = Scented Rice; SDW = Semi Deep Water; DW = Deep Water; IRSA = Irrigated Saline Alkaline

along with days to heading, yield, and relative advantage ($\hat{Y}_{ij}$) of the entries over the check in Table 3. The grid mean is the average yield of check variety planted on either side of ten test entries, which gives an indication of varying stress levels across length and breadth of the field.

Out of the 200 released varieties that were evaluated, 27 were identified as suitable for growing under non-flooded, irrigated (aerobic) conditions. Of those, 10 were from irrigated system, 8 from Rainfed Upland (RUP), (including HRUP), 6 from Rainfed Shallow Lowland (RSL) and 2 from SCR group. Heading was affected differentially depending on the ecological group. There was a general delay in heading by about 8-10 days from their normal in most RUP and IR' varieties. On the contrary, it was early in most of the RSL and HRUP varieties by 10-15 days. The average yield of HRUP varieties was the highest (146 g). As mentioned earlier, all the four HRUP varieties tested recorded >80 g of yield. But, only two of them showed yield advantage over the check variety Rasi, which means that the other two varieties recorded higher yields where the

Table 3. Promising varieties identified for aerobic (non-flooded, irrigated) conditions

Name	Parentage	Ecology	Days to heading	GY(g)/ 5pl	Standardized yield (g) (Yij)^	Grid mean (Rasi)
Shyamala	R 60-2712/R 2386	RSL	100 (110)	97.3	98.40	49.1
Nagavali	RGL1/IR 8	RSL	86 (130)	109.3	28.14	85.3
Jaisree	Jaya/Mahsuri	RSL	107 (120)	106.2	68.30	63.1
Shakuntala	Pankaj/BR-8	RSL	107 (120)	127.3	47.80	86.1
Salivahana	RP5-32/Pankaj	RSL	117 (128)	94.4	79.90	52.4
Dharitri	Pankaj/Jagannath	RSL	120 (120)	77.1	47.00	52.4
Average				**101.9**	**61.60**	
WGL 14377	Line from Warangal, AP	RUP	67 (-)	54.0	38.70	38.9*
Aditya	M 63-83/Cauvery	RUP	80 (70)	69.4	26.20	55.0
Anjali	PR19-2/RR149-1129	RUP	82 (65)	68.5	8.60	63.1
IR 30864	IR 17-18/IR 7801-1-2-1//IR 46/Khaola	RUP	92 (75)	75.0	52.90	49.1
Kalarata	Derivative of Rata	RUP	96 (-)	101.9	107.70	49.1
Ravi	M63-83//RP 19-51 Rikotu Norin 21	RUP	97 (75)	76.3	20.90	63.1
Average				**74.2**	**42.50**	
VL Dhan 16	JP5/YRL-1	HRUP	90 (95)	151.1	48.40	101.8
China 988	Selection from China 988	HRUP	83 (110)	140.5	71.30	82.0
Average				**145.8**	**59.80**	
IR 54	Tangkai Rotan/IR 19	IRE	87 (-)	100.5	22.50	82.0
IR 50	IR 2153-14-6-6-2/IR28/IR 2070-625-1-25	IRE	88 (85)	86.6	5.60	82.0
Remya	Jaya/PTB 33	IRE	89 (84)	103.0	9.40	94.1
Dhanyalakshmi	Sabarmati/W 12708	IRE	92 (84)	93.2	13.60	82.0
Vikas	TKM 6/IR 8	IRE	98 (84)	102.6	95.60	52.4
Prasad	IR 747B-26-3/IR 57948	IRE	100 (90)	85.5	24.00	68.9
Sita	IR 8/IR 12-178-2-3	IRM	104 (105)	72.2	14.40	63.1
Mahamaya	Asha/Kranti	IRM	107 (100)	58.3	18.80	49.1
IET 8116	Vikram/Andrewsali	IRM	112 (100)	54.5	11.10	49.1
Average				**84.0**	**23.90**	
Himalaya-1	IR 8/Tadukan	HRIR	98 (95)	101.1	18.50	85.3
Taraori Basmati	Pure line selection from local Basmati	SCR	90 (105)	76.1	45.10	52.4
Ambika	A Selection from local Basmati	SCR	106 (88)	71.0	44.70	49.1
Average				**73.5**	**44.90**	
JR 353	-		93 (-)	102.0	9.60	93.1
Rasi	**TN1/CO 29**	**IRE**	**82 (84)**	**71.0**	-	-
Vandana	**C 22/Kalakeri**	**RUP**	**69 (65)**	**46.7**	-	-

* = Check Vandana; Figures in brackets represent Days to heading of entries in their respective ecologies

must be possessing special characteristics/genes, which enable them to adapt not only to hill's environments, but also to the water stress situations.

The list of promising cultures identified as suitable for growing under aerobic environments is presented check yield was also higher indicating that they performed well under favourable moisture conditions. RSL varieties recorded an average yield of 102 g, where all the five entries, which recorded 80 g of yield showed yield advantage over the check. While the IR varieties recorded an average yield of 84 g, where only six of 11 entries which showed 80 g of yield exhibited superiority over Rasi. As observed earlier, most of IR' varieties also performed better under favourable moisture conditions only. Similar observations have been made by earlier workers [10, 11] where popular, high yielding, lowland varieties such as IR 20 and IR 72 showed drastic yield reductions under aerobic soil culture. The average yield of RUP and SCR varieties was 74 g. On the other hand, there were 11 entries which recorded 80 g of yield, yet they showed yield advantage over Rasi, because their performance was better under moisture stress conditions where the check yield was low. Though, the average yield of irrigated varieties was higher than that of SCR varieties, the mean advantage of SCR varieties was higher, because the irrigated varieties recorded higher yields where grid mean was higher, which means their performance was relatively better under favourable moisture conditions. However, ideally, one would be looking for those cultures whose performance do not change drastically or show minimal yield reduction under limited water/aerobic environments.

A careful examination of Table 3 reveals that six varieties *viz.*, VL Dhan 16, China 988, Jaisree, Sahkuntala, Kalarata and Vikas recorded higher yields *per se* and higher yield advantage over the check variety Rasi. The highest yield advantae of 108% was recorded by Kalarata which was followed by an irrigated variety Vikas (96%) at lower grid mean values indicating that these two varieties are expected to perform well under moisture deficit conditions. Of the two RSL varieties, Jaisree and Shakuntala the former appeared to be promising under moisture stress environments, since it recorded higher yield advantage where grid mean was low. The variety Shakuntala is expected to perform better under relatively stress free conditions. Between the two HRUP varieties; VL Dhan 16 and China 988, the latter found to be more promising under moisture stress conditions.

The results of the present study suggests that most of the released varieties are not suitable for growing under aerobic environments, which necessitates special breeding programmes aimed at developing suitable varieties. Of the promising cultures identified as suitable, most were selected under stress prone 'environments such as rainfed shallow lowland and rainfed uplands. However, a few of the irrigated lowland varieties such as Vikas may found to be suitable for aerobic environments, which must not have been exposed to moisture stress during the selection process.

The varieties identified as suitable may be evaluated further by other workers to confirm and to utilize them for growing under aerobic conditions. Besides, efforts should be made to evaluate all the released varieties particularly, from those ecologies, which have been identified as more promising in the present study to select suitable varieties for their direct utilization till improved germplasm specially bred for non-flooded irrigated (aerobic) condition with high yield potential becomes available.

Besides, the method of evaluation using check varieties at regular intervals as grids was not only found to be very useful in detecting varying levels of moisture stress across the length and breadth of the field but also helps in identifying suitable cultures for varying levels of stress.

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