



Changes in yield and grain quality characteristics of irrigated rice (*Oryza sativa*) genotypes under aerobic conditions

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ABSTRACT

Twenty-seven rice (*Oryza sativa* L.) genotypes were evaluated in two planting systems, viz. aerobic (dry direct seeded) and conventional flood irrigated transplanting under puddle conditions. There was a significant change in yield and morpho-physicochemical grain quality traits when grown under aerobic system of planting. Per cent yield reduction was varying between 2.45% in IR 71703-587-1-3 and 79.44% in IR 73435-8-2-2-1. Differences for days to 50% flowering, plant height and effective tillers/m² were also observed over the planting systems. Planting systems significantly affected total rice recovery, head rice recovery, test weight of paddy, brown rice and milled rice, alkali spreading value and amylose content. However, grain length, grain breadth and L:B ratio were not affected. Genotypic differences over planting method for susceptibility index (SI) and mean relative performance were also observed. Genotypes which are suitable in flooded system may not be suitable for aerobic system. However, among these genotypes IR 73944-143-3-2-3-3, IR 71701-28-1-4, PAU 201, IR 71703-587-1-3 and IR 72158-11-5-3-2 were found to be better candidates for the aerobic system. Possibility of improving rice yield and quality using genotypes suitable for aerobic system in the breeding programmes was explored.

Key words: Aerobic system, Flood irrigated system, Grain quality, Rice, System comparison, Yield

Rice (*Oryza sativa* L.) is a principal food crop of Asian countries and supports nearly half of the world population. It holds the key for food security and prosperity. In Asia, flood irrigated rice uses more than 45% of total fresh water consumption (Bouman *et al.* 2005) and more than 80% of total irrigation water for its production (Bouman *et al.* 2007). Since per capita availability of water, used in agriculture is declining, a water crisis for rice is approaching. By 2025, 15 out of 75 million ha of Asia's flood irrigated rice crop will experience water shortages (Tuong and Bouman 2003). The situation is worst in north-west plain zone of India where underground water is being used injudiciously to irrigate rice, as a consequence the water-table in this area is going down at an alarming rate (Rodell *et al.* 2009). There are strong indications that declining water availability is threatening the sustainability of the rice-wheat cropping system in this region.

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Alternatives must be found and technologies need to be developed to reduce water loss and increase water productivity of the rice crop. This is possible if rice could be grown under aerobic soil conditions such as wheat and maize. Aerobic rice is high-yielding rice system, grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soils. It is responsive to high inputs, can be rainfed or irrigated and capable to tolerate occasional flooding (Bouman and Tuong 2001). In our study, aerobic rice refers to direct seeded rice crop grown in un-puddled and non-flooded lowland soils with need based supplementary irrigation.

Upland rice varieties are available but are targeted at unfavourable environments without access to irrigation, low inputs and hence poor in productivity. On the other hand, high yielding lowland varieties under aerobic conditions have shown great potential to save water but sacrificing much on yield. Therefore, new high-yielding rice varieties, adapted to aerobic conditions, need to be developed to make this system viable option for the farmers. Reasons for yield gap between aerobic and flooded rice were speculated but have not been studied extensively. Information on extent of yield loss, available variability and understanding the basis underlying it, is vital for identifying the morphological and physiological traits to select suitable genotypes for aerobic rice breeding programmes.

Grain quality is one of the major determinants in selecting parents for any breeding programme. Water status in the soil has a dramatic influence on rice grain quality (Michael and Pierre Yves 1996). However, little is known regarding the influence of reduced water supply on grain quality. Grain filling pattern has marked influence on final grain quality (Xie *et al.* 2001) which may be due to differential filling rates and assimilate competition (Zhang *et al.* 2002). Since the grain development conditions are different under flood irrigated and aerobic system, it would be interesting to record the possible effect of these two systems on grain quality characteristics and their genetic variation. Therefore, the objectives for present study were: (1) to compare the crop performance between aerobic and flood irrigated rice, and (2) to determine the differences in grain quality characteristics between these two systems.

MATERIALS AND METHODS

The field experiment was conducted at the Punjab Agricultural University, Ludhiana (Latitude, 30° 54' N; Longitude, 75° 48' E; Altitude, 247m above mean sea level) during 2006 and 2007 in two cropping/water management systems, i.e. dry direct-seeded aerobic (aerobic) and transplanted in puddled soils followed by flood irrigations with alternate wetting and drying (flooded). The soil type of the experimental plot was loamy sand with soil pH of 7.7. Twenty seven diverse rice genotypes including second phase new plant type genotypes (24) from International Rice Research Institute, Philippines and high-yielding medium to mid early-maturing recommended varieties (3) for this region.

These genotypes developed for lowland irrigated ecology were evaluated in two environments following augmented design where checks, PR 111 and PR 115 early maturing varieties commercial cultivated in the region, are replicated and entries are non-replicated in each block. The aerobic condition was maintained by applying flash irrigation (5cm) every time when the soil moisture tension at 15cm depth reached to -15kPa. During reproductive stage the irrigation was applied at -10kPa soil moisture tension. Under conventional transplanted system field was ponded for the first 15 days and thereafter, it was repeatedly flood irrigated two days after the water infiltrated in the soil until two weeks before harvesting. The net plot size was 2.4m² (five rows of 2.4m length) and row-to-row spacing was kept 20cm under both the systems. In direct-seeded plots the seed rate was kept 20kg/ha, whereas in transplanted plots the spacing between plant were kept at 15cm. The sowing of transplanted crop was done seven days before the direct sowing crop and 30 days old nursery was transplanting which ensured same climatic conditions for both the planting systems. Standard cultural practices were followed to raise a good crop.

The data were recorded on yield/plot (g), plant height (cm), days to maturity and effective bearing tillers/meter square (EBT). The yield/plot (kg) was later on converted into

yield per m² (g) for analysis. Adjusted means for all the traits were calculated using IRRISTAT 5.0 software. The susceptibility index (SI), which determines adaptability of genotypes to the new system in this study, was computed using following formula given by Fisher and Maurer (1978):

$$SI = (1 - Y_s / Y_p) / D \text{ where,}$$

Y_s = grain yield of genotype under moisture stress condition (aerobic)

Y_p = grain yield of genotype under irrigated condition and

D = stress Intensity, where, $D = 1 - (Y_{sm} / Y_{pm})$ where, Y_{sm} = Mean yield of all strains under moisture stress condition (aerobic) and

Y_{pm} = mean yield of all strains under irrigated condition

Mean relative performance (MRP) of the genotypes was calculated as per following formula:

$$MRP = [Y_s/Y_{sm} + Y_p/Y_{pm}]$$

Data on milling and physico-chemical quality parameters were recorded on total rice recovery (%), head rice recovery (%), test weight (g), Alkali spreading value, amylose content, grain length (mm), grain breadth (mm) and length breadth ratio (L:B) following standard methods. Three replications of each sample were considered for conducting this study and analysis was done using factorial complete randomized design.

Weighed samples of clean paddy, with a moisture content of 13–14%, were dehusked in a Satake Rubber Roll Laboratory Sheller and the shelled rice (brown rice) samples were milled (McGill miller No. 2). The time of polishing was adjusted to obtain a 6 % degree of polish in all the samples (Sharma *et al.* 2008). Percent recovery of total rice and head rice was determined using the following formulae:

$$\text{Total Rice Recovery (\%)} = \frac{\text{Weight of brown rice}}{\text{Weight of rough rice}} \times 100$$

$$\text{Head rice Recovery (\%)} = \frac{\text{Weight of head rice}}{\text{Weight of rough rice}} \times 100$$

The simplified procedure of Juliano (1971) was used for estimating the amylose content. On the basis of their amylose content the rice varieties can be grouped into waxy (0–2%), very low (3–9%), low (10–19%), intermediate (20–25%) and high (>25%). Alkali spreading value (ASV) is the indirect method of estimation of gelatinization temperature (GT), which involves the visual rating of grain integrity after incubation in 1.7% KOH based on the 7-point numerical spreading scale (Little *et al.* 1958). Rice varieties with an alkali spreading value of 1.0–2.0 were classified as high GT (>74°C), 3.0 high intermediate, 4.0–5.0 as intermediate GT (70–74 °C) and 6.0–7.0 as low GT (55–69°C).

RESULTS AND DISCUSSION:

The yield differences between aerobic and flood irrigated rice ranged from 2.45% in IR 71703-587 to 1–3 to 79.44% in IR 73435-8-2-2-1 with an average yield reduction of 27.61% in the aerobic system. The range of susceptibility index was varying from 0.09 to 2.96 and mean relative performance varies from 1.1 to 2.61 for this trait (Table 1). Yield decline up to 40% was also reported by Peng *et al.* (2006) under aerobic system. Aerobic system, when compared to flooded system, implies a low intensity water stress, particularly with low relative humidity (Dingkuhn *et al.* 1989). Additionally, the soil water status changes soil mechanical impedance, oxygen supply to roots, accumulation of gases such as ethylene and carbon dioxide predominantly in roots, nature of nitrogen source and soil microbial activity (Voesenek and van der Veen 1994). Aerobic system enhances root development to the deeper soil layers and root shoot ratio (Bañoc *et al.* 2000), thus, creating competition between root and shoot for photosynthates within the plant leading to low yields.

Under aerobic conditions, six genotypes, viz. PAU 201, IR 72158-11-5-3-2, IR 71703-587-1-3, PR 115, IR 71701-28-1-4 and IR 72158-68-6-3 were found to be significantly higher than the mean for paddy yield. However, genotypes PAU 201, IR 73895-33-1, IR 72158-11-5-3-2, IR 75282-58-1-2-3, IR 72158-10-2-1-3 and IR 73895-33-1-3-2 observed significant higher yield and above average performance under normal transplanted conditions (Table 1). PAU 201, IR 71703-587-1-3, IR 72158-11-5-3-2 and IR 72158-68-6-3 were having higher yield, low susceptibility index, up to 10% yield reduction and higher mean relative performance indicating that these genotypes are better adapted than others for their establishment in aerobic system.

As expected for days to 50% flowering, an indicator of maturity, genotypes take about 10 days less in aerobic system than in flooded conditions, as there is no transplanting shock in aerobic system. Out of 27, five genotypes attained lesser plant height in aerobic system than in flooded condition, indicating that there is in general, an increase in plant height under this new system with some exceptions. In general, effective tillers/m² was lesser in aerobic direct-seeded than normal transplanted system. This may be due to little higher seed rate demand in the line sowing and hence higher competition between plants in the former system. Lafitte *et al.* (2002) also demonstrated that differences in cultivar response to environment are associated with panicle number/m². It seems that for stabilizing the reproductive fitness these genotypes are making some morpho-physiological adjustments and thus these are either having below average or above average performance under aerobic planting system.

There were significant differences between the planting systems for total rice recovery, head rice recovery, test weight of paddy, brown rice and milled rice, ASV and amylose content. However, for grain length, grain breadth and L:B

ratio this difference was non significant. For total rice recovery differences between the systems are variable and it is, in general, lower in genotypes raised under aerobic system based on their mean value (Table 2). Similar results were observed for head rice recovery.

Test weight of paddy, brown rice and milled rice was consistently lower in aerobic system than in flooded system and was variable over genotypes, with few exceptions. The response of the planting methods was recorded significant. Genotypes, viz. IR 72969-143-5, IR 73895-33-1-3-2, IR 73435-8-2-2-1 and IR 77186-122-2 are highly sensitive to aerobic conditions, whereas, PR 26703-3B-PJ7, IR 71701-28-1-4, IR 73943-120-5-3-2, IR 73944-143-3-2-3-3, PAU 201, IR 72158-11-5-3-2 and IR 71703-587-1-3 genotypes exhibited higher head rice recovery and minimum deviation for this trait from the favorable system when grown under aerobic system.

Alkali spreading value of genotypes decreased in aerobic situation except for genotypes IR 59547-235-3-3, PR 26703-3B-PJ7 and IR 75282-58-1-2-3 where although a slight increase in the alkali spreading value was observed with almost no change in the gelatinization temperature over the methods of planting. Data in Table 2 also reveals that amylose content does not show a consistent trend, however the differences between the planting methods was evident. It significantly increased in the samples of some genotypes in aerobic system while in some it exhibited a significant decrease. Highest significant increment for amylose content in aerobic system was observed in IR 74963-262-5-1-3-3 and highest decrease was observed in PR 26703-3B-PJ7. There was no change in the amylose content of genotype IR 71701-28-1-4 over both the planting methods. For length, breadth and length breadth ratio, there were no significant differences in performance of genotypes under two planting methods (Table 2) however, as expected, differences between the genotypes was evident. Such changes were also reported by Villareal *et al.* (1990) by comparing upland varieties with irrigated cultures.

Large gaps in yield (Peng *et al.* 2006) and grain quality (Micheal and Pierree-Yves 1996) traits between aerobic and flood irrigated systems could thus overweigh the benefits of its water saving. However, there are genotypic differences in the expression of yield and quality traits under aerobic system indicating that there is scope for its improvement through directional selection/breeding. Considering that yield is the most important breeding objective, direct selection for yield under stress is effective and heritability for yield under stress is usually higher than heritability for related morpho-physiological traits (Fischer *et al.* 2003). Furthermore, to support present study we need to understand the physiological basis of the trait differences between aerobic and flooded system, which would further help us in identifying the physiological and morphological traits to support selection in high-yielding aerobic system.

Table 1 Adjusted means, susceptibility index (SI) and mean relative performance (MRP) of yield and morphological characters of rice genotypes/varieties grown under direct-seeded aerobic and conventional transplanted conditions

Genotype/ variety	Grain yield/m ² (g)			50% flowering (days)			Height (cm)			Effective tillers/ m ²						
	A*	F	SI	MRP	A	F	SI	MRP	A	F	SI	MRP				
C4842-2-2-1-1	472 (52.17)	987	1.95	1.76	89.5	103.2	1.35	1.94	62.6	80.6	-4.02	1.71	308	364	0.36	2.68
IR 59547-235-3-3	299 (60.84)	763	2.27	1.26	91.5	107.2	1.49	2.00	65.6	84.6	-4.04	1.80	245	314	0.51	2.21
PR 26703-3B-P17	820 (11.55)	927	0.43	2.21	84.5	103.2	1.85	1.89	89.6	85.6	0.84	2.09	338	380	0.26	2.89
IR 73435-8-2-2-1	165 (79.44)	800	2.96	1.10	101.5	109.2	0.72	2.12	76.6	68.6	2.10	1.73	271	426	0.84	2.68
IR 73896-51-2-1-3	804 (12.68)	920	0.47	2.17	100.5	114.2	1.22	2.16	83.6	80.6	0.67	1.95	199	341	0.97	2.68
IR 71701-28-1-4	861 (11.78)	976	0.44	2.32	85.5	102.9	1.72	1.89	98.6	90.3	1.65	2.25	169	367	1.25	2.05
IR 72158-10-2-1-3	701 (30.60)	1010	1.14	2.12	94.5	100.9	0.65	1.97	101.6	100.3	0.23	2.40	195	301	0.82	1.97
IR 72158-11-5-2-3	636 (28.59)	890	1.07	1.89	99.5	104.9	0.52	2.06	85.6	83.3	0.50	2.01	156	334	1.24	1.91
IR 72158-16-3-3-1	659 (23.40)	860	0.87	1.90	99.5	104.9	0.52	2.06	88.6	79.3	2.11	2.00	162	347	1.24	1.80
IR 73895-33-1-3-2	601 (40.04)	1002	1.49	1.96	95.5	104.9	0.91	2.02	88.6	82.3	1.38	2.03	175	334	1.10	1.87
IR 73943-120-5-3-2	751 (12.90)	862	0.48	2.03	95.9	100.5	0.47	1.98	94.6	88.9	1.15	2.18	190	342	1.03	1.90
IR 73944-143-3-2-3-3	686 (20.89)	868	0.78	1.94	90.9	104.5	1.33	1.97	92.6	97.9	-0.97	2.27	184	335	1.05	2.00
IR 74963-262-5-1-3-3	681 (18.05)	831	0.67	1.90	88.9	102.5	1.35	1.93	99.6	85.9	2.87	2.21	91	289	1.59	1.95
IR 75282-58-1-2-3	733 (31.09)	1063	1.16	2.22	86.9	102.5	1.55	1.90	98.6	93.9	0.90	2.29	151	381	1.40	1.33
IR 71703-587-1-3	879 (2.45)	901	0.09	2.26	96.9	102.5	0.56	2.01	87.6	83.9	0.79	2.04	177	447	1.40	1.92
IR 72158-11-5-3-2	955 (10.99)	1073	0.41	2.56	96.9	105.2	0.80	2.04	95.6	80.3	3.43	2.09	186	336	1.04	2.25
IR 72158-68-6-3	845 (6.24)	901	0.23	2.21	94.9	103.2	0.82	2.00	88.6	83.3	1.15	2.05	199	356	1.02	1.97
IR 72164-13-7-2	782 (18.92)	965	0.71	2.19	93.9	103.2	0.92	1.99	95.6	79.3	3.70	2.08	159	290	1.05	2.09
IR 72969-143-5	350 (66.31)	1038	2.47	1.63	96.9	104.2	0.71	2.03	79.6	81.3	-0.38	1.92	179	284	0.86	1.69
IR 73435-8-2-2-1-1	349 (53.91)	757	2.01	1.33	101.9	117.2	1.33	2.20	86.6	66.3	5.51	1.81	172	237	0.64	1.78
IR 73895-33-1	741 (30.79)	1070	1.15	2.24	91.2	97.2	0.63	1.90	87.6	77.9	2.24	1.97	133	272	1.19	1.50
IR 73896-51-2-3	447 (52.88)	949	1.97	1.68	93.2	96.2	0.32	1.91	80.6	74.9	1.37	1.85	192	285	0.76	1.85
IR 76165-10-2-6	598 (23.82)	785	0.89	1.73	98.2	103.2	0.49	2.03	81.6	81.9	-0.07	1.95	199	345	0.98	2.06
IR 77186-122-2	787 (21.43)	1001	0.80	2.24	85.2	101.2	1.61	1.87	88.6	77.9	2.47	1.98	146	358	1.37	1.82
PAU 201	979 (10.10)	1089	0.38	2.61	98.4	113.4	1.35	2.13	82.8	79.0	0.87	1.93	203	332	0.90	2.04
PR 111 (Check)	750 (13.54)	868	0.51	2.04	98.4	104.0	0.55	2.04	74.6	73	0.39	1.76	208	339	0.90	2.09
PR 115 (Check)	861 (11.21)	970	0.42	2.31	87.8	103.2	1.52	1.92	87.4	76.8	2.48	1.95	192	350	1.05	2.04
Mean	673.67 (27.61)	930.59			94.16	104.4			86.28	81.74			191.9	337.2		
LSD (5%)	47	64			2.19	0.77			14.52	4.52			88.12	69.35		
CV	11.98	6.43			1.22	0.38			9.45	3.15			23.25	10.82		

A, Direct-seeded aerobic condition; F, flood irrigated transplanted conditions

*, In parenthesis- per cent yield reduction in aerobic system (direct seeded) as compared to flooded system (transplanted)

Table 2 Physico-chemical grain quality characteristics of different rice entries/varieties when grown under aerobic (direct-seeded) and conventional transplanted (flood irrigation; AWD) conditions

Entry	Test weight																			
	Total rice recovery (%)				Head rice recovery (%)				Paddy				Brown rice				Milled rice			
	A	F	Mean	A	A	F	Mean	A	A	F	Mean	A	A	F	Mean	A	A	F	Mean	A
C4842-2-2-1-1	69.56	72.01	70.78	56.59	63.86	60.22	20.51	22.64	21.57	16.14	18.33	17.23	15.28	17.70	16.49					
IR 59547-235-3-3	66.37	75.12	70.74	58.71	67.92	63.31	20.03	24.13	22.08	15.70	19.67	17.68	14.93	18.72	16.82					
PR 26703-3B-PI7	72.90	72.96	72.93	66.49	67.40	66.95	23.95	24.16	24.06	19.51	19.16	19.33	18.63	18.39	18.51					
IR 73435-8-2-2-1	65.22	70.56	67.89	56.41	64.17	60.29	17.72	22.46	20.09	13.91	19.89	16.90	13.14	18.93	16.04					
IR 73896-51-2-1-3	71.55	74.79	73.17	60.56	65.78	63.17	24.40	25.71	25.06	21.05	22.01	21.53	20.19	21.85	21.02					
IR 71701-28-1-4	70.65	70.21	70.43	60.21	61.46	60.83	22.30	23.25	22.77	18.46	19.47	18.96	17.69	18.75	18.22					
IR 72158-10-2-1-3	73.91	74.48	74.19	64.33	66.25	65.29	20.47	22.11	21.29	17.17	18.00	17.59	16.42	16.97	16.69					
IR 72158-11-5-2-3	70.46	72.60	71.53	53.47	60.30	56.89	21.71	24.85	23.28	18.52	20.60	19.56	17.61	19.30	18.45					
IR 72158-16-3-3-1	70.89	73.63	72.26	54.25	60.94	57.59	21.72	26.30	24.01	18.62	21.14	19.88	17.80	19.31	18.55					
IR 73895-33-1-3-2	68.77	71.31	70.04	46.71	59.69	53.20	20.89	26.44	23.66	17.80	21.14	19.47	17.03	20.53	18.78					
IR 73943-120-5-3-2	70.45	70.57	70.51	53.70	54.65	54.18	20.43	22.63	21.53	16.86	17.98	17.42	15.53	16.83	16.18					
IR 73944-143-3-2-3-3	70.18	70.88	70.53	53.54	53.53	53.53	19.88	22.47	21.17	16.78	18.46	17.62	15.30	17.62	16.46					
IR 74963-262-5-1-3-3	68.73	68.89	68.81	43.11	51.26	47.18	24.34	27.24	25.79	20.19	21.54	20.86	18.07	20.45	19.26					
IR 75282-58-1-2-3	72.60	72.19	72.40	54.42	58.90	56.66	24.18	24.47	24.32	20.46	19.99	20.22	18.58	19.22	18.90					
IR 71703-587-1-3	70.96	71.48	71.22	63.10	64.29	63.69	19.35	21.66	20.50	17.49	17.31	17.40	15.87	16.64	16.25					
IR 72158-11-5-3-2	73.68	73.72	73.70	61.90	62.47	62.19	26.04	27.98	27.01	22.43	22.28	22.36	21.04	21.29	21.17					
IR 72158-68-6-3	73.50	73.99	73.74	61.25	63.88	62.56	25.07	28.57	26.82	20.67	22.98	21.82	19.55	22.08	20.81					
IR 72164-13-7-2	72.29	72.97	72.63	58.79	62.45	60.62	22.53	26.72	24.62	20.29	20.81	20.55	19.46	19.66	19.56					
IR 72969-143-5	67.73	73.74	70.74	35.83	61.33	48.58	19.51	28.97	24.24	16.98	22.77	19.87	14.92	21.64	18.28					
IR 73435-8-2-2-1-1	68.13	72.74	70.43	53.15	66.19	59.67	19.84	25.73	22.78	18.62	20.49	19.56	17.93	19.16	18.54					
IIR 73895-33-1	70.55	73.34	71.94	57.26	63.63	60.44	25.57	28.40	26.98	21.72	22.50	22.11	20.54	21.62	21.08					
IR 73896-51-2-3	70.71	73.35	72.03	55.27	64.79	60.03	22.26	27.32	24.79	19.92	22.66	21.29	18.60	21.77	20.18					
IR 76165-10-2-6	69.23	73.52	71.37	52.97	61.42	57.19	20.42	22.39	21.40	18.36	18.44	18.40	16.92	17.22	17.07					
IR 77186-122-2	70.16	73.57	71.87	51.23	63.65	57.44	23.06	23.37	23.21	18.98	18.94	18.96	17.95	17.69	17.82					
PR 111	67.60	67.51	67.55	45.91	51.59	48.75	19.83	22.75	21.29	17.52	17.85	17.68	16.14	16.57	16.35					
PR 115	69.02	69.00	69.01	49.23	53.53	51.38	23.47	24.56	24.01	18.73	19.92	19.33	17.67	18.90	18.28					
PAU 201	72.26	73.00	72.63	63.80	64.25	64.03	24.24	24.45	24.34	20.34	19.22	19.78	19.16	18.21	18.68					
Mean	70.30	72.30		55.26	61.46		21.99	24.88		18.64	20.13		17.48	19.15						
CD (5%)																				
Planting method (E)	0.55			0.58			0.17			0.13			0.12							
Variety (V)	1.94			2.09			0.61			0.47			0.43							
E x V	2.75			2.96			0.86			0.66			0.61							
CV	1.92			2.52			1.82			1.7			1.66							

A, Aerobic conditions; F, flood irrigation with alternate wetting and drying (AWD)

Contd.

Table 2 concluded

Entry	ASV			Amylose content			Length of grain (mm)			Breadth of grain (mm)			L:B		
	A	F	Mean	A	F	Mean	A	F	Mean	A	F	Mean	A	F	Mean
	C4842-2-2-1-1	4.3	5.5	4.9	21.5	23.3	22.4	6.35	6.67	6.51	2.06	2.09	2.07	3.09	3.20
IR 59547-235-3-3	7.0	6.0	6.5	21.2	22.1	21.7	6.80	6.86	6.83	2.02	2.14	2.08	3.37	3.21	3.29
PR 26703-3B-PI7	6.5	6.0	6.3	19.5	23.1	20.3	6.75	6.84	6.79	2.01	2.11	2.06	3.36	3.25	3.30
IR 73435-8-2-2-1	5.0	5.0	5.0	20.6	17.7	19.2	5.97	6.66	6.31	1.96	2.16	2.06	3.05	3.08	3.06
IR 73896-51-2-1-3	4.5	5.5	5.0	22.5	22.1	22.3	6.62	6.56	6.59	2.37	2.37	2.37	2.80	2.77	2.78
IR 71701-28-1-4	4.0	5.5	4.8	20.6	20.6	20.6	6.81	6.95	6.88	2.13	2.10	2.11	3.21	3.31	3.26
IR 72158-10-2-1-3	4.0	5.5	4.8	19.4	20.6	20.0	5.93	6.28	6.10	2.14	2.13	2.13	2.77	2.96	2.86
IR 72158-11-5-2-3	4.0	5.5	4.8	21.2	20.6	20.9	6.39	6.36	6.38	2.27	2.31	2.29	2.82	2.76	2.79
IR 72158-16-3-3-1	4.5	5.5	5.0	23.1	21.3	22.2	6.25	6.33	6.29	2.27	2.34	2.31	2.76	2.71	2.73
IR 73895-33-1-3-2	4.0	5.5	4.8	19.0	21.7	20.4	6.45	6.50	6.47	2.19	2.32	2.26	2.95	2.80	2.87
IR 73943-120-5-3-2	2.5	4.0	3.3	22.5	19.4	21.0	7.06	7.30	7.18	1.83	1.95	1.89	3.86	3.76	3.81
IR 73944-143-3-2-3-3	2.8	4.0	3.4	23.3	18.7	21.0	7.33	7.35	7.34	1.88	2.04	1.96	3.91	3.62	3.76
IR 74963-262-5-1-3-3	4.0	4.5	4.3	25.6	18.8	22.2	7.28	7.41	7.35	2.05	2.09	2.07	3.56	3.55	3.56
IR 75282-58-1-2-3	4.8	4.0	4.4	22.9	20.8	21.9	7.07	7.19	7.13	2.05	2.11	2.08	3.45	3.41	3.43
IR 71703-587-1-3	4.1	5.3	4.4	21.0	18.6	19.8	6.46	6.49	6.48	2.05	2.04	2.04	3.16	3.19	3.18
IR 72158-11-5-3-2	4.0	5.5	4.8	22.7	19.3	20.5	6.75	6.68	6.71	2.39	2.38	2.38	2.83	2.82	2.82
IR 72158-68-6-3	4.0	6.3	5.1	21.9	19.8	20.9	6.33	6.45	6.39	2.34	2.37	2.35	2.71	2.73	2.72
IR 72164-13-7-2	2.9	5.3	4.1	20.6	14.8	17.7	6.56	6.68	6.62	2.21	2.26	2.24	2.97	2.96	2.96
IR 72969-143-5	4.0	5.8	4.9	20.6	22.5	21.6	6.37	6.62	6.49	2.25	2.43	2.34	2.84	2.73	2.78
IR 73435-8-2-2-1-1	4.0	6.0	5.0	20.8	22.1	21.5	6.62	6.61	6.61	2.15	2.21	2.18	3.09	2.99	3.04
IIR 73895-33-1	4.0	5.8	4.9	22.5	20.2	21.4	6.55	6.56	6.55	2.32	2.39	2.35	2.83	2.75	2.79
IR 73896-51-2-3	4.0	5.8	4.9	21.7	22.3	22.0	6.55	6.61	6.58	2.32	2.37	2.34	2.83	2.80	2.81
IR 76165-10-2-6	4.3	6.0	5.1	22.9	17.9	20.4	6.51	6.56	6.53	2.10	2.15	2.12	3.10	2.99	3.04
IR 77186-122-2	4.3	6.0	5.1	20.8	19.4	20.1	7.28	7.29	7.28	1.92	1.98	1.95	3.79	3.69	3.74
PR 111	4.6	4.8	4.7	21.0	22.5	21.8	7.09	7.07	7.08	2.04	2.11	2.07	3.49	3.36	3.43
PR 115	5.4	5.5	5.4	17.1	18.3	17.7	6.85	6.78	6.81	2.17	2.20	2.18	3.17	3.08	3.12
PAU 201	5.2	5.5	5.3	17.1	18.3	17.7	6.61	6.69	6.60	2.21	2.22	2.22	2.99	3.01	3.00
Mean	4.4	5.5		21.1	20.1		6.64	6.75		2.13	2.20		3.13	3.09	
CD (5%)															
Planting method (E)	0.12			0.36			NS			NS			NS		
Variety (V)	0.42			1.31			0.21			0.06			0.13		
E × V	0.60			1.85			0.29			0.09			0.18		
CV	6.09			5.11			2.17			2.09			2.91		

A, Aerobic conditions; F, flood irrigation with alternate wetting and drying (AWD)

Aerobic rice varieties with least yield gap, when compared with favourable environment, have to be developed before taking up aerobic rice cultivation at commercial scale. This improvement in yield is expected to result from improved partitioning, as has occurred in lowland rice cultivars (Lafitte *et al.* 2002). High-yielding genotypes with good grain quality traits, viz. IR 73944-143-3-2-3-3, IR 71701-28-1-4, PAU 201, IR 71703-587-1-3 and IR 72158-11-5-3-2 probably have gene constellations which adjust well to such change in planting and water regimes and keep the metabolic processes intact. These genotypes can further be used for development of cultivars suitable for aerobic conditions. Separate aerobic breeding programme is needed to get higher yields and good grain quality of rice in the new water-saving system.

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