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GENETIC IMPROVEMENT OF RICE IN AEROBIC SYSTEM

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ABSTRACT

Rice is the staple food in Asia and is the single biggest user of fresh water Amudha *et al*., 2009). The declining availability of water threatens the traditional way of irrigated rice production and necessitates water use efficiency in rice production. Aerobic rice system is the cultivation of high yielding varieties in unpuddled, unsaturated soil (Bouman, 2001). Aerobic ice is targeted to water short areas where irrigation water supply is insufficient for growing lowland rice in flooded condition and to rainfed areas where rainfall is sufficient to frequently bring the soil water close to field capacity. China started aerobic rice research from 1980 onwards and developed varieties like Han Dao 297, Han Dao 277, Han Dao 502, Danjing 5, Danjing 8 etc. Screening trials at IRRI, Philippines identified Magat, UPLRi -7, APO and CT-6510-24-1-2 for aerobic culture. CNA 8557 and BRS Talento had been identified as rice varieties suited for aerobic condition in Brazil. Rice varieties under aerobic system should have better input use efficiency, weed competitiveness and drought tolerance to attain high yield. Experiments to study the physiological traits of aerobic rice genotypes revealed that root characteristics (root volume, root number and root length, proline content and relative water content are the major factors that influence drought tolerance of aerobic rice. Rice variety, PMK 3 with high proline content, high relative water content and favorable root characteristics, performed better in aerobic condition (Sritharan and Vijayalakshmi, 2007). Genotypes for aerobic system can be developed through hybridizing weed competitive, drought tolerant upland varieties with high yielding, input responsive lowland varieties (Amante *et al*., 2010). Combination breeding and heterosis breeding are mainly adopted to achieve this goal. Huaqi *et al*., (2010) reported that in China, combination breeding resulted in the development of a group of new-generation elite aerobic varieties such as Han Dao 297 (Mujiao 78-595 x Khaoman), Han Dao 277 (Qiuguang x BanLi) and Han Dao 502 (Qiuguang x Hongkelaoshuya). These elite varieties showed breakthroughs in traits such as stronger drought tolerance, reduced plant height, increased lodging resistance, erect upper leaves, higher yields, stronger resistance to blast and better grain quality. MAS 946-1 and MAS 26 are the varieties developed through marker assisted selection from UAS, Bangalore (Hittalmani *et al*., 2012). qDTY6. 1 is a major QTL associated with grain yield in aerobic environment and is closely linked to two SSR markers viz., RM 510 and RM 19367 (Venuprasad *et al*., 2012). At TNAU, Coimbatore, hybrids for aerobic condition were developed using six drought tolerant male sterile female lines and seven male parents. Four heterotic hybrids for yield viz., IR 67684 A x CT-6510-24-1-2, IR 68885 A x IR 73718-3-1-3-3, IR 70369A x IR 73718-3-1-3-3 and IR 70372 A x PSBRC 80 showed better adaptability to aerobic condition (Amudha *et al*., 2010).

INTRODUCTION

Rice is the staple food for nearly half of the world population. Globally rice is cultivated in 140 M ha with annual production of 600 MT (Amudha *et al*., 2009). But the water use efficiency of rice field is low compared to other cereals. Thus it is the single biggest user of fresh water. 5000L of water is required for producing 1kg rice grain. Water shortage is emerging as a threatening proble in rice cultivation.

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According to Toung and Bouman, the physical water scarcity will extend to 30 M ha out of the 140 M ha of rice area even in wet season. So it is necessary to adopt water saving strategies such as saturated soil culture and alternate wetting & drying method. In saturated soil culture, field is maintained in a saturated condition by keeping water level of 1-2 cm. But the problem is low water use efficiency than upland system. In alternate wetting and drying system, irrigation will be given at a water level of 4-5 cm after 4-5 days of the disappearance of flooded water. But the yield obtained from this system is very low to the level of 3tonnes/ha (Amudha *et al*., 2009).

So to avoid these problems China introduced a new system of rice cultivation which is currently known as aerobic system of rice cultivation. In this system rice is cultivated in unpuddled and unflooded aerobic soil. This system requires special varieties with characters like high yielding, drought tolerance etc.

Aerobic system

The term aerobic rice was coined by China. This system refers to the cultivation of high yielding rice varieties in unpuddled and unflooded aerobic soil (Fig. 1). Field is kept moist throughout the season. High water productivity is the main advantage of this system. It is about 1.5 times than the lowland system. China conducted a study on the water productivity of different rice system like aerobic system and lowland system (Table.1). The cropping pattern studied were rice alone and wheat- rice sequential cropping. Aerobic system had shown better water productivity in both cropping patterns (Huaqi, *et al*., 2010).

Fig. 1. Aerobic system of rice cultivation

Comparison of yield from different systems

The yield from the different rice systems are varying. Lowland system, aerobic system and upland system had given yield of about 9, 5 and 3t/ha respectively (Amudha *et al*., 2009). Lowland system has the highest productivity next to aerobic system. The yield from the upland system is least when compared with other systems.

Targeted areas

The targeted areas of aerobic system are water short areas including lowland, upland or slopes according to the situation. The lowland area where water is insufficient for cultivation of lowland rice can be selected for cultivation of aerobic rice due to less use of water.

Types of aerobic system

There are two types of aerobic system namely rainfed aerobic system and irrigated aerobic system. In rainfed aerobic system rainfall is the source of water and field is kept below field capacity. Sprinkler or flash irrigation will be given in the case of irrigated aerobic system and field is always kept in between 70% saturation and field capacity (Zao *et al*., 2010).

Differences between traditional upland and aerobic system

However there are differences between traditional upland and aerobic system. There is no practice of irrigation in traditional upland system. But in the case of aerobic system better irrigation will be given. Recommended doses of fertilizers are applied in aerobic system whereas the usage of fertilizer is less in traditional upland system. Aerobic system is made use of better input responsive varieties than the traditional upland system. So finely the yield from aerobic system will be higher than the traditional upland system.

Aerobic rice improvement programmes across world

The main countries working on aerobic rice improvement programmes are Brazil, China, Philippines and India. China is the pioneer country in this area. Chinese introduced two terms for specific rice types adapted to water shortage situation namely are *viz., Ju Dao* and *Han Dao*. *Ju Dao* is rice types grown in upland area whereas *Han Dao* is the specific high yielding rice varieties grown in aerobic system alone. In China breeding programme on aerobic rice improvement has been initiated from 1980's onwards (Huaqi, *et al*., 2010). The China Agricultural University, The China Academy of Agricultural Sciences, The Liaoning Province Academy of Agricultural Sciences and The Dandong Academy of Agricultural Science are main institutes working on aerobic rice in China. China have started a national network for aerobic rice improvement and developed few varieties like Han DAO 297, Han Dao 277, Han Dao 502, Danjing 5, Danjing 8, Quinai, Heda 77-2, Zhongyuan 1 and Zhongyuan 2. Beijing is one of the state where aerobic rice is grown in large area.

Philippines started a project, entitled "A System for Temperate and Tropical Aerobic Rice (STAR) in Asia" in 2004. APO and UPLRi 7 are the first generation aerobic rice varieties developed through this project. Brazil is the one of the country where aerobic rice is grown in large area. Mont Gresso has about 3 lakhs ha of aerobic rice cultivation (Pinheiro, 2006), using sprinkler irrigation. Sprinkler method is mainly used for irrigation. BRS Talento and CAN 8557 are some of the selected varieties for aerobic cultivation in Brazil.

Aerobic rice improvement programme in India

University of Agricultural Science (Bangalore), Directorate of Rice Research (Hyderabad), Tamil Nadu Agricultural University (Coimbatore) and Kerala Agricultural University (Thrissur) are conducting research on aerobic rice. Among this, University of Agricultural Science is the pioneer institute and developed first aerobic rice varieties *viz*., MAS 946-1 and MAS 26 developed in 2007 and 2008 respectively. In Kerala work is going at RARS Pattambi and College of Agriculture, Vellayani. In a trial at RARS Pattambi, released varieties like Naveen, Triguna, PA -6201, PA -6444 and PHB -77 were evaluated in both aerobic and lowland system in Pattambi. The data from all location specific trials revealed that all these varieties have same yield and biomass in both aerobic and lowland system. At College of Agriculture, Vellayani work is progressing on productivity analysis of aerobic rice and selection protocols for weed competitiveness (Jincy, 2012).

Table 1. Study of water productivity in single rice and wheat –rice cropping pattern

Cropping pattern	System of rice cultivation	Irrigation frequeny (yr)	Irrigation amount (mm)	Yield (t/ha)	Irrigation water productivity (g grain/kg water)
Single rice	Lowland system	12-15	1500	7.5	0.5
	Aerobic system	4-5	375	6	1.6
Wheat -rice	Lowland system	7-12	1200	7.5	0.6
	Aerobic system	2-3	225	5.3	2.3

Table 2. Root characteristics of aerobic rice lines

Genotypes	Root weight (g)	Root length (cm)	Root number	Root volume (cc)	Yield (q/ha)
BI -43	7.8	29.3	128	51.5	37.1
Rasi	6.9	24.6	119	48.8	32.8
BI-27	6.0	21.8	114	45.8	23.5
KRH -2	5.5	18.2	104	46.2	18.0
H - 9	4.7	18	91	40.1	8.4

Table 3. Weed competitiveness of different genotypes

Cultivar	Yield (t/ha)		Yield loss		Weed biomass	Weed rating (score)
	F	W	(g/m^2)	%		
UPLRi - 7	3.96	2.5	1.46	36.9	135.5	2
IR – 55423 -01	3.84	2.42	1.42	36.9	142.7	1.6
C22	3.53	2.27	1.26	35.6	151.1	1.8
CT 6510-24-1-2	3.5	2.34	1.15	32.9	156.4	1.6
IR – 47686-30-32	3.49	2.11	1.38	39.4	155.7	3.4
IR5419 -04	3.34	1.88	1.46	43.7	139.9	1.6
UPLRi -5	3.3	1.83	1.48	44.7	172.5	3.5
B61FF-MR-6-0-0	3.28	2.36	0.92	28.1	128.2	2.3

Desirable characters of aerobic varieties

The desirable characters for aerobic varieties are drought tolerance, weed competitiveness, input responsiveness and finally high yield.

Drought tolerance

Drought tolerance is the first and foremost criteria of aerobic rice to sustain in unfavorable conditions. Drought tolerance is contributed by several factors like root system, proline content, RUBISCO content, chlorophyll content, membrane integrity and transpiration rate. All the factors are directly proportional to the drought tolerance capacity of particular genotypes. Genotypes, which have deeper root system always can absorb water from deeper layers of soil thereby have more drought tolerance capacity. A field experiment, to reveal the effect of root system on yield was carried out in College of Agriculture, Shimoga.

The study involved five genotypes viz. BI-43, Rasi, BI-27, KRH-2 and H-9 replicated four times. The results (Table 2) revealed that BI-43 under aerobic condition recorded significantly higher grain yield (37.1q ha-1) as compared to BI-27, KRH-2 and H-9 under puddle conditions. Significantly higher root volume (51.5 cc), root weight (9.1 g), root length (27.9 cm) and root number (155.2) were recorded under aerobic condition compared to puddling. From the study it is concluded that genotype BI-43 under aerobic situation is the better practice to increase yield under rainfed upland situations (Sridhara *et al.,* 2005).

Chlorophyll stability index

Chlorophyll stability is a reliable index to assess the drought tolerance or resistance in plants. High CSI value means that stress does not have much effect on drought tolerance of the plant. Higher CSI helps to withstand in stress due availability of chlorophyll which in turn leads to increased photosynthetic rate.

An experiment was carried out in Tamil Nadu Agricultural University in 2006 to study the effect of different physiological characters on yield in aerobic condition (Sritharan and vijayalakshmi, 2007). Six rice cultivars were used namely OMK 3, ASD 16, MDU3, MDU 5, CO 47 and RM 96019. Among these genotypes variety PMK 3 had shown high chlorophyll stability (Fig.2).

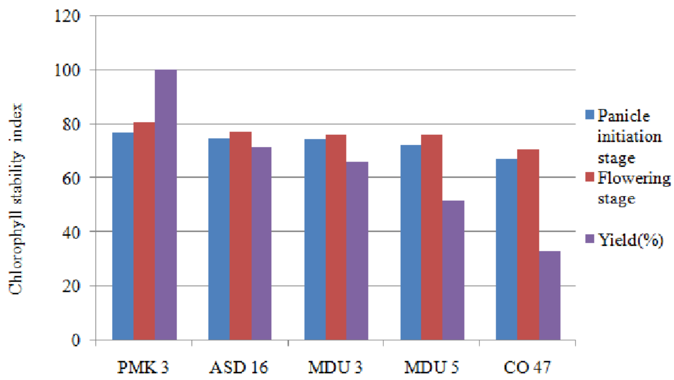

Fig. 2. Chlorophyll stability index and yield of different genotypes under aerobic system

Proline content and relative water content

Accumulation of proline is high in water stress and saline condition. The plants which have high proline content show better tolerance capacity in water stress condition. Results of the present study indicated that the genotype CO 47 recorded lower proline accumulation and hence yield poor under aerobic condition (Sritharan and Vijayalakshmi, 2007) and cultivar PMK 3 showed high proline accumulation than other genotypes in the aerobic condition (Fig. 3), and hence high yield also.

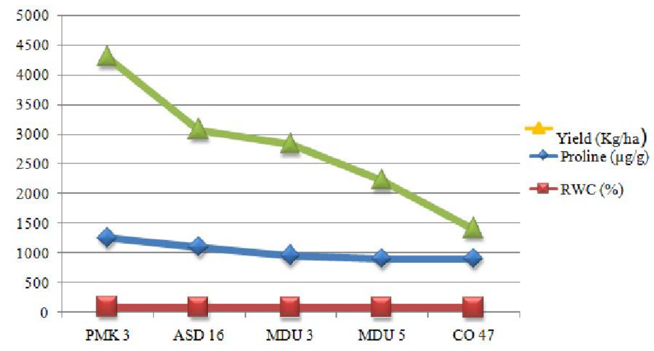

Fig. 3. Yield and proline content of rice cultivars in aerobic system

Weed competitiveness

Weed is a big constraint to the production of rice in aerobic ecology. The occurrence of weed is as a constant component of the aerobic ecosystem and resulted in large reduction in yield. Favorable situation is persisting for weed growth in aerobic ecology due to the absence of submerged condition. A work was conducted in China to study the weed competitiveness of different genotypes. These genotypes were raised in both weedy and weed free ecology. Yield loss, weed biomass and weed rating of each genotype were estimated (Table 3). UPLRi 7 is the check variety in this experiment (Fig. 4.). IR – 55423 - 01, C22 and CT 6510-24-1-2 had showed superior performance than other genotypes includes check variety (Zhao *et al*., 2006).

Fig. 4. Weed competitiveness of UPLRi 7

Breeding methods

The desirable characters were incorporated in the rice genotypes aimed for aerobic cultivation by different breeding methods.

Combination breeding and heterosis breeding are the main breeding methods employed in aerobic rice improvement programmes.

Combination breeding

Combination breeding is the transfer of one or more characters from different individuals to single individual by hybridizing between the donors. The resulted progenies will be subjected for selection for different years. The selected uniform progenies will be released as varieties. Combination breeding consists of three steps namely identification of donors, hybridization and selection. Selection methods followed in combination breeding of aerobic rice are pedigree selection, bulk selection and marker assisted selection. In aerobic rice improvement programme, superior characters from both upland and lowland varieties are combined into one variety. The superior characters of upland varieties are drought tolerance and weed competitiveness whereas high yield and input responsiveness are the superior characters of lowland varieties. So donors are to be identified from the existing germplasm.

Donor identification

Donor identification is the first step of combination breeding and donor identification is with several criteria like early vigour, response to high inputs, profuse tillering, resistance to lodging, high harvest index etc.

Screening trials at Kerala

For donor identification several screening trials had been conducted all over the India. An evaluation trial was conducted in College of Agriculture, Vellyani, Kerala with Aisharya, Uma, MAS 946-1and PMK -3(Jincy, 2012). These varieties evaluated in both aerobic and flooded situation. MAS 946-1 had shown superiority in both growth and physiological parameters and grain yield is also higher for MAS 946-1 than other varieties (Fig. 5).

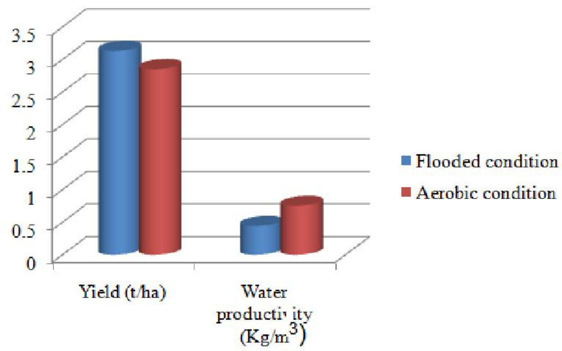

Fig. 5. MAS 946-1 under flooded and aerobic condition

Donor identification at Hyderabad

During wet season 2003, two hundred rice varieties including lowland varieties and upland varieties were screened in aerobic condition with Vandana and Rasi as check varieties. The checks known for their adaptation to water stress were planted at regular intervals to serve as controls.

Twenty seven varieties showed yield advantage over the check Rasi. Some of the selected varieties are listed in the Table 4. The popular varieties grown under irrigated conditions such as Jaya, IR 8, IR 64 etc. were found unsuitable for aerobic system. 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 (Vijayakumar *et al*., 2006). 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.

Table 4. Selected rice varieties as donors for hybridization

Varieties	Days to heading	Grain yield (g/5pl)
Jaisree	107	106.2
Shakuntala	107	127.3
Kalarata	96	101.9
Dhan 16	90	151.1
China 988	83	140.5
Vikas	98	102.6
Rasi	82	71
Vandana	69	46.7

Similar experiments were conducted all over the world and identified donors for the each location. PMK 3, ASD 16 and MDU 3 were the some of the varieties selected at Tamil Nadu. In China, selected aerobic rice varieties include Heda 77-2, Qunai, Danjing 5 and Danjing 8. CNA 8557, BRS Talento are varieties selected from Brazil for hybridization purpose. IRRI selected several upland and lowland varieties suitable for aerobic condition like Magat, CT-6510-24-1-2, APO and UPLRi -7. Among these varieties Magat is upland variety and all others are lowland varieties.

Hybridization

After donor identification the next step is hybridization between these donors. China conducted first hybridization programme in which upland varieties were selected from Yunnan Province, Lao and Thailand and lowland varieties from northern China and Japan (Huaqi, 2002). The resulted progenies were subjected to several pedigree and bulk selection for several generations.

Pedigree selection

Pedigree selection is selection method mostly practiced in self pollinated plants like rice, wheat etc. Progenies from the cross are planted as bulk in the first generation and space planted in the next generation. In the F_3 generation, the seeds of the selected plants will be raised as plant rows.

The succeeding three generations will be raised as families of plant rows. From the F_7 onwards, yield trial will be conducted for four generations. The seeds of the selected plants will be released as varieties. Pedigree selection is digrmatically represented in Fig. 6.

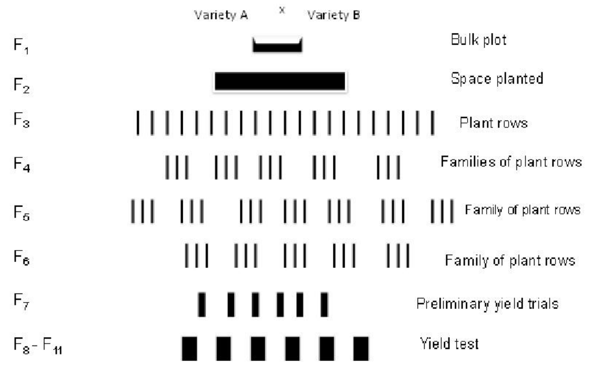

Fig. 6. Pedigree selection

Bulk selection

The progenies of the cross will be raised as bulk plot up to F_5 generation. In F_6 generation space planting will be followed for seeds of the selected plants from F_5 generation. From the succeeding generation onwards plant rows will be raised and preliminary yield trials will be conducted. The selected seeds will be released as varieties. Steps of the bulk selection are diagrammatically represented in Fig. 7.

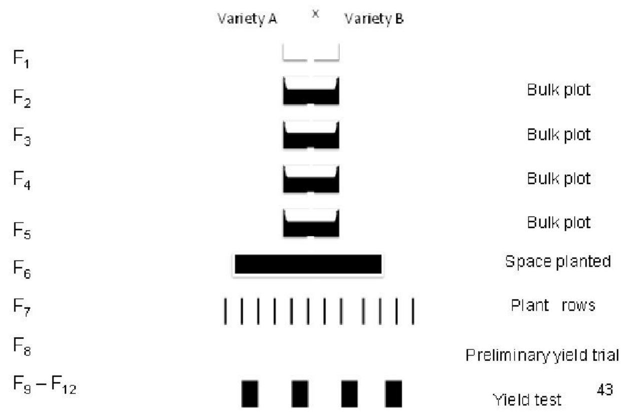

Fig. 7. Bulk selection

Aerobic rice varieties selected from hybridization

Three promising aerobic rice varieties were developed from the hybridization programme conducted in China. The details of the varieties are given in the Table. 5. These varieties in general had characters like stronger drought tolerance, reduced plant height, increased lodging resistance, higher yields, stronger resistance to blast and better grain quality (Huaqi *et al*., 2002).

Table 5. Aerobic rice varieties selected from hybridization

Varieties	Parents		Yield
	Upland variety	Lowland variety	(t/ha)
Han Dao 297	Khaoman	Mujiao 78-595	5.25 -6.0
Han Dao 277	BanLi 1	Qiuguang	5.25 -6.75
Han Dao 502	Hongkelaoshuy	Qiuguang	4.5- 5.25

In International Rice Research Institute, Phillippines, breeding lines were evaluated under both stressed and non stressed condition.

Table 6. Performance of aerobic rice lines at IRRI, Philippines

Genotypes	Early vigor(1-9)		Height (cm)		Lodging (%)		Harvest index		Yield (t/ha)	
	N. S	S	N. S	S.	N. S	S	N. S	S	N. S	S
IR 74371-46-1-1	5.8	6.0	101	94	12	1	0.40	0.19	3.81	1.73
IR 74371-54-1-1	5,7	6.3	101	95	3	0	0.37	0.17	3.49	1.49
IR 71524-44-1-1	5.8	5.7	120	98	12	1	0.27	0.17	2.98	1.34
IR 71525-19-1-1	4.9	5.5	114	102	17	0	0.32	0.24	2.92	1.77
Vandana	6.3	7.2	108	92	1	0	0.37	0.31	1.91	1.69
UPLRi -7	5.6	5.0	107	90	5	0	0.32	0.14	3.17	1.06
APO	5.0	5.5	107	89	5	0	0.33	0.13	3.12	1.07

Table 7. Performance of MAS 946-1

Locations Bangalore Urban	Grain yield (q/ac)				Straw yield (q/ac)			
	MAS 946-1*	RASI**	Yield advantage over Rasi	Increase over Rasi (%)	MAS 946-1	RASI	Yield advantage over rasi	Increase over Rasi (%)
1	41.00	28.00	13.00	46.42	45.00	36.40	8.60	23.62
2	35.60	28.40	7.20	25.35	42.00	35.00	7.00	20.00
3	38.00	32.50	5.50	16.92	47.50	41.00	6.50	15.85
4	24.00	21.00	3.00	14.28	26.00	23.50	2.50	10.63
5	18.60	13.80	4.80	34.78	21.00	15.00	6.00	40.00
6	19.20	14.20	5.50	35.21	22.00	15.60	6.40	41.02
7	26.04	20.60	5.44	26.40	26.00	22.00	4.00	18.18
8	29.24	19.92	9.32	46.78	30.00	20.48	9.52	46.48
9	20.40	15.64	4.76	30.43	21.00	16.80	4.20	25.10
Mean	28.00	21.56	6.44	29.87	31.17	25.08	6.08	24.28

Table 8. Standard heterosis for yield and yield components in hybrid rice

Hybrids	Productive tillers/plant	Relative water content (%)	Grain yield/plant (g)
IR 67684A/ CT-6510-24-1-2	57.78**	4.00*	61.51**
IR 68885 A/ IR 73718-3-1-3-3	27.78**	1.85	51.51**
IR 70369A/ IR 73718-3-1-3-3	16.67	0.62	58.73**
IR 70372A/ PSBRC 80	29.44**	2.15	41.96**
IR 70372/ IR 73005-23-1-3-3	-3.33	-4.00*	4.82
IR-70372/IR 73718-3-1-3-3	6.67	-1.35	34.37**

Twenty six genotypes out yielded the reference varieties Apo and UPLR i – 7 by more than 10% under both non stress and stress conditions. High harvest index and vegetative vigour accounted for the increased yield of the newly developed genotypes (Zhao *et al*., 2010). The elite germplasm identified in this study is likely to be useful to farmers in water short irrigated and rainfed areas in the tropics. Some of the elite genotypes are listed in Table 6.

Marker Assisted Selection

Marker Assisted Selection (MAS) is a selection method in which selection of particular trait of interest is based on the presence of particular segment of DNA. Two types of markers were used for the improvement of rice for aerobic system namely markers associated with drought tolerance in aerobic condition and markers associated with yield. Four SSR DNA markers were identified for drought tolerance *viz.,* RM-518, RM- 72, RM-228, RM -20A on chromosomes 4, 8, 10, and 12 respectively (Lin *et al.,* 2007). The first aerobic rice varieties by employing Marker Assisted Selection from India are MAS 946-1 and MAS 26 developed at Marker Assisted Selection Laboratory, Department of Genetics and Plant Breeding, University of Agricultural Science, Karnataka in the year 2007 and 2008 respectively (Hittalmani *et al.,* 2012). IR 64 and Azucena are the parents of these promising varieties. The new aerobic rice varieties which are the progenies of the cross between upland and lowland varieties have the high yielding trait from lowland rice and stress tolerant character from the upland line. These varieties maintain rapid growth in soils with moisture content at field capacity or below.

Features of MAS -946-1 & MAS 26

The first aerobic rice varieties, MAS 946-1 and MAS 26 have good root system, plant stand and vigour and tolerate brief water stress at both vegetative and reproductive stages. These varieties matured in 115 to 120 days duration and yields 5.5 tons of grain and 6 tons of fodder yields per ha. Aerobic rice variety MAS 946-1, which is medium fine grain and MAS 26 fine grain. These varieties are highly adapted to dry zone of Karnataka. These varieties are erect with long slender grain. Irrigation have to given only at the time of direct seeding and whenever there is drought. The new aerobic rice varieties are tolerant to most of the fungal and bacterial diseases. Blast is common problem in aerobic system however the new aerobic varieties are showing high level of tolerance to blast diseases.

These varieties saved 50-60% water than the lowland varieties with high yield.

Performance evaluation: MAS 946-1

A study was conducted in South Eastern dry zone in Karnataka to assess the performance and identify constraints in adoption of the new water saving aerobic rice variety MAS 946-1. This study involved the popularization of MAS 946-1 and results of this study revealed the initial impact of aerobic rice cultivation by selected farmers as against their experience with traditional irrigated puddle rice cultivation. The results of the trial conducted on farmer's field presented in Table 7. The farmers harvested an average grain yield of 28.00 q/acre with an yield advantage of 29.87 per cent over the existing variety, Rasi (Venkathesh *et al*., 2012). The superior characters of the MAS 946-1 and farmers' acceptance motivated several combination breeding experiments using this variety. A hybridization programme was conducted in Tamil Nadu with the aim of incorporation of superior characters from MAS 946-1. 166 lines from F_2 and 10 lines from F_3 were selected during the selection process. After employing several generations of selection, lines like L77, L21, L34, L91, L60, L19 etc. were selected for aerobic system due to the superiority in good grain yield, good spikelet fertility, high chlorophyll content, high relative water content and high membrane stability index (Prakash and Anandan, 2012).

Markers associated with grain yield

Yield is a polygenic character, including several genes of different characters. So the chance of association of grain yield with specific QTL is high. QTLs are stretches of DNA containing or linked to the genes that control a quantitative trait. QTLs were used as markers for aerobic rice improvement programmes. QTLs can be two types minor QTL and major QTL. Minor QTL involves more number of genes but in major QTL the number of genes is less. So the effect of major QTL is high and minor QTL is less. Two major QTLs were identified for yield of rice under water stress aerobic condition.

qDTY 6.1 is a major QTL associated with yield in aerobic condition identified by Venuprasad and coworkers in 2012. Two markers namely RM 510 and RM 19367 are linked with this QTL which located in chromosome 6 of the rice plant. But this QTL where identified only in few genetic backgrounds viz. Vandana x IR 72, Apo x Swarna and Apo x IR 72. Among this Apo and Vandana are upland varieties adapted to aerobic condition. IR 72 and Swarna are high yielding lowland varieties. The second major, qtl 2.1 was identified in association with RM 511 and RM 28048 on chromosome 12 of the rice plant (Bernier *et al*., 2007). This QTL is found in cross of the Vandana and Way rarem. These QTLs are made use by incorporation to high yielding varieties of rice by introgression for getting adaptation in aerobic condition.

Heterosis breeding

Heterosis breeding was also attempted in aerobic rice improvement programmes. Heterosis is the increased growth vigor of hybrid over parents. This vigor will tend to decrease in F_2 generation onwards. So F_1 are used as varieties, particularly known as hybrids. An experiment was undertaken to identify heterotic rice hybrids for aerobic condition based on physiological and morphological characters associated with water stress tolerance in rice under aerobic ecology. Experiment was carried out with 42 rice hybrids under aerobic condition at Paddy Breeding Station in Tamil Nadu Agricultural University. The experimental material comprising forty two rice hybrids were obtained by crossing six drought tolerant CGMS lines with seven male parents (testers) in Line x Tester design. Four hybrids viz., IR 68885A / IR 73718-3-1-3-3, IR 67684A / CT-6510-24-1- 2, IR 70369A / IR 73718-3-1-3-3 and IR 70372A/ PSBRC 80 (Table 8) exhibited heterotic vigour for yield and maximum number of yield components and showed better adaptability to aerobic conditions. These hybrids can be commercially exploited under aerobic condition (Amudha *et al*., 2010).

Genetic engineering

Genetic engineering is a novel tool in plant breeding and this uses incorporation of foreign gene in to a particular plant type. The desirable characters can be included to a particular genotype by different methods of gene incorporation. In the case of aerobic rice improvement, the main strategy is enhancement of drought tolerance capacity. Arabidopsis HD-ZIP transcription factor have the capacity of drought tolerance, so it can be make use in the rice genetic improvement programme for aerobic system (Yu *et al*., 2013). These are the main breeding methods adopted in aerobic rice improvement programme. From this it is clear that genetic improvement of rice in aerobic system is in infant stage even though the system is highly water productive in nature.

Conclusion

Rice cultivation in aerobic system saves about 50% of total water usage in the lowland system. Special varieties are required for this system with desirable characters like drought tolerance, weed competitiveness, input responsiveness and finally high yield. From the various parts of the world several varieties were selected for cultivation in aerobic system. China is the pioneer country in aerobic rice improvement programme and identified and released varieties like Han Dao 297, Han Dao 502, Danjing 5 Danjing8, Heda, Qunai, Heda 77-2 and Zhongyuan 1. IRRI follows by China in aerobic rice breeding and selected varieties from both upland and lowland system for cultivation in aerobic condition.

Magat and APO are upland varieties selected for aerobic system from IRRI. Brazil is one among the leading country in aerobic rice cultivation. CNA 8557, BRS Talento are some of the selected varieties from Brazil. PMK3, ASD16, Rasi, Vandana, Jaisree, Shakuntala, China 988, Vikas are varieties selected from India. The main methods adopted in aerobic rice improvement programme are combination breeding, heterosis breeding and molecular breeding. IR 74371-46-1-1 and IR 74371-54-1-1 are two genotypic lines developed by combination breeding in IRRI. Results of heterosis breeding experiment conducted in Paddy Breeding Station, Tamil Agricultural University selected two heterotic combinations for aerobic condition *viz.,* IR 67684A/ CT-6510-24-1-2 and IR 68885 A/ IR 73718-3-1-3-3. Several molecular experiments were conducted all over the world for genetic improvement rice in aerobic system. This is achieved through markers associated with drought tolerance and yield. RM 510 and RM 19367 are few markers already used in this programme. In India, using this technology developed first two aerobic rice varieties MAS 946 -1 and MAS 26 from Marker Assisted Selection Laboratory, University Agricultural Science.

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