The first high yielding saline tolerant rice variety suited to the *Kaipad* tidal farming ecosystem of Kerala, India, and suited for flood prone and water scarce environments: 'Ezhome-1'

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Abstract

Kaipad is a saline prone naturally organic tidal rice farming tract of North Kerala, India, fringed by mangroves. It is an integrated organic farming system in which rice cultivation and aquaculture are practiced together. Poor yielding traditional cultivars having undesirable characteristics but tolerant to salinity and having good cooking and nutritional qualities are cultivated in various *Kaipad* fields of Kerala. Development of high yielding, non-lodging rice varieties for the *Kaipad* ecosystem with favourable qualities has long been a demand of the local farmers. Here we report the development of the first high yielding rice variety suited to the *Kaipad* ecosystem, 'Ezhome-1', having the favourable traits demanded by farmers. This new variety was developed by adopting the combined strategy of conventional breeding linked with novel strategies of organic plant breeding and participatory plant breeding and growing the entire filial generations and with early trials in the target area of farmers, unlike in conventional breeding programmes. In addition to the saline *Kaipad* ecosystem it is also suited for non–saline flooded and non-flooded ecosystems as well, unlike the land races of *Kaipad*. It is a long duration variety during the *Kharif* season and a short duration variety during *Rabi* season with red kernel colour, a trait much preferred by people of Kerala state in India, and having cooking and nutritional qualities akin to *Kaipad* land races.

Keywords: Saline tolerance, salinity tolerance, abiotic stress, tidal farming, naturally organic tract, *Pokkali,* India.

Introduction

Salinity is one of the major abiotic stresses that threaten the food supply in the world. Explosive increase in world population, deterioration of arable land, and the uncertain availability of quality irrigation water are forcing crop production into more and more marginal environments facing abiotic stresses (Sharma & Goyal, 2003). In future, one cannot expect a major increase in land area available for cropping. At the same time, cultivated area is declining fast in most of the developing countries. It is estimated that half of the world's farms have been damaged by salt (Pearse, 1987).

Breeding for salt tolerance is a more promising, energy efficient, economic and socially acceptable approach than major engineering processes or soil amelioration which are beyond the reach of marginal farmers. In spite of a significant amount of research on the effect of salinity on plants, there has been little success in putting salt resistant plants into farmers' field (Flowers & Yeo,1995). As rice is one of the major food crops, the development of new cultivars with enhanced salt stress-tolerance and well suited for both saline and non-saline areas can have an important effect on global food production. Soil salinity tolerance of rice is a complex trait of several physiological characters (Flowers & Yeo,1988) and research on the development of rice varieties tolerant to salinity is meagre.

Kaipad is the saline prone tidal farming rice production tract of Kerala, India, like the *Pokkali* tract of South Kerala. The *Kaipad* system of rice cultivation is an integrated organic farming system in which rice cultivation and aquaculture are practised together in coastal brackish water marshes which are rich in organic matter. Rice farming is carried out in a peculiar way in *Kaipad,* purely in a natural way relying on the monsoon and the sea tides. Most of the *Kaipad* fields either lie fallow or produce low yields. Traditional cultivars tolerant to low and medium salinity are cultivated in various *Kaipad* fields of Kerala.

The average rice yield of these local cultivars is about 2000 Kg ha $^{-1}$ making commercial rice cultivation in this region unprofitable. Then non-realization of the potential of high yielding rice varieties for this rain fed shallow low land was the major reason for the low productivity and the shrinkage of *Kaipad* fields. The traditional cultivars are susceptible to lodging, because of its poor culm strength and excessive culm length. Further, lodging is of staggered mode on all sides which makes harvesting a tedious task, especially salient in the present scenario of the shortage of farm labourers. Further, the grain qualities of traditional cultivars are poor with awn on grains, long bold, and heavy shattering of grains. Panicles of these cultivars are long but low in the number of grains.

However, these cultivars are resistant to all pests and diseases in the natural field conditions of *Kaipad* and the cooked rice is very delicious and also nutritionally rich. Development of saline tolerant high yielding varieties with favourable grain and cooking qualities for the *Kaipad* ecosystem has been the demand of the farmers for a long time. Here we report the development of the first high yielding rice variety of the unique *Kaipad* ecosystem through a challenging breeding project which began in 2003.

Materials and methods

A combined strategy of pedigree breeding, organic plant breeding techniques (Bueren, 2003) and a farmer participatory breeding approach (Morris & Bellon, 2004) was followed during the variety development programme. The entire experiment was conducted directly at the target area, of saline sea coastal problem area, to harvest the genetic potential under field conditions. Inter-varietal hybridization was carried out between high yielding saline susceptible varieties, namely 'Jaya' and 'Mahsuri' which are under cultivation at the proximity of *Kaipad* fields, and the popular saline tolerant traditional land races of *Kaipad*, such as 'Kuthiru' and 'Orkayama' which have multiple favourable traits including salinity tolerance, biotic stress tolerance, excellent cooking and nutritive qualities and which have not been exploited so far in breeding programmes (Vanaja & Mammootty, 2010). All the filial generations as per pedigree breeding, and yield trials, were raised as on-farm trials in the *Kaipad* fields, ensuring the participation of farmers in the selection process of promising progenies from the segregating filial generations as per strategies of participatory plant breeding, unlike in conventional breeding programmes where farmer participation is done at the farm trial stage only.

The F_2 filial generation comprising six thousand two hundred ninety two progenies was raised in the field adjacent to the saline problem area having intruded slight salinity (2dS m^{-1}) and organic rice farming practices. Only 1028 progenies survived in the slight salinity. Single plant pedigree selection was followed in the F_2 generation. All of the F_2 progeny surviving the slight saline condition were carried forward to the F_3 generation in the problem area of *Kaipad*. From the F_3 generation onwards, all advanced filial generations were evaluated directly in the target area having medium salinity. Fourteen high yielding stabilized rice cultures were evaluated in replicated yield trials in saline *Kaipad* fields along with local lodging check (Kuthiru) and non-lodging *Pokkali* check (Vytilla 6).

The *Pokkali* tract in Kerala is similar to the *Kaipad* tract but differs in soil structure and rice genotypes cultivated. Further, different yield trials were also conducted in the *Pokkali* tract and non-saline wetlands to test the suitability of cultures in non-saline areas. The design of yield trials was random block design (RBD) with three replications. The promising cultures were also screened under National Saline Alkaline Screening trials of AICRP also. Pests and disease scoring were done under the natural saline field condition of *Kaipad* and also under artificial infection in the non-saline wet land condition of Regional Agricultural Research Station, Pattambi, Kerala, India. The standard evaluation system for rice (IRRI, 1988) was used for describing the cultures.

The efficiency of breeding for salt tolerance was perceived to be low because of the evident genetic complexity of the trait, large genotype x environment interactions, and the problem of controlling relevant environmental variables during field based selection (Flowers & Yeo, 1995). Hence, in order to improve the suitability of the varieties produced to specific local farming situations, the new approach of farmer participatory varietal selection (Bennet & Khush, 2003) was integrated to develop high yielding varieties suited for *Kaipad* rice fields.

Participatory Plant Breeding (PPB) is a strategy to integrate an end user based participatory approach (Morris & Bellon, 2004). It is based on a set of methods that involve close farmer-researcher collaboration to bring about plant genetic improvement within a crop. It is expected to produce more benefits than the traditional global breeding model in situations where a highly centralized approach is inappropriate. Participatory plant breeding methods are designed to incorporate the perspective of farmers usually by inviting farmers to participate in selection within the unfinished segregating material exhibiting a high degree of genetic variability. Realizing the fact that modern varieties developed for favourable production conditions have not always diffused readily into marginal environments, the procedures like selection of parents and segregating progenies were done in the target area of farmers. We regard the participation of farmers is imperative when crops are grown in agriculturally difficult and environmentally challenging situations.

By involving farmers in the genetic improvement process, plant breeding programmes will be able to produce better varieties that will be adopted more widely and generate greater benefits in aggregate. PPB provides a means of assessing so-called ‘subjective traits’. In food crops these include taste, aroma, appearance, texture, and other characteristics that determine the suitability of a particular variety for culinary use. These traits are difficult to measure quantitatively because they are a function of human perceptions.

Results and discussion

A sustained research effort adopting new frontiers of crop improvement resulted in the development of an array of high yielding saline tolerant rice cultures for the first time to the unique ecosystem of the *Kaipad* (Vanaja *et al* 2009). Thereafter, these diverse rice cultures were tested in various farm trials in the saline *Kaipad* ecosystem, the saline *Pokkali* ecosystem, with saline screening trials of AICRP and also in non saline wetlands of North Kerala. The details of performance of Culture JK70 which was released under the name ‘Ezhome-1’ for commercial cultivation in Kerala state of India are summarized below.

Grain yield

The pooled data of preliminary and comparative yield trials and pedigree of saline tolerant Kaipad rice cultures are given in Table 1. A preliminary evaluation trial was conducted separately for both non-lodging and lodging genotypes. A comparative evaluation trial was conducted for good performing non-lodging and lodging genotypes together. In comparative yield trials, five non-lodging cultures, namely, JK 70, JO 345, MK 22, JO 532-1 and JO 583, and one lodging culture, JK 59, showed significantly higher yield performance compared to that of *Kaipad* and *Pokkali* check varieties. These cultures have wide genetic bases because one of the parents is a local cultivar having abiotic and biotic stress resistance.

The mean grain and straw yield of ‘Ezhome-1’ (Culture JK 70) in farm trials in *Kaipad* tracts during *Kharif* seasons are given in Table 2. Culture JK 70 showed a 70% greater yield than the local check ‘Kuthiru’.

The yield performance of ‘Ezhome-1’ in National Saline Alkaline Screening trials of AICRP is given in Table 3. In alkaline soils, alkaline normal soils, coastal saline soils and in coastal saline normal soils, compared to coastal check (CST 7-1), ‘Ezhome-1’ showed higher yield performance. This variety was also high yielding in saline *Pokkali* tracts of South Kerala with a yield potential of 4.4tones/ha.

Table 1. Saline tolerant *Kaipad* rice cultures in PYT and CYTs in farmer's field.

Sl.N0	Genotypes	Parentage	Pooled PYT Grain yield (t /ha)	Pooled CYT Grain yield (t /ha)
1	**Non-lodging genotypes** MK 22	Mahsuri x Kuthiru*	6.61 [a]	5.69 [a]
2	MK 146	- do-	2.26	-
3	MK 162	- do-	1.08	-
4	JK 23	Jaya x Kuthiru	0.99	-
5	OK 43	*Orkayama x Kuthiru	5.73 [a a]	-
6	JK 67	Jaya x Kuthiru	1.11	-
7	JO 560-2-1	Jaya x Orkayama	1.08	-
8	JK 74	Jaya x Kuthiru	6.08 [a a]	-
9	JO 583	Jaya x Orkayama	7.30 [a]	4.70 [a]
10	JK 76	Jaya x Kuthiru	4.88	-
11	JK 70(Ezhome-1)	- do-	7.54 [a]	6.0 [a]
12	JO 532-1	Jaya x Orkayama	6.89 [a]	6.23 [a]
13	JO 556	- do-	1.33	-
14	JO 345	- do-	7.20 [a]	5.86 [a]
15	Vytilla 6	Non-lodging *Pokkali* check	1.91	2.58
	C D (1%)		0.93	-
16	**Lodging genotypes** JK 46	Jaya x Kuthiru	3.20	-
17	JK 59	- do-	4.71 [a a]	4.9 [a]
18	KO 5	Kuthiru x Orkayama	1.35	-
19	JK 15	Jaya x Kuthiru	7.33 [a]	4.0
20	KO 43	Kuthiru x Orkayama	1.68	-
21	JO 32-2	Jaya x Orkayama	1.03	-
22	OK 45	Orkayama x Kuthiru	3.23	-
23	MK 61-1	Mahsuri x Kuthiru	4.70 [a a]	-
24	JO 91	Jaya x Orkayama	3.08	-
25	OK 38	Orkayama x Kuthiru	4.97 [a a]	-
26	JK 58-1	Jaya x Kuthiru	1.05	-
27	JK 58-2	- do-	1.30	-
28	Vytilla -1 (Pokkali lodging check)	lodging *Pokkali* check	2.01	-
29	Kuthiru (Kaipad lodging local check)	local check- lodging	2.10	2.10
	C D (1%)		0.72	2.05

* Land races of *Kaipad* ecosystem; [a] Within a column, means followed by the same alphabet character do not differ significantly from each other: PYT: Preliminary Yield Trial: CYT: Comparative Yield Trial.

Table 2. Mean grain yield and straw yield of culture JK 70 in multi location/farm trials during *Kharif* seasons.

Name of culture/ variety	Mean Grain yield (t/ha)					Mean Straw yield (t/ha)				
	2008[a]	2009	2010[b]	2011[b]	Pooled Mean	2008[a]	2009	2010[b]	2011[b]	Pooled Mean
JK 70(Ezhome-1)	3.45	3.40	3.14	3.45	3.36	6.43	5.20	5.71	5.95	5.82
Kuthiru (local check)	2.12	1.93	1.90	1.98	1.98	3.92	3.93	3.73	3.85	3.86

[a] Pooled over 8 locations; [b] Pooled over 5 locations.

Table 3. Mean grain yield of 'Ezhome-1' in National Saline Alkaline Screening trials of AICRP.

Name of culture/ Variety	Mean yield under different situations(Kg/ha)						
		IET No	Alkaline [a]	Alkaline Normal [b]	Coastal Saline [c]	Coastal Saline normal [d]	Inland saline [e]
'Ezhome -1'		22604	3058	4342	3677	3617	1094
Coastal check (CST 7-1)		--	2644	3538	3321	2466	1709

[a] Mean of 4 locations (Kanpur, Karnal, Karaikal & Lucknow).
[b] Mean of 4 locations (Nawagam, Annamalainagar, Trichy &Masodha).
[c] Mean of 3 locations (CRRI, Canning & Machilipatnam).
[d] Mean of 3 locations (Chinsurah, Panvel & Navasari).
[e] Mean of 2 locations (Karnal & Gangavati).

A peculiarity of 'Ezhome-1' unlike traditional land race (male parent of 'Ezhome-1') is that it performs well in non-saline wetland tract also, with an average grain yield of 5.0 - 6.0 t/ha under organic management with the same duration as that in *Kaipad* fields, 135 - 140 days and 110 - 115cm height during the *Kharif* season. The gene recombination due to hybridization might have changed the genetic assembly from stress induced yield enhancement to epigenetic yield enhancement. In addition to the resistant nature of 'Ezhome-1' to the tidal flood condition of saline *Kaipad,* it can tolerate flooded /submerged conditions of non-saline wetland tracts immediately after sprouting and at early seedling stages during the *Kharif* season with an average grain yield of 4.0 t/ha under organic management.

At seedling stage submergence it decays at the beginning but later rejuvenates when the water level subsides. Another special trait of 'Ezhome-1' is that it shows reduced duration of 90-95 days, reduced height (70-75cm) and comparatively less yield (2.5 -3.0 t/ha under organic management) during the *Rabi* season which is preferred by those farmers who need a short duration variety in the areas where there is a water shortage.

Cooking and nutritive qualities

As quality is more important in organic agriculture, the cooking and nutritive qualities of the variety is evaluated in detail. Sensory evaluation for cooking qualities showed that 'Ezhome-1' possesses superior taste and appearance as cooked rice appealing to both consumers and millers. Cooking and nutritive traits of 'Ezhome-1' are given in Table 4. Most of the cooking qualities are on par with the traditional land race 'Kuthiru'.

Table 4. Cooking and nutritive qualities of 'Ezhome-1'.

Item	Ezhome -1 (Cul. JK70)	Kuthiru (*Kaipad* check)
Cooking qualities Volume expansion	3.4	3.5
Kernel elongation ratio	1.45	1.52
Water uptake	1.60	1.69
Cooking time required(minutes)	47	49
Alkali spreading value	4.3	4.0
Amylose content	26.4	25.0
Taste, texture, aroma and appearance of cooked rice as per sensory evaluation	Delicious and non-sticky like 'Kuthiru'. Color, texture, flavor, and appearance are more acceptable and appealing than ' 'Kuthiru'. Cooked rice is swollen and tender unlike the split and hard nature of that of 'Kuthiru'.	Delicious with acceptable and appealing appearance, and non-sticky. Cooked rice is hard and split.
Nutritive qualities Fe content (mg /Kg)	59.8	121
Zn content (mg/Kg)	12.9	21.1
Ca (mg/Kg)	194	154
K (mg/Kg)	10519	8359
Crude fiber (% by wt.)	10.6	10.7

The cooking qualities of the traditional land race 'Kuthiru' is very much appreciated by the *Kaipad* farmers. Cooked rice of 'Ezhome-1' is delicious and non-sticky like 'Kuthiru'. Colour, texture, flavour, and appearance are more acceptable and appealing than 'Kuthiru' (Table 4). Cooked rice is swollen and tender unlike the split and hard nature of that of 'Kuthiru'. The nutrient quality analysis showed that 'Ezhome-1' possesses a higher content of Ca and K than the traditional land race, 'Kuthiru'. Fe and Zn content are greater in the traditional land race (Table 4).

Pest and disease resistance

There is no incidence of pests and diseases in the saline *Kaipad* ecosystem, this may be partly due to the high potassium content of soil and salinity induced biotic stress tolerance. When screened at wet land conditions of RARS Pattambi it is revealed that 'Ezhome-1' is resistant to some pests (gall midge, leaf folder and case worm) and moderately resistant to others pests (whorl maggot, stem borer, blue beetle) and diseases (sheath blight, blast and bacterial leaf blight) (Tables 5 & 6).

Table 5. Reaction of Cultures JK 70('Ezhome-1') to important pests when screened at non-saline wet land condition of RARS, Pattambi.

Culture/ Local variety	Gall midge (% SS)		Leaf folder (% DL)		Whorl maggot (% DL)		Case worm (% DL)		Stem borer (% WE)		Blue beetle (% DL)	
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	50 DAT
JK 70 (' Ezhome -1')	0	7.5	0.62	3.0	13.5	5.4	3.7	1.4	1.2	27.5	19.4	3.6
Kuthiru(local land race)	0	4.6	1.90	6.3	22.2	3.9	11.1	0.0	0.0	100	37.0	5.8

*In *Kaipad* ecosystem there is no pest attack; < 10% infection = resistant; 10 -30% infection = moderately resistant; >30% infection = susceptible.

Table 6. Reaction of 'Ezhome-1'to important diseases when screened at non-saline wet land condition of RARS, Pattambi.

Culture/ Local variety	Score (0-9 SES scale)			
	Sheath blight	Brown spot	BLB	Blast
'Ezhome-1'	3.0	3.7	1.7	3.0
Kuthiru	1.0	4.0	1.0	3.0

Score 1 = resistant., Score 2 & 3 = moderately resistant., (20% infection = score 5; 10% infection = score 3).

Besides the proven yield potential, pest and disease tolerance, and other desirable characteristics of 'Ezhome-1' to saline and flooded areas, it possesses desirable grain qualities including awn-less, fair shattering and medium bold grains, unlike the awned, shattering and bold grains of traditional landraces.

Salient characteristics of 'Ezhome-1'

Agronomic and physico-chemical traits of 'Ezhome-1' in comparison with the *Kaipad* land race, 'Kuthiru', are given in Table 7. As it is an organic variety developed for a naturally organic tract adopting the concepts and strategies of organic plant breeding, when we do cultivation in non-saline *Kaipad* tract, the management should be organic. It is a long duration variety (130-135days) having high grain and straw yield with a high harvest index and tolerant to low to medium salinity (4 - 6 dS m^{-1}).

Unlike 'Kuthiru', it has intermediate plant stature (110cm) (Figure 1) with strong and sturdy culm with wide angle orientation, and hence tolerant to lodging. Panicle is compact with 150 grains panicle^{-1}. Healthy flag leaf and stay green index during reproductive stage shows its photosynthetic ability and efficient source sink relationship.

Table 7. Agronomic and physico-chemical traits of 'Ezhome-1' in comparison with local land race, 'Kuthiru' of the *Kaipad* ecosystem.

Characteristics	**'Ezhome-1'**	**'Kuthiru'** **(Lodging *Kaipad* land race)**
Average grain yield (t/ha): In saline Kaipad soil during *Kharif* In non-saline wetland *Kharif* *Rabi*	3.5 6.0 2.5	2.2 Not cultivated
Straw yield (t/ ha)	13.74	6.45
Harvest index	0.35	0.25
Plant height (cm) *Kharif* *Rabi*	100-110 75 – 85	140-145 NA
Duration (days) Kharif Rabi	135-140 90-95	120-125 NA
No.of tillers plant^{-1}	18-20	7-10
*No.of panicles plant^{-1}	21 – 23	10 – 13
Panicle length (cm)	25.5	27.1
Panicle type	Compact	Intermediate
Grains panicle $^{-1}$	150	90
1000 grain weight (g)	28.3	31.3
Lodging habit	Non lodging because of strong and sturdy culm	Staggered lodging at the time of flowering on all sides because of it's poor culm strength and excessive culm length
Kernel colour	Red	Red
Lemma and palea colour	Straw	Brown furrows on straw back ground
Awning	Awn less	Long & partly awned
Shattering	Fair shattering	Highly shattering
Hulling %	79.1	81.1
Milling % (In lab) (In commercial mill)	76.9 69.0	74.8 69.7
Head rice recovery %	62.0	68.9
Length of grain (L) (mm)	8.3	8.7
Breadth of grain (B) (mm)	3.0	3.3
L/B ratio	2.76	2.63
Classification	Medium	Medium

*In *Kaipad* ecosystem due to branching habit of tillers, number of panicles are seen more than tillers.

Figure 1. Ezhome 1 rice crop in Kerala.

Conclusion

One of the major reasons some farmers have moved away from the *Kaipad* tidal farming ecosystem has been the unfavourable characteristics of the locally available cultivars. 'Ezhome-1', the first high yielding rice variety, with favourable grain, cooking and nutritional qualities, suited to this saline prone naturally organic tract. It is equally suitable and high yielding in non-saline flooded as well as non flooded wetlands during *Kharif* season. The non-lodging nature of the variety helps in easy harvest both manually and using machine. Its reduction of duration from 135days during *Kharif* to 90 days during *Rabi*, makes it suitable as a crop in areas where there is shortage of water during the third crop season.

The entire development stages of the variety were conducted in farmers' fields adopting Participatory Plant Breeding. This emerging strategy in the area of plant breeding to integrate end user based participatory approach involves close farmer-researcher collaboration to bring about plant genetic improvement within a crop, and the farmers are very much convinced about the yield potential and suitability of this variety to *Kaipad* saline flooded conditions. Farmer participation ensured revival of rice cultivation in *Kaipad* without much extension effort and helped in easy and early adoption of the variety. As there are increasing demands for organic rice across the world market, development of this type of rice variety, suited to organic production systems, is timely.

Development and commercial release of the high yielding 'Ezhome-1' rice variety of *Kaipad* contributes to transforming these vast, less productive, saline prone, naturally organic tracts into an arable and highly productive farming land which will lead to enhancement of nutritional and livelihood security, in addition to aiding the food security of small and marginal farmers of rural Kerala. This project demonstrates the value of breeding varieties specifically suited to organic agriculture and in involving farmers in the process.

Acknowledgements

We gratefully acknowledge Dr. P. Raji and Dr. K. Karthikeyan of RARS, Pattambi of Kerala Agricultural University for disease and pest screening.

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