Development of organic indica rice cultivar (*Oryza sativa* L.) for the wetlands of Kerala, India through new concepts and strategies of crop improvement

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Abstract

Developing crop varieties that are less dependent on the heavy application of synthetic fertilizers is essential for the sustainability of agriculture. Here we report the development of a new rice cultivar, the first of its kind possessing the general criteria for an organic rice variety, at the same time suitable for chemical agriculture as well, and with favourable cooking and nutritive qualities. The method adopted for cultivar development was a combined strategy of pedigree breeding, organic plant breeding, and farmer participatory breeding approaches. Considering its high grain and straw yield potential even under organic management and unfavorable soil conditions, and its other favorable quality and organic varietal traits, farmers have started large scale cultivation of this cultivar even before its commercial release. The cultivar, namely culture MK 157, is at the pipe end of variety release in the Kerala state of India.

Keywords: Organic farming, organic plant breeding, organic rice, sustainable agriculture, participatory plant breeding.

Introduction

A ecological aim for the present era is fostering an evergreen revolution focusing upon organic farming for health as well as for environment protection. Organic farming systems aim at resilience and buffering capacity in the farm eco-system, by stimulating internal self regulation through functional agro-biodiversity in and above the soil, instead of external regulation through chemical protectors (Bueren et al., 2002). As organic farming management and environments are fundamentally different from chemical, organic farmers need specific varieties that are adapted to their lower input farming system and can perform higher yield stability than conventional varieties (Bueren et al., 2002). Many breeding programs took yield potential as the primary target. However, with the increasing living standards and the improvements in cooking, the eating and appearance quality of the rice grain has become a priority (Zhang, 2007.) For further optimization of organic product quality and yield stability, new varieties are required that are adapted to organic farming systems (Bueren et al., 2002).

In the current agricultural scenario, varieties having traits amenable for organic farming (organic varieties) are the missing link in the organic production chain. As organic agriculture is at its development stage, it is currently reliant on conventionally bred

 ISSN 1177-4258

varieties developed for farming systems in which artificial fertilizers and agro-chemicals are widely used. Further, most of the current new varieties are derived from a limited number of parental lines and are thus genetically related to each other. Broadening the genetic basis becomes important when we want to search for adaptation to organic farming.

It is an advantage of breeding within organic systems to be able to select for individual traits like weed tolerance, nutrient use efficiency, and field resistance against pests and diseases, as well as interactions among these traits. In the short and middle long run, the organic market segment can utilize the best available varieties among the existing conventionally bred varieties which can also be propagated organically. But in the long term, breeders can influence further improvement of organic seed production by integrating organic varietal traits in varieties (Bueren et al., 2002).Here we report the development of an organic indica rice variety which is at the pipe end of commercial variety release.

Materials and methods

A combined strategy of pedigree breeding, organic plant breeding (IFOAM, 2002; Bueren 2003) and farmer participatory plant breeding (PPB) approach (Morris & Bellon, 2004) was followed during the entire variety development programme. As available research institutional set ups were not tuned at that time of 2002 to take up organic farming, and fields of research stations were of fertilized by chemical fertilizers, farmers' fields being maintained under organic management were selected as the experiment site for raising all filial generations, initial and preliminary yield trials. In the hybridization program one of the parents of crosses effected was two land races namely, 'Kuthiru' and 'Orkayama' for a broader genetic basis as a source for adaptation ability (Heyden & Bueren, 2000) and which are adapted to a unique organic saline prone ecosystem of Kerala, India called, 'Kaipad' (Vanaja & Mammootty, 2010). Further, these land races have good cooking and nutritive qualities ,and resistance to major pests and diseases in the field condition. Two other parents included in the breeding programme were the varieties, 'Jaya' and 'Mahsuri' which are usually cultivated by farmers under low input conditions.

Hybridization between these four parents in all possible combinations under organic conditions was carried out. Out of all possible cross combinations between the four rice varieties/ land races, F_1 seeds were obtained only from six cross combinations. In organic agriculture, as the variety has to expect a large plant x environment x management interaction under the lower (organic) input conditions, the most efficient way is to select progenies from the filial generations, under organic farming conditions, as early in the selection process as possible (Bueren et al., 2002; Jongerden et al., 2002). Hence, 6292 F_2 progenies obtained from the six cross combinations were raised in farmers' fields under organic management.

Seventy four promising F_2 progenies were selected out based on yield, lodging resistance, plant stature, and other subjective traits. Single plant pedigree selection was followed in the F_2 generation. In the succeeding filial generations, only those progenies responding well to organic management were carried forward to initial and preliminary yield trials. Separate comparative yield trials for organic and chemical management practices were conducted to select out the genotype which performs best under both managements. Close farmer–researcher collaboration was ensured to produce more benefits than the traditional global breeding for easy and early adoption of the cultivar by the end user. The design used for replicated trial was a randomised block design (RBD) with three replications for preliminary yield trials (PYTs) and four replications for comparative yield trials (CYTs). As organic farmers prefer yield stability to higher yield, Multi location/ Farm trials under organic management were carried out for several seasons and locations.

Since organic farming demands higher quality, detailed cooking quality and nutritive quality analyses were also conducted. As crop health has to be given due consideration in the case of variety developed for organic agriculture, pest and disease screening was started parallel to the initial yield trials itself. Initially, absolute screening for pests and diseases was conducted for 12 cultures which were evaluated in the initial yield trials under organic management. Those cultures which showed better biotic stress tolerance, yield performance and belong to different parental combinations were carried forward to further yield trials under both organic and conventional managements. Once again screening for biotic stresses was done to select out the best culture which shows better tolerance for biotic stresses, at the same time stable yielding under both management practices. Standard evaluation system for rice was used for evaluating and description of cultures, and for scoring pest and disease incidence (IRRI 1988).

Results and discussion

Grain yield

The average grain yield data of 12 cultures in Initial yield trials (IYTs), preliminary yield trials (PYTs) and comparative yield trials (CYTs) along with their parentage are presented in Table 1.All the cultures evaluated under IYTs and PYTs were subjected to biotic stress screening. Those high yielding cultures which showed better biotic stress tolerance and belong to different parental combinations were carried forward to comparative yield trials under both organic and conventional managements. Accordingly, cultures MK 157, JK 14 and JK 59 were carried forward to CYTs. The culture MK 157 which showed the highest yield in CYTs under both managements was carried forward to multi location or on- farm trials. The result of multi location/ farm trials conducted in various districts of Kerala under both organic and conventional managements are presented in table 2. The culture MK157 showed the highest grain yield under both organic and conventional managements along with very high straw yield. Higher yield of both grain (18%) and straw yield were seen under conventional management than under organic management. Twenty to thirty percentage yield reduction have been reported in the case of winter and spring wheat in the Netherlands under organic farming (Spiertz,1989, Mader et al., 2002), and in legumes (Seufert et al., 2012) .Yields in organic agriculture can be 20% lower due to a lower nitrogen input and no split application of nitrogen, and in some cases due to pests and diseases (Mader et al., 2002). Further, in organic agriculture yield should be expressed in economic return instead of Kg/ha which is for organic farmers the optimal combination of grain production and the premium price for high grain quality (Bueren & Osman, 2002). Organic farmers prefer yield stability to higher yields. They need a reliable variety which can cope up with the fluctuations in weather conditions and disease pressure without large fluctuations of yield and quality of both grain and straw. Organic farmers aim to optimize yield while satisfying the conditions of organic production, and natural principles and methods are applied (Bueren et al., 2002).

 ISSN 1177-4258

Table 1. Parentage and grain yield of different cultures in IETs, PYTs and CYTs.

Name of culture/ variety*	Parentage	IET ($t\ ha^{-1}$) Organic management	PYT ($t\ ha^{-1}$) Organic management	CYT ($t\ ha^{-1}$)	
				Organic management	Conventional management
MK 157	Mahsuri x Kuthiru**	9.0	6.5	6.0	5.8
MK 129	- do-	6.0	4.3	-	-
MK 121	- do-	5.5	3.9	-	-
MK 134	- do-	5.5	3.7	-	-
MK 130	- do-	4.9	4.2	-	-
MK 125	- do-	4.0	3.6	-	-
MK 132	- do-	3.9	4.5	-	-
MK 136	- do-	4.0	3.9	-	-
JK 14	Jaya x Kuthiru	5.0	5.5	4.0	1.2
JK 59	- do-	2.8	4.8	3.7	1.6
JK 28	- do-	3.9	3.7	-	-
JO 74	Jaya x Orkayama**	2.5	5.3	-	-
Jyothy		-	2.0	-	-
Mahsuri		-	2.1	-	-
Athira		-	-	5.5	2.4
Uma		-	-	3.9	1.7
Varsha		-	-	4.7	2.1
CD(0.01)		-	0.89	1.20	1.54

* Cultures are organically bred & varieties are conventionally bred;
** Land races of a naturally organic ecosystem;
IET= Initial yield trial (wet and dry seasons 2006);
PYT = Preliminary Yield Trial (wet and dry seasons 2007);
CYT = Comparative Yield Trial (dry season 2009 and wet season 2010).

Table 2. Grain and straw yield of culture MK 157 in multi location/farm trials.

Culture/ variety*	Pooled grain yield and straw yield in parenthesis under organic management[1] ($t\ ha^{-1}$)	Pooled grain yield and straw yield in parenthesis under conventional management [2] ($t\ ha^{-1}$)
Culture MK 157	4.9 (8.4)	5.8 (11.7)
Check variety-Jyothy	2.1 (1.9)	3.1 (2.9)
Check variety- Uma	3.3 (4.3)	3.6 (5.6)
Check variety- Athira	2.8 (2.6)	3.5 (3.5)

* Culture is organically bred, variety is conventionally bred.
[1] Pooled over seven seasons at eight locations.
[2] Pooled over four seasons at five locations.

With crop cultivars bred within and adapted to the distinctive conditions inherent in organic systems, organic agriculture will be better able to realize its full potential as a high yielding alternative to conventional agriculture (Spiertz, 1989). In farm trials, the average yield and the potential yield exhibited by the culture under organic management was 4.9 t/ha (Table 2) and 6.6 t/ha, respectively. The ‘potential yield’ reported here is the maximum yield recorded across the seven seasons and eight locations. Conventionally bred different check varieties were used in on-farm trials (OFTs) depending upon the popularity of the variety in that locality. The average grain yield of culture MK 157 in farm trials under organic and conventional managements was 48% and 61% more than the highest yielding check variety, respectively. The result of initial yield trials, comparative yield trials and farm trials from different farmers field shows that, the yield performance of conventionally bred varieties used in this experiment widely varies with seasons and locations under organic management and conventional management unlike the organically bred culture MK 157 which shows a stable yield irrespective of season and location under both managements.

The fact that all organically bred cultures need not perform well under conventional management is also evidenced from the result of comparative yield trials. Hence, the strategy followed may be, among the organically bred hybrid derivatives, that selection should be done for those progenies responding equally well for both managements in order to have a wider use to satisfy both organic and conventional farmers. This result reiterates the opinion of Bueren et al.(2002) that organically bred varieties in the future will benefit not only organic farming systems, but also for conventional systems moving away from high inputs in nutrients and chemical pesticides. The average straw yield of culture MK 157 in farm trails was 95% and 109% more than the best check variety under organic management and conventional management respectively.

The results of comparative yield trials (Table 1) and farm trials (Table 2) using chemical fertilizers indicate that the culture is also suited for conventional systems moving away from high inputs of nutrients and chemical pesticides, which is the added advantage of this new organically bred culture as organic agriculture is only in the development stage in the state of Kerala, India.

Cooking quality

In the sensory evaluation, culture MK 157 out ranked the popularly consumed conventionally bred variety ‘Jyothy’ of Kerala, for all the parameters tested (Table 3). The taste and acceptability of cooked rice were confirmed through an organoleptic test conducted by a team involving farmers, consumer representatives, millers, extension officials and scientists. The milling recovery of the culture in the commercial mill was 74.4% with 62% head rice recovery. Similarly, it was characterized by good cooking qualities (Table 4) having higher volume expansion (68%), water uptake (270%), and kernel elongation (33%) than the check variety ‘Jyothy’ (Table 4). In addition to the excellent cooking qualities, which are very much appreciated by farmers who did OFTs, they also certified that it is very good for making ‘temple prasadam’ and ‘Payasam’ (sweet gruel). Farmers who did OFTs replaced their regular rice varieties with culture MK 157 for consumption.

 ISSN 1177-4258

Table 3. Sensory evaluation score of culture MK 157 in comparison with the popularly consumed conventionally bred variety 'Jyothy'.

Name of culture/ variety	Taste(score out of 10)	Flavor (score out of 10)	Stickiness	Appearance (score out of 10)	Over all performance (score out of 10)
MK 157	6.73	5.0	Non sticky	6.9	6.6
Jyothy	6.70	4.9	Non sticky	6.5	6.3

Nutritional quality

The culture has comparatively very good nutritive qualities (Table 4),having 121.8% higher iron, 33.3% more protein, 33.6% more calcium, and 22.4% more potassium content than 'Jyothy' variety, which may be a combined effect of inheritance from its male parent 'Kuthiru' which is a land race, and may be due to organic breeding and management practices. Similar case of enhanced quality traits was experienced by Heyden & Bueren (2003) in their organic breeding program of cabbage, and Kunz & Karutz (1991) in organic wheat breeding.

Table 4. Cooking and nutritive qualities of culture MK 157.

Cooking /Nutritive qualities	Culture MK 157	Jyothy*
Cooking qualities Volume expansion	4.0	2.4
Kernel elongation ratio	1.6	1.2
Water uptake	2.11	0.57
Alkali spreading value	4.0	4.0
Amylose content	25.7	25.7
Shape of milled rice	Bold	Medium
Nutritive qualities Protein (% by wt.)	0.4	0.3
Total sugar (% by wt)	0.6	0.6
Total fat(% by wt)	2.4	1.7
Total carbohydrate (% by wt.)	83.9	82.2
Starch (% by wt.)	26.1	24.8
Phosphorus as P(mg/100g)	195	240
Crude fiber (% by wt.)	10.2	10.9
Iron (mg /Kg)	165	74.4
Zinc (mg/Kg)	24	32.7
Potassium (mg/Kg)	10130	8279
Calcium(mg/Kg)	183	137
Magnesium(mg/Kg)	733	754

* Popularly consumed conventionally bred variety in Kerala.

Pest resistance

In all experiment fields of the culture MK 157, there was field resistance for most of the pests. The mean score for pests and diseases when evaluated for absolute resistance is presented in Table 5.The culture MK 157 showed resistance to leaf folder and case worm, moderate resistance to gall midge, whorl maggot, sheath blight, brown spot, but was susceptible to blast. The resistance might have transferred from the male parent, 'Kuthiru', and the blast susceptibility might have inherited from its female parent 'Mahsuri'. Swer et al. (2011) reported significant positive correlation between fungal populations and organic carbon in a maize–french bean organic trial. That there was no root disease or pest attack in any of the experiment or farm trials is consistent with the report of Bruggen (1995) that in organic crop production, root disease and pests are generally less of a problem than foliar diseases, because foliar disease development is much more determined by climatic factors.

One of the central tenets of organic farming is to improve soil health and productivity by increasing soil carbon levels, particularly humus and such practices can increase water use efficiency (Leu, 2009). The consequences of losses due to pests and diseases in organic farming systems differ considerably depending on region, crop, and farm structure. In the case of wheat, Tamis & Brink (1999) reported that the disease pressure in organic wheat production is in most years lower than in conventional systems, but in some years the disease pressure can be larger than in conventional systems.

Table 5. Reaction of culture MK 157 to important pests and diseases when screened for absolute resistance.

Culture/ Variety	Gall midge (% SS)		Leaf folder (% DL)		Whorl maggot (% DL)		Case worm (% DL)		Score (0-9 SES scale)			
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	50 DAT	Sheath blight	Brown spot	BLB	Blast
MK 157	0	12.2	0.80	0.88	16.4	4.0	4.0	3.5	1.7	1.7	3.7	4.0
Jyothy	0	5.26	1.66	8.84	18.9	11.2	7.8	2.7	5.0	4.0	5.0	5.7

Note: DAT = Days After Planting; SS = Silver Shoots, DL = Dead Leaves; BLB = Bacterial Leaf Blight; SES: Standard Evaluation System; < 10% infection = resistant, 10 -30% infection = moderately resistant, >30% infection = susceptible, Score 1 = resistant, Score 2 & 3 = moderately resistant.

The height of seedlings of the culture is short, making transplantation an easy process including transplanting by machine, but two months after transplanting the height of the seedlings increases suddenly and forms a thick canopy over the soil. The dense crop canopy influenced by its canopy architecture of long and broad leaves, leaf stiffness and leaf shape, and its robust nature with large number of tillers improves the crop's ability to compete with weeds. The weed suppressive ability of varieties can contribute to the self regulation principle of the organic farming system. Organic farmers require varieties that have a rapid juvenile growth with a good tillering ability and the ability to cover or shade the soil in an early stage of crop development to outcompete weeds for light. It was also observed that the culture comes up well in those wetlands which are shaded at the border due to conversion of paddy land for other plantation crops or for construction purposes. The culture is characterized by a long stay green index of the upper leaves, expressing the ability to use all available nutrients and light efficiently which is an important criterion for organic varieties (Bueren & Osman, 2002).The plant architecture of culture MK 157 with its taller erect leaf canopy and drooping panicles is of a more productive type in terms of photosynthesis (Yuan, 2001).

In the fields of MK 157 under organic management, the crop was seen to resist lodging, but in some conventionally managed trials the crop is seen partially lodged. A similar case has been reported in the case of wheat (Tammis & Brink,1999). In the organic farming fields of the culture MK 157, there was immense growth of micro-organisms on the soil which satisfies the organic varietal characteristic to interact with beneficial soil micro-organisms. During the 2010 wet season, in Arayidam padasekharam of Kannur district, Kerala which has been an organic farming tract for several years and one of our farm trial fields, we raised culture MK 157 along with a conventionally bred rice variety. The bad weather conditions during this period adversely affected the conventionally bred variety but culture MK 157 remained unaffected. Similarly in an iron-toxic field, when a conventionally bred high yielding variety showed reduced root growth and thereby yield reduction, the culture showed healthy roots and better yield. In a farmer's field which was left uncultivable due to secondary salinization, this culture showed better production. Hence, the culture satisfies the criteria of being a 'reliable variety' for organic farming (Bueren et al., 2002).

A comparative study of yield component traits of conventionally bred varieties and the newly developed organically bred culture, under organic and conventional management revealed that, in the case of cultures developed through organic plant breeding, the difference in measurement of traits under organic and conventional management is comparatively less. But in the case of varieties developed through conventional breeding, there is much difference in measurement of traits under organic and conventional managements with high value for conventional management (Data not given).

The other favourable traits of the culture certified by farmers are: less chemical fertilizer required for conventionally managed crop, and excess fertilizer causes deleterious effect; less chaff production; high germination percentage; possible for ratoon crop; parboiling time 20 minutes less than other varieties; and lightly scented at the time of flowering and seedling. As the major part of the experiment was conducted in farmers' fields adopting participatory plant breeding, the farmers expressed favourable views of the yield potential, quality, and suitability of the culture to organic agricultural practices in wet land conditions. Due to its yield potential, and considering its good cooking quality and taste, there is a demand from farmers for the seeds. Farmers very well accepted the newly developed rice culture for large scale cultivation under the control of scientists before its commercial release, and at present the culture is in the pipe end of variety release in the Kerala state of India.

Salient characteristics of the organic rice cultivar

Culture MK 157 is a high yielding, photo insensitive, rice cultivar giving high yield under both organic and conventional management regimes, and is resistant to leaf folder and case worm, moderately resistant to gall midge, whorl maggot, sheath blight and brown spot. It exhibits increased rooting density leading to adaptation to organic soil fertility management (low input), and also adverse soil conditions. However, it responds very well to chemical fertilizers also. The short seedling height of the culture becomes suddenly tall two months after transplanting and forms a thick canopy over the soil which suppresses weed growth. The plant is tolerant to lodging with robust plant architecture (Figure 1a), there is a large number of strong sturdy culm with average height of 119cm, the long and broad leaves, with a nice and vibrating leaf canopy and drooping panicles, offer a favourable architecture against pest attack, and the cultivar has a comparatively high straw content. MK 157 has long, compact panicles with a large number of comparatively small grains with lemma and palea colour - gold furrows on straw back ground (Figures 1b & 1c), and attractive bold white kernel which can be very specifically distinguished from other varieties (Figures 1d & 1 e). Other favorable traits of this organic rice culture are, long stay green index of upper leaves even at harvest stage with attractive plant stature, tolerant to shade in the wetland, and it is lightly scented at the time of seedling and flowering stages.

(a) (b)

(d) (e)

Fig 1. Characteristic features of culture MK 157

(a) Crop in farmer's field having robust plant architecture with taller stem and erect leaf canopy (b) Long, compact panicles with large number of comparatively small grains with long stay green index of upper leaves even at the time of harvest (c) Small grains with lemma and palea colour- gold furrows on straw back ground which can be very specifically distinguished from other varieties (d) &(e) Attractive bold parboiled and raw rice with appealing appearance.

Conclusion

Culture MK 157 is the first organic wetland rice cultivar suitable for both organic farming and conventional farming, developed through the combined plant breeding strategies of

 ISSN 1177-4258

pedigree breeding, organic plant breeding and participatory plant breeding. It possesses the general criteria for desirable variety characteristics for organic farming systems. It is a medium duration cultivar (125-130 days for wet and 115-120 days for dry seasons) having high grain and straw yield and yield stability, with tall plant stature during wet seasons and medium tall stature during dry seasons, comparatively very good cooking and nutritive qualities than the popularly consumed conventionally bred variety of Kerala.

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