

13 Hybrid Rice in Africa: Challenges and Prospects

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Introduction

The 2008 food crisis and the increasing gap between rice consumption and production in Africa underline the need to accelerate the introduction and adoption of higher-yielding rice varieties. Hybrid rice technology has contributed significantly to food security, environmental protection, and employment opportunities in China since the early 1980s (Yan *et al.*, 2010). Hybrid technology may contribute to food security in Africa through two avenues: (i) exploitation of heterosis in order to increase crop productivity, and (ii) attracting and encouraging private-sector involvement in seed production research and development (R&D) (Naseem *et al.*, 2010). Heterosis, or hybrid vigour, is the occurrence of a superior offspring from mixing the genetic contributions of its parents. In hybrid rice, the extent of heterosis depends on the relationship between the parental lines, and heterosis for grain yield ranges between less than 10% and more than 40% (El-Namaky, 2008). Availability of suitable pollination control systems and the extent of out-crossing between female and male parents are the key factors determining the success of commercial exploitation of heterosis (Mao *et al.*, 1998).

Since the early 1990s, several other countries (Bangladesh, Egypt, India and Vietnam) have developed and introduced hybrid rice technology to their farmers. The availability of adequately trained human resources is an essential prerequisite for developing and using hybrid rice technology. Hybrid rice breeding uses several concepts, skills and procedures that are strikingly different from those used for 'traditional' inbred rice breeding (Virmani *et al.*, 1997).

During the first decade of the 2000s, several African countries (Côte d'Ivoire, Liberia, Madagascar, Mozambique, Nigeria, Tanzania and Uganda) started to evaluate and cultivate rice hybrids from China. Only Egypt has succeeded in developing a hybrid rice breeding programme and produces Egyptian hybrids on a commercial scale. Grain yields obtained with hybrids have been in the order of 12–14 tonnes per hectare (Bastawisi *et al.*, 2003). The programme developed a seed production system for the multiplication of cytoplasmic male sterile (CMS) lines (A/B) and hybrid rice (A/R). Cropping practices and recommendations for CMS multiplication, hybrid seed production and hybrid rice cultivation were developed by the national programme. In addition, the programme features a special strategy to develop

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aromatic hybrid rice and hybrids tolerant to salinity and drought.

In this chapter, we present the Africa Rice Center (AfricaRice) strategy for developing hybrid rice for sub-Saharan Africa and its preliminary results.

Hybrid Rice Breeding and Distribution Strategy

Breeding strategy

Building on hybrids developed by partners outside of Africa: the Green Super Rice project

The Green Super Rice (GSR) project (2009–2011) was jointly coordinated by the Chinese Academy of Agricultural Sciences (CAAS), AfricaRice and the International Rice Research Institute (IRRI), and implemented in seven countries in Asia, six provinces in China and eight African countries (Liberia, Mali, Mozambique, Nigeria, Rwanda, Senegal, Tanzania and Uganda). The development and cultivation of GSR hybrid and inbred cultivars with high nutrient use efficiency and stress resistances are expected to provide a sustainable way of reducing food insecurity and poverty in sub-Saharan Africa and Asia. Building on the tremendous capacity in breeding and genomic technology of China, the short-term (3-year) goals of the project were to enter at least 15 rice varieties in national trials in project countries and develop capacity in hybrid seed production.

The **general strategy** was to identify Chinese hybrid lines that have good adaptability and high yield potential for the rainfed lowland and irrigated areas of sub-Saharan Africa, and further improve their tolerance to major stresses – including drought, nitrogen (N) and phosphorus (P) deficiencies, pests (e.g. African rice gall midge) and diseases (e.g. blast, bacterial leaf blight, *Rice yellow mottle virus*) – using conventional and molecular breeding approaches.

Developing an in-house hybrid rice breeding programme

Started in 2010 dry season, the programme is based at AfricaRice Sahel station in Saint-Louis,

Senegal. The aim is to: (i) evaluate the performance of rice hybrids in multi-locational yield trials under African conditions; (ii) develop new parental lines from local varieties; (iii) determine adaptability of some CMS lines in Africa; and (iv) establish a hybrid rice seed-production system in, among others, Senegal and Mali.

Hybrid seed production and marketing strategy

The technology of hybrid rice seed production has been developed and practised successfully not only in China, but also in many other countries with temperate and tropical conditions. Technologically, there should be no serious barrier to hybrid rice seed production in Africa. The 1–2 t/ha seed yield obtained in many countries under different conditions is economically viable. National partners involved in the seed sector in Senegal and Mali are being trained in hybrid seed production. Furthermore, farmers, private sector and NGOs involved in the rice sector will be sensitized about hybrid rice technology and trained in hybrid rice technology and seed production. Various models will be established for hybrid rice seed production and industry in different countries and regions.

Preliminary Results

Multi-locational evaluation of hybrids

Experimental methods

In 2010, some 122 hybrids and eight checks were evaluated in observational yield trials in six African countries (Mali, Mozambique, Nigeria, Senegal, Tanzania and Uganda) using an augmented design and local fertilizer recommendations. Each block consisted of 17 plots with replicated checks included in 10 blocks. At the same time, the varieties were also evaluated under greenhouse conditions for resistance to the main rice diseases and insect pests in Africa – namely bacterial leaf blight (BLB), blast and *Rice yellow mottle virus* (RYMV) in Benin, and African rice gall midge (AFRGM) in Ibadan, Nigeria.

Yield, days to maturity and yield-component data were analysed using SAS mixed model under SAS/STAT 9.2 (Littell *et al.*, 1996). Multiple comparison adjustment for the *P*-values was then performed to test differences between hybrids and the best check for each country at a significance level of $P < 0.05$.

Results

Very highly significant genotype (G) by environment (E) or country interactions were observed for yield, yield components and crop duration, indicating that the hybrids and check varieties performed differently across environments (Table 13.1). Given this G×E interaction, hybrid performance was analysed on country-by-country basis.

The mean grain yield of the 122 hybrids was lower than the check variety in all countries except Mozambique (Table 13.2), while mean grain yield of the top ten hybrids in each country was higher than the yield of the best check variety in the same country. Non-significant differences for days to 50% flowering were observed between the mean of the 122 hybrids, the mean of the top ten hybrids and the local check, except in Mozambique where the local check was of longer duration (101 days) and in Nigeria where mean duration of the ten top hybrids was 106 days. QY1, HanF1-35, 3LYR24, HLY9348, GLYR24 and HXY836 were the best hybrids in Senegal, Mali, Nigeria, Tanzania, Uganda and Mozambique, respectively, with grain yields of 10.55, 12.50, 5.12, 8.20, 8.56 and 3.24 t/ha, respectively. Milling rate for the best hybrids

ranged between 61.7% and 68.0%. All of the promising hybrids were long grained (grains 6.3–7.2 mm long). Regarding disease and insect resistance, all promising hybrids were susceptible to AfRGM under natural conditions, but only QY1 was highly susceptible to blast under natural infestation. All promising hybrids were susceptible to RYMV under artificial inoculation in screen house.

These preliminary results confirmed the fact that while some hybrids developed in Asia can perform well in Africa for yield potential, given their susceptibility to African diseases it would not be prudent to rely on them for commercial rice production. Developing local hybrids with high yield potential and resistance to biotic stresses will be more efficient. Many countries, such as Egypt, India, Pakistan, Philippines and Vietnam, have succeeded in establishing hybrid rice programmes and releasing local hybrids.

Developing new hybrids

In order to develop new hybrids with high yield potential and tolerance to biotic and abiotic stresses at AfricaRice, 300 test crosses were performed between three CMS lines (IR68886A, IR69625A and IR58025A) and various African varieties with the aim of identifying new restorer and maintainer varieties from local materials resistant to insects and diseases. The preliminary results indicated that there were 15 promising restorer lines with good phenotypic acceptability and with grain yield of 25.8–70.7 g/plant for the F_1 fertile combinations. At the same time, hybrids with about ten varieties showed complete sterility with the CMS line, which indicates that these varieties could be used as potential maintainer lines. Backcrosses were performed with three NERICA-L varieties to transfer cytoplasmic male sterility into these varieties. However, sterility of the NERICA-L varieties was not stable, so they were replaced by three breeding lines (ARSH 46-6-3-B, ARSH-23-1-2-2 and ARSH -23 3-1-2). The same three CMS lines were used with some local restorers like Sahel 108, Sahel 134, Giza 178 and Giza 182 to establish small plots for hybrid seed production (Fig.13.1). To increase cross-pollination, flag leaves were cut, a rope was pulled across the rice plants (Fig. 13.2) and gibberillic acid was applied. These seed-production experiments yielded 1–2.5 tonnes of hybrid seeds per hectare.

Table 13.1. Analysis of variance results for yield of 122 F_1 hybrid rice varieties across six countries (Mali, Mozambique, Nigeria, Senegal, Tanzania and Uganda). (Data from GSR project.)

Effect	Num DF ^a	Den DF ^b	F-Value	Prob F
Genotype (hybrids)	136	199	3.4529	<0.0001
Environment (country)	5	30	118.2648	<0.0001
G×E (hybrids × country)	596	199	2.2987	<0.0001

^aNumerator and ^bdenominator degrees of freedom associated with the *F* statistic (SAS mixed model uses a likelihood-based estimation scheme, it does not directly calculate or display sums of squares).

Table 13.2. Comparison of mean grain yield, days to 50% flowering, grain quality, insect and disease resistance of 122 hybrids, top ten hybrids, best hybrid and best check varieties in six sub-Saharan African countries.

Country	Check variety Name	Check variety		122 hybrids				Best ten hybrids ^a				Name	Best hybrid				Resistances to diseases and pests		
		Yield (t/ha)	DTF	Yield (t/ha)		DTF		Yield (t/ha)		DTF			Yield (t/ha)	DTF	Milling rate (%)	Grain length (mm)	AfRGM	Blast	RYMV
				Mean	SD	Mean	SD	Mean	SD	Mean	SD								
Senegal	Sahel 108	7.35	87.5	7.09	1.68	83.6	3.9	9.78	6.5	84	4.6	QYI	10.55	80.0	68.0	6.30	S	HS	S
Mali	WITA9	10.23	96.5	6.33	2.85	95.8	7.8	11.20	0.75	93.9	7.4	HanF1-35	12.50	88.1	66.4	6.72	S	MR	S
Nigeria	WITA4	3.23	81.5	2.55	1.01	92.8	5.4	4.61	0.63	106	7.7	3LYR24	5.12	112.0	61.7	7.19	S	R	S
Tanzania	WITA9	5.13	88	4.08	1.49	81	8.3	6.98	0.76	84	9.8	HYL9348	8.20	85.0	65.3	6.50	S	R	S
Uganda	NERICA-L 19	5.54	81.7	5.00	1.55	80.1	1.4	7.73	0.47	80.0	0.0	GLYR24	8.56	80.5	63.2	7.17	S	R	S
Mozambique	WITA9	1.83	100.7	1.84	0.45	86.91	4.2	2.74	0.25	85.2	5.8	HXY836	3.24	87.0	64.7	6.85	S	R	S

DTF, days to 50% flowering; sd, standard deviation; MR, moderately resistant; HS, highly susceptible; R, resistant; S, susceptible.

^aAverage of best ten hybrids.



Fig. 13.1. Small plots of hybrid seed production, Ndiaye, Senegal, 2010. (Photo: R. El-Namaky.)



Fig. 13.2. Using a rope for supplementary pollination in a small plot for hybrid seed production, Fanaye, Senegal, 2010. (Photo: R. El-Namaky.)

Challenges and Prospects

Hybrids are one of the key forms of biological intellectual property rights (IPR) in agriculture. Because the yield gains conferred by heterosis tend to decline dramatically after the first generation (F_1) of seed, farmers must purchase new F_1 seed each season to continually capture such yield gains. The major challenges of hybrid rice are high seed cost, necessity of changing seed every crop season, and continuous dependence on the external source for supply of seed. Establishing efficient infrastructure for seed production, processing, certification and distribution are very important. This cannot be done successfully without an efficient seed industry, very-high-performing hybrids (compared to the best inbred varieties available), and a robust training programme for farmers, and technicians in the public and private sectors.

Testing of Chinese hybrid lines in Africa showed promise in terms of high yields but susceptibility to African insect pests and diseases. Progress made in the hybrid rice research programme at AfricaRice, Senegal will allow testing of AfricaRice developed hybrids in 2014.

We conclude that hybrid technology not only offers the potential of increasing rice productivity, but can also serve as a mechanism for leveraging private-sector investment in rice R&D in Africa.

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