m borer, and shoot fly, and various
:hogens, including the parasitic
ed *Striga*. Forty male-sterile lines
1 75 genotypes conferring varying
els of insect resistance have been
iluated for their utility in breeding
w parental lines.
To summarize, ICRISAT
rmplasm research and development
has been useful in assisting both public and private breeding efforts within India. For MAHYCO, the impact of ICRISAT germplasm has been particularly strong in the pearl millet research program aimed at development of improved parental lines and hybrids based on CMS systems.

1998

Evaluating Hybrid Technology for Pigeonpea

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Pigeonpea (*Cajanus cajan* [L.] Millspaugh) is an important pulse crop grown mainly in tropical areas, especially south Asia, eastern Africa, the Caribbean region, and south and central America. Also known as redgram in south Asia, about 90% of world pigeonpea production is grown in India (Nene and Sheila 1990), where it is cultivated on 14% of the land area and provides 20% of the national pulse crop. Pigeonpea varieties differ in terms of their yield advantages and unit cost reduction, but the discovery of genetic male-sterility (GMS) at ICRISAT in 1974 offered exciting new potential for plant breeders (Saxena et al. 1996). Ultimately ICRISAT developed the world's first hybrid pigeonpea in 1991.

This paper examines the use of hybrid pigeonpea technology by national agricultural research systems (NARS) and seed companies. The study also investigates present GMS technology and its further development toward pigeonpea hybrids based on cytoplasmic male-sterility (CMS).

There are four main users of hybrid pigeonpea technology — farmers/seed growers, NARS, public seed companies, and private seed companies. In this study, all four users were assessed to:

- examine the use of GMS pigeonpea hybrids by NARS and seed companies in their breeding programs;
- assess the role of ICRISAT's GMS lines in their hybrid pigeonpea breeding program; and
- identify constraints faced by NARS, seed companies, and seed growers in adopting the hybrid pigeonpea technology.

Hybrid technology for pigeonpea

In the process of searching for new avenues in pigeonpea breeding, there were several important milestones. In 1974, a wide search was undertaken at

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8331

ICRISAT to identify genetic male-sterility among 7 216 germplasm lines and 124 F_4 derivatives of crosses between *C. cajan* and its wild relatives. In 1977, nine genetic male-sterile based hybrids were tested at ICRISAT-Patancheru, of which two performed better than the others with 33% and 24% heterosis over the best varietal control (ICRISAT 1990, Saxena et al. 1996). During 1978, studies indicated that male sterility in pigeonpea is controlled by a single recessive gene ms_1, and the anthers are translucent (Reddy et al. 1978). In 1981, another source of male sterility controlled by a non-allelic single recessive gene ms_2 was identified in Australia, which has brown arrowhead-shaped anthers (Saxena et al. 1983).

In 1988, a study was undertaken by ICRISAT and Tamil Nadu Agricultural University (TNAU) to determine the cost of producing hybrid pigeonpea seed (Murugarajendran et al. 1990). In 1989, a special project was launched by the Indian Council of Agricultural Research (ICAR) at nine centers in India to strengthen research and development of pigeonpea hybrids (Saxena et al. 1996). These nine centers are the Indian Institute of Pulses Research (IIPR), Kanpur; Punjab Agricultural University (PAU), Ludhiana; Haryana Agricultural University (HAU), Hisar; Indian Agricultural Research Institute (IARI), New Delhi; Gujarat Agricultural University (GAU), S K Nagar; Panjabrao Krishi Vidyapeeth (PKV), Akola; Tamil Nadu Agricultural University (TNAU), Coimbatore; Narendra Dev University of Agriculture and Technology (NDUAT), Faizabad; and Rajasthan Agricultural University (RAU), Dholi. In addition, other centers such as Banaras Hindu University (BHU), Varanasi; University of Agricultural Sciences (UAS), Bangalore; Bhabha Atomic Research Centre (BARC), Trombay; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru; and Maharashtra Hybrid Seed Company (MAHYCO), Jalna collaborated as voluntary centers (Srivastava and Asthana 1993, ICAR 1996).

First three hybrids

In 1991, ICPH 8, the world's first commercial hybrid pigeonpea, developed by ICRISAT, was released by the Indian seed release committee (Saxena et al. 1996). This was a breakthrough in plant breeding. Scientists at TNAU released another hybrid, CoH 1 in 1994 (Rathnaswamy et al. 1994). In the same year, a third pigeonpea hybrid, PPH 4, was developed and released by PAU in Ludhiana for cultivation in Punjab and the northern belts in India (Verma and Sidhu 1993, ICAR 1996).

All three GMS pigeonpea hybrids were short-duration, high yielding, and drought tolerant, with vigorous growth and wide adaptation to different agroclimatic conditions. They all have the same weakness, however, of a high labor requirement for seed production. At ICRISAT, the male-sterile gene was transferred into the diverse genetic background of different maturity groups. A mid to late disease-resistant male-sterile line *ms* ICP 3783 was used to develop disease-resistant medium- and late-maturing hybrids. Hybrids have a demonstrated 20–30% yield advantage in farmers fields.

Research on ICPH 8

The total R&D time from searching for genetic male sterility to seed production and technology exchange for hybrid pigeonpea ICPH 8 was about 22 years (Tables 1 and 2). Private and

Table 2. Research lag for development of ICPH 8.

Period	Activity	Years
1974–77	Basic research	4
1977–83	On-station adaptive research/applied research	6
1984–89	On-farm adaptive research/applied research	6
1991	Release of hybrid ICPH 8	2
1991	Seed multiplication and technology transfer	4
Total research lag		22

Table 1. Steps in the research process leading to the release of pigeonpea hybrid ICPH 8.

Year	Research step
1974	An extensive search was made at ICRISAT for male sterility among 7 216 germplasm lines and 124 F_4 derivatives of crosses between *C. cajan* and its wild relatives (Saxena et al. 1996)
1977	Nine genetic male-sterile based hybrids were tested at ICRISAT, of which two were found to perform well with 32% and 24% heterosis over the best varietal control (ICRISAT 1990)
1977 onwards	Experimental hybrids that exhibited high heterosis were subsequently tested in multilocational trials for stability and adaptability to different environments (Saxena et al. 1996)
1984–89	Multilocational testing under ICAR's collaborative trials and ICRISAT's 41 on-farm trials found 40–50% superior to control cultivars UPAS 120 and Manak (ICRISAT 1990)
1989	Tested in minikit trials at 12 locations in the Central Zone (Saxena et al. 1996)
1990	Submission of proposal to release to central sub-committee on crops standards, notification, and release of varieties (ICRISAT 1990)
1991	ICPH 8 released as the first hybrid in Central Zone of India

public seed companies have been producing hybrid seed since 1992.

Cytoplasmic male-sterility

Commercial hybrid pigeonpea seed producers using the GMS technology faced several problems, including timely removal of about 50% of fertile flowering plants, maintenance of male-sterile lines in a heterozygous state, and additional costs of labor, land, and supervision (Verma and Sidhu 1993). To overcome these problems, researchers at all the cooperating institutions are attempting to develop cytoplasmic male-sterility through mutagenesis and wide hybridization. In mutagenesis, gamma radiation and mutagenic chemicals are used, while wide hybridization uses wild pigeonpea species (Kumar et al. 1995; Saxena et al. 1996).

The first consultative group meeting on CMS in pigeonpea was held at ICRISAT in 1994, and several major priority issues for future research were identified (Saxena 1996):

- characterization of available CMS sources using cytological studies, DNA marker studies, and field testing;
- identification of new cytoplasmic sources;
- studies on stability of CMS and sensitivity to temperature;
- use of diverse pollinators to identify new maintainers and restorers;
- studies on the extent of pod setting through open pollination in isolation;
- use of pigeonpea derivatives from wide hybridization involving wild cytoplasm to investigate use in a CMS system; and
- preparation of a protocol for isolation of CMS in pigeonpea through wild hybridization, mutagenesis, and other methods.

Research activities to develop a CMS system are in progress at most of the research institutes (ICAR 1996). Results at ICRISAT confirmed that around 99% of male sterility is always obtained through CMS research in five progenies at ICRISAT. Crosses with 2-33 line appeared most promising (Table 3) (Saxena 1996).

Table 3. Developments in CMS breeding at ICRISAT.

Progeny	Total plants	Sterile plants	Percentage of steriles
2-33 × 85010-15	19	18	95
2-33 × 85010-109	6	6	100
2-33 × 85010-62	16	16	100
2-33 × 85010(OP) Bulk	32	32	100
Total	73	72	98

Source: Saxena 1996.

Research methods

This study drew on diverse sources of data — selected scientists from NARS, private and public seed companies, and seed growers. Primary data were gathered through personal interviews with scientists, officers in public and private seed companies, and seed growers. An open-ended questionnaire facilitated data collection. Secondary data were gathered through reports, publications, newsletters etc., available in all the research institutions, and seed companies.

Results and discussion

Scientists from NARS, seed companies (private and public), and seed growers had varying perceptions of the hybrid pigeonpea program.

Seed companies

The National Seed Corporation tried to produce hybrid pigeonpea in the early 1990s, but stopped due to technical difficulties.

MAHYCO has developed four pigeonpea hybrids — MTH 22, MTH 23, MTH 9507, and MTH 9343, and in addition, two experimental hybrids, METH 104 and METH 115, were identified. During the period 1990–95 they produced 16 t of seed and sold 9.5 t at the rate of Rs. 100 kg^{-1}.

Suraj Seed Company purchased 10 kg of a GMS line and 5 kg of a pollinator line from the Central State Farm, Raichur, Karnataka in 1993/94. Their experiments were conducted in Yavatmal district, Maharashtra during 1993/94, but the company discontinued work for the next two years because the program failed. In 1996, they obtained parental lines from ICRISAT —2 kg of *ms* Prabath DT (GMS line) and 1 kg of the pollinator line ICPL 161. Trials were conducted at Nandyal, Andhra Pradesh.

National agricultural research systems

Department of Agriculture, Andhra Pradesh. The biggest problem farmers face in this area is that pure seed is seldom available. Farmers are reported willing to pay even higher prices for authentic hybrid seed.

Panjabrao Krishi Vidyapeeth. Long-duration pigeonpea is usually inter-cropped using a relatively low seeding rate (about 6 kg ha^{-1}), which farmers can afford to buy. All of the GMS hybrid pigeonpeas thus far mature early and are intended for sole cropping at a seeding rate of 40 kg ha^{-1}. The average farmer can not afford the cost of this hybrid seed when facing an uncertain profit margin. A pigeonpea crop is highly susceptible to pod borer damage, therefore yield is more uncertain than with other semi-arid crops. A yield advantage of 30% in pigeonpea hybrids over varieties is not very encouraging for farmers.

At Akola during 1996, 25 farmers were given parental materials of hybrid pigeonpea for seed production. This was an opportunity for them to compare their own varieties to the hybrid.

Gujarat Agricultural University. GAU obtained parent materials of ICPH 8 from ICRISAT for hybrid seed production and produced some hybrid seeds. But in 1996 they were not growing ICPH 8 because:

- farmers in Gujarat prefer relatively large seeds, about 10 g per 100 seed, while the 100 seed mass of ICPH 8 is about 7 g, and
- Farmers prefer white seeds, but ICPH 8 is red.

Banaras Hindu University. The normal practice in this northeastern plain zone is to grow long-duration pigeonpea (245 days) as an intercrop. Bahar is the predominant variety grown in this zone. Basic research on hybrid pigeonpea technology through GMS was started in 1989. ICRISAT male-sterile line ICP 383 was used for producing experimental hybrids. The male-sterile line for producing experimental hybrids was *ms* 3783. Based on multilocational trials beginning in 1991, hybrids VPH 1145, VPH 1164, and VPH 1184 were identified as promising and showed 30–40% superiority over Bahar. These hybrids had to be entered in ICAR's coordinated trials that required large quantities of seed. A funding shortage and lack of isolated land for seed production prevented production of the necessary bulk seed.

The main contribution from Banaras Hindu University to hybrid pigeonpea technology was the development of a long-duration GMS, HUA 7, which is brown, bold-seeded, and resistant to sterility mosaic disease. Basic research was undertaken during 1989–95, and bulk seed was produced in 1996/97 at GAU, Sardar Krishi Nagar. This seed is now available.

Basic research was started in 1989 on CMS through wide hybridization using wild species of pigeonpea. In the process of CMS development, male-sterile plants were isolated in progenies derived from wide hybridization, but when tested, were genetically male sterile. The development of CMS through mutagenesis required a large land area, hence no such work was initiated because there was not enough area at the research station.

Cost of hybrid seed production

Primary information. Cost of production data on hybrid pigeonpea were collected from a progressive farmer (Viswambhar Anna Kale) in Wahegaon village, Jalna, Maharashtra in October 1996. The farmer owned 5.6 ha of operational land on which nine crops were cultivated. Hybrid pigeonpea (MTH 9507) was sown in 0.4 ha in 1996 using parental materials from MAHYCO. Marketing of the hybrid seeds was not a problem because MAHYCO had already arranged to purchase the crop. The company also provided advice to the farmer.

Based on the farmer's data, labor and costs were calculated:

- Roguing, spraying, and fertilizer application were the main labor-demanding operations. Of the total labor requirement (in days), 58% was for roguing, 17% was for spraying (Endosulfan®), 11% was for fertilizer application, and the balance (14%) was for other operations.
- Of the total variable costs, 55% was spent on fertilizer (diammonium phosphate and farmyard manure), 20% on a pesticide (Endosulfan®), 13% was for labor, and the remaining (12%) was on other inputs.

Secondary information. Several studies have indicated the cost of hybrid seed production in different years. These studies are based on three hybrids that were released by ICAR (Table 4).

Constraints to use of hybrid technology

Several constraints to the adoption of hybrid technology were reported.

Roguing fertile female plants. About 50% of the female plants have to be rogued out at flowering to maintain genetic purity of the hybrid seed. Farmers usually do not like to rogue out the flowering plants because they think they lose money; they do not realise that roguing maintains the purity of hybrid seed.

High seeding rate. Usually long-duration pigeonpea is intercropped with a fast-growing crop. In that situation, the seeding rate for pigeonpea is relatively low, about 6 kg ha^{-1}. But when hybrid pigeonpea is grown as a sole crop, the seed requirement is about 30 kg ha^{-1}, which the average farmer cannot afford.

Shortage of parental seed. Because production of parental materials (male sterile and pollinator) is still mainly with scientists, it will require some time before seed companies routinely produce hybrid pigeonpea seed.

Heavy damage from pod borer. Most of the current GMS lines are susceptible to pod borer damage, thus farmers must use heavy doses of pesticides for control, an added cost of production.

Knowledge of seed production. Farmers lack knowledge about seed production, including use of several pollinator lines at the same time to produce hybrid seed.

Knowledge about input use. As a new crop in non-traditional areas, farmers apply too much pesticide and fertilizer, which in turn increases the cost of production.

Table 4. Cost of hybrid seed production based on the literature.

Year	Hybrid	Cost (Rs kg^{-1})	Source
1978/79	ICPH 8	1.54	Saxena et al. 1996, ICRISAT 1979
1979/80	ICPH 8	2.00	Saxena et al. 1996, ICRISAT 1979
1988	ICPH 8	6.25	Murugarajendran et al. 1990
1990	*ms* 3783 × ICP 11231	6.25	Srivastava and Asthana 1993
1992	PPH 4	13.80	Srivastava and Asthana 1993
1994	CoH 1	28.35	Rathnaswamy et al. 1994

Low price to hybrid seed growers. Growers do not like to sell their product at the rate set by the seed companies, therefore there is always a conflict between grower and seed companies.

Problems in grow-out test for genetic purity. Seed companies require 90% or higher genetic purity from growers, and most of the time the seed lots do not reach this level. Farmers must then sell their seed for a lower price, and hence will not contract to grow hybrid seed again.

Scarce labor for roguing. Roguing female plants is a labor-intensive operation. During the peak roguing period, most laborers are engaged in other crop cultivation operations from which they earn a considerable amount of money. It is very difficult to find laborers at the peak roguing period.

Competition from other crops. Cereal crops have a higher profit margin than pigeonpea hybrids.

Impact of ICRISAT hybrid pigeonpea technology on NARS

The hybrid pigeonpea program was initiated by a group of scientists at ICRISAT. There was no NARS research program at the time, and both basic and applied research results were disseminated to the Indian NARS (Table 5). In this manner, ICRISAT played an important role in the development and improvement of research capabilities in the Indian NARS for hybrid pigeonpea technology. Further, ICRISAT acted as a catalyst by creating an awareness among administrators, researchers, and farmers about hybrid pigeonpea technology. This collaboration paved the way for ICAR to begin research on hybrid pigeonpea.

In addition to basic and applied research, seed production technology was also disseminated to NARS and seed companies through training sessions, consultations, group meetings, field visits, and demonstrations.

Table 5. Parental materials and their sources for pigeonpea hybrids.

Hybrid	Parents	Source of female parent	Source of male parent
ICPH 8	*ms* Prabhat DT × ICPL 161	ICRISAT	ICRISAT
PPH 4	*ms* Prabhat DT × AL 688 NDT	ICRISAT	PAU
CoH 1	*ms* T 21 × ICPL 87109	ICRISAT	ICRISAT
MTH 22	*ms* T 21 × PL 173	ICRISAT	MAHYCO
MTH 23	*ms* T 21 × PL 653	ICRISAT	MAHYCO
MTH 9507	*ms* Prabhat DT × PL 927	ICRISAT	MAHYCO
MTH 9343	*ms* BDN 1 × PL 043	Unfinished *ms* lines supplied by ICRISAT	MAHYCO
METH 104	*ms* BDN 1 × PL 104	Unfinished *ms* lines supplied by ICRISAT	MAHYCO
METH 115	*ms* 3a 275 × PL 115	Unfinished *ms* lines supplied by ICRISAT	MAHYCO

Basic research on CMS hybrid pigeonpea technology was started in 1990 and is likely to be completed by 1999 (10 years). Since GMS technology has already been completed, it provides a solid platform for replacement by CMS technology. Seed production technology is similar, and one could replace the other with the added benefit of the elimination of roguing. Reduced costs of seed production would boost adoption at the farmer level (Table 6).

Table 6. Latest developments in CMS research.

Type of hybrid	Fertile plants (%)	Sterile plants (%)
GMS	50	50
CMS	0	100
New ICRISAT lines		98.6

Recommendations

Application of three broad recommendations would increase the adoption of hybrid pigeonpea:

- farmer education about hybrid technology is important so that multiple and perennial production systems of hybrid pigeonpea can be followed;
- incentives should be given to seed companies to adopt hybrid technology, with benefits extended to seed growers by paying higher prices for their hybrid seeds; and
- male sterile hybrid technology should be introduced to seed growers so that most constraints could be overcome.

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Screening Techniques to Identify Resistance to Downy Mildew of Pearl Millet and Sorghum Midge

S D Singh and K V Hari Prasad[1]

Host plant resistance is the most economical method to control insect pests and diseases, and the technique most friendly to the environment. One prerequisite to producing disease- and insect-resistant cultivars is the availability of effective and reliable field and greenhouse screening techniques. These techniques allow identification of resistance sources and enable their transfer into agronomically elite backgrounds to produce high-yielding cultivars. At ICRISAT in India, screening techniques have been developed for two highly devastating biotic constraints — downy mildew (*Sclerospora graminicola* [Sacc.] Schroet.) in pearl millet, and midge (*Stenodiplosis sorghicola* [Coquillette.]) in sorghum. This paper describes the research process for these techniques.

Pearl millet downy mildew

Downy mildew is the most widespread and destructive disease of pearl millet in India and western Africa. The disease is a major constraint in attaining the yield potential of single cross F_1 hybrids. The disease is systemic and plants that are infected early either fail to produce earheads or produce malformed earheads, resulting in total yield loss. In the past, the disease occurred several times in epidemic forms in India and severely affected food grain production and food security of rainfed farmers. With the advent of downy mildew resistant cultivars, the disease has been controlled.

Maintenance and production of inoculum

The availability of viable inoculum in sufficient quantity is the key requirement

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