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HETEROSIS BREEDING FOR HIGHER YIELD IN PIGEONPEA

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ABSTRACT

Since the identification of genetic male sterility in 1974, a considerable progress has been made in developing commercial pigeonpea hybrids by taking the advantage of its partial outcrossing characteristic. The first pigeonpea hybrid ICPH 8 was released recently and some more promising new hybrid combinations have been identified. Experimental plot yields as high as 5 t ha^{-1} have been obtained from some of hybrids which signify a breakthrough in yield. This paper besides summarizing the performance of experimental hybrids, reviews the progress made in identification of heterotic combinations, diversifying male sterile base, understanding the physiological basis of heterosis and stability of yield. Limitations posed by genetic male sterility in hybrid seed production and some viable alternatives to reduce the seed production cost are also discussed.

1. INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millspaugh) is a short-lived perennial shrub and is cultivated as an annual crop in South and South-East Asia, East Africa, the Caribbean region, and Southern and Central Americas. It is chiefly grown for its seeds which are consumed either as dry split peas (*dal*) or as a green vegetable and its stems provide a good source of fuel wood. Research on the genetic improvement of pigeonpea started with the selection of disease resistant genotypes from landraces in the early part of this century and later some cultivars were also developed from hybridization programmes. However, at present, most of the adapted cultivars are landraces or selections from these landraces. In experimental plots, these cultivars can give yield up to about 3 t ha^{-1}, although yields in the traditional farming systems remain around 700 kg ha^{-1} mainly due to a number of yield reducing abiotic and biotic constraints. There has been a tremendous success in incorporating resistances to major pigeonpea diseases (e.g. fusarium wilt, sterility mosaic) into potentially high yielding adapted cultivars, which could substantially help in reducing this yield gap. However, little progress in the genetic improvement of yield potential is apparent.

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Pigeonpea is a partially cross-pollinated crop and traditionally additive genetic variation has been exploited through pedigree selection for developing high yielding pure lines in different maturity groups. A review of the quantitative genetic studies in pigeonpea by Saxena and Sharma (1990) shows the presence of a substantial level of non-additive genetic variation for yield which can be exploited profitably through heterosis breeding for a possible quantum jump in grain yield.

For any viable commercial hybrid seed production programme there are two pre-requisites: an efficient mass pollen transfer mechanism and a stable male sterile source. In pigeonpea, natural out-crossing was noticed as early as 1919 but its utilization in commercial hybrid breeding programme was ruled out (Singh 1974; Royes 1976) mainly due to the non-availability of male sterility.

The recently identified sources of genetic male sterility and the presence of partial natural out-crossing have made it possible to explore this potential breeding avenue in pigeonpea. At ICRISAT Center, considerable research efforts have been devoted to identify heterotic cross combinations and to develop their economic hybrid seed production technology. With a view to strengthen research and development on hybrids Indian Council of Agricultural Research (ICAR) launched a special project in 1989 at nine centers in India. The work has been initiated on diversification of male steriles, synthesis and evaluation of hybrids, seed production technology research, and on-farm research. Emphasis is being given to the identification of heterotic combiners and population improvement for the improvement of parental lines. This paper, besides discussing the prospects for hybrid pigeonpea, summarizes the present status of research in identifying heterotic combinations, diversification of male sterile base, seed production technology, and transfer of the technology.

2. CROSS-POLLINATION

Pigeonpea is a predominantly self-pollinated crop with considerable level of cross-pollination. Researchers in India (2-70%), Kenya (12-50%), Trinidad (26%), Uganda (8-22%), and Australia (2-40%) have reported a considerable range of natural cross-pollination. Onim (1981) listed 24 insect species which are capable of transferring pollen from one flower to another within and across fields. In a recent review Saxena *et al.* (1990) concluded that in pigeonpea natural cross-pollination is a universal event and its extent varies from one environment to another, depending on activity and availability of pollinating insects.

Natural cross-pollination in pigeonpea is considered to be a major bottleneck in pure line breeding and varietal maintenance programmes since it not only leads

to a rapid genetic deterioration of pure lines but also influences the efficiency of pedigree selection under open-pollination. The discovery of male sterility, however, has changed the scenario and soon after its identification programmes were developed to use out-crossing in genetic improvement of the crop through hybrid breeding and recurrent selection.

3. MALE STERILITY

3.1. Types

With the sole objective of exploiting natural cross-pollination for economic gains, a deliberate search for male sterility was made in germplasm at ICRISAT Center in 1974. In ICP 1596, a line from Maharashtra (India), male sterility associated with translucent anthers was identified. This form of male sterility was controlled by a single recessive gene ms_1 (Reddy *et al.* 1978). Later, a different source of male sterility, characterized by brown arrow-head shape anthers, and controlled by a single recessive gene ms_2, was identified in Australia (Saxena *et al.* 1983). Both the male sterile types have prominent anther morphology which provides an effective and easy way of identifying male sterile plants in field before anthesis.

3.2 Marker linked with male sterility

The use of genetic male sterility poses practical limitations in the commercial seed production of hybrids since it requires manual roguing of fertile plants from the rows of the female parent. This problem could be eased to some extent if there were some marker genes closely linked with the male sterile gene, as reported in lettuce (Lindquist 1960) and water melon (Watts 1962).

Attempts made at ICRISAT and elsewhere have not been successful in identifying any such linked marker in pigeonpea. A chance observation made by Singh *et al.* (1993), however, indicated a possible linkage between male sterile gene ms_1 and temperature sensitivity. In the population of a male sterile line ms ICP 3783 the pod set was found to be influenced under low temperatures. They reported that when the minimum temperature dropped below 10°C and the mean day temperature below 18°C, the male sterile plants shed floral buds whereas the fertile segregants seem to have greater tolerance to low temperature.

The floral bud abscission at the temperatures below 10°C was exclusively on the male sterile plants, suggests that this trait may be linked to the male sterile gene ms_1. More experiments under varied field and controlled environmental conditions are required to confirm these preliminary observations and to identify critical day/night temperatures which can induce complete floral bud abscission in male sterile plants. These findings, if confirmed, may have significant impact on the hybrid seed production technology by enabling effective and economical roguing of fertile plants and thereby ensuring the production of high quality seed.

3.3 Diversification of male sterile base

Traditionally pigeonpea is grown in a number of cropping systems requiring cultivars differing in plant type and maturity. Resistance to wilt and sterility mosaic diseases are also essential to stabilize pigeonpea yields. In our efforts to find such desirable types we continue to look for new spontaneous male sterile mutants in germplasm and breeding materials. In addition, the ms_1 gene has been transferred through backcrossing into promising diverse genotypes. To hasten the process of conversion, the backcrosses are made onto the heterozygote BCF_1s on an individual plant basis which are identified by a selfed progeny-row test. We are maintaining at present 11 male sterile lines at ICRISAT Center (Table 1). These include two lines with high level of resistance to both wilt and sterility mosaic diseases.

Table 1 : Important characteristics of pigeonpea male sterile lines developed at ICRISAT Center through backcrossing

Line	ms gene	Growth habit	Plant spread	Days to flower	Plant height (cm)	Seeds/ pod	100-seed mass (g)	seed color	Disease reaction	
									Wilt	SM
IMS-1	ms_1	DT	C	56	75	3.5	7.4	B	S	S
IMS-1 (Imp)	ms_1	DT	C	58	90	6.0	10.0	B	S	S
QMS-9	ms_2	DT	C	61	89	3.9	7.3	B	S	S
ms Prabhat (DT)	ms_1	DT	C	68	111	3.7	7.5	B	S	S
QMS-2	ms_2	DT	C	69	105	3.6	10.4	B	S	S
QMS-7	ms_2	NDT	SS	70	117	3.3	7.7	B	S	S
ms ICPL 87091	ms_1	DT	C	72	115	6.5	13.4	Cr.	S	S
ms ICPL 288	ms_1	NDT	C	78	174	3.2	9.3	Cr.	R	R
ms Prabhat (NDT)	ms_1	NDT	SS	80	158	4.5	6.9	B	S	S
ms T 21	ms_1	NDT	SS	99	225	3.5	8.9	B	S	S
ms ICP 3783	ms_1	NDT	SS	118	180	4.0	9.2	Cr.	R	R

DT = Determinate; NDT = Indeterminate
C = Compact; SS = Semi-spreading
B = Brown; Cr = Cream
S = Susceptible; R = Resistant

Studies on the combining ability conducted on six male sterile lines showed that for yield QMS 7, ms ICPL 288, ms T 21 were good general combiners. Significant general combining ability effects were also recorded for earliness in QMS 2, QMS 9 and ms Prabhat (DT) and for plant height and seed size in ms ICPL 288 (Table 2).

Table 2 : General combining ability effects of six pigeonpea male sterile lines

	Days to		Plant height (cm)	100 seed weight (g)	Seeds per pod	Pods per plant	Yield per plant	Yield (kg/ha)
	50% fl.	75% mat.						
QMS 2	-3.06**	-2.85**	-16.97**	0.64**	0.02	-5.58	-1.17	-333.41*
QMS 7	9.51**	9.82**	17.94**	-0.20	-0.03	11.95*	2.91	565.06**
QMS 9	-8.87**	-6.13**	-21.97**	-0.98**	-0.05	-11.04	-4.71*	-834.17**
ms Prabhat (DT)	-4.92**	-5.85**	-18.63**	-0.94**	0.08	-0.62	-2.44	-268.94*
ms ICPL 288	1.17	-1.04	17.79**	1.26**	-0.04	-2.64	2.68	401.68*
ms T 21	6.17**	6.06**	21.84**	0.22	0.03	7.93	2.73	829.59**
SE (gi)	±0.530	±0.439	±2.456	±0.104	±0.065	±4.131	±1.314	±90.408
SE (gi-gj)	±0.750	±0.622	±3.473	±0.172	±0.092	±5.842	±1.859	±127.856

The need for diversifying male sterile base has also received a high priority by ICAR at nine research centers engaged in hybrid pigeonpea research in India. At present the male sterile gene is being transferred into 28 lines embracing significant diversity for plant type, maturity, adaptation and resistance to important diseases.

3.4. Progress in developing cytoplasmic male sterility

Concerted efforts are being made at ICRISAT Center to develop cytoplasmic male sterility (CMS) through mutagenesis and wide hybridization. Gamma radiation as well as mutagenic chemicals specific to cytoplasm organelles such as streptomycin sulphonate, mitomycin-C, sodium azide, ethidium bromide and ethyl methane sulphate were applied at varying dosages on male sterile lines ms Prabhat (DT), ms Prabhat (NDT), QMS 1, and QMS 9 and pigeonpea cultivars ICPL 87, Prabhat, ICPL 89029 and ICPL 88039. It has been possible to recover high levels of maternal inheritance within the derived lines (Table 3). In one of the M_5 progenies of 31 plants, 27 were sterile. A preliminary electrophoretic assay of esterase indicated that the sterile lines developed through mutation were different from ms_2 type male steriles. This information together with the segregation pattern suggests that the mutagenic treatment has had some effect on inducing maternal inheritance of sterility.

Table 3 : Per cent male sterile plants observed in some lines appeared promising for gene-cytoplasmic male sterility

Line/Treatment	Pedigree	Generations				
		M_2	M_3	M_4	M_5	M_6
Sodium-azide	1894-1-1-1	71.7	88.9	90.0	87.5	85.7
0.025%		(38:15)	(8:1)	(9:1)	(7:1)	(12:2)
48 hr.						
(QMS-1)	1894-4-1-1	71.7	69.2	85.7	100	
		(38:15)	(9:4)	(6:1)	(11:0)	
	1894-2-1-1	71.7	77.8	84.6	87.5	
		(38:15)	(7:2)	(11:2)	(7:1)	
	1894-3-1-1	71.7	58.3	71.1	87	
		(38:15)	(21:15)	(27:11)	(27:4)	
Streptomycin	1392-1-1-1	80.0	52.2	91.7	83.3	
sulphonate		(16:4)	(12:11)	(11:1)	(4:1)	
500 ppm						
24 hr.						
(QMS-1)						

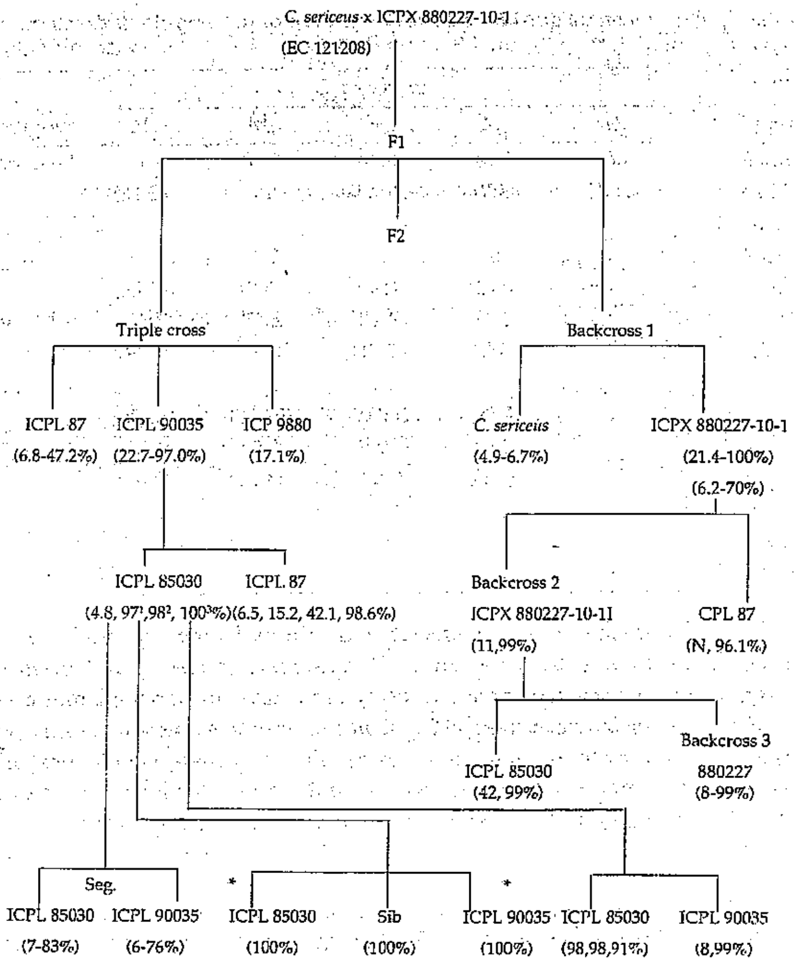
In order to induce CMS through wide hybridization the aim has been to place the pigeonpea genome in foreign (wild) cytoplasm. To achieve this, the wild species were used as a female parent in crossing programme. Some derivatives from the crosses involving C. *sericeus* look very promising. The results are summarized in Fig. 1. The level of male sterility has shown progressive increase with each backcross generation. The range of male sterility available is from 64 to 100%. In one case 75% of the progeny expressed almost complete sterility (R.P. Ariyanayagam, personal communication).

The work on isolation of CMS is also in progress at various ICAR centers and Bhabha Atomic Research Center (BARC), Trombay. At BARC, male sterile plants have been isolated from cross C. *sericeus* x TT5. The male sterility in the derived lines was restored by some segregants of the same cross. Some of the segregants appeared to maintain the male sterility (S.E. Pawar, personal communication).

4. HIGH YIELDING HYBRIDS

4.1 ICPH 8-the first pigeonpea hybrid

Among the short-duration hybrids developed at ICRISAT Center, ICPH 8, a cross between ms Prabhat (DT) and ICPL 161 was found to be the most promising. It



1. Its progeny displayed 97% male sterility, was temperature-sensitive, partially abnormal for leaf morphology, and reverted to partial sterility at low temperature.
2. Its progeny displayed 98% male sterility, was morphologically normal, and retained sterility throughout.
3. Its progeny displayed 100% male sterility had one or two branches with abnormal leaf morphology, and maintained sterility throughout.

N = Normal; * Gene-cytoplasmic male-sterile progeny.

Fig. 1. Interspecific hybridization between *C. sericeus* and *C. cajan*.

is an indeterminate which matures in about 140 days. This hybrid was released for cultivation in central zone of India in 1991. The performance of ICPH 8 in diverse Indian environments from 1981 to 1989 is summarized in Table 4. The hybrid ICPH 8 was evaluated in 100 trials and on an average it was 30.5% superior to UPAS 120 and 34.2% superior to Manak used as standard controls. In North West plains, Central and Southern zones where ICPH 8 was tested extensively it clearly established its superiority over the controls.

Table 4 : Zonal weighted mean yield of ICPH 8 in different zones in India over years

Zone	Years	No. of trials	Yield (t/ha)			% increase over	
			ICPH 8	UPAS 120	Manak	UPAS 120	Manak
North-west plains	6	36	2.85	2.10	2.34	35.0	31.0
Central	4	30	1.56	1.16	0.93	32.9	52.5
Southern	4	30	1.42	1.22	1.26	23.6	27.3
North-western hills	1	2	1.56	1.50	1.19	4.3	31.0
North-eastern hills	1	1	1.68	1.15	-	45.6	-
Western	1	1	2.06	1.41	1.59	45.6	29.5
Overall mean		100	1.99	1.53	1.35	30.5	34.2

4.2 New experimental hybrids

At ICRISAT Center, so far a total of 1737 experimental pigeonpea hybrids have been made and evaluated. These include 1224 short-,282 medium-, and 231 long-duration hybrids. The performance of some selected hybrids is summarized in Table 5. IPH 550, 526, 583, 732 and 495 yielded over 5 t ha^{-1} in the small experimental plots. Of these, IPH 732 has been identified by Tamil Nadu Agricultural University (TNAU), Coimbatore, India for release in the State.

Hybrids have also demonstrated high yield potential in All India Coordinated Pulses Improvement Programme's (AICPIP) Advanced Varietal Trials (AVT). During 1991-92, in 4 out of 9 varietal-cum-hybrid trials the hybrids ranked first and percentage superiority over best control ranged between 14.6% and 40.0%. Similarly, in 6 out of 12 trials during 1992-93, the hybrids ranked first and the superiority of the hybrids ranged between 10.7% and 82.3% (Table 6).

5. PHYSIOLOGICAL STUDIES IN PIGEONPEA HYBRIDS

5.1 Initial growth vigor

Pigeonpea is a slow growing crop in the early stages which make it a less efficient crop for monocropping. Limited screening of germplasm and lines have revealed that pigeonpea hybrids despite their low average seed size have higher seedling vigor. The differences in growth vigor which begin to appear during the early seedling stage become pronounced with time (Table 7). This attribute of hybrids makes them more suitable for sole cropping than varieties as it enables them to establish quickly and utilize light and water resources more efficiently.

Table 5 : Yield of some promising short-and medium-duration pigeonpea hybrids at ICRISAT Center

Year	Hybrid No.	Yield (t/ha)		% superiority over best control
		Hybrid	Control	
Short-duration				
1988	IPH 550	5.08	1.75	189
	IPH 575	4.81	2.13	125
	IPH 526	5.28	3.19	66
	IPH 583	5.33	2.79	91
	IPH 656	4.82	2.78	73
	IPH 732	5.51	2.38	131
	IPH 700	4.49	2.15	109
	IPH 719	4.93	2.15	130
	IPH 503	4.82	2.43	98
	IPH 495	5.00	2.43	105
1989	IPH 752	4.53	2.44	76
	IPH 786	4.64	2.99	55
	IPH 784	4.10	2.99	37
	IPH 1227	3.80	2.57	48
Medium-duration				
1988	IPH 487	4.35	2.61	67
	IPH 479	4.18	2.61	60
	IPH 482	4.01	2.61	54
	IPH 481	3.53	2.61	35
	IPH 480	3.78	2.61	45
	IPH 483	3.90	2.61	50
	IPH 490	3.76	2.61	44

5.2 Population responses

Seed rate is an important agronomic consideration for obtaining high and stable yields. For hybrids it assumes additional importance in view of the high cost of seeds. Pigeonpea hybrids such as ICPH 8 and ICPH 9 show very high plasticity and do not exhibit any decline in yield even when grown at half of the recom-

Table 6 : Hybrids obtaining first rank in the AICPIP advanced varietal trials

Year	Trial	Zone (No. of locations)	Hybrid	Yield (t/ha)	% superiority over best control
1991-92	EACT (AVT 1)	CZ (8)	MTH 23 ICPH 8 (control)	1.24 0.89	40.0
	ACT 2 (AVT 1)	CZ (2)	MTH 26 BDN 2 (control)	2.42 2.09	16.0
	ACT 2 (AVT 1)	SZ (2)	MTH 26 BDN 2	1.84 1.61	14.6
	Pre-Rabi (AVT 1)	CZ (3)	MTH 12 Bahar (control)	1.56 1.23	27.2
1992-93	EACT (AVT 2)	CZ (4)	MTH 23[1] UPAS 120 (control)	1.51 1.20	25.5
	EACT (AVT 1)	NWPZ (8)	PPH 4 H 82-1	2.02 1.82	10.7
	EACT (AVT 1)	CZ (4)	MYPH 28[1] UPAS 120 (control)	1.40 1.13	23.7
	EACT (AVT 1)	SZ (1)	MYPH 1115[1] UPAS 120 (control)	1.48 0.81	82.3
	ACT 1 (AVT 1)	SZ (2)	MTH 15[1] T 21 (control)	2.09 1.25	67.6
	Pre-Rabi (AVT 2)	CZ (1)	MTH 12[1] C 11 (control)	1.52 1.02	49.6

1. Selected for final yield trial (AVT 2) during 1993-94.

mended population of 33 plants m^{-2} for short-duration pigeonpea (Saxena *et al.* 1992). This suggests that optimum seed rates of hybrids are much less than those of varieties.

5.3 Physiological basis of heterosis

In cereals and some of the legumes such as groundnut much of the variation in yield among genotypes and environments is accounted for by differences in partitioning. By contrast, in pigeonpea variation in yield is chiefly accounted for by the differences in crop growth rates. The hybrids are higher yielding mainly due to their higher crop growth rates than the varieties. It is interesting to note that higher crop growth rates can also be achieved by increasing plant population, but this does not necessarily result in increased yield because of its negative effect on partitioning. However, hybrids have higher crop growth rates while maintaining their partitioning at least at the same level as that of varieties (Chauhan *et al.* 1994). An improvement in the density of pods and seeds per pod has been recorded in hybrids (Saxena *et al.* 1992).

Table 7 : Shoot and root weight (g/plant) of short-duration pigeonpea genotypes and hybrids in pots of Alfisol at different days after sowing (DAS)

Genotype	19 DAS		30 DAS		46 DAS		50 DAS	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
ICPL 87	0.355	0.089	1.110	0.285	2.933	0.747	6.212	1.693
ICPL 151	0.160	0.060	1.333	0.305	3.365	0.951	5.913	1.562
ICPH 8	0.260	0.106	1.597	0.407	4.023	1.144	7.690	2.055
UPAS 120	0.170	0.082	1.195	0.315	3.097	0.921	5.985	1.553
T 21	0.173	0.066	1.083	0.260	3.273	0.853	5.483	1.516
SE	± 0.0566	± 0.0143	± 0.1857	± 0.0723	± 0.6320	± 0.3330	± 0.7140	± ~~1600~~ 0.160

5.4 Biomass production

Higher crop growth rates of pigeonpea hybrids eventually result in higher biomass production. Total biomass production in excess of 20 t ha^{-1} has been recorded in hybrids in sub-tropical environments (Chauhan *et al.* 1994). A significant proportion (18-20%) of this biomass is returned to the soil in the form of fallen leaves thus contributing to the pool of organic matter. In addition the harvested stems also provide useful fuel wood.

5.5 Drought resistance

Pigeonpea is generally grown under rainfed conditions and is subjected to both intermittent and terminal drought stresses. Enhancing drought resistance is therefore an important requirement to stabilize its production under rainfed conditions. Hybrids of the crop such as maize and sorghum have been found to perform well under dry conditions. In a comparison of pigeonpea hybrids with parents and other cultivars for drought resistance, two of the pigeonpea hybrids ICPH 8 and ICPH 9 exhibited higher yield levels than parents and controls irrespective of soil moisture regimes (Fig. 2). This suggests that pigeonpea hybrids have potential to perform well in both dry as well as optimum soil moisture environments. Better performance of hybrids in dry environments may be related to their superior ability to maintain relative water content (Lopez *et al.* 1994). This in turn may be related to their vigorous root system (Table 7).

The better performance of hybrid ICPH 8 (Fig. 2) at a range of soil moisture levels is consistent with its superior performance in multilocation trials where moisture availability invariably differs. Thus hybrids could be suitable for irrigated areas as well as the areas where rainfall is unpredictable and soil moisture is frequently limiting.

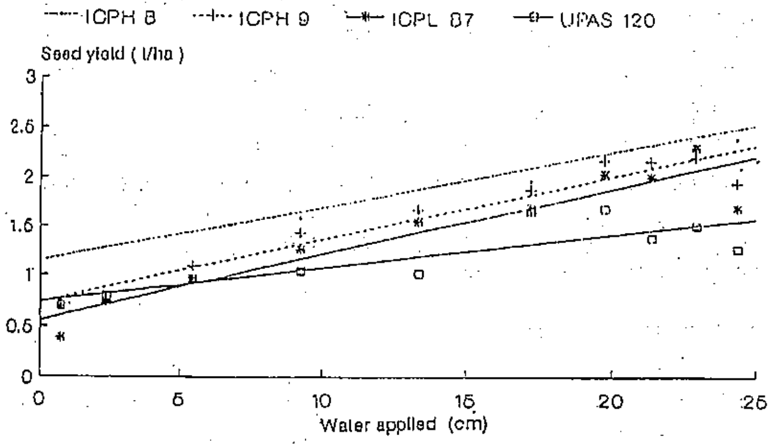


Fig. 2. Response of ICPL 87, ICPL 81, ICPH 8 and UPAS 120 to applied irrigation through line
Source : ICRISAT Center, 1986/87.

6. HYBRID SEED PRODUCTION SYSTEM

6.1 Recommended method

For producing large quantities of hybrid seed of selected cross combinations, the male sterile and pollen parents must be grown in isolation. On account of the wide range of out-crossing reported among pigeonpea genotypes the isolation specifications are also equally variable (Saxena *et al.* 1990). An isolation distance from a minimum of 180 m to a maximum of 360 m is, however, recommended (FAO Agric. Series No. 55).

Experiments conducted at ICRISAT Center indicated that full seed set is obtained if one fertile row is planted after each six male sterile rows (Saxena *et al.* 1986). Since male sterility in pigeonpea is genetic in nature, manual labour for roguing of fertile segregants within the male sterile rows is essential. For this the first bud that appears on each plant must be opened and the male sterile plants tagged, while the fertile segregants must be rogued out before anthesis. In the absence of sufficient pod load in the beginning of the reproductive phase, the sterile plants continue to flower for a considerable period. In the pollinator rows, flowering terminates once full potential pod-load is achieved. This, in certain situations, may result in poor pod-set on male sterile plants. The flowering period of pollinators, however, can be extended by periodic removal of young developing pods and frequent irrigations. In certain environments the recommended 1 male : 6 female ratio may not optimize the hybrid seed yield due to variation in the population of pollinating vectors and therefore local recommendations with appropriate modifications need to be developed.

6.2 Estimated cost of hybrid pigeonpea seed

Information on the production cost of hybrid seed is essential for their acceptance by seed producers and farmers. Hence, on this aspect, a joint study was undertaken to determine the cost of producing hybrid pigeonpea seed by Tamil Nadu Agricultural University (TNAU) and ICRISAT during the 1988 rainy season.

The parents of the released hybrid ICPH 8 were sown according to the recommended procedure in an isolated block measuring 0.16 ha. In this experiment 813 kg ha^{-1} hybrid seed was obtained in a single harvest and the estimated cost of producing one kilogram seed was Rs. 6.25 only.

The major proportion (45.12%) of the production cost, as expected, was attributed to roguing. The estimates showed that for roguing a seed production block of 1 ha, 200 labour days equivalent to the employment of 15 workers for a fortnight would be required (Murugarajendran *et al.* 1990).

Studies conducted on the production costs of male sterile and hybrid seeds at Punjab Agricultural University (PAU), Ludhiana showed a large variation. In male sterile line ms Prabhat (DT), 275 kg ha^{-1} seed was harvested in 1990 with production cost of Rs. 39.41 kg^{-1}. In 1992, however, they harvested 1040 kg ha^{-1} yield which resulted in a significant reduction in the cost of Rs. 3.7 kg^{-1} (Table 8). For hybrid PPH 4, the estimated production cost was Rs. 13.8 kg^{-1} (Srivastava and Asthana 1993).

The effectiveness of management of a seed production crop, especially with respect to insects and diseases, plays an important role in yield maximization and consequently in determining its cost of production.

These studies clearly suggest that under good management the cost of producing pigeonpea hybrid seed is not as high as feared in the initial stages because of the utilization of genetic male sterility and it should be acceptable to both seed grower-farmers as well as seed companies.

Table 8 : Cost (Rs.) of producing hybrid (PPH 4) and male sterile (ms Prabhat (DT)) seeds at Punjab Agricultural University, Ludhiana

Item	ms Prabhat (DT)			PPH 4
	1990	1991	1992	1992
Gross expenditure	13194	13194	13194	13194
Seed yield (kg/ha)	275	630	1040	800
Fertile plants yield (kg/ha)	315	720	1275	257
Value of commercial grains	2205	5040	8924	1799
Value of by product	375	375	375	375
Value of total seed	10614	7779	3894	11020
Cost of one kg seed	39.4	12.3	3.7	13.8

Notes :

1. Estimated cost does not include fixed costs such as land rent, land revenue, depreciation, and interest on fixed cost
2. Net seed yield after 15% losses in cleaning and grading
3. Source: Srivastava and Asthana (1993)

6.3 Use of multiple harvests in reducing production cost

The cost can be reduced further by adopting a multiple harvest system, more appropriate agronomy (mainly spacing), effective management of pod borers, and limiting the roguing operation for 15 days form flowering. In tropical environments with warm winter, pigeonpea plants can produce several flushes of pods within a year (Chauhan *et al.* 1987). The perennial nature of this crop can also be exploited profitably to produce quality hybrid seed at low cost. At ICRISAT, in an experiment designed to assess the feasibility of multiple harvests of cross-pollinated seeds in the 1985/86 season, four harvests were taken within a year. In a 0.11 ha seed production block of ICPH 8, a total of 73 kg of hybrid seed was obtained from four harvests (Table 9). Multiple harvests therefore can help in reducing the cost of hybrid seed production substantially because there is no further need for roguing in the subsequent crops. The same seed production nursery can also be retained for use in the subsequent year(s). However, the plants under this system should be ratooned at a manageable height as they might grow tall making insect control and harvesting difficult. This system, however, can be applied only in frost and disease free conditions or with disease resistant parental lines.

Table 9 : Multiple harvests of cross-pollinated seed of hybrid ICPH 8 in a seed production block at ICRISAT Center during 1985-86 season

Harvest number	Date of harvest	Seed yield (kg)
1	October 10, 1985	28.0
2	November 25, 1985	24.5
3	January 22, 1986	7.3*
4	March 10, 1986	13.3
	Total	73.1

* High pod fly damage

Area : 0.11 ha
Planting date : June 25, 1985
Spacing : 75 x 25 cm
Ratio : 1 Male : 6 Female

7. GENERAL DISCUSSION AND CONCLUSIONS

Pigeonpea is a unique pulse crop because its reproductive biology permits the options of utilizing both additive as well as non-additive genetic variance in breeding programmes. However, being predominantly a self-pollinated crop, breeding methods tailored to exploit additive genetic variance have been used in the past for developing high yielding pure line cultivars. The substantial amount of non-additive genetic variance and hybrid vigor, available in this crop, could not be profitably tapped for upgrading its yield levels mainly because of non-availability of stable male sterility system.

A successful search for easily identifiable stable male sterility at ICRISAT in 1974 paved the way for the commercial exploitation of hybrid vigor in pigeonpea and the first hybrid ICPH 8 was released for cultivation in 1990. Physiological studies have shown that pigeonpea hybrids are superior to pure line cultivars with respect to seedling vigor, crop growth rate, biomass production, drought resistance, and yield. In addition, they also require less seed rate.

A hybrid programme based on genetic male sterility suffers from an inherent bottleneck in its large scale seed production because of the manual requirement in roguing which accounts for about 50% of the production cost. Limited studies on the seed production technology using genetic male sterility, however, suggest that the production cost of pigeonpea hybrids is within a reasonable limit and it is still a viable proposition economically. Adoption of improved agronomic practices ensures high hybrid seed yields.

It appears that adoption of the technology in the past two years has not met with the expected success. Informal discussions with various public and private seed companies revealed that there is a tremendous demand for hybrid seeds and farmers have willingly purchased the hybrid pigeonpea seeds even at prices as high as Rs. 100 kg^{-1}. From a seed production point of view it was observed that seed grower-farmers faced no difficulty in rouging and the family members including children could easily distinguish between fertile and sterile plants. The reluctance of some farmer-growers in removing the fertile segregants and delay in payments due to lack of a quick grow-out test appeared to be the main reasons for the discouragement. In general the following bottlenecks were observed in the technology transfer:

(i) Limited seed availability of male sterile parent

(ii) Poor insect management in the seed production plots resulting in low yields

(iii) Reluctance of some grower-farmers to remove fertile segregants

(iv) Inadequate knowledge of multiple and perennial seed production system

(v) Competition from other high remunerative crops

Availability of cytoplasmic male sterility holds the key for full commercial exploitation of hybrid vigor in this crop. Preliminary work done in this direction using chemical mutagens and wild relatives of pigeonpea has shown a considerable promise and once it is established the seed production will become very easy. Indication of linkage between male sterility gene ms_1 and low temperature sensitivity also holds some promise and this could be used in producing quality hybrid seed in certain specific environments.

Pigeonpea hybrid research and development programme is still in its initial stages and the results of recent research activities are very encouraging. However, to exploit the present technology on a large scale concerted efforts are required to modify the seed production technology to suit local conditions. Even greater efforts are needed to demonstrate the technology to seed producers and farmer-growers.

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