PROSPECTS FOR HYBRID PIGEONPEAS

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ABSTRACT

Pigeonpea *(Cajanus cajau* (L.) Millsp*)* is a predominantly self-pollinated crop and traditionally additive genetic variation has been exploited in breeding high yielding pure lines in different maturity groups. A number of genetic studies, however, have shown the presence of significant non-fixable genetic variation in this crop. The identification of genetic male sterility in pigeonpea at ICRISAT has made it possible to exploit non-additive genetic variation through the economical production of hybrid pigeonpeas. This paper describes identification and development of male sterile sources, examines the nature and magnitude of heterosis in experimental hybrids, outlines the system for producing hybrid seed and discusses the prospects of utilizing commerical pigeonpea hybrids.

Pigeonpea *(Cajanus cajan* (L.) Millsp.*)* is grown under a wide range of cropping systems tropical and sub-tropical countries. It is an important source of protein for people in India, arts of Africa and the Caribbean. India produces about 2.4 million t of pigeonpea annually from 3.2 million ha of land, which constitutes about 90% of the world's production. Attempts to improve pigeonpea started early in this century. Although many selections from crosses have been made, even today most of the cultivars grown are landraces or selections from these landraces. There is a wide range of genetic variability for virtually all important agronomic characters (Sharma and Green 1977) that can be effectively exploited by planned plant breeding efforts for developing high-yielding, improved cultivars for different agro-climatic conditions and cropping systems.

Heterosis has been extensively used to realize substantial gains in yield levels in many crops (Rai 1979). Among legumes, Pal (1945) published the first report on heterosis in chickpea. Subsequently, heterosis for yield has been reported in many legumes. Singh (1974), reviewing this literature, concluded that, although appreciable heterosis was present in pulse crops, the development of commercial hybrids could be ruled out as the important prerequisites, sufficient natural outcrossing and suitable male sterile lines, were absent in these crops.

Reddy *et al.* (1978) reported a genetic male sterile in pigeonpea identifiable by its translucent anthers. This character allowed an easy and early detection of male sterile plants. This, coupled with the high level of natural outcrossing by insects in pigeonpea, provided the features needed to economically produce hybrid seed.

The present paper describes for pigeonpea the extent of heterosis that has been found in hybrids made at ICRISAT, problems encountered with these hybrids, the development of different male sterile lines, a system for producing hybrid seed, and discusses the prospects of commercial hybrids.

BREEDING HYBRID PIGEONPEA AT ICRISAT – EXPLORATORY WORK

1. The search for male sterility

When the ICRISAT pigeonpea breeding program started in 1973, the only report of male sterility in pigeonpea was by Deshmukh (1959). Unfortunately, this male sterile was associated with female sterility. Therefore a deliberate search was made for male sterile plants in more than 7,000 accessions grown at ICRISAT Center in 1974. The 72 plants identified as sterile were classified into five aberrant floral types (Reddy *et al.* 1977). Of these only one type, characterized by

Table 1. Range of standard heterosis obtained in medium-maturing experimental hybrids using MS3A and MS4A male steriles at ICRISAT Center 1977-1981.

Year	Female parents	No. of pollen parents	Range of heterosis (%)	Hybrids with heterosis >10%	>20%
1977	MS-3A	9	-20.9 to 31.6	2	1
	MS-4A		-21.9 to 23.6	3	1
1978	MS-3A	11	-17.4 to 21.4	4	1
	MS-4A		-13.6 to 27.1	5	3
1979	MS-3A	11	-26.0 to 39.0	2	1
	MS-4A		-13.3 to 29.1	2	1
1980	MS-3A	10	-24.2 to 15.7	1	0
	MS-4A		-23.0 to 6.9	0	0
)81	MS-3A	12	-38.3 to 9.5	0	0
	MS-4A		-11.1 to 6.5	0	0
Total		53	-38.3 to 39.0	19	9

translucent anthers, and the absence of pollen grains, was selected for study. The male sterile lines were, MS3A, found in ICP 1555, and MS4A, in ICP 1596. Both came from field collections in India. This form of male sterility, caused by non-separation of tetrads associated with a persistent tapetum, is controlled by the single recessive gene, msl (Reddy *et al.* 1978). The marker, white translucent anther, provided an efficient and fast way of recognizing male sterile plants in the field before their flowers open. This male sterility has been stable over years and environments. This means that it could be successfully used in developing pigeonpea hybrids.

2. The feasibility of commercial hybrids

(a) Experimental hybrids: To study the feasibility of breeding useful pigeonpea hybrids, a total of 53 elite, medium maturity lines were each crossed with MS3A and MS4A between 1977 and 1981. In each year the hand-pollinated hybrids were tested in sets consisting of the pollen parent flanked by its two related hybrids. Four-meter long 4-row plots were grown in 2 to 4 replications pending on seed availability.

The range of standard heterosis (heterosis over the control cultivar) for seed yield in different crosses was from -38.3 to 39.0% (Table 1). Of the 106 hybrids, 19 showed heterosis of more than 10% and 9 over 20%. In 1977, the highest yielding parent, C 11, produced the best hybrid with MS3A giving a 32% increase over the control cultivar. In 1978 four hybrids outyielded the control by more than 20%. Three out of 22 hybrids tested in 1979 gave more than 20% standard heterosis. In 1980 and 1981 the hybrids were heavily attacked by fusarium wilt and none of the 44 hybrids tested performed well. This alerted us to the high level of wilt susceptibility in these hybrids.

(b) Multilocation tests: Our station trials over years indicated that ICPH 2, a cross involving MS4A × BDN 1, was the most promising medium maturity hybrid we had. This hybrid was therefore tested in the All India Coordinated Trials (Table 2). In 1980, over 7 locations, ICPH 2 outyielded the standard control by 23%. In 1981 and 1982 respectively this advantage declined to 11.1 and 6.4% over the control. This reduction in the performance of ICPH 2 was attributed to its high susceptibility to wilt and sterility mosaic diseases. In 1982, more than 60% wilt incidence was observed at some locations. In spite of the good performance of ICPH 2, this hybird was withdrawn from further testing because of its high susceptibility to diseases. However, its performance had given a good demonstration of the exploitable heterosis available in this crop. It also indicated that resistance to major diseases, such as wilt and sterility mosaic, is essential for such hybrids to succeed.

3. Producing hybrid seed

(a) Natural outcrossing: Although the floral biology of pigeonpea favors self-pollination considerable natural outcrossing occurs (Pathak 1970, Onim 1981). The average outcrossing is around 20%

Table 2. Comparison of the yield of medium-maturing hybrid ICPH 2 with standard control C 11 over 3 years of multilocational coordinated tests in India.

Year	Locations	Mean yield kg/ha		Mean standard heterosis (%)
		C 11	ICPH 2	
1980	7	649	801	23.4
1981	8	1484	1649	11.1
1982	16	1405	1495	6.4
Mean		1179	1315	11.5

it sometimes exceeds 40%. Several species of bees, in particular *Megachile* spp., and *Apis* *llifera*, are the main pollinators (Onim 1981). A large number of factors determine the degree of outcrossing in pigeonpea. These include the number of insect pollinators present in relation to the number of flowers, the flowering habit of the varieties, the location of the field in relation to the insect habitat or barrier crops, and environmental factors such as temperature, humidity, and wind velocity and direction (Bhatia *et al.* 1983).

In a comparison of five male sterile and five fertile sibs in each of MS3A and MS4A the yield/plant and pods/plant were similar on fertile and sterile segregants (Table 3). However, the flower drop in the sterile plants was significantly higher. This was probably because the male sterile plants had to produce more flowers before enough pods were set by insect pollination to stop further flowering. This experiment suggested that under field conditions sufficient cross-fertilization occurs on the male steriles to economically produce hybrid seed. This conclusion has been subsequently confirmed in practice.

Table 3. Percentage flower drop, pods/plant, and yield/plant in fertile and sterile sibs of MS 3A and MS 4A at ICRISAT Center, 1976.

Character	MS 3A		MS 4A		Mean	
	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile
lower drop (%)	42	51**	49	60**	45	55**
ods/plant	320	320	247	262	283	291
Yield/plant (g)	69	66	43	57	55	61

** Significant at 1%.

(b) Maintenance of male sterile stocks: Since this genetic male sterility in pigeonpea is conditioned by a single recessive gene, msl, it can be maintained as a heterozygote by harvesting seed from male sterile (ms_1 ms_1) plants pollinated by fertile heterozygotes (Ms_1 ms_1). The resulting progeny segregate into a ratio of 1 fertile:1 male sterile.

To produce seed of male sterile lines the seed harvested from male sterile plants is grown in isolation. At flowering the 50% of the plants that are male sterile are tagged and seed is harvested only from these tagged plants. If necessary the immature pods from fertile plants can be removed to extend the period of pollen availability.

(c) Hybrid seed production: Identification of heterotic crosses requires testing many combinations. The seed for these experimental hybrids in pigeonpea is best produced by hand-pollinating male sterile plants. One trained person can make about 400 pollinations in a day. From these pollinations there is normally around 30-40% pod set. Thus the equivalent of one day's crossing gives sufficient ed to include that hybrid in a small replicated test.

To produce hybrid seed in quantity, seed from the male sterile plants in the maintenance block is planted along with the required pollen parent in isolation. Tests at ICRISAT indicate that full seed set is obtained if one fertile row is planted after each six male sterile rows. Unlike cytoplasmic male sterility, genetic male steriles do not eliminate all manual labor for within the male sterile rows the first bud that appears on each plant must be opened and the male sterile plants tagged while fertile sibs must be rogued out before their flowers open and their pollen is transfered to the sterile plants. Periodic picking of the immature pods from the pollinator rows will prolong their flowering. The hybrid seed set on the male sterile plants is harvested. It is possible to produce several hybrids in one isolation block using a common male parent and several male steriles if their flowering can be synchronized.

For hybrid seed production, and male sterile maintenance identification of fertile sibs at an early stage is costly but essential. This problem could be eased if there was some marker gene closely linked with the msl, as in watermelon (Watts 1962), and lettuce (Lindgvist 1960). At present no such marker is known in pigeonpea.

(d) Isolation requirement: Bhatia *et al.* (1983) showed that at a distance of 100 m outcrossing in pigeonpea was reduced from about 20% to about 3.0%. Although no information on isolation distance is available using male steriles, our experience indicates that a distance of 150 to 200m is sufficient for hybrid seed production and maintenance of male steriles.

(e) Cost of hybrid seed production: Relatively low cost, hybrid seed is necessary for acceptance of hybrids by farmers. Estimates from trials at ICRISAT Center and at Maharashtra Hybrid Seed Company (MAHYCO) at Jalna indicate that 1 kg of hybrid pigeonpea seed can be produced for less than two rupees when land costs are not included. This means that the cost of hybrid seed should not pose a problem for the acceptance of pigeonpea hybrids by Indian farmers.

The cost of seed production should be reduced if the number of pollinator rows could be reduced. A trial at ICRISAT, with a varying number of male sterile rows per pollinator row to test this, showed that there was no yield reduction per male sterile row when there were as many as 15 male sterile rows per pollinator row. Costs can also be reduced by certain management practices. For example, ratooning the crop can produce more than one harvest from the same plants, removing the need to rogue fertiles from the male sterile rows in the subsequent crops.

DIVERSIFICATION OF PIGEONPEA HYBRIDS

1. Broadening the genetic base of male steriles

Pigeonpea is grown under many cropping systems, requiring diverse genotypes differing in plant type and maturity. These differences are so great that it is impossible to have a specific breeding program for each cropping system. However, specific maturity, plant type, and the resistance to wilt and sterility mosaic diseases are essential features in any pigeonpea breeding program including one for breeding hybrids.

In an effort to find such desirable plant types we continue to search for new spontaneous male sterile mutants in germplasm and breeding material. In addition, the ms_1 male sterile gene is being transferred through backcrossing into promising genotypes of different maturities, and plant types. Seven promising lines have already been bred in this way at ICRISAT Center. To hasten the process of conversion to sterility in these lines, backcrosses have been made onto BC_1 F_1s on an individual plant basis. In the succeeding generations backcrosses were made onto the heterozygote fertile plants, which were identified by a selfed progeny test. To avoid any potentially deleterious effects of having a single source of cytoplasm the recurrent parent was used as the female parent in the final backcross. The msl gene has also been transferred to a photo-insensitive line (Saxena *et al.* 1981). In addition a new male sterile gene ms_2 has been recovered in 10 diverse genotypes (Wallis *et al.* 1981, Saxena *et al.* 1983).

As resistance to the two important diseases of pigeonpea, wilt and sterility mosaic, is controlled by recessive genes both parents must be resistant in order to produce resistant hybrids. We therefore have been developing wilt and sterility mosaic resistant male sterile lines through backcrosses using resistant lines as the recurrent parent and screening the progenies in the appropriate disease nursery. We now have male sterile lines resistant to both diseases (Table 4).

2. Hybrids from new male sterile stocks

Early-maturity hybrids: Early-maturity pigeonpeas are becoming more important because of their ability to fit into a wide variety of cropping systems and because they are adapted to high latitudes. ICPH 8 is the most promising early maturity hybrid of the several we have tested over the last four years. In 1981, 1983 and 1984 this hybrid averaged 48% more yield than the control cultivar UPAS 120 (Fig. 1).

Table 4. Characteristics of some promising male sterile lines maintained at ICRISAT Center.

Line	Days to fl.	Height (cm)	Habit	Plant spread	Seeds/ pod	g/100 seeds	Seed color	Remarks
IMS-1	60	85	DT	C	3.5	7.0	B	Photo-insensitive
QMS 7	56	125	DT	C	6.0	11.0	W	
QMS 9	52	90	DT	C	4.0	10.0	W	
MS Prabhat	69	87	DT	C	3.6	6.6	B	Good com bining
MS T 21	83	152	NDT	SS	3.9	7.5	B	Good com bining
MS BDN 1	101	143	NDT	SS	3.5	9.0	B	Wilt resistant
MS C 11	124	207	NDT	SS	3.6	10.0	B	Wilt resistant
MS 3A	110	230	NDT	SS	3.5	9.5	B	
MS 4A	110	230	NDT	SS	3.5	9.5	B	
MS 7035	136	176	NDT	SS	4.8	19.1	P	Wilt and SMD resistant
MS 3783	132	235	NDT	SS	4.8	18.1	W	Wilt and SMD resistant
MS NP (WR) 15	147	230	NDT	C	3.5	8.7	W	Wilt resistant

DT = Determinate, NDT = Indeterminate, C = Compact, SS = Semi- spreading,
B = Brown, W = White, P = Purple.

To study its adaptation ICPH 8 was evaluated in 1984 with four control cultivars at 22 locations in different agro-climatic zones. In the 15 trials with less than a 23% coefficient of variation the yield of ICPH 8 ranged from 480 to 4310 kg/ha and its superiority over the best control cultivar UPAS 120 ranged from -5 to 124%, averaging 26%. Of the 15 test sites the hybrid ranked first at 8 and second at 4. At 6 locations the hybrid significantly outyielded the control cultivar UPAS 120. Eberhart and Russell's (1966) stability analysis showed that both the hybrid and the control cultivar had similarly high stability parameters (Fig. 2). Next year we plan to do large scale testing to confirm the performance of ICPH 8.

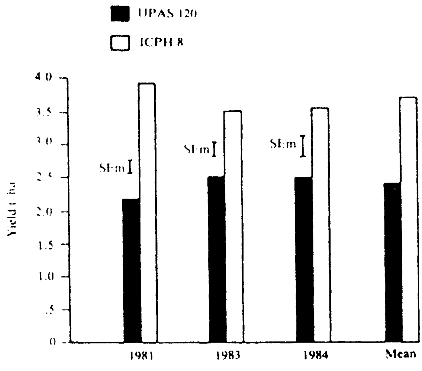

Fig. 1. Performance of pigeonpea hybrid ICPH 8 and control cultivar UPAS 120 at Hisar in 3 years.

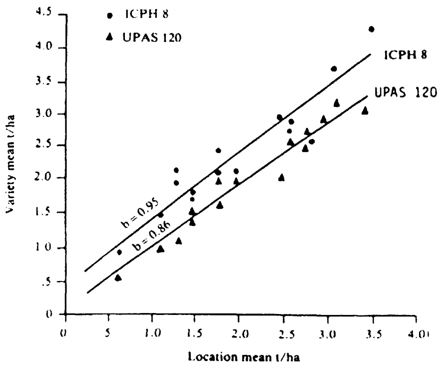

Fig. 2. Performance of pigeonpea hybrid ICPH 8 and control cultivar UPAS 120 at 15 different Indian locations in 1984.

(b) Wilt resistant hybrids: In 1983 for the first time hybrids made from wilt resistant male sterile lines and wilt resistant pollen parents were evaluated at ICRISAT. The heterosis over the control cultivar in the nine hybrids ranged from -29 to 49%. Of these hybrids, four exhibited positive heterosis, the most promising being MS C 11 × DT 230. Several new wilt and sterility mosaic resistant hybrids are presently under test.

PROSPECTS FOR HYBRID PIGEONPEAS

Unlike other pulses the presence of natural outcrossing in pigeonpea coupled with the discovery of a stable genetic male sterile makes large scale hybrid seed production fairly easy and cheap. This has opened the possibility of commercially exploiting the heterosis which has been shown to exist in pigeonpea. Extensive testing of the early ICPH 8 (Fig. 1 and 2) and the medium maturity hybrid ICPH 2 (Table 2) at ICRISAT and in the Indian National Trials has clearly shown that substantial gains in seed yield are possible in pigeonpea hybrids over a range of conditions.

To stabilize the performance of hybrids across environments and production systems improved male steriles, with high combining ability, different maturities, large seed, and resistance to major diseases, are being developed at ICRISAT. Several are already available (Table 4). The real test will come when the results from yield tests of hybrids bases on these new male sterile lines become available. The first such line, ICPH 8, already looks very promising. We expect that some of the new combinations will show even better performance.

At ICRISAT we have identified a cytoplasmic male sterile but the system is not yet stable and is associated with many deleterious factors. Although we are working with this material we do not expect it to be available for producing hybrid pigeonpea seed in the foresseable future. However, if cytoplasmic male sterile lines that produce high yielding hybrids can be developed, pigeonpea hybrids may become even more attractive than at present.

The heterotic advantage shown by pigeonpea hybrids over commercial varieties has attracted the attention of two private seed companies in India. At present they are testing a large number of hybrid combinations based on diverse genetic male steriles developed at ICRISAT. Several of these hybrids are in multilocational trials in India. Although no hybrid pigeonpea seed is available commercially at present it seems only a matter of time before it will be.

REFERENCES

Bhatia, G.K., D. Sharma and D.G. Faris. (1983). Maintenance of genetic purity in pigeonpea seed. *Intl. Pigeonpea Newsletter* 2:27-28.

Deshmukh, N.Y. (1959). Sterile mutants in tur *(Cajanus cajan)*. *Nagpur Agric. Coll. Mag.* 33:20-21.

Eberhart, S.A. and W.A. Russell (1966). Stability parameters for comparing varieties. *Crop Sci.* 6:36-41.

Lindqvist, K. (1960). Inheritance studies in lettuce. *Hereditas.* 46:387-470.

Onim, J.F.M. (1981). Pigeonea improvement research in Kenya. Proc. Intl. Workshop on Pigeonpea, 15-19 Dec. 1980, ICRISAT Patancheru, A.P. India, Vol 1: 427-436.

Pal, B.P.·(1945). Studies in hybrid vigor, notes in the manifestation of hybrid vigor in gram. *Ind. J. Genet.* 5:106-121.

Pathak, G.N. (1970). Red gram. *In* Kachrou, P., ed., Pulse Crops of India. Indian Council of Agriculture Research, New Delhi.

Rai, B. (1979). Heterosis Breeding. Agro-biological Publications, Delhi.

Reddy, B.V.S., L.J. Reddy and A.N. Murthi (1977). Reproductive variants in *Cajanus cajan* (L.) Millsp. *Trop. Grain Legume Bull.* 7:11

Reddy, B.V.S., J.M. Green and S.S. Bisen (1978). Genetic male sterility in pigeonpea. *Crop. Sci.* 18:362-364.

.xena, K.B., E.S. Wallis and D.E. Byth. (1981). Development of photo-insensitive male sterile line of pigeonpea *(Cajanus cajan* (L.) Millsp.). *Trop. Grain Legume Bull.* 20:22-23.

Saxena, K.B., E.S. Wallis and D.E. Byth (1983). A new gene for male sterility in pigeonpeas. *Heredity,* 51(1):419-421.

Sharma, D. and J.M. Green. (1977). Problems and prospects of upgrading yield levels in pigeonpea. *Proc. Third Intl. Cong. SABRAO. 2:6-10*

Singh, K.B. (1974). Exploitation of heterosis in pulse crops. Ind. J. Genet. 34(A): 752-756.

Watts, V.M. (1962). A marked male sterile mutant in watermelon. *Proc. Amer. Soc. Hort. Sci.* 81:498-505.

Wallis, E.S., K.B. Saxena and D.E. Byth (1981). A new source of genetic male sterility in pigeonpea. Proc. Intl. Workshop on Pigeonpeas, 15-19 Dec. 1980, ICRISAT Patancheru, A.P. India, Vol 2: 105-108.

1986. New frontiers in breeding
researches: proceedings of the Fifth Int'l Congress
Society for Advancement of Breeding Researches in
Asia and Oceania (SABRAO), 25-29 Nov 1985, Bang
Thailand. Bangkok, Thailand: Kasetsart University
Faculty of Agriculture