(75)

Evolution of Hybrid Breeding Technology in Pigeonpea

K B Saxena
Principal Scientist

ICRISAT
Science with a human face

International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India
2009

Published in IIPR Milestones in Food Legumes Research Conference at 2009

Milestones in Food Legumes Research
Eds.: Masood Ali and Shiv Kumar © 2009, IIPR, pp 82-114

6

Evolution of Hybrid Breeding Technology in Pigeonpea

K.B. SAXENA

INTRODUCTION

Bulk of the food proteins in India is derived from pulse crops that are generally grown under low input and risk - prone marginal environments with repeatedly low and unstable yields. At present, the protein availability in India is already less than one - third of its normal requirements and with the projected (1.5 - 2.0%) population growth and stagnation of yield, it is likely to decline further. A continuous increase in population generally leads to fragmentation of already small farm landholdings that cannot sustain even small size families. This encourages migration of rural masses and results in further shrinkage of cultivable rainfed lands where these pulses are grown. Therefore, providing appropriate quantities of quality food at national level with limited resources is difficult and, therefore, serious attention is required to address this issue at different levels of research, production, and marketing. Since the food production balance in the country will always remain in favour of cereals, the issue of protein availability assumes a greater significance. The options like increasing pulse growing area, intensive cropping, and enhanced use of inputs have their definite boundaries. Hence for harvesting additional protein – rich pulses there appears no option except to increase their productivity.

Among pulses, pigeonpea (*Cajanus cajan* L. Millsp.) occupies an important place. Globally, it is cultivated on 4.92 m ha and 3.58 m ha (72.7%) of it is confined to India alone. In Asia besides India, Myanmar (560,000 ha), China (150,000 ha), and Nepal (>20,000 ha) are other major pigeonpea growing countries. In African continent Kenya, Malawi, Uganda, Mozambique and Tanzania produce considerable amounts of pigeonpea (Table 1). The Caribbean islands and some

Table 1. Global pigeonpea production trends in 2006

Country	Area (ha)	Production (t)	Yield (kg/ha)
Bangladesh	4000	2000	500
Burundi	2000	1800	900
China	150000	NA	NA
Comoros	440	320	727
Congo	8000	5700	713
Dominican Republic	17000	16065	945
Grenada	520	500	962
Haiti	6000	2400	400
India	3580000	2740000	765
Jamaica	1100	1300	1182
Kenya	196261	110662	5634
Malawi	123000	79000	642
Mozambique	85000	NA	NA
Myanmar	560000	530000	946
Nepal	20703	19085	922
Panama	4800	1949	406
Philippines	813	1258	1547
Puerto Rico	272	218	802
Tanzania	68000	50000	735
Trinidad and Tobago	400	952.5	2381
Uganda	86000	88000	1023
Venezuela	3344	3015	903
Total/Mean	4917653	3654224.5	898.2

Source: FAO and other resources.

South American countries also have reasonable cultivated areas under pigeonpea. In India, de-hulled split cotyledons of pigeonpea are cooked to make *dal* (thick soup) for eating with bread and rice while in southern and eastern Africa and South America, whole dry and immature seeds are used as vegetable. Its nutritious broken seeds, husks, and pod walls are fed to cattle; while its dry stems make an important household fuel wood.

Pigeonpea is credited to be the most suitable crop for subsistence agriculture because it is drought tolerant, needs minimum inputs, and can produce reasonable quantities of food even under unfavorable production conditions. Its seeds contain about 20 - 22% protein and reasonable amounts of essential amino acids. In India, the new pigeonpea cultivars are attracting rainfed farmers and for this reason the cropped area has witnessed a significant increase from 2.3 m ha in 1950 to

3.6 m ha in 2006. Unfortunately, such an increase has not been witnessed in its productivity that has remained consistently low. To overcome this constraint, Indian Council of Agricultural Research (ICAR) initiated a multi-disciplinary pigeonpea improvement programme in 1967 in almost all the major agro - climatic zones. This mega project has so far released about 100 pure line varieties which helped in increasing pigeonpea area and production by significant margins but without any change in its productivity. This issue of plateauing productivity over the decades has been a subject of discussion at national level in a number of brain - storming sessions and conferences, but it still remains a challenge.

The quantum jumps in yields as recorded in some cereal, vegetable, and food crops is partly attributed to the development of high yielding hybrids. To achieve a breakthrough in pulses, the deployment of similar non - conventional breeding approach is warranted. However, the hybrid breeding approach in this group of crops could not be used due to their high self - pollinating nature and inability to produce hybrid seed economically. Faba bean (*Vicia faba*) and pigeonpea are the two exceptions where a reasonable level of natural out-crossing occurs and this offered opportunities to breed commercial hybrids in these crops. In faba bean such efforts have been unsuccessful due to technical limitations in large - scale hybrid seed production (Bond et al. 1966). In pigeonpea, ICRISAT scientists initiated the concept of hybrid breeding using its natural out – crossing behaviour. This endeavour began in 1974 with the identification of a genetic male - sterility (GMS) system. Subsequently, efficient cytoplasmic - nuclear male - sterility (CMS) systems were also developed. So far six CMS systems have been bred in diverse cytoplasms which offer ample opportunities to develop commercial hybrids in pigeonpea. The results of recent research in this direction have offered optimism for a breakthrough in yield potential of pigeonpea. In the last few years a significant progress has been made to breed and take the hybrid technology to Indian farmers. Most of the major issues related to large - scale hybrid seed production have been sorted out and now this technology is ready for the grab by seed sector and farmers. This presentation discusses the recent achievements dealing with the technology itself, hybrid advantages, and future prospects for pigeonpea hybrids in India.

POTENTIAL OF HYBRIDS IN ENHANCING PIGEONPEA YIELDS

During the past 4 - 5 decades, pigeonpea productivity in India has remained almost stagnant around 700 kg/ha.There may be a number of climatic, edaphic, and crop management factors for low productivity but lack of high yielding cultivars appears to be a major factor underlying this bottleneck. In India, the annual pigeonpea grain production of 2.74 million tonnes falls short of domestic demand, and about 0.5 to 0.6 million tones is imported mainly from Myanmar and southern and eastern Africa. Therefore, in order to meet the ever growing demand of this pulse its productivity has to be increased significantly by adopting new technologies.

Pigeonpea has a considerable extent of natural out - crossing (Saxena et al. 1990) and the first report of this event was published by Howard et al. in 1919. The natural out-crossing (Table 2) in pigeonpea was always treated as a constraint in breeding and maintenance of varieties. Since most pigeonpea farmers save seed for next season's planting year – after - year, their crops in the fields exhibit tremendous variation for most of the economic traits. This not only leads to high incidence of pests but also results in low and inconsistent yields. It has also been observed that varieties bred for specific traits such as disease resistance *etc.*, quickly loose their quality in farmers' fields. On the contrary pigeonpea breeders have made use of natural out - crossing to breed high yielding hybrids.

Shull (1908) was first to describe the phenomenon of hybrid advantage or heterosis in crop plants and considering its potential in enhancing yield, the breeders developed synthetics, composites, or hybrid varieties. Sinha and Khanna (1975) and Srivastava (1981) reviewed various theories proposed from time to time to explain the complex phenomenon of heterosis at genetic, molecular, biochemical, physiological, developmental, and gene regulation levels. They concluded that some complementary inter - genomic and non - allelic interactions operating at different structural and functional levels are responsible for the expression of hybrid vigour at gene product as well as phenotypic levels. Besides this, some intra - and inter - genomic (genome - plasmone) interactions also play an important role in the manifestation of hybrid vigour (Srivastava 1981). The differences observed for hybrid vigour in reciprocal crosses also emphasize the importance of cytoplasmic - nuclear interactions in the expression of heterosis. Since dominant genes in a given population are known to have evolutionary advantage (Fisher, 1930), the heterosis was initially considered a discernible phenomenon of only cross - pollinated crops but later commercial exploitation of hybrid vigour in cereals and vegetables also established its utility in self - pollinating crops. Sharma and Dwivedi (1995) argued that since over - dominance and dominance gene actions are not common for yield in both self - as well as cross - pollinated crops, the additive gene action and additive x additive inter - allelic

Table 2. Natural outcrossing in pigeonpea recorded at various locations/ countries

Country/place	% Out crossing	
	Range	Mean
India		
Pusa	2.3 - 12.0	
Pusa	1.6 - 3.4	
Nagpur	3.0 - 48.0	
Nagpur		25.0
Niphad	11.6 - 20.8	16.0
West Bengal		30.0
Ranchi	3.8 - 26.7	
Coimbatore		13.7
Varanasi		10.3 - 41.4
Badnapur	0.0 - 8.0	
Coimbatore	10.0 - 70.0	
Hyderabad		27.9
Hyderabad	0.0 - 42.1	
Hyderabad	3.0 - 15.1	
Hyderabad	4.0 - 26.0	
Kenya		
Katumani		17.7
Kibos		12.6
Makucni		21.0
Mtwapa		22.0
Kabete (low pollinators)		23.3
Kabete (high pollinators)		45.9
Other countries		
Hawaii		<1.0
Hawaii	5.9 - 30.0	15.9
Puerto Rico	5.5 - 6.3	
Trinidad		26.4
Australia	2.0 - 40.0	
Uganda	8.0 - 22.0	
China		24

and inter - genomic interactions also play an important role in the expression of hybrid vigour. From practical view point, however, to exploit this phenomenon, it is necessary to identify correct cross combinations and also develop an economically viable commercial seed production technology. The likelihood of obtaining heterotic cross combinations in pigeonpea is relatively high because it has an inherent capacity to carry a considerable hidden genetic load of recessive genes due to its partial out - crossing nature and with little efforts the breeders can make use of such gene combinations in breeding programmes aimed at exploiting the hybrid vigour. Scanning of literature on gene action and heterosis (Saxena and Sharma 1990) in pigeonpea showed that important economic traits such as yield, pods/plant, plant height, seed size, and seeds/pod are controlled by both additive as well as non - additive gene actions and the level for hybrid vigour for yield is comparable with other crops where the commercial hybrids have made success stories.

MALE – STERILITY SYSTEMS IN PIGEONPEA

Genetic Male – Sterility

It was in 1974, when pigeonpea breeders at ICRISAT started exploring the possibilities of breeding commercial hybrids by using the natural out - crossing and heterosis of the crop. The major component for commercial hybrid breeding that was missing at that point of time was the availability of an efficient male - sterility system. Therefore an elaborate search for male - sterility was made in pigeonpea germplasm. In this endeavour, a breakthrough was achieved by Reddy et al. (1977), when they found some male - sterile plants with translucent anthers in an Indian germplasm line. This was found to be a source of genetic (ms_1) male - sterility (Reddy et al. 1978). Five years later, Saxena et al. (1983) also reported another source of genetic male - sterility (ms_2) that was characterized by brown arrow - head shaped anthers from the University of Queensland, Australia. The allelic relationship studies revealed that both the male – sterility genes (ms_1 and ms_2) were non - allelic and monogenic recessive. The male - sterile lines derived from ms_1 source were extensively used in hybrid breeding programmes at ICRISAT and some ICAR institutions.

Cytoplasmic - Nuclear Male – Sterility

Cytoplasmic - nuclear male - sterility (CMS) system is most widely accepted means of producing commercial hybrids in field crops. The expression of CMS, in part, is controlled by genetic factor carried only through the female parent, which is never lost or diluted in succeeding generations of reproduction. This cytoplasmic factor is referred to as 'N' for normal male - fertile cytoplasm and 'S' for the male - sterile cytoplasm. The male - sterile female (A - line) lines are maintained by these two important cytoplasmic factors. The A - lines must have 'S' cytoplasm and be homozygous recessive (*msms*) for nuclear male – sterility genes, and its male – fertile maintainer, B – line, must have a normal (N) cytoplasm and also be homozygous recessive (*msms*) for nuclear genes. The hybrid plants between A - and B - lines will always be male - sterile since the 'N' cytoplasm, responsible for male - fertility in B - line, is not transferred to its F_1 hybrid progeny. For producing male - fertile hybrid seeds, the A - line with 'S' cytoplasm is crossed with a male - fertile line (R – line) carrying fertility restoring gene (*MsMs*) housed in its nucleus. Such genes are commonly known as '*Fr*' genes. To sum up, the three - line hybrid system is geared for multiplying A - line seed with the help of B - line and for producing hybrid seed, the A - line is pollinated with R - line.

Considering the limitations of large - scale seed production of GMS hybrids, the development of CMS became imperative. The strategy was to induce CMS by placing pigeonpea genome into the cytoplasm of wild relatives of pigeonpea through wide hybridization. It was believed that the interaction of wild species cytoplasm with nuclear genome of cultivated type would produce male - sterility that would be inherited maternally. The first unsuccessful attempt to develop such a system in pigeonpea was made by Reddy and Faris (1981) by crossing a wild relative (*Cajanus scarabaeoides*) of pigeonpea and a cultivar. Considering the importance of CMS in hybrid breeding, various ICAR research centres also joined hands with ICRISAT.

So far, six CMS systems have been developed in pigeonpea with varying degrees of success. Out of these, A_4 cytoplasm has shown good promise because of its stability under various environments and availability of good maintainers and fertility restorers. A brief description of A_1 to A_6 CMS systems in pigeonpea is presented hereunder.

Cajanus sericeus (A_1) Cytoplasm : The CMS lines derived from *C. sericeus* (Fig. 1a) are not stable (Saxena et al. 2004). Under short photo - period and low temperatures (< 10°C) the male - sterile plants revert back to male - fertility. This tendency is more pronounced in early maturing male - sterile lines. In long duration types, however, such reversions are not so common. The A - lines derived from this species produce good heterosis (K. B. Saxena, unpublished) but presence

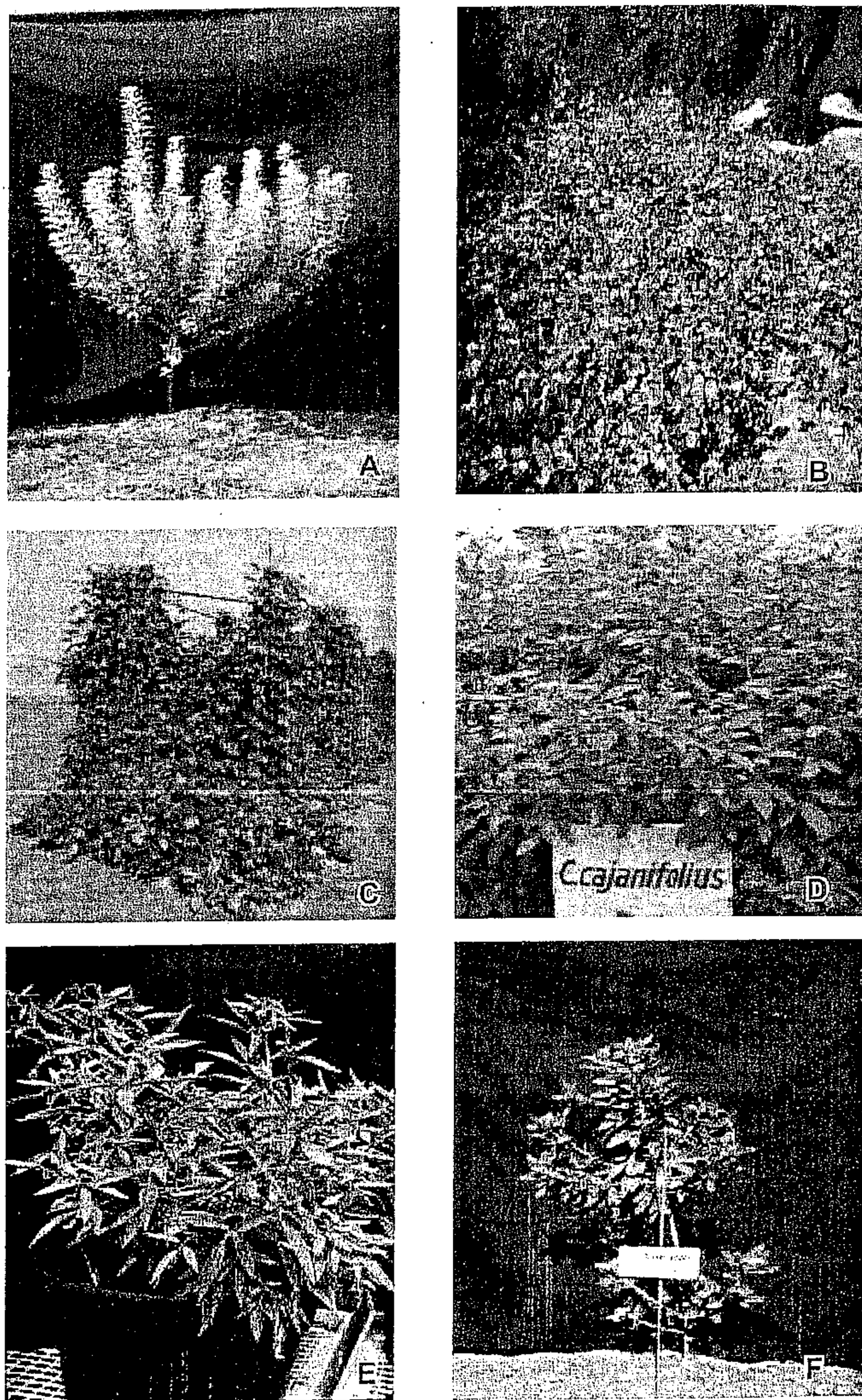

Fig. 1 : Wild relatives of pigeonpea used in developing CMS lines : (a) *C. sericeas*, (b) *C. scarabaeoides*, (c) *C. Volubilis*, (d) *C. cajanifolius*, (e) *C. acutilofius*, (f) *C. lineatus*

of certain proportion of pollen shedders in A - lines, and absence of good maintainers made it commercially non - viable for hybrid seed production.

Cajanus scarabaeoides **(A_2) cytoplasm**: The CMS system derived from *C. scarabaeoides* (Fig 1b) was reported to be very stable (Saxena and Kumar 2003; Tikka et al. 1999). Though this system has shown promise in hybrid breeding (IIPR 2007), the inconsistencies in its fertility restoration have been observed under diverse environments. This appears to be a critical factor in the large – scale acceptance of this technology by seed growers.

Cajanus volubilis **(A_3) cytoplasm**: Wanjari et al. (1999) selected some male - sterile plants with maternal inheritance from segregating populations of a cross between *C. volubilis* (Fig 1c) and *C. cajan* (var. ICPL 83024). However, the CMS lines developed from this species also could not become popular due to their poor fertility restoration.

Cajanus cajanifolius **(A_4) cytoplasm**: *C. cajanifolius* (Fig. 1d) is the most closely related wild species of pigeonpea and it is considered as the progenitor of cultivated type that differs only by a single gene (De 1974). The CMS system derived from this species (Saxena et al. 2005) is the best among the CMS systems developed so far. This CMS system has a good number of maintainers and restorers. The male - sterile lines have been found stable across locations and years. The F_1 hybrid plants with fertility restoring lines produce excellent pollen load and pod set.

Cajanus cajan **(A_5) cytoplasm**: In an attempt to develop CMS lines with cytoplasm of cultivated type, Mallikarjuna and Saxena (2005) crossed *C. cajan* as female parent and *C. acutifolius* (Fig 1e) as pollen parent. This system produced CMS lines with perfect fertility restoration by most cultivated pigeonpea accessions. However, the male - sterility is maintained only by its wild parent. Attempts are underway to breed for its maintainers among the cultivated types (Mallikarjuna, personal communication).

Cajanus lineatus **(A_6) cytoplasm**: In 2002, a naturally out–crossed plant was spotted in the population of *C. lineatus* grown in a Vertisol field. The growth habit of this plant was different from rest of the population and it had very little pollen grains. This plant was crossed with a pigeonpea line ICPL 99044 and its hybrid produced partial male – sterile plants. At present we have BC_4 material with 100% male - sterility and it is being maintained by ICPL 99044.

FERTILITY RESTORERS AND MALE – STERILITY MAINTAINERS

Both fertility restorers and male – sterility maintainers are vital components of any CMS – based hybrid breeding programme. To develop hybrids for different environments, it is imperative to breed genetically and morphologically diverse hybrid parents. In the last 4 – 5 years, the hybrid pigeonpea breeding activities at ICRISAT are being undertaken with CMS lines derived from A_4 cytoplasm. A total of 748 cross combinations were made to identify fertility restorers. Of these, 471 (63%) crosses restored male - fertility; 62 (8.3%) maintained male – sterility; and 215 (28.7%) were found segregating for fertility and sterility. The high frequency of fertility restorers of this cytoplasm is a good indication of its potential in hybrid breeding programmes. This material will allow breeding of diverse parents and hybrids.

Genetic Variation among Male – Sterility Maintainers

The extent of pollen - sterility among the male - sterility maintainers ranged between 95 and 100%. These maintainers had considerable variation (Table 3) for flowering (60 to 140 days), maturity (90 to 205 days), plant height (69 to 275 cm), and 100 - seed mass (6.8 to 16.4 g). Lines ICPA 2086, ICPA 2101, ICPA 2078, ICPA 2043, ICPA 2046, and ICPA 2048 exhibited resistance to both *Fusarium* wilt and sterility mosaic diseases, while ICPA 2040, ICPA 2080, and ICPB 2049 were resistant to sterility mosaic only. These A - lines can be used in hybrid breeding programmes for developing hybrids for disease - prone areas.

Table 3. Observed variation for important agronomic traits among A/B lines of A_4 cytoplasm at Patancheru, 2007 rainy season

Trait	Maturity group				
	Extra short	Short		Medium	
	NDT	DT	NDT	Maruti	Asha
Seed yield (kg/ha)	340-1388	224-1012	730-854	506-2753	1215-2704
Days to flower	60-105	79-87	67-89	107-118	117-140
Days to maturity	90-140	120-133	110-128	159-176	179-205
Plant height (cm)	69-184	127-148	145-192	107-252	240-275
Seeds/pod	3.6-4.1	3.8-6.7	3.7-3.8	3-4	4-5
100-seed mass	7.9-12.3	8.4-13.7	7.6-9.9	7.7-12.4	6.8-16.4
Fusarium wilt (%)	12-92	May-92	31-78	0-88	0-84
Sterility mosaic (%)	0-79	0-58	33-67	0-74	0-44

In the present study, 215 F_1 combination hybrids exhibited considerable intra-accession variation for pollen fertility and it could be due to differential inter-genomic or cytoplasmic - genomic interactions. Such interactions usually involve complex genetic phenomenon like complementation, inhibition, epistasis, accumulation, etc., which render the male-fertility restoration control highly subtle and fragile. In addition, the role of specific environmental factors (Kaul 1988) and genetic impurity (Saxena and Kumar 2003) also cannot be ruled out in determining pollen fertility/sterility. According to Abdalla and Hermsen (1972), the polymorphism, arising due to differential gene actions also results in inconsistent expression of male fertility. In pigeonpea, where a considerable level of heterozygosity in the germplasm exists due to natural outcrossing, the chances of getting such abnormal interactions are always high.

Genetic Variation among Male – Fertility Restorers

The genetics of fertility restoration was studied in cross ICPA 2067 (A_1 cytoplasm) × ICP 12320. In F_1 generation, all the plants were male fertile indicating the dominance of fertility restoring genes. Out of 359 F_2 plants grown, 303 were fertile, whereas 56 exhibited male sterility. This segregation fit well to a ratio of 13 fertile: 3 sterile [χ^2 = 2.34, P (0.01)]. In BC_1F_1 generation out of 175 plants, 121 were male fertile and 54 had sterile anthers, which showed a good fit for a 3 fertile: 1 sterile [χ^2 = 3.20, P (0.01)] ratio. These segregation patterns indicated the presence of one basic and an additional inhibitory gene for determination of fertility restoration in CMS line ICPA 2067. Since, in the present experiment only one cross was studied, its conclusions should not be generalized and more such studies with diverse parents are needed to fully understand the genetic systems underlying the fertility restoration of A_1 CMS system in pigeonpea.

The observations on F_1 hybrids of A_1, A_2 and A_4 cytoplasms indicated that in A_1 and A_2 the fertility restorers were available, but at a low frequency. A high proportion of genotypes were heterogeneous for fertility restoration gene(s). In some genotypes there was only partial fertility restoration and it was found to be confounded by environmental factors such as temperature. So far, the A_4 cytoplasm system appears to be the best because of its stability and quality fertility restoration in F_1 generation with plenty of pollen grains. The pollen load and seed set on F_1 plants was as good as in the control cultivars.

Among restorers, there was a considerable variation for important agronomic traits such as flowering (66 to 142 days), maturity (110 to 206 days), plant height

Table 4. Observed variation for important agronomic traits among R lines of A_4 cytoplasm at Patancheru, 2007 rainy season

Trait	Maturity group		
	Extra short	Short	Medium
Seed yield (kg/ha)	479-865	890-1754	922-3157
Days to flower	66-118	78-90	121-142
Days to maturity	110-155	121-134	183-206
Plant height (cm)	125-207	158-198	220-280
Seeds/pod	3.6-4.0	3.7-4.0	3.8-5.4
100-seed mass	7.5-10.3	7.0-9.4	7.2-14.4
Fusarium wilt (%)	32-96	30-100	0-78
Sterility mosaic (%)	0-72	0-76	0-63

(125 to 280 cm) and 100 - seed mass (7.0 to 14.4 g) (Table 4). Some lines with dual resistance against both wilt and sterility mosaic diseases with good agronomic base have also been developed. Some of the promising disease resistant restorer lines are ICPR 3467, ICPR 3963, ICPR 3801, ICPR 3349, ICPR 3374, ICPR 3516, ICPR 3405, ICPR 3519, ICPR 3407, ICPR 3426, ICPR 3337, ICPR 3463, ICPR 3470 and ICPR 2679.

TRAIT - BASED DIVERSIFICATION OF HYBRID PARENTS

To produce heterotic hybrids for diverse environments, it is important to have ample genetic diversity among both male as well as female parental lines.

Maturity

The traditional pigeonpea cultivars and most landraces are of medium (160 -180 days) to long (>250 days) maturity durations. However through breeding efforts, some early maturing types have also been developed and the earliest maturing variety, ICPL 88039 flowers in 45 days and matures in 85 days at Patancheru (17^0 N). Between these two extremes, there exists almost a continuous variation for maturity (Table 5) and it plays an important role in the diversification of cropping systems and provides an opportunity to extend pigeonpea cultivation in new production niches. The plants of early maturing varieties are relatively short in height and produce less biomass and, therefore, require high plant density (330,000 plant/ha) for optimizing yield. These cultivars are generally cultivated as a sole crop. Pigeonpea is known to be a short - day plant and flowering in this species is induced by long periods of darkness. The photo-period sensitive reaction

Table 5. Pigeonpea maturity groups developed on the basis of days to 50% flowering at Patancheru (17^0 N)

Maturity Group	Days to 50% flowering	Reference cultivars
0	< 60	ICPL 88039
I	61-70	Prabhat
II	70-80	UPAS 120, ICPL 87
III	81-90	Pusa Ageti, T 21
IV	91-100	ICP 6
V	101-120	Maruti, BDN 1
VI	121-130	Asha, C 11
VII	131-140	Hy 3C, ICP 7035
VIII	141-160	Bahar
IX	>160	NDA 1, MAL 13

in pigeonpea germplasm is positively linked to their maturity duration and biomass production. The early maturing genotypes are relatively less sensitive to photo-period and the long duration types are most sensitive (Wallis et al. 1981).

Since the long duration cultivars are sensitive to photo–period, they produce greater biomass on an individual plant basis and these are traditionally grown either as intercrop or hedges. In any commercial hybrid breeding programme, the flowering of male and female parents should be more or less similar and involvement of long duration photo - sensitive and short duration insensitive parents in a cross combination be avoided, as the large - scale seed production of their hybrid will be difficult and uneconomical.

Plant Growth Patterns

There are two major growth patterns in pigeonpea; the determinate types have pods in clusters at the top of the canopy and plant growth ceases after flowering and maturity is more or less uniform. These types, however, are more susceptible for pod borer attack and both *Helicoverpa armigera* and *Maruca testulalis* cause serious yield losses. On the contrary, in the non - determinate types the pods are borne in the auxiliary clusters. In general, these types can tolerate biotic as well as abiotic stresses to some extent. Pigeonpea is a short - lived perennial shrub and this unique trait of the species helps in its adaptation to stress environments. Its strong and deep root system, large food reserves, capacity to regenerate, and some undefined built-in stress compensation mechanisms helps the crop to overcome such stresses and encourage regeneration of vital plant parts as soon as the climate becomes conducive.

Disease Resistance

Although pigeonpea plants are prone to dozens of seed, root, and foliar diseases but only a few causes serious economic losses (Reddy et al. 1990). In Indian context, the diseases such as Fusarium wilt caused by *Fusarium udum;* sterility mosaic caused by a virus, phytophthora stem blight caused by *Phytophthora drechsleri,* Alternaria blight caused by *Alternaria tenuissima* are important of specific areas. Of these, wilt and sterility mosaic together cause great losses every year in most pigeonpea growing areas of Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Madhya Pradesh, Uttar Pradesh, Bihar, and Orissa. Therefore, the hybrid breeding programme was geared up to breed parental lines and hybrids resistant to wilt and sterility mosaic diseases.

Other Traits

In the hybrid parent breeding programme besides major yield components, certain commercially important traits such as seed size, seed colour, seed shape, pod size (for vegetable purposes), and cooking parameters (cooking time, taste, hard seeds *etc.*) are also being given due importance. In this context, it is important to mention that hybrid ICPH 2671 yields over 70% *dal* recovery and has good aroma and taste. In a preference test conducted in 2008 at ICRISAT, the *dal* of this hybrid was rated by >80% respondents as better than market samples and the remaining found it as good as market samples.

HETEROSIS FOR SEED YIELD

GMS – Hybrids

The world's first pigeonpea hybrid ICPH 8 was released in 1991 by ICRISAT and ICAR (Saxena et al. 1992). This is considered a milestone in the history of food legume breeding. The evaluation of ICPH 8 in 100 yield trials showed that it was superior to control varieties UPAS 120 and Manak by 30.5 and 34.2%, respectively. Subsequently, five more GMS - based hybrids were released by various institutions of ICAR. In 1993, Punjab Agriculture University (PAU), Ludhiana, released a short duration hybrid PPH 4 (Verma and Sidhu 1995). In multilocation trials conducted for over two years, PPH 4 out - yielded the control varieties T 21 and UPAS 120 by a margin of 47.4% and 32.1%, respectively. A year later, Tamil Nadu Agricultural University (TNAU), Coimbatore, also released another short duration hybrid CoH 1. In 17 on - farm trials this hybrid recorded 32% higher yield than control variety VBN 1 (Murugarajenran et al. 1995). In 1997, this university released its second pigeonpea hybrid CoH 2 that out-yielded the hybrid CoH 1 by 13% and variety Co 1 by 35%. Subsequently, two more GMS - based hybrids (AKPH 4104 and AKPH 2022) were released by PDKV, Akola in 1997 and 1998, respectively (Wanjari et al. 1999).

However, despite demonstrating high yields, these hybrids could not reach farmers' fields due to their high cost and quality concerns. These inherent constraints were associated with the seed multiplication of their female parents. In every generation of maintenance of these genetic male sterile lines about 50% of the plants, segregating for male – fertility, need to be rogued within a short period of 5 - 7 days before they could contaminate the neighbouring male – sterile segregants. On a field scale, this operation required a large number of farm labours thereby increasing the cost of hybrid seed production. Niranjan et al. (1998) reported that the seed cost in the GMS - based hybrid technology was within affordable limits and the hybrid advantage was also salable, but the technology itself suffers from a major bottleneck, when it comes to large scale hybrid seed production. The scientists at PDKV, Akola tried to enhance the hybrid seed yield by modifying the seed production technology by introducing hill plantings with 2 – 3 seeds and roguing the fertile segregants from each hill but this alteration also failed to attract seed growers. This experience forced pigeonpea breeders to breed hybrids based on CMS systems that would totally eliminate the painful process of roguing in the population of female parents.

Fig. 2. Fifty days old seedling of hybrid 2671 (left) and pure line Maruti (right)

CMS – based Hybrids

After the development of a stable CMS system, several experimental hybrids were produced and evaluated.

Kandalkar (2007) found that CMS-based hybrids recorded standard heterosis up to 156% for grain yield, whereas Saxena (2007) reported yield advantage of 50 to 100% over the popular varieties/checks. In multi-location trials, the performance of hybrids was very encouraging. In the short duration trials conducted at 7 locations (Table 6), ICPH 2433 recorded the highest yield of 2419 kg/ha with 123% superiority over the control ICPL 88039. This was followed by ICPH 2438 (2377 kg/ha). Similarly in the medium duration hybrid trials conducted at 11 locations in 2007, ICPH 3341 (3074 kg/ha) recorded 35% higher yield than the best control variety Maruti (Table 7). The other important hybrids were ICPH 3337 (32% superiority), ICPH 3496 (28% superiority) and ICPH 3462 (26% superiority). These hybrids also have resistance to fusarium wilt and sterility mosaic disease. Hybrids in cereals (maize, sorghum, and rice), oilseeds (sunflower, rapeseed, mustard) and vegetables (tomato, brinjal, *etc.,*) have revolutionized the productivity worldwide. The hybrids in pigeonpea also shares the similar advantages over the pureline varieties.

A promising medium duration pigeonpea hybrid ICPH 2671 : The new hybrids developed on improved A lines have shown promise with respect to yield, seed size, and disease resistance. Among medium duration hybrids ICPH 2671, which matured in 180 days, produced 41.6% greater yield than control Maruti over 21 trials conducted from 2005 to 2007 seasons (Table 8). This hybrid has large attractive seeds, greater plant height and is highly resistant to wilt and sterility mosaic disease, a primary need of medium maturity group. In 29 on - farm trials (Table 9) conducted during 2007, ICPH 2671 (1783 kg/ha) recorded 28.5% higher yield as compared to control Maruti (1388 kg/ha).

Table 6. Yield (kg/ha) of four promising short duration pigeonpea hybrids at 7 locations, 2007

Location	Hybrid				Control	SEm(±)	CV %
	ICPH 2433	ICPH 2438	ICPH 2363	ICPH 2429	ICPL 88039		
Pioneer (Aurangabad)	4051	4533	3624	3735	1313	263	11
Mahyco (Jalna)	1825	615	1463	979	563	104	15
Nuzuveedu (Hyderabad)	3040	3472	2855	2932	1427	321	16
Nimbkar (Phaltan)	2833	2340	3248	2623	1159	192	12
Krishidhan (Jalna)	817	1367	967	927	983	67	9
Nath (Aurangabad)	2667	2833	2333	2333	1083	164	10
Mahabeej (Akola)	1701	1478	1570	1617	1072	99	10
Mean	2419.1	2376.9	2294.3	2163.7	1085.7		
Superiority over control (%)	123	119	111	99			

Table 7. Yield (kg/ha) of four promising medium-duration pigeonpea hybrids at 11 locations during 2007

Location	ICPH 3341	ICPH 3337	ICPH 3496	ICPH 3462	Control Maruti	SEm(±)	CV%
ICRISAT (Patancheru)	2740	2172	2515	2162	1873	210	14
Bioseed (Hyderabad)	2625	3032	1608	2350	2077	324	21
Pioneer (Aurangabad)	6002	5373	4568	6383	4679	374	10
JK Seeds (Hyderabad)	2964	3571	2464	2881	1393	381	21
Mahyco (Jalna)	1217	1433	1008	1346	1317	158	17
Nuzuveedu (Hyderabad)	3480	4483	3688	4001	2751	652	26
Pradham (Hyderabad)	2125	2169	2820	2150	1514	134	10
MAU (Parbhani)	3351	3483	4471	3066	2937	131	6
Nimbkar (Phaltan)	4097	3668	3597	3268	2518	88	4
Krishidhan (Jalna)	1717	1583	1700	1750	1483	87	9
Nath (Aurangabad)	3500	2042	3666	2208	2542	313	17
Mean	3074.4	3000.8	2918.6	2869.5	2280.4		
Superiority over control (%)	34.8	31.6	28.0	25.8	-		

BULK SEED PRODUCTION OF PIGEONPEA HYBRIDS

The efficiency of any commercial hybrid seed production programme depends on the effectiveness of controlled natural mass pollen transfer mechanism from male to female parent. This ensures quality hybrid seed production at economically viable costs. In the three - parent hybrid breeding programme, the quality seed production of all the genotypic components such as male parent (A - line), their maintainer parent (B - line), female parent (A x B), and hybrid (A x R) is essential and needs appreciable isolation distance for seed production. It is interesting to note that on one hand, the seed production plots of B - and R - lines need to be protected from pollinating insects while on the other hand the seed production plots of female parents and hybrids need these insects to pollinate the male - sterile plants.

Flower Structure and Pollination

In pigeonpea, there are 10 stamens in di - adelphous (9 +1) configuration. Of these, four stamens have short filaments and six, including the odd posterior one have long filaments. The odd stamen has a groove for the passage of nectar that is secreted from the base of the filaments. The anthers are ellipsoid, about 1 mm long, dorsifixed, and light or dark yellow in colour. Bahadur et al. (1981) observed that pigeonpea pollen grains show dimorphism with regard to grain size and

Table 8: Summary performance of pigeonpea hybrid ICPH 2671 and control cultivar Maruti in different during 2005-07

Trait	Year			Mean	Superiority over Maruti (%)
	2005 (5 locations)	2006 (5 locations)	2007 (11 locations)	(21 locations)	
Yield (kg/ha)					
Hybrid	3183	2694	2702	2860	41.6
Control	1855	2066	2140	2020	
Seed size(g)					
Hybrid	11.2	10.9	10.8	10.96	
Control	10.3	10.4	10.3	10.33	
Maturity (days)					
Hybrid	181	184	180	182	
Control	178	175	174	176	
Flowering (days)					
Hybrid	120	119	116	118	
Control	123	118	115	119	
Plant height (cm)					
Hybrid	226	215	222	221	
Control	199	205	213	206	
Seeds/pod					
Hybrid	3.7	3.8	4.0	3.83	
Control	3.7	3.8	3.7	3.73	

1. ICRISAT, Patancheru; JK Seeds, Secunderabad; Zuari Seeds, Bangalore; Mahyco, Jalna; TNAU, Coimbatore

2. ICRISAT,Patancheru; TNAU, Coimbatore; Krishidhan, Jalna; Nimbkar Seeds, Phaltan;Nuziveedu Seeds.

3. ICRISAT, Patancheru; Bioseeds, Hyderabad; Pioneer, Aurangabad; JK Seeds, Secunderabad; Mahyco, Jalna; Nuziveedu Seeds, Secunderabad; Pravardhan Seeds, Pargi; MSSCL, Akola; Nimbkar seeds, Phaltan, Krishidhan Seeds, Jalna, Nath Seeds, Aurangabad

exine structure. In general, the pollen grains in the short stamens are larger than those in the long stamens. They also reported that the growth of short stamens is faster than those of longer ones. The maturity period of short stamens coincides with that of stigma receptivity. They postulated that pollen grains produced by short stamens are predominantly responsible for self - fertilization, whereas those produced by long stamens are utilized in insect - aided out-crossing. The self - pollination occurs in the buds before their petals open while the cross - pollination

Table 9. On-farm demonstrations of pigeonpea hybrid ICPH 2671 at various locations, 2007

Location	Number of trials	ICPH 2671		Maruti		Increase over Maruti (%)
		Area (ha)	Yield (kg/ha)	Area (ha)	Yield (kg/ha)	
Pradham Bio-tech, Karnataka	1	0.2	1200	0.2	700	71.40
SFCI,BV Nagar, Nandyal	1	1.2	2500	0.4	1875	33.33
SFCI, Jawalgera, Raichur	1	0.5	650	0.5	350	85.70
Mahyco, Maharastra	13	0.4 each	1820	0.4	1588	14.61
Mahyco, Karnataka	6	0.4 each	1700	0.4	1570	8.28
Mahyco. Andhra Pradesh	5	0.4 each	2020	0.4	1710	18.12
Mahyco, Madhya Pradesh	2	0.4 each	2588	0.4	1925	34.40
Mean/Total	29	12.3	1783	11.5	1388	28.45

takes place at a later stage when the petals of the flowers unfold and insects visit the flowers to collect nectar.

In a young pigeonpea bud, the stigma is placed slightly above the level of anthers, and the style is curved at the tip in such a way that the stigmatic surface is directed towards the anthers. The anthers inside flower are arranged around the style in two groups, one above and another below stigma. As the bud grows, the anther filaments elongate and bring anthers to the level of stigma. This growth is completed before anthers starts dehiscing in closed buds. The anthers of majority of the flowers dehisce before they open. The duration of flower opening depends on environmental conditions such as temperature, sunlight intensity, and relative humidity. Mahta and Dave (1931) observed that pigeonpea flowers remained open for 48 h at Pusa (Bihar), while at Nagpur, they remained open for only 6 h. In West Bengal, Reddy (1973) found that pigeonpea flowers began to open from 0630 h and remained open for 15 to 24 h and anthesis continued until 1400 hrs with the maximum anthesis taking place between 1030 and 1230 hrs. Pathak (1970) reported that those flowers which open in evening usually remain so throughout the night and close before noon on the following day. It has also been found that the stigma become receptive for pollination 68 h before anthesis, and remains in same condition for about 20 h after anthesis (Prasad et al. 1977). According to Onim (1981), although anthers dehisce during bud stage but the pollen grains do not start germinating until the flower starts to wither *i.e.* 24 - 28 h after dehiscence. Dalvi and Saxena (unpublished) reported that under Hyderabad conditions it takes around nine days for unfertilized buds to complete their life cycle and abscise. Only 2% pod set was observed when pollinations were done 48 h before flower opening and on the subsequent day, the pod set improved rapidly and it was highest (98%) when pollinations were made on the day of flower opening and the pod set remained in the high regime for another two days. Subsequently, the pod set declined with time and there was no pod set after 96 h flower opening.

Datta and Deb (1970) reported that pollen tube growth within the style is slow when pollinated with pollen from the same flower, taking 54 h to reach the base of the ovary. Reddy and Mishra (1981) also reported that the proportion of self plants was negligible when flower buds were pollinated with foreign pollen without emasculation. These observations suggest that the foreign pollen has an advantage in affecting fertilization over the plant's own pollen. Such mechanism in pigeonpea offers a sufficient time gap for foreign pollen to be introduced onto stigma, favouring out crossing.

Pollinating Insects

Pathak (1970) reported *Apis mellifera* and *Apis dorsata* as main pollinating vectors. At ICRISAT Centre, Patancheru, Williams (1977) found a that *Megachile* spp. and *A. mellifera* were main pollen transferring agents. She estimated between 5500 and 107333 pollen grains on the body of each insect and > 90% of these belonged to pigeonpea. In Kenya, Onim (1981) reported that each insect visit to pigeonpea flower lasts between 15 - 55 seconds and 24 insect species are capable of affecting natural out – crossing. Brar et al. (1992) recorded *Apis mellifera, A. dorsata, Xylocopa* spp., *Megachile lanata,* and *Ceratina binghami* visit pigeonpea flowers in Ludhiana and *M. lanata* and *A. dorsata* played an important role in cross - pollination. A wide range of natural out - crossing reported from different places (Table 2) is primarily due to large variation in number of pollinating insects.

Hybrid Seed Production Technology

Availability of genetically pure seeds is crucial for realizing their productivity. An efficient seed production system that could provide quality seeds at economically viable costs is the backbone of any hybrid breeding technology. The benefits of hybrids cannot be fully realized until sufficient quantities of pure and healthy seeds are commercially produced at affordable costs.

Due to considerable out–crossing in pigeonpea, a safe isolation distance is essential to produce quality seeds of parental lines and hybrids. The commercial seed production of pigeonpea involves large scale seed production of female line (A/B), restorer line (R line), and hybrid (A x R) combination. For seed increase of A/B lines, breeder seed of both A - and B - lines are planted using a row ratio which ranges from 4:1 to 8:1 (female : male), depending upon the insect activity. In case of higher insect activity 8:1 ratio also gives good seed yield through the 4:1 row ratio gives optimum seed yield at most locations. At maturity, the B line should be harvested first and then the seeds set on the A-line be harvested. For the hybrid seed production (A x R), the row ratios, as in case of A x B seed multiplication, may range between 4:1 to 8:1 depending upon insect activity. In this case also, 8:1 row ratio is recommended at location with high activity of pollinating vectors. Roguing and strict crop monitoring is the critical component of hybrid seed production. In general, roguing is done at seedling, flowering and podding stages. The available variety descriptors should be used as a guide to rogue the off types.

On-farm Seed Production of Hybrid ICPH 2671

In 2007, an attempt was made to produce hybrid seed of ICPH 2671 under diverse on – farm situations in Maharashtra, Karnataka, Madhya Pradesh, and Andhra Pradesh. A total of 39 locations were chosen for A x R seed production. The amount of seed produced varied a lot from 60 – 2267 kg/ha. The reasons identified for low yields were lack of pollinating insects, poor growth of crop and lack of synchrony between male and female parents. Eleven locations where satisfactory harvests were made are listed in Table 10. These data indicated that a fine – tuning of the technology is essential to harvest good yields at diverse locations.

Cost of Hybrid Seed Production

An attempt was also made to estimate the cost of hybrid seed production at Indore (Madhya Pradesh). The details of cost estimates and returns are given in Table 11. In this experiment, a 4:1 ratio was used and the crop was well managed. The cost of one kilogram of hybrid seed was estimated to be Rs.10.57. In order to get realistic information on this issue, there is a need to conduct such trials in different areas.

Table 10. Record of hybrid ICPH 2671 (A x R) seed production in 15 locations during 2007

State	District	Location	Area (ha)	Seed yield (kg/ha)	Productivity (kg/ha)
Andhra Pradesh	Ranga Reddy	Shadnagar	1.6	1400	875
Andhra Pradesh	Nandyal	Gadivemula	1.6	1000	625
Andhra Pradesh	Kurnool	Alamur,	1.6	1000	625
Andhra Pradesh	Kurnool	MK Puram	1.2	1000	833
Andhra Pradesh	Warangal	Manapur,	1.2	1275	1063
Andhra Pradesh	Nandyal	Yallur	1	1000	1000
Andhra Pradesh	Medak	Patancheru	0.4	500	1250
Andhra Pradesh	Ranga Reddy	Medchal	0.4	500	1250
Andhra Pradesh	West Godavari	Eluru-loc.1	1.2	750	625
Andhra Pradesh	West Godavari	Eluru-loc.2	1.2	750	625
Andhra Pradesh	West Godavari	Eluru-loc.3	1.6	1146	716
Andhra Pradesh	Nizambad	Renjal	0.4	700	1750
Andhra Pradesh	Ranga Reddy	Manoharabad	0.68	856	1258
Madhya Pradesh	Indore	Indore	0.15	340	2267
Gujarat	Ahmedabad	Ahmedabad	0.8	850	1063

ADVANTAGES OF PIGEONPEA HYBRIDS

Increased Plant Vigour and Reduced Seed Rates

Inherently, pigeonpea is a slow growing plant, particularly in early stages of growth, which makes it less efficient as far as competition with weeds is concerned. Hybrids of pigeonpea have greater plant vigour (Saxena et al. 1992) compared to the pureline cultivars. The faster growth rates of hybrids help in their quick establishment and faster canopy development than pureline cultivars. This makes hybrids more competitive to weeds. The large seeded genotypes have relatively better initial growth rate but the hybrids, despite of their small seed size, produce higher seedling vigour. The differences in growth vigour which begin to appear during early seedling stage become pronounced with time. This attribute of hybrids makes them more suitable for intercropping than varieties as it enables them to establish quickly and utilize light and water resources more efficiently. In an experiment aimed to study relative root and shoot growth of pigeonpea hybrids and pure lines, it was observed that in comparison to pure line cultivars, the one month old seedlings of hybrids produced 43.9 % higher shoot and 42.8 % higher root mass. Such differences were maintained up to 50 days after sowing (Table 12).

Table 11: Estimated cost of hybrid (ICPH 2671) seed production of pigeonpea at JNKVV, Indore in 2007-08

Item	Labour used (Mandays)	Cost (Rs/ha)
A) Gross expenditure		
Field preparations	-	2000
Inputs (fertilizer, seed treatments)	-	3205
Seed cost	-	900
Sowing	40	3740
Weeding & interculture	58	5423
Roguing	20	1870
Spraying	22	2057
Harvesting	45	4208
Threshing	32	2992
Total (A)	**217**	**26395**
B) Gross returns (Rs/ha)		
Hybrid seed harvested (1400 kg/ha)		
Pollen parent seed (800 kg/ha; @ 14/kg)		11200
Dry stubbles (bulk sale)		400
Total (B)		**11600**
C) Cost of hybrid seed		
Cost of producing hybrid seed [A-B]		14795
Cost of one kg hybrid seed		**Rs.10.57**

Date of sowing : 27 June 2007
Soil: Medium black
Female: male row ratio = 4:2
Spacing: 75 x 30 cm

In cereals a considerable proportion of yield variation among genotypes and environments is accounted for by differences in partitioning. By contrast, in pigeonpea such variation is chiefly accounted for by the differences in crop growth rates. High yields in pigeonpea hybrids are attributed to their relatively higher crop growth rates (Chauhan et al. 1994) and similar partitioning as that of varieties. Higher crop growth rates of pigeonpea hybrids eventually result in higher biomass production and high yield. Total biomass production in excess of 20 t/ha has been recorded in hybrids in subtropical environments. 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. The harvested stems also provide additional fuel wood.

Table 12. Shoot and root weight (g/plant) of short duration pigeonpea genotype and hybrid in pots of Alfisol at different days after sowing (DAS)

Sampling Time	Component	Hybrid ICPH 8	Pure line UPAS 120	Advantage of hybrid (%)
19 DAS	Shoot	0.260	0.170	52.9
	Root	0.106	0.082	29.3
30 DAS	Shoot	1.597	1.195	33.6
	Root	0.407	0.315	29.2
46 DAS	Shoot	4.023	3.097	29.9
	Root	1.144	0.921	24.2
50 DAS	Shoot	7.690	5.985	28.5
	Root	2.055	1.553	32.3
Mean	Shoot	3.393	2.612	29.9
	Root	0.928	0.718	29.2

The experiments conducted at Hyderabad, Gwalior, and Vadodara showed that the hybrid ICPH 8 showed good plasticity at plant populations ranging from 16 to 66 plants/m^2 without adversely affecting seed yield. The yield advantage of hybrid was also maintained at each population level. Increased yield and biomass were harvested even at low plant populations. From these studies, Chauhan et al. (1994) concluded that yield advantage of hybrid was due to higher total dry matter production. Pigeonpea hybrids also produce more number of primary and secondary branches with wider canopy and have greater plasticity without adversely affecting yield. This translates to the reduced seed rate by 40 - 50% compared to the traditional varieties. This will offset the higher seed cost which farmers may have to incur for purchasing hybrid seeds.

Greater Drought Tolerance

In comparison to pure line cultivars the pigeonpea hybrids, by virtue of their higher root mass and greater root depth, have greater ability to draw water from soil profile from different depths. Their faster root growth also helps the plants tide over drought conditions. Pigeonpea is generally grown under rainfed conditions and is subjected to both intermittent and terminal stresses. Short duration pigeonpea has less root mass than the traditional medium and long duration types and thus is more prone to drought stress. Under such conditions, hybrids are likely to perform better than pureline varieties. Comparative performance of pigeonpea hybrids under water - limited conditions, creating a gradient of soil moisture with line source sprinkler irrigation indicated that the hybrids performed better than their male parents or control genotypes at all the levels of moisture applied. This indicated that hybrids performed well not only under optimum soil moisture conditions but also under drought stress. Lopez et al. (1996) attributed superiority of hybrids to their increased ability to maintain relatively high water content than pure line varieties. The better performance of hybrids at a range of soil moisture levels is in agreement with its widespread superior performance in multilocation trials when soil moisture availability would have also varied. It, therefore, appears reasonable to assume that in pigeonpea hybrids we may not only achieve higher yield potential but also a greater ability to adapt to drought, a characteristic which is otherwise difficult to improve through breeding.

Greater Disease Resistance

Fusarium wilt and sterility mosaic diseases are the major biotic stresses in India and together they cause tremendous yield losses every year. In general, medium and long duration types are more prone to these diseases. Results of limited experiments conducted at ICRISAT showed that disease resistant pigeonpea hybrids offer more resistance to the disease attack than resistant pure lines by virtue of their greater resilience (Saxena et al. 1992). Evaluation of a few wilt and sterility mosaic resistant pigeonpea hybrids and pureline cultivars in disease free as well as sick plots indicated that under disease sick conditions, both the hybrids as well as pure line cultivars, expressed high level of disease resistance (<1%). However, under disease sick and disease free conditions the hybrids vigour differed significantly. The hybrids exhibited 19.7% superiority over pureline cultivars under disease free conditions. While the level of superiority of the hybrids under disease sick conditions was enhanced three folds to 60% (Table 13). Hence it appears that in addition to the specific antifungal/viral resistance mechanisms, the hybrids have an extra degree of genotypic plasticity which helps them to tolerate such stresses better and produce higher yields in comparison to pure lines. In general, the hybrid plants recover faster and are capable to assimilate greater biomass. The hybrids also express better environmental buffering capacity compared to the pure line cultivars. The yield fluctuations brought about by various biotic and abiotic stresses could be reduced by introducing pigeonpea hybrids.

Greater Adaptability

In most field crops, hybrids in general show wide adaptation and stability of yield across environments. In pigeonpea, information on this aspect was generated

Table 13. Yield (t/ha) of some disease resistant hybrids and varieties in disease - free and sick fields at Patancheru, 1993 and 1994

Hybrid	Disease free field			Disease sick field		
	1993	1994	Mean	1993	1994	Mean
Hybrids						
IPH 1326	2.6	2.5	2.53	2.1	1.2	1.64
IPH 1395	2.2	2.3	2.26	2.0	1.5	1.72
IPH 1327	2.4	1.8	2.13	1.9	1.5	1.67
Mean	2.40	2.2	2.31	2.0	1.4	1.68
Varieties						
ICPL 87119	2.6	1.9	2.25	1.07	0.7	0.88
ICPL 87051	1.5	1.6	1.60	1.32	0.9	1.11
Mean	2.05	1.75	1.93	1.20	0.8	1.00
Advantage of hybrid (%)	17.1	25.7	19.7	66.7	75.0	68.0

by comparing hybrid with the control at 15 locations. At most locations, the hybrid out-yielded the control and it expressed greater stability in performance when a comparison was made across the environments. Lopez et al. (1996) also reported higher adaptability of hybrids in comparison to inbred cultivars under different moisture and soil regimes. It appears that besides genetic factors, the ability of the hybrids to produce greater biomass throughout its growth cycle imparted greater ability not only to utilize available moisture and nutrients but also to tolerate yield reducing stresses such as drought, waterlogging, disease various biotic stresses.

Potential of Pigeonpea Hybrids under Changing Climates

Global climate change is now a reality. It is expected to have a strong negative impact on productivity of crops as well as livestock and thereby undermining the long - term sustainability of already fragile dryland environments. In developing countries, production losses due to climate change may drastically increase the number of under - nourished people, severely hindering progress in combating poverty and food security. Among poor farmers the opportunities for alternative sources of income are already limited and the efforts to overcome the ill effects of climate changes may not be very effective in overcoming the poverty and malnutrition. Under these circumstances, pigeonpea and its hybrids may prove a boon in agriculture because the hybrids have speedy growth rate, greater root and shoot biomass, and greater resilience to combat drought, salinity and diseases.

Under changed climate, a healthy crop of hybrid not only will provide nutritive food and fodder but also improve soil fertility and structure.

FUTURE STRATEGIES

The strategies for future hybrid pigeonpea programme can be divided into two major groups. The foremost important thing is to develop high yielding hybrids for diverse agro-ecological conditions of the country, and the other deals with taking these high yielding hybrids to farmers in a minimum possible time.

The hybrid breeding in pigeonpea is a new area of research and development and to take full advantage of this technology, it is essential to understand various aspects of the expression of heterosis at agronomic, genetic and biotechnological levels. In summary, the following areas are to be emphasized for planning and implementing dynamic hybrid pigeonpea programmes:

- Diversification of hybrid parents to develop high yielding hybrids for specific agro – ecological regions suitable for environment and market needs.
- Incorporation of utilize stable sources of resistances to major diseases (*Fusarium* wilt, sterility mosaic, *Phytophthora* blight) and insects (*Helicoverpa, Maruca,* pod fly).
- Since the hybrid seed production technology is dependent on the pollinating insects, fine tuning of the technology with respect to planting time, male and female row ratio *etc.*, will help in optimizing its efficiency and returns.
- Expansion of research and development base involving more number of state Agricultural Universities and public and private seed companies which will help in taking this technology to farmers.
- Organized capacity building of partners in various aspects of hybrid breeding, combining ability studies, utilization of new germplasm, development of new CMS sources, identification of heterotic groups, seed production, and maintenance of male and female genetic stocks will be useful in building a strong hybrid programme.
- Development of easy grow - out test and establishment of various seed quality parameters for hybrids and parents will help in maintaining hybrid seed quality.

- Conducting basic breeding and agronomy research for increased productivity.
- Using biotechnological tools to enhance the efficiency of hybrid parent breeding.
- Information sharing using latest technologies.

CONCLUSIONS

Even after centuries of cultivation and natural selection, pigeonpea continues to remain a wild plant and it has retained its unique characteristics such as perennial nature, indeterminate growth, low harvest index, and photo thermal sensitivity. Perhaps its ability to survive and produce food and fodder even under high stress conditions has helped in its adoption by subsistence farmers and even today pigeonpea is considered the most ideal crop of small holding rainfed farmers. Although in the last few decades, some progress has been made towards its domestication through breeding photo – insensitive, extra short duration, and determinate types but a large scope for further improvement still exists.

In recent years, pigeonpea production in India has recorded a significant growth and it is primarily attributed to the development of short duration and medium duration disease resistant varieties. Since the domestic requirement for pigeonpea is ever increasing and the scope for area expansion is limited, the attention of researchers is now focusing on increasing its yield potential. The pureline variety breeding programme that was implemented decades ago did not produce desired results as far as productivity is concerned and yield remained consistently low. The development of stable CMS lines and partial natural cross pollination has opened a new era of hybrid breeding in pigeonpea. It is visualized that the exploitation of heterosis and restructuring of plant type are two probable ways of increasing yielding ability of pigeonpea. In the recent past, vital breakthroughs in physiological research laid the foundation of green revolution in important food crops. For example, in rice and wheat, it was resistance to lodging while in maize, the ability to withstand increase in plant density provided the breakthrough. In soybean, slower declines in photosynthetic rates helped in the genetic enhancement of its yield potential. However, in pigeonpea, this information gap still exists and it needs to be researched at physiological and genetic levels. In the sub tropical environments where plants have plenty of biomass, the inefficient partitioning is the major yield limiting factor.

The CMS based hybrid pigeonpea technology appears to be ready for take off with all its major components in place. However, considering a vast variation in agro ecological conditions, tuning of the seed production technology is essential to suit local environments. The level of hybrid vigour for yield observed in the hybrids conclusively demonstrated that the hybrids of early and medium maturity durations have higher yield potential. Now, our major responsibility is to take this new research product to the clients - the farmers of rainfed agriculture. Considering the high potential of the technology, it is expected that farmers with both, small as well as large holdings will adopt the hybrids. Since pigeonpea is predominantly cultivated by small and resource poor farmers, it is important to keep the seed costs within the reach of such farmers. In India, both public and private seed sectors are strong and these resources should be used to improve accessibility of hybrid seed to farmers.

The partnership between ICRISAT and private sector seed companies has evolved over time. In the early years, ICRISAT played a nurturing role to the fledgling industry through informal networks. As private seed industry grew, it started to develop a significant research capability of its own, particularly in the larger companies. The private sector also became a major channel for delivering high yielding hybrids developed from ICRISAT bred parent materials to farmers. Private seed sector is considered as research partner – both as a source of funds and complementary expertise, especially in the area of development and marketing of hybrid seed (Gowda et al. 2004). Considering that each partner will contribute small amount of funds, ICRISAT launched a concept of "consortium", under which its each member provides a small grant to augment research efforts at ICRISAT. So far 22 seed companies have joined the mission of developing commercial hybrids in pigeonpea. Since last four years, this consortium model is operating smoothly, and a large number of breeding materials and hybrid parents have been made available to the partners.

A comparison of pigeonpea with the other crops where commercial hybrids are already in cultivation shows that the magnitude of realized heterosis for yield in pigeonpea is more or less similar to those of other crops. This phenomenon could be exploited commercially since a grower - friendly mass hybrid seed production technology is now available. Research on diversification and stability of CMS lines, combining ability analyses, breeding high yielding diseases resistant 'A', 'B' and 'R' lines, and identification of heterotic cross combinations will require attention. It is believed that in pigeonpea, the first breakthrough in yield is likely to come from hybrids. In this area, a good beginning has already been made and it is not far when Indian farmers will reap the benefits of this technology.

REFERENCES

Abdalla MMF and Hermsen JGT. 1972. Plasmons and male-sterility types in *Solanum verrucosum* and its interspecific hybrid derivatives. *Euphytica* 21: 209–220.

Bahadur B, Madhusudana Rao M and Likendar Rao K. 1981. Studies on dimorphic stamens and pollen (SEM) and its possible role in pollination biology of *Cajanus cajan* (L.) Millsp. *Indian Journal of Botany* 4: 122-129.

Bond DA, Fyfe JL and Clarke TC. 1966. Male sterility in field beans IV. Use of cytoplasmic male sterility in the production of F_1 hybrids and their performance in trials. *Journal of Agriculture Science* 66: 369-377.

Brar HS, Jhajj HS and Gatoria GS. 1992. Abundance and activity of the bee visits to pigeonpea (*Cajanus cajan* (L.) Millsp.) and role of *Apis mellifera* (L.) in its pollination. *Indian Bee Journal* 54 :76-80.

Chauhan YS, Johansen C and Saxena KB. 1994. Physiological basis of yield variation in short-duration pigeonpea grown in different environments of the semi-arid tropics. *Journal of Agronomy and Crop Science* 174: 163-174.

Datta PC and Deb Arati. 1970. Floral biology of *Cajanus cajan* (L.) Millsp. var bicolor DC. (Papilionacear) *Bulletin of Botanical Society of Bengal* 24 (1-2): 135-145.

De DN. 1974. Pigeonpea. In: Evolutionary studies in world crops. J. Hutchinson, (ed.), Cambridge University Press, London. 79-87 pp.

Fisher RA. 1930. The genetical theory of natural selection. Oxford Press, U.K.

Gowda CLL, Reddy BVS, Rai KN and Saxena KB. 2004. ICRISAT collaboration with seed industry in Asia. Paper presented at Asian Seed Congress 2004, Hotel Lotle Jamsil, Seoul, Korea, September 13 -17, 2004.

Howard A, Howard GC and Khan AR. 1919. Studies in pollination of Indian crops. I. Memoirs, Department of Indian Crops, India. *Botanical Series* 10: 195-200.

IIPR. 2007. Enhancing yield and stability of pigeonpea through heterosis breeding. Progress Report, Indian Institute of Pulses Research, Kanpur 208 024, India. 86 pp.

Kandalkar VS. 2007. Evaluation of standard heterosis in advanced CMS based hybrids for grain yield, harvest index and their attributes in pigeonpea. Presented at 7th International Conference on Sustainable Agriculture for Food, Bio-energy and Livelihood Security, Jabalpur, Madhya Pradesh. February 14–16, 2007.

Kaul MLH. 1988. Male-sterility in higher plants. Springler-Verlag. New York. 1005 pp.

Lopez FB, Chauhan YS and Johansen C. 1996. Effects of timing of drought stress on phenology, yield and yield components of short-duration pigeonpea. *Journal of Agronomy and Crop Science* 177: 311-320.

Mahata DN and Dave BB. 1931. Studies in *Cajanus indicus*. Memoirs, Department of Agriculture India, Botany Series 19: 1-25.

Mallikarjuna N and Saxena KB. 2005. A new cytoplasmic nuclear male-sterility system derived from cultivated pigeonpea cytoplasm. *Euphytica* 142: 143–148.

Murugarajendran C, Khan A, Rathnaswamy WM, Rangasamy R, Rai Kesavan SSR, Kalaimagal T, Saxena KB and Kumar RV. 1995. IPH 732 – a new hybrid pigeonpea for Tamil Nadu. *International Chickpea and Pigeonpea Newsletter* 2: 55-57.

Niranjan SKDFF, Bantilan MCS, Joshi PK and Saxena KB. 1998. Evaluating hybrid technology for pigeonpea. In: Proceedings of the International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, held 2-4 December 1996 at ICRISAT Center, A P, India. 231-240 pp.

Onim JFM. 1981. Pigeonpea improvement research in Kenya. In: Proceedings of the. International Workshop on Pigeonpeas, 15-19 December 1980 at International Crops Research Institute for the Semi-Arid Tropics, A P, India. Vol. 1: 427-436.

Pathak GN. 1970. Pulse crops of India. Indian Council of Agricultural Research, New Delhi.

Prasad S, Prakash R and Haque Md. F. 1977. Floral biology of pigeonpea. *Tropical Grain Legume Bulletin* 7: 12.

Reddy BVS, Reddy LJ and Murthi AN. 1977. Reproductive variants in *Cajanus cajan* (L.) Millsp. *Tropical Grain Legume Bulletin* 7: 11.

Reddy BVS, Green JM and Bisen SS. 1978. Genetic male-sterility in pigeonpea. *Crop Science* 18: 362-364.

Reddy LJ and Faris DG. 1981. A cytoplasmic-genetic male-sterile line in pigeonpea. *International Pigeonpea Newsletter* 1: 16-17.

Reddy LJ and Mishra AK. 1981. Is emasculation necessary for pigeonpea hybridization? *International Pigeonpea Newsletter* 1: 12-13.

Reddy LJ. 1973. Interrelationship of *Cajanus* and *Atylosia* species as revealed by hybridization and pachytene analysis. Ph.D. thesis, Indian Institute of Technology, Kharagpur, India.

Reddy MV, Sharma SB and Nene YL. 1990. pigeonpea diseases management. In: The Pathology of Food and Pasture Legumes. D.J. Allen and J.M. Lenne (eds), CAB International, Wallingford, U.K. and ICRISAT, Patancheru, India. 517-558 pp.

Saxena KB, Ariyanayagam RP and Reddy LJ. 1992a. Genetics of a high-selfing trait in pigeonpea. *Euphytica* 59: 125-127.

Saxena KB, Chauhan YS, Johansen C and Singh L. 1992b. Recent developments in hybrid pigeonpea research. In: New Frontiers in Pulses Research and Development. Proceedings of National Symposium held during 10-12 November 1989, Kanpur 208024, India: Directorate of Pulses Research. 58-69 pp.

Saxena KB, Faris DG, Reddy LJ, Sharma D, Reddy BVS, Gupta SC and Green JM. 1986. Prospects for hybrid pigeonpea. In: New Frontiers in Breeding Research. Proceedings of Fifth International Congress, SABRAO, Bangkok, Thailand. 379-388 pp.

Saxena KB, Wallis ES and Byth DE. 1983. A new gene for male-sterility in pigeonpea (*Cajanus cajan* (L.) Millsp.). *Heredity* 51:419-421.

Saxena KB and Sharma D. 1990. Pigeonpea Genetics In: The pigeonpea. (Nene YL, Hall SD and Sheila VK (eds). CAB International, Wallingford, U.K. 137-158 pp.

Saxena KB, Singh L and Gupta MD. 1990. Variation for natural out-crossing in pigeonpea. *Euphytica* 39:143-148.

Saxena KB and Kumar RV. 2003. Development of a cytoplasmic-nuclear male-sterility system in pigeonpea using *C. scarabaeoides* (L.) Thouars. *Indian Journal of Genetics and Plant Breeding* 63(3): 225-229.

Saxena KB, Tikka SBS and Mazumdar ND. 2004. Cytoplasmic genic male-sterility in pigeonpea and its utilization in hybrid breeding programme. (in) *Pulses in New Perspective.* Ali M, Singh BB, Kumar S and Dhar V (eds). 132-146 pp.

Saxena KB, Kumar RV, Srivastava N and Shiying B. 2005. A cytoplasmic-nuclear male-sterility system derived from a cross between *Cajanus cajanifolius* and *C. cajan*. *Euphytica* 145: 291-296.

Saxena KB. 2007. Breeding hybrids for enhancing productivity in pigeonpea. Paper presented at 7th International conference on Sustainable Agriculture for Food, Bio- energy and Livelihood Security. February 14-16, 2007. 3 pp.

Sharma D and Dwivedi S. 1995. Heterosis in grain legume crops – scope and use. (in) *Genetic Research and Education: Current Trends and the Next Fifty Years.* Sharma B (ed). Indian Society of Genetics and Plant Breeding. Indian Agricultural Research Institute, New Delhi, India. 960-979 pp.

Shull AF. 1908. The composition of a field of maize. *American Breeding Association Report* 4: 296-301.

Sinha SK and Khanna R. 1975. Physiological, biological, and genetic basis of heterosis. *Advances in Agronomy* 27: 117-195.

Srivastava HK. 1981. Intergenomic interaction, heterosis and improvement of crop yield. *Advances in Agronomy* 34: 117-195.

Tikka SBS, Parmar LD and Chauhan RM. 1997. First record of cytoplasmic-genic male-sterility system in pigeonpea (*Cajanus cajan* (L.) Millsp.) through wide hybridization. *Gujarat Agriculture University Research Journal* 22: 160-162.

Verma MM and Sidhu PS. 1995. Pigeonpea hybrids: historical development, present status and future perspective in Indian context. (in) *Hybrid Research and Development*. Rai M and Maruia S (eds). Indian Society of Seed Technology. Indian Agricultural Research Institute, New Delhi, India. 121-137 pp.

Wallis ES, Byth DE and Saxena KB. 1981. Flowering responses of thirty-seven early maturing lines of pigeonpea. In: International Workshop on Pigeonpeas, Vol 2, 15-19 Dec1980, ICRISAT, Patancheru, AP, India. 143-150 pp.

Wanjari KB, Patil AN, Manapure P, Manjaya JG and Manish P. 1999. AKPH-4101: a short duration pigeonpea hybrid for central zone of India. *International Chickpea and Pigeonpea Newsletter* No. 6: 39-40.

Williams IH. 1977. Behaviour of insects foraging on pigeonpea (*Cajanus cajan* (L.) Millsp.) in India. *Tropical Agriculture* 54: 353-363.