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Hybrid technology in enhancing productivity of grain legumes

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ABSTRACT

Grain legumes are considered as the best option for diversification and intensification of agriculture because of their intrinsic values such as nitrogen fixing ability, higher protein content, and ability to thrive well in poorly endowed environments. These are invariably grown under unfavorable marginal lands with low average productivity over the last few decades. Among these grain legumes, pigeonpea *[Cajanus cajan* (L.) Millspaugh] offers an opportunity for breaking the yield barrier through hybrids. In the last few years five different CMS sources have been bred. Among these A_2 *(C. scarabaoides)* and A_4 *(C. cajanifolius)* are being used in hybrid breeding programmes. Two commercial hybrids GTH 1 and ICPH 2671 have recorded 25 - 40% yield advantage over standard varieties in farmers' fields.

Introduction

The exploitation of hybrid vigour in food legumes offers optimism for a breakthrough in the yield potential as it has been witnessed in a number of field crops. Among the grain legumes pigeonpea offers an opportunity for development of commercial hybrids as it meets the major prerequisites such as well established male sterility system and substantial out crossing. To make use of out-crossing in pigeonpea improvement, various population breeding schemes were proposed (Byth *et al.*, 1981; Khan, 1973). Of these some schemes were tried with out significant gains in the realized yields. Pigeonpea breeders have developed plans to use the partial natural out-crossing to breed commercial hybrids. The objective of this endeavor was to enhance the stagnant productivity of pigeonpea by a significant margin through breeding of an excellent and stable hybrid system. It has given us an opportunity to breed high yielding hybrids for different agro-ecological zones of the country. Now the pigeonpea breeders have strong challenges and opportunity before them to breed exceptionally high yielding hybrids to break the yield plateau in this pulse crop.

Genetic male sterility based hybrid pigeonpea technology

Emphasis of pigeonpea breeding program was to make use of the natural out crossing. Heterosis breeding was an obvious choice. Research interests on hybrid pigeonpea were also kindled by reports of existence of considerable magnitude of heterosis (Solomon et al., 1957; Saxena and Sharma, 1990). An elaborate search for male sterility system was made in the germplasm and a breakthrough was achieved by Reddy et al. (1978), who reported a genetic stock with translucent anthers, which turned out to be a stable genetic male-sterile source (ms_1). Five years later, Saxena et al. (1983) reported another source of genetic male sterility characterized by brown arrow-head shaped anthers from the University of Queensland, Australia. Studies revealed that ms_1 and ms_2 genes were non-allelic and monogenic recessive. The male-sterile lines derived from ms_1 source were extensively used in hybrid breeding programs.

ICAR allocated considerable resources to achieve a breakthrough in hybrid breeding technology in pigeonpea. The outcome of this effort was the release of ICPH 8 in 1991 in India (Saxena et al., 1992), which is considered a milestone in the history of legume breeding. Evaluation from 100 yield trials showed that ICPH 8 was superior to controls UPAS 120 and Manak by 30.5% and 34.2%, respectively. Subsequently, a few more GMS bred hybrids were released by national program of ICAR. In 1993, Punjab Agriculture University, Ludhiana, released a short duration hybrid PPH 4 (Verma and Sindhu, 1995). In the multi-location trials conducted for over two years, PPH 4 out yielded the check variety T 21 and UPAS 120 by 47.4% and 32.1%, respectively. A year later, in 1994 Tamil Nadu Agricultural University, Coimbatore, released another short-duration hybrid CoH 1. It recorded 32% higher yield over control VBN-1 in 17 on-farm trials (Murugarajendran et al., 1995). In 1997 the university released its second pigeonpea hybrid CoH 2. This hybrid out-yielded CoH 1 by 13% and CO 1 by 35%. Subsequently, two more pigeonpea hybrids AKPH 4101 and AKPH 2022 were released by PDKV, Akola in 1997 and 1998, respectively. AKPH 2022, a medium-duration hybrid suitable for Maharashtra recorded 64% superiority over control BDN 2. AKPH 4101 was identified at national level for central zone of India (Wanjari et al., 1999), while AKPH 2022 was identified for Vidarbha region of India.

However, the GMS based hybrids, though high yielding, could not reach farmers' fields due to the inherent constraints associated with the maintenance of the male sterile line and hybrid seed production. In every generation about 50% of the plants had to be rogued out, thereby significantly inflating the cost of hybrid seed. Niranjan et al. (1998) concluded that though cost of hybrid pigeonpea seed may be within affordable limits and the hybrid advantage is salable, but the technology itself suffers from major bottlenecks, when it comes to large scales seed production

Development of CMS systems in pigeonpea—a major breakthrough

Considering the limitations in large-scale hybrid seed production of GMS hybrids, the development of cytoplasmic nuclear male-sterility (CMS) became imperative. The strategy was to induce CMS by placing pigeonpea genome in wild cytoplasm through wide hybridization. It was believed that the interaction of wild cytoplasm with cultivated nuclear genome would produce male sterility. So far, five such systems have been reported in pigeonpea with varying degrees of success. Out of these, A_2 cytoplasm has shown promise because of its stability under various agro-climatic zones and availability of good maintainers and restorers. A brief description of A_1 to A_5 CMS systems of pigeonpea is presented as under.

(i) ***Cajanus sericeus*** **(A_1) cytoplasm:** The CMS lines derived from this species (Saxena et al., 1997) are not stable at low temperatures ($\leq$ 10ºC). Under such conditions the male-sterile plants revert back to male fertility (Saxena, 2005). This tendency is more pronounced in the early maturity male-sterile lines. In the long duration types such instability was not so prominent. The CMS derived from this species produced good heterosis (K. B. Saxena, unpublished). However, the presence of some proportion of pollen shedders in female line, and absence of good maintainers made it commercially non-viable for hybrid breeding.

(ii) ***C. scarabaeoides*** **(A_2) cytoplasm:** The CMS system derived from this species was reported to be very stable (Saxena and Kumar, 2003; Tikka et al., 1997). This system has shown promise in terms of yield (IIPR, 2007).

(iii) ***C. volubilis*** **(A_3) cytoplasm:** Wanjari et al. (2001) isolated CMS genotypes with maternal inheritance from the derivatives of a cross between *C. volubilis* and *C. cajan* (var. ICPL 83024). However, the CMS lines developed from this species could not become popular due to their fertility restoration problems.

(iv) ***C. cajanifolius*** **(A_4) cytoplasm:** *C. cajanifolius* is the most closely related wild species of pigeonpea and the progenitor of cultivated type differing only by a single gene (De, 1974). The CMS system derived from this species is the best among the CMS systems developed so far. This CMS system has good number of maintainers and restorers. The male-sterile lines were found stable across locations and years. The F_1 hybrid plants produce excellent pollen load and pod set (Saxena et al., 2005).

(v) ***C. cajan* (A_5) cytoplasm:** It is interesting to note that cytoplasm of cultivated species placed along with nuclear genome of a wild relative of pigeonpea also produced cytoplasmic nuclear male-sterility. In this case Mallikarjuna and Saxena (2005) used *C. cajan* as female parent and *C. acutifolius* as pollen parent. This system shows perfect fertility restoration by cultivated accessions. However, the male-sterility is maintained only by its wild relative parent. Attempts are underway to breed for its maintainers among the cultivated types (K. B. Saxena, personal communication).

Hybrid vigor in CMS-based hybrids

Although systematic pigeonpea breeding began in the early part of 20^{th} century, the first report of hybrid vigor in the crop was published by Solomon et al. in 1957. In the absence of CMS in pigeonpea the potential of hybrid vigor was utilized by developing GMS-based commercial hybrids such as ICPH 8, PPH 4, CoH 1, CoH 2 etc. These hybrids exhibited 20 to 40% superiority over the control cultivar. Kandalkar (2007) found that CMS-based hybrids recorded standard heterosis up to 156% for grain yield.

Hybrid seed production technology

Availability of genetically pure seeds of improved cultivars is crucial for realizing their productivity and adoption in different agro-ecological niches. An efficient seed production system that could provide quality seeds at economically viable costs is the backbone of any hybrid breeding technology. The benefit of new hybrids cannot be fully realized until sufficient quantities of genetically pure and healthy seeds are commercially produced and sold at a cost affordable to the farmers.

Since pigeonpea exhibits natural out-crossing, a safe isolation distance is essential to produce quality seed of parental lines and hybrids. The commercial seed production of pigeonpea involves large scale seed production of female line (A/B), restorer line (R), and hybrid (A x R) combination. Each set of material demands isolation distance of at least 500 m from other pigeonpea. For seed increase of A/B lines, breeder seed of both A- and B- lines are planted at the same time using a row ratio which ranges from 4:1 to 6:1 (female : male), depending upon the insect activity. In case of higher insect activity 6:1 ratio also gives good seed yield. Whereas 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) also, the row ratios, as in case of A x B seed multiplication, may range between 4:1 to 6:1 (female to male). In this case also, 6:1 row ratio is recommended in location with high activity of pollinating vectors, otherwise, 4:1 row ratio is found optimum for most locations. In this program also the R-line be harvested first. This will enhance the seed purity.

Roguing and strict crop monitoring is the critical aspect of hybrid seed production. In general, the roguing is done at seedling and flowering stages. The variety descriptors prepared may also be used to rogue the off-types.

Trials were conducted for two seasons at IIPR ,Kanpur to standardize the cost effective seed production of A line. UPAS 120B and its A lines were planted in three ratios viz. 1B: 4A, 1B:6A and 1B:8A. Maximum yield of A line was found when 'B' and 'A' lines were planted in 1:6 ratio..

ICRISAT have given encouraging results. In both A x B and A x R seed production programs, a row ratio of 4:1 gave good yield. Using this technology an average of 1135 kg ha^{-1} of A-line seed (A x B) was harvested. Similarly for hybrid seed (A x R), an average of 975 kg ha^{-1} yield was recorded.

Fertility restorers

In any CMS based hybrid technology, fertility restoration is a vital component. The observations on F_1 hybrids of A_1, A_2 and A_4 cytoplasms indicated that in A_1 and A_2 cytoplasms 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

Table 1: Performance of hybrid ICPH 2671 in multi-location trials

Year	Location	Fertility restoration (%)	ICPH 2671	Maruti (control)	SEm	CV (%)	% Heterosis
2005	Medchal (JK Seeds)	100	2996	1041	±331.6	21	188
	Coimbatore (TNAU)	98	4262	2538	±252.7	17	71
	Patancheru (ICRISAT)	100	2671	1677	±207.7	14	59
	Jalna (MAHYCO)	100	3416	2541	NR	07	34
2006	Parbhani (MAU)	98	4779	2648	±173.4	0.6	80
	Jalna (Krishidhan)	100	1948	1092	±91.8	10	78
	Coimbatore (TNAU)	100	1823	1100	±324.7	28	66
	Phaltan (Nimbkar Seeds)	-	3208	2243	±147.3	20	43
	Patancheru (ICRISAT0	100	2660	1919	±140.7	08	39
	Bangalore (UAS)	-	1603	1462	±289.9	20	-

was only partial fertility restoration and it may be confounded by environmental factors such as temperature and photo-period. So far, the A_2 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 the control cultivars.

Development of CGMS based hybrids

Following two hybrids have been released:

1. GTH-1

World's first CGMS based pigeonpea hybrid, 'GTH-1' developed at S D A U, S K Nagar, has been identified and released for cultivation in Gujarat state. Parents of this hybrid are GT 288 A (CMS line/female having cytoplasm of *Cajanus scarabaeoides*) and GTR-11 (restorer/male). Based on yield trials (2000-2003), GTH 1 (1760Kg/ha) gave 42% yield superiority over the best check AKPH 4101 (1240 kg/ha) a latest released GMS based hybrid and 32% yield superiority over the best local variety, GT 101 (1330 kg/ha). This hybrid is early in maturity duration (140 days) and possess indeterminate plant type and large white seeds. This hybrid has got notified in 2007. This variety was used as check in multilocational trials conducted for evaluation of pigeonpea hybrids in IHT and AHT. In these trials this hybrid gave the highest yields in Central Zone as compared to the experimental hybrids. Therfore, now this hybrid has been identified for release and cultivation in whole Central Zone.

2. ICPH 2671

ICRISAT, along with Private-Sector partner Pravardhan Seeds, released the cytoplasmic nuclear male sterility (CMS) pigeonpea hybrid, ICPH 2671, (Pushkal) for commercial use at a function held in Hyderabad on 15 July. This hybrid possesses a high yield potential (Table 1) with the added advantages of wilt and sterility-mosaic virus resistance, a trait absent in many high yielding varieties.

Advantages of pigeonpea hybrids

Hybrids in cereals (maize, sorghum, and rice), oilseeds (sunflower) and vegetables (tomato, brinjal etc.) have revolutionized the productivity worldwide. Hybrid pigeonpea also shares the advantages over varieties in the following areas:

i) **Increased grain yield:** Hybrid pigeonpea produces greater biomass than the varieties of the comparable duration. The growth rates are higher compared to the varieties. Hybrids utilize inputs like sunlight, water and nutrients more efficiently, while maintaining their partitioning at least at par with the varieties leading to higher grain yield.

ii) Increased seedling vigor: Hybrid pigeonpea has greater plant vigor compared to the pure line cultivars. The faster growth rate helps the crops in establishing themselves firmly and develop their canopy faster than pure line cultivars. This makes hybrids more competitive than the weeds under inter-cropping situations especially during the initial crop growth stages.

iii) Reduced seed rate: Pigeonpea hybrids produce more number of primary and secondary branches with wider canopy. Agronomic trials indicate that hybrids exhibit greater plasticity at plant populations ranging from 16 to 66 plants m^{-2} without adversely affecting the yield. This translates to the reduced seed rate by 40-50% compared to the traditional varieties. Reduced seed rate will offset the higher seed cost which the farmer may have to incur for hybrids.

iv) Greater drought tolerance: Hybrid pigeonpea, by virtue of its greater root mass compared to the varieties have greater ability to draw water from deeper soil profiles. The deep root system also helps the hybrids to tide over the drought conditions prevailing during the different phases of the crop growth.

v) Greater disease resistance: Hybrids recover faster and are able to assimilate greater biomass. Evaluation of a few wilt and sterility mosaic resistant pigeonpea hybrids and pure line cultivars in disease free as well as sick plot indicated that under sick plot conditions both hybrids as well as pure line cultivars the level of disease resistance expressed was high with less than 1% incidence. However, under disease sick and disease free conditions the hybrids vigor differed significantly. The hybrids exhibited an average of 19.7% superiority over pure line cultivars under disease free conditions. The level of superiority of the hybrids was enhanced to 60% under disease sick conditions. Hence it appears that in addition to the specific anti-fungal/viral resistance mechanisms, the hybrids have an extra degree of genotypic plasticity which helps them to tolerate and produce higher yields under stress conditions compared to the pure lines.

In general the hybrids 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 introduction of pigeonpea hybrids.

Future strategies

The following areas are to be emphasized for planning and implementing a dynamic hybrid pigeonpea breeding programs.

Develop high yielding hybrids for specific agro- ecological regions

Diversify hybrid parents to suit target environments

Incorporate resistances to biotic and abiotic stresses, especially wilt, sterility mosaic, phytophthora, and pod borers

Fine tune the hybrid seed production technology for increased efficiency

Develop seed quality parameters for hybrids and parents

Conduct basic breeding and agronomy research for increased productivity

Identify/develop heterotic groups

Undertake molecular characterization of hybrids and their parents

Use biotechnological tools to enhance hybrid parent breeding efficiency

References

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

Byth DE., Saxena KB and Wallis ES. 1981. Evaluation of a population of early maturing pigeonpea lines derived from a triple cross introduced from ICRISAT. Proceedings of . ICRISAT/ICAR International Workshop on Pigeonpeas, Dec. 15-19, **2:** 151-158.

De DN. 1974. Pigeonpea. Pages 79-87 *in* Evolutionary studies in World Crops. (J. Hutchinson, ed.), Cambridge University Press, London.

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 ISOPOM Project. Indian Institute of Pulses Research, Kanpur, India p 61.

Kandalkar VS. 2007. Evaluation of standard heterosis in advanced CMS based hybrids for grain yield, harvest index and their attributes in pigeonpea. P.195. *In* Proc. 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, pp.1005.

Khan TN.1973. A new approach to the breeding of pigeonpea (*Cajanus cajan* (L.) Millsp.) formation of composites. Euphytica **22:** 373-377

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

Murugarajendran C, Ali Khan WM, Rathnaswamy R, Rangasamy SRR, Rai Kesavan R, 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 SK, Bantilan MCS, Joshi PK and Saxena KB. 1998. Evaluating hybrid technology for pigeonpea. Pages 231-240 *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.

Ramaswami B, Pray CE and Kelley TG. 2001. The Impact of economic reforms on R&D by the Indian seed industry. Food Policy **26**(6): 587-598.

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

Saxena KB and Sharma D. 1990. Pigeonpea Genetics. Pages 137-158. In: Pigeonpea. Eds. Nene, Y.L. *et al*. CAB International, Wellingford, U.K.

Saxena KB, Kumar RV, Singh L and Raina R. 1997. Development of a cytoplasmic-male-sterility system in pigeonpea. Progress Report Forth Consultative Group Meeting on Cytoplasmic Male-Sterility in Pigeonpea March 3-4, 1997. Bhabha Atomic Research Centre, Trombay, India. pp 19.

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.2005. Pigeonpea (*Cajanus cajan* (L.) Millsp.) Pages 85-115. *In*: Genetic Resources, Chromosome Engineering, and Crop Improvement, Vol 1: Grain Legumes (R. J. Singh and P.P. Jauhar, Eds.) CRC Press, USA..

Saxena KB, Kumar RV, Madhavi Latha K and Dalvi VA. 2006. Commercial pigeonpea hybrids are just a few steps away. Indian Journal of Pulses Research **19**(1): 7 – 16.

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

Solomon S, Argikar GP, Salanki MS and Morbad IR. 1957. A study of heterosis in *Cajanus cajan* (L.) Millsp. Indian Journal of Genetics and Plant Breeding **17:** 90–95.

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 Sindhu PS. 1995. Pigeonpea hybrids: historical development, present status and future prospective in Indian context. Pages 121-137. *In*: Hybrid Research and Development. M.Rai and S.Mauria (Eds). Indian Society of Seed Technology, Indian Agricultural Research Institute, New Delhi, India.

Wanjari KB, Patil AN and Patel MC. 1999. AKPH- 4101: a short duration pigeonpea hybrid for Central Zone of India. International Chickpea and Pigeonpea Newsletter No. **6:** 39-40.

Wanjari KB, Patil AN, Manapure P, Manjaya JG and Manish P. 2001. Cytoplasmic male-sterility in pigeonpea with cytoplasm from *Cajanus volubilis*. Annals of Plant Physiology **13:** 170–174