Hybrid Pigeonpea – A Reality

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Pigeonpea is the most important rainy season pulse crop, considering it's extensive use and nutritional value in the vegetarian diet of the majority (approximately 70%) of the population in India. However, the *per capita* availability of pigeonpea has steadily declined due to the limited increase in the total production of crop unable to keep pace with the growing population (about 2% per annum). The production area of 2.48 million ha in 1972-73 increased to 3.57 million ha in 1990-91, but the total production increased from 2.48 million tones to 2.63 million tones only during the same period. Average yield of pigeonpea has been fluctuating considerably over years at the national level and in the states. It is estimated that there was an increase of 8.2% in productivity of pigeonpea during the time period of 1972-73 to 1990-91. However, such productivity estimates are greatly influenced by the time period one chooses and are not realistic. In spite of an all round development in agriculture due to increased availability of irrigation and fertilizers and the associated technological advances, pigeonpea yield has been fluctuating between 600-700 kg/ha since early nineteen hundred with some exceptional years, for example 1960-61, when national average touched 849 kg/ha mark. Crop improvement programmes to breed improved pigeonpea varieties were initiated quite early. However, production of the crop remained confined to landraces and the selections from them, primarily under rainfed conditions with minimum inputs on residual soil moisture and a variety of cropping and crop management systems. A major setback to pigeonpea improvement has been the lack of sustained systematic research efforts at any one place.

Indian Council of Agricultural Research (ICAR) established a multidisciplinary crop improvement project in 1967 for research and development of pulse crops with pigeonpea naturally being an important component. However, the establishment of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in 1972 and inclusion of pigeonpea as one of the five mandate crops of the institute

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provided great impetus to the systematic sustained pigeonpea improvement research in the country in collaboration with various ICAR institutes and Agricultural Universities. Since 1974, evaluation and utilization of the extensive pigeonpea germplasm (7090) by the ICRISAT centre and ICAR's All India Coordinated Pulses Improvement Project, has resulted in releasing a number of pigeonpea varieties for different agro-ecological regions. The released varieties had early maturity, better seed size, disease resistance and marginal improvement in yield potential. The limited yield improvement of the varieties could not reflect any gain in pigeonpea productivity at the national level as the new varieties have not been adopted by the farmers on a large scale, due to diverse crop growing environments, non-availability of pure seeds and various socio-economic reasons.

Experience in crops such as maize, sorghum, pearl millet, cotton and lately, rice has shown that quantum jump in yield potential of these crops, once their yields reached a plateau, which was possible by commercial exploitation of the genetic phenomenon of hybrid vigour or heterosis.

Initially, the genetic phenomenon of heterosis (hybrid vigour) was considered an expression of the linked dominant genes and was thought to be confined to the cross-pollinated crops, where dominant genes have evolutionary advantage. However, since then studies on general and specific combining abilities and gene action on cross and self-pollinated crops have shown that inter-and intra-allelic interactions (epistasis) both are important in the expression of heterosis. The extent of heterosis and gene action involved in grain legumes revealed that the hybrid vigour in these crops is mainly due to the complementary inter-allelic interaction of additive x additive type, which is greatly supported by the fact that there is no inbreeding depression in these crops. Therefore, the pollination system of pigeonpea does not pose any restriction on the expression of the heterosis, one only needs to find an ideal cross combination. The hybrid vigour for grain yield in pigeonpea was comparable with other crops where commercial hybrids have been successfully used.

Development of hybrid pigeonpea varieties

Pigeonpea is an often cross-pollinated crop. The extent of out-crossing ranging from 0-70% depending on the location and the presence of pollinating insects (mainly *Apis mellifera*, *Apis dorsata* and *Megachile* spp.) has been reported. In India for the first time, the success of hybrid varieties in cotton, an often cross-pollinated crop, prompted the utilization of hybrid vigour through development of hybrid varieties to substantially increase the productivity of pigeonpea. As a first step, efforts began in 1974 at ICRISAT for search of a stable male-sterility system to develop a controlled natural out-crossing of the female parent for developing effective hybrid seed production technology. After examining 7090 germplasm accessions, success was achieved in identifying a dependable male-sterile source devoid of any pollen grains and having translucent anthers. The translucent anther character allowed easy identification of the male-sterile plants in the field and was controlled by a single recessive gene "ms_1" , which could be easily incorporated in agronomically suitable female parent. The details of developing suitable male-sterile lines and field scale seed production technology based on this genetic male-sterility system have been worked out at ICRISAT and the ICAR institutes and resulting in development of a large number of experimental hybrids for field testing which showed 20 to 64% yield advantage over the appropriate check cultivar.

In 1991, the Indian Council of Agricultural Research released the first pigeonpea hybrid variety ICPH 8 developed at ICRISAT, after extensive testing in All India Coordinated Programme. Evaluation in 100 yield trials showed that the hybrid ICPH 8 was superior to standard checks UPAS 120 and Manak by 30.5 and 34.2 per cent, respectively. Following this development, the Agricultural Universities of Punjab, Tamil Nadu and Akola (Maharashtra) also developed a number of experimental pigeonpea hybrids and released six hybrids in different states. Some seed companies among which MAHYCO was the leader also produced hybrids based on genetic male-sterility system. However, hybrid varieties of pigeonpea based on genetic male-sterility could not be widely adopted due to the constraints of seed production technology, mainly the requirement of timely roguing of the 50% fertile sibs within the female parent.

Development of cytoplasmic-genetic male-sterility system and hybrid varieties

Scientists at ICRISAT, considering the limitations posed by the genetic male-sterility system in large-scale seed production, had initiated work on developing cytoplasmic nuclear male-sterility (CMS). The initial efforts had a rather limited success. However, the work created an environment of scientific discussion and exchange of materials, particularly wild species from ICRISAT.

The research at ICRISAT and ICAR institutes namely Indian Institute of Pulses Research (IIPR), Kanpur; Indian Agricultural Research Institute (IARI), New Delhi; Gujarat Agricultural University (GAU), SK Nagar; Punjabrao Krishi Vidyapeeth (PKV), Akola; Tamil Nadu Agricultural University (TNAU), Coimbatore; Punjab

Agricultural University (PAU), Ludhiana; and Banaras Hindu University (BHU), Varanasi involved a number of wild relatives of pigeonpea as a source of CMS cytoplasm. However, stable CMS lines have been reported from crosses involving *C. scarabaeoides* from GAU and ICRISAT and *C. sericeus* from ICRISAT.

Encouraged by the development of stable CMS lines at ICRISAT and at the GAU, the Indian Council of Agricultural Research set up the hybrid pigeonpea research project in 1999 under the Technology Project (NATP) in mission mode to provide the necessary thrust at IIPR, Kanpur; GAU, S.K. Nagar; PDKV, Akola; and NDUA&T, Faizabad with IIPR being the lead center. Work at the PDKV, Akola center has resulted in identifying a new source of CMS cytoplasm, it's maintainer, and the restorer from *C. volubilis* (Wanjari *et al.* 2001). The material is being purified for stabilizing this CMS source.

The CMS line GT 288 from GAU, S.K. Nagar derived from *C. scarabaeoides* cytoplasm is the only line which has been tested at different locations in the All India Coordinated Pigeonpea Improvement Programme and has been found to be stable and 100% sterile (Tikka *et al.* 1997). A large number of maintainers and restorer (B and R lines) lines have also been developed for the A line. Similarly at ICRISAT, a number of maintainers and restorers in early and medium maturity groups have been found for *C. sericeus* CMS. In the past couple of years a number of test hybrids have been made at the above two locations and also by the other three locations. Presently, CMS lines are available in a number of diverse maturity and plant types for developing an array of test hybrids.

The research work done on CMS system, development of hybrid seed production and diversification of female parent (A line) lines clearly meets the basic three technological requirements *viz.*,

- expression of sufficiently high degree of hybrid vigour in the crop,
- dependable stable male-sterility CMS system – which involve development of agronomically good A and B lines and a good combiner with 100% fertility restorer pollinator line (R-line),
- economic hybrid seed production technology – based on high natural transfer of pollen from the pollinator (R line) to the male-sterile female parent (A line).

No doubt hybrid varieties are a reality within about 20 years of sustained research on the subject. However, we have just climbed the first step on the arduous long ladder of incremental improvement of pigeonpea productivity through the development, release and large-scale adoption of the hybrid varieties. Only a limited number of pigeonpea test hybrids have been developed. The All India Coordinated Pulses Improvement Programme has evaluated the performance of nine test hybrids (five hybrids from NDAU, Faizabad and four hybrids from GAU, S.K. Nagar), at Kanpur; S.K. Nagar; Faizabad; and Akola. The restoration of pollen fertility in these hybrids ranged from 12.2 to 88.6 percent and the grain yield ranged from 663 kg/ha to 2105 kg/ha. Since the days of flowering and the duration of the crop or any other factor have not been reported, it is difficult to explain the wide difference in the yields of the hybrid, except incomplete fertility restoration in the hybrids. The hybrids based on the CMS line GT 288 have shown 100% fertility restoration at S.K. Nagar only. Moreover the discrepancy in the yield levels of the hybrids becomes more difficult to explain, when the yield levels for A and B lines have been reported to range from 1597 kg/ha to 2986 kg/ha. However, a good number of test hybrids evaluated at ICRISAT using *C. sericeus* and *C. scarabaeoides* CMS have an encouraging programme.

Pigeonpea growing agro-ecological environments, management systems and varietal productivity

The early hybrid varieties seem to have potential in sole crop cultivation in North-West zone of the country in irrigated areas where pigeonpea – wheat rotation is becoming popular. The medium duration hybrid varieties grown in mixed cropping under rainfed conditions may have limited contribution towards the national pigeonpea production unless there is substantial change in the production and management system of the crop, which is unlikely. We may carefully analyse the situation with regard to sorghum and pearl millet crops, which traditionally overlap pigeonpea growing areas of central and southern states and are mostly grown under rainfed conditions.

The situation in case of sorghum and pearl millet clearly indicates that inspite of very high yield potential of the sorghum and pearl millet hybrid varieties under irrigated conditions and their superior performance even under unirrigated conditions, the hybrid variety based technology could not be adopted on a large scale under rainfed conditions. The over all productivity of these crops remains about 10% of the potential of the hybrid varieties of these crops and is comparable in magnitude with average productivity of the crop in the better pigeonpea growing environments of northern India.

Late duration pigeonpea (200 to 300 days duration) predominantly grown in the northern states show a much higher productivity levels at the state and the district levels in Bihar and Uttar Pradesh, where the state average yield is over 1200 kg/ha. In Uttar Pradesh district average yield in good pigeonpea growing areas range from 1400 kg/ha to 3700 kg/ha in good years. It would suggest that some individual farmers must be attaining 4500 to 5000 kg/ha yield levels and a good number must attain 2500 kg/ha and above yield levels. These yields are really very high, particularly in the light of the fact that most late pigeonpea yield trials from Kanpur, Faizabad and Varanasi hardly touch the trial average yield of 2000 kg/ha.

The expression level of heterosis in long duration pigeonpea hybrid was poor. This may be due to the limited testing of the test hybrids and lack of genetic diversity among the parents. However, the matter needs to be carefully researched to determine the extent of the hybrid variety yield advantage in case of the medium and late maturity varieties, since the maximum heterosis observed is in case of the early maturing hybrids with decreasing trends in case of medium and late maturity hybrids. The pigeonpea research workers need to work and standardize the crop management system, which expresses the full potential of the hybrid varieties at the experiment station and is distinctly superior to the farmer level yields in the region.

Issues in realizing the reality of hybrid pigeonpea varieties

Fairly good diverse CMS lines have been developed from *C. scarabaeoides* (GT 288 at GAU, and CMS 88039A, CMS 88034A and CMS 87A at ICRISAT) and *C. sericeus* (several lines at ICRISAT). Also a few sources of restorer (R) lines, mainly from the pigeonpea germplasm collection have been identified. However, restoration of fertility in F_1 has been good in a few combinations only, and variable in others, depending on the genetic background of A line and the environment.

With the development of three components A, B, and R lines of the CMS based hybrid seed production technology the hybrid pigeonpea varieties are a technological reality. However, so far only a limited number of test hybrids (9) have been evaluated for yielding ability and the results are not very encouraging (partial restoration in some combinations and locations). Genetic purification for fertility restoration and limits of environment allowing full expression of fertility restoration will have to be determined.

GMS based hybrids in yield tests have given considerably high yield performance over the standard check cultivars. This was probably due to the fact that both the parents invariably were agronomically good established cultivars with good general combining ability and specific combinations gave high hybrid vigour. In case of the CMS based hybrids, the R lines are derived from the germplasm and the F_1s involve random parents due to limited R lines available for restoring fertility in combinations with specific A line. Therefore, for success of the CMS based hybrid breeding programme in pigeonpea as a first step, we need to breed high yielding 'A' and 'R' lines and then identify good heterotic combinations :-

1. Development of A lines – This is some what easy, because well adapted agronomically superior genotype/variety with high general combining ability is crossed and if the F_1 is sterile, the genotype of the pollen parent is reconstituted by successive backcrossing to the segregating sterile plants and recover agronomically similar A and B lines.
2. Identify stable restorer genotype for each specific A line.
3. Develop a number of agronomically superior R lines. This can be done either by back-crossing an agronomically superior genotype to the source R line or by crossing good R lines together and recover a superior R line through line breeding. In pigeonpea at present most restorer sources are unadapted germplasm lines.
4. Make a number of test crosses and evaluate them for their yield performance in multilocation trials to select high performing specific cross for wide adaptation.

From the above scheme it may be realized that the success of hybrid breeding programme depends a great deal on a very strong conventional line breeding base-programme. It is likely that at the first instance one may find a reasonable good cross combination by chance in limited number of crosses. However, the experience in maize and sorghum shows that out of a large number of lines only a few appear in commercial hybrids (about one in 10,000 lines). Therefore, it needs to be emphasized here that available facilities of land, personnel and finances are highly inadequate at the pigeonpea breeding centres. As a matter of fact, lately the conventional breeding programme has been greatly neglected, which really forms the backbone of any hybrid breeding programme, particularly in highly self pollinated crops, where highly heterotic combinations are not easy to find.

Development of hybrid pigeonpea varieties as an overall strategy of breeding improved varieties does not seem to be a very practical approach. Since, the available results clearly indicate that hybrid vigour is more in early and the medium maturity hybrid combinations, it would be desirable to emphasize on the development of hybrids in these groups.

In case of medium maturity appreciable gain in productivity through use of hybrid varieties will accrue from pure crop management system under irrigated conditions in the central and southern states, instead of largely inter cropping of pigeonpea in rainfed as well under irrigated conditions along with some cash crops such as cotton, chilies, groundnut, *etc.* The analysis of yield levels in sorghum and pearl millet clearly shows that inspite of availability of hybrid varieties in these crops for more than 30 years, the productivity of the crop under rainfed conditions has hardly changed. Most of the gains in productivity of these crops come from the irrigated areas. The percent yield gap between the national average yield and the experimental yields in case of sorghum, pearl millet, wheat and rice is much more than in case of pigeonpea.

In case of late duration pigeonpea, while efforts are directed towards developing high yielding lines, converting them to A line and look for good restorer sources and development of good R lines, attempts should be made to determine the extent of heterosis expressed in this group of the genotypes. Long crop growing period makes it difficult to work with long duration genotypes. Unless there is clear evidence of sizeable hybrid vigour (30% or more over the standard variety) breeding hybrid varieties would be a futile exercise. The long duration pigeonpea breeding programme should be planned in such a way that line breeding ensures high yielding lines which could be either used as varieties or subsequently used as parents for a hybrid variety, if the extent of heterosis warrents it.

Open pollinated landraces grown in the farmers' fields are highly heterogeneous and therefore were well buffered against biotic (diseases and pests) and abiotic (drought, water-logging) stresses. But uniformity of hybrids would require that hybrids carry a high degree of resistance to pests and diseases and are managed well to avoid any stress caused by the weather conditions.

Development of CMS system in pigeonpea is certainly a path breaking step but lot more efforts and planning is required to make pigeonpea hybrid varieties a commercial reality and substantially increase the productivity of the crop at the national level.