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HYBRID PIGEONPEA BREEDING : PRESENT STATUS AND FUTURE PROSPECTS

R. S. RAJE[1], I. P. SINGH[2] AND S. R. MALOO[3]

INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important high protein food crop of family *Leguminosae*. It is one of the major legume crops of tropics and subtropics. It is a crop of resource poor farmers that provides to them not only quality food and fodder but also fuel wood (4350 KCal kg^{-1}). Its soil rejuvenation qualities such as release of soil-bound phosphorous, fixation of atmospheric nitrogen, recycling of soil nutrients, and addition of organic matter make pigeonpea an ideal crop of sustainable agriculture in semi-arid situations.

Pigeonpea is the fourth most important pulse crop in the world with all production confining to developing countries. Globally in 2006, it was grown on 4.68 m ha area producing 3.65 m tones with an average yield of 780.37 kg/ha(FAO, Stat., 2007). Pigeonpea is grown in Asia, North and Central America, South America and Africa. In Asia, area under pigeonpea was 4.16 m ha with production of 3.29 m tones and productivity of 790 kg/ha in 2006 (FAO, Stat., 2007). In recent years pigeonpea has been successfully introduced in Myanmar (555,000 ha) for export of grains and in China (100,000 ha) for conservation of soil in hilly areas. In sub-Sahara Africa long duration pigeonpea constitute an important component of rainfed agriculture. In this region it is mainly cultivated in Kenya, Malawi, Tanzania, Uganda, and Mozambique.

In India during 2006, pigeonpea was grown on about 3.5 m ha area with production of 2.74 m tones and productivity of 765.36 kg/ha (FAO, Stat., 2007). India accounted for 74.97% of the globle output of pigeonpea in the year 2006. In India, pigeonpea is a major pulse crop of Maharashtra (1.1 m ha), Karnataka (0.58 m ha) Andhra Pradesh (0.51 m ha), Uttar Pradesh (0.41 m ha), Madhya Pradesh (0.32 m ha), and Gujarat (0.35 m ha). These six states account for 78.9% of the total pigeonpea area. It is grown in diverse cropping systems. The short duration early maturing (120-140 days) are grown as a pure crop mainly in pigeonpea-wheat rotation, while the medium (160-180 days) and long duration (more than 200 days) varieties are grown as an intercrop with pearlmillet, sorghum, cotton, groundnut etc.

The Problem of Yield *Plateau*

Like other crops, in pigeonpea also a number of biotic and abiotic stresses are known to affect its overall productivity and

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some of the biotic stresses have been adequately addressed through resistance breeding or integrated crop management practices. Since the realized yield in a given environment is the product of interactions of such stress factors with varieties and other environmental factors, considerable yield variations are always observed.

This review paper discusses the progress, current status and prospects of genetic enhancement of yield through hybrid breeding for breaking the yield *plateau* in pigeonpea.

Sincere efforts towards genetic enhancement at national level have succeeded in developing pigeonpea varieties resistant / tolerant to various biotic and abiotic stresses and also high yielding short duration varieties fitting well in the pigeonpea-wheat rotation. This resulted in the phenomenal increase in the pigeonpea area from 2.3 m ha in 1950 to 3.8 m ha in 1998. However, such an increase has not been witnessed in productivity and present average productivity has not changed over the decades. In the past 50 years the area and production of pigeonpea have recorded positive growth, but the mean national productivity has remained unchanged. This is a matter of concern since the domestic demand of pigeonpea is rapidly increasing and the Indian Government has resorted to import this pulse. Since further increase in the area will be limited, it is essential to enhance its productivity by a significant margin to meet the demand of domestic market.

There may be a number of climatic, edaphic, and crop management factors for the low productivity but lack of high-yielding cultivars appears to be an important factor underlying the constantly poor harvests. The annual pigeonpea grain production in the country, amounting to about 3 m tones, falls short of annual domestic demand, and about 0.5 to 0.6 m tones of pigeonpea is imported mainly from Myanmar and southern and eastern Africa. The per capita availability of protein in the country is already one-third of the requirement and if the production of major pulses is not increased the problem of malnutrition among the poor will further aggravate. Thus, to meet the protein needs of the ever growing population it is essential to increase the production substantially. The production could be alleviated either by increasing the area or increasing the productivity of the crop. The opportunities of horizontal increase in the cultivated area are limited. Therefore, pigeonpea productivity has to be increased significantly. Alternative breeding approaches need to be evolved and implemented to develop high yielding varieties.

Hybrid Cultivars for High Yield

Pigeonpea production can be increased through exploitation of heterosis. Pigeonpea is an often cross–pollinated crop and substantial degree of heterosis for grain yield is present (standard heterosis–from 25-30 %). Scientists initiated the idea of breeding hybrids in pigeonpea using its natural out-crossing for enhancing the productivity, as has been demonstrated in many food crops. Earlier, GMS system was developed in pigeonpea and the first hybrid ICPH 8 was also developed and released in 1991. This hybrid recorded 25-30 % higher yield over the best available check. Subsequently, 5 more GMS based hybrids were developed. However, these hybrids never became popular due to limitations in the seed production. It took 30 years to develop an efficient CMS system. Now, CMS systems have been developed in different cytoplasms and offer ample opportunities to breed commercial hybrids in pigeonpea. The issues related to large-scale hybrid seed production have also been sorted out and now the hybrid technology is ready for the grab by seed sector.

Converting Constraint to Opportunity

Pigeonpea has a considerable natural out-crossing. The first report of this event was published by Howard *et al.* (1919) but since then this phenomenon has always been treated as a constraint in breeding and maintenance of pigeonpea varieties. Since most pigeonpea farmers save the seed for the next season's planting year-after-year, their pigeonpea crop in the field exhibits tremendous variation for most of the economic traits. This leads to low and inconsistent yields. Also it has been observed that the varieties bred for specific trait(s) such as disease resistance. quickly loose their identity if the seed is not maintained under controlled pollination. Pigeonpea breeders, however, have made use of this opportunity and selected a number of natural recombinants to developed good varieties for the farmers. 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 without significant gains in the realized yields.

Scientists 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*.

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 (*ms₁*). Five years later, 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 Agricultural 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 IPH 732 (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. 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 scale seed production.

Development of CMS Systems in Pigeonpea - a Major Breakthrough

Considering the limitations in large-scale hybrid seed in production in 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, four such systems have been reported in pigeonpea with varying degrees of success. Out of these, cytoplasm from *C. scarabaeoides* has shown promise because of its stability under various agro-climatic zones and availability of good maintainers and restorers.

***i) Cajanus sericeus* cytoplasm**: The CMS lines derived from this species are not stable at low temperatures (10°C). Under such conditions the male-sterile plants revert back to male fertility. This tendency is more pronounced in the early maturity male-sterile lines. The CMS derived from this species produced good heterosis. 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* cytoplasm**: The CMS system derived from this species was reported to be very stable (Tikka *et al.*, 1997). This system has shown promise in terms of yield (IIPR, 2007).

***iii) C. volubilis* 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*** **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, 2005).

Current Status of Heterosis Breeding in Pigeonpea

In pigeonpea heterosis can be exploited by using the newly developed CMS system which has been developed using cytoplasm from wild species like *C. sericeus* (A_1 cytoplasm), *C. scarabaeoides* (A_2 cytoplasm), *C. volubilis* (A_3 cytoplasm), *and C. cajanifolius* (A_4 cytoplasm). Already, one CMS based hybrid GTH-1 has been released. This is world's first CGMS based pigeonpea hybrid, it was developed at S D A U, S K Nagar and 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 GMS based hybrid and 32% yield superiority over the best local variety, GT 101 (1330 kg/ha). This hybrid is early in maturity (140 days) and possess indeterminate plant type and large white seeds. This hybrid was notified in 2007 and 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. Therefore, now this hybrid has been identified for release and cultivation in whole Central Zone. Currently efforts are also being made to develop CMS system using *Cajanus cajan* cytoplasm (A_5 cytoplasm) and *C. lineatus* cytoplasm at ICRISAT (Mallikarjuna and Saxena, 2005).

Out of all the available CMS sources mainly A_2 and A_4 cytoplasm are being utilized for developing heterotic hybrids. The CMS system derived from *Cajanus scarabaeoides* species was reported to be very stable. This system has shown promise in terms of yield. *C. cajanifolius* is the most closely related wild species of pigeonpea and the progenitor of cultivated type differing only by a single gene. The CMS system derived from this species is the best among the CMS systems developed so far as this CMS system has good number of maintainers and restorers. The F_1 hybrid plants produce excellent pollen load and pod set. The CMS lines derived from *Cajanus sericeus* cytoplasm are not stable at low temperatures (≤ 10°C). Under such conditions the male-sterile plants revert back to male fertility. This tendency is more pronounced in the early maturing male-sterile lines. The CMS lines developed from *C. volubilis* cytoplasm could not become popular due to their fertility restoration problems.

Currently efforts are being made towards development of high yielding hybrids in the project entitled "Enhancing yield and stability of pigeonpea through

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