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PIGEONPEA HYBRIDS - A REVIEW

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ABSTRACT

The present review focuses on international and indigenous research efforts in developing pigeonpea hybrids for harnessing higher productivity *per se*, strengthening of seed research and seed production. Hybrid vigour and exploitation of heterosis for earliness, uniformity in maturity, better partitioning and yield potential of hybrids has been reviewed critically. Availability of male sterility, genetic as well as cytoplasmic and genetics of male sterility have been evaluated. Development and diversification of male sterility system led to release of hybrids *viz.*, ICPH8, PPH4, IPH 732 and AKPH 4101 etc. Due to lack of effective seedling markers, hybrids based on GMS have limited scope, however, efforts are on in stabilizing cytoplasmic male sterility and its use in development of hybrids with increased yield potential in pigeonpea.

Because of vegetarian food habit, pulses are a major source of protein for large section of Indian population, yet their per capita availability has declined from 64.6 g/day in 1951-56 to about 43 g/day in 1996-98 as against recommended 85 g/day. While area under pulses in India since 1970-71 till date, has remained almost constant at 20-24 million ha, though, production and productivity have shown positive trends. It is estimated that, to make pulses available at the recommended level of 85 g/day, India will require an annual pulse production of 31.02 million tonnes for its 1 billion population in the year 2001.

The data reveal that India dominates the scene for pigeonpea cultivation. The world trends largely reflected the situation in India, where, growth rate of area and production, exceeded 2%/year from 1970-90 (Srivastava *et al.*, 1998). However, the growth rate of yield in India were almost stagnant during the aforesaid period. This stagnant growth in pigeonpea productivity may be related to the crops of relatively low status in the cropping system. Even today, pigeonpea like other pulses also considered a subsidiary crop. It is often sown to marginal soil and is usually intercropped with crops such as sorghum, pearlmillet and cotton. Pigeonpea as a crop of secondary importance in many of these systems, neither it receives little or no purchased inputs like fertilizer, herbicide, pesticide etc. nor does it attract much of the crop management attention. Though, release of early, medium and late pigeonpea varieties/ hybrids in recent years showed that the production has attained upward growth and also confirms the impact of new technology. Recent release of pigeonpea hybrids *viz.*, ICPH-8, PPH-4, COH-1 etc. may be more profitable for farmers and crop may gain a status as a cash crops with appropriate transfer of technology under lab to land programme.

Prospects and opportunities of hybrids

Pigeonpea has shown substantial amount of non-additive genetic variance (Sharma *et al.*, 1973; Reddy *et al.*, 1981; Saxena *et al.*, 1981) and hybrid vigour for yield (Solomon *et al.*, 1957). The discovery of stable genetic male sterility (Reddy *et al.*, 1978) coupled with its outcrossing nature, has opened the possibility of commercial utilization of the heterosis in pigeonpea.

The genetic male sterility of translucent anthers requires roguing of 50% of the normal fertile plants from the female rows in hybrid seed production blocks at flowering and the identification and collection of seeds from male sterile plants in the maintenance block. To date, it has been demonstrated that full seed set is obtained if one fertile pollinator parent is sown after every six male sterile rows (Saxena *et al.*, 1986). The available sources of male sterility have been transferred to several genetic backgrounds in different phenological groups that also have resistance to various diseases (Saxena *et al.*, 1986). Generally successful hybrids are produced from combinations, where, SCA effects result in considerable heterosis in the F_1 generation. However, to find these combinations and develop a successful hybrid programme, it will be necessary to test a large number of hybrids.

The available technology for pigeonpea hybrids production has potential to double the productivity of pigeonpea. Hybrids recorded more than 25% increase in grain yield over improved local varieties under demonstrations and encouraged farmers to grow hybrids with more confidence. For forming strategies for sustainable hybrid production, developmental efforts on hybrids are essential. Focus should be on breeding hybrid varieties resistant to biotic and abiotic stresses, stabilizing of yields and enhancing productivity in pigeonpea.

Genetic male sterility

I. Mechanism

The discovery of three sources of genetic male sterility (Reddy *et al.*, 1978, Wallis *et al.*, 1981, Dundas *et al.*, 1982) and the prevalence of sufficient natural outcrossing by several insect species (Williams, 1977, Onim, 1981) led to the development (Gupta *et al.*, 1983) of pigeonpea hybrid. The three sources of male sterility were found to occur due to the failure, at different stages, of male meiosis. Reddy *et al.* (1978) reported that male steriles were identifiable by non-dehiscent, flat, translucent anthers. This type of male sterility is designated ms_1. Male meiosis proceeded normally in this male sterile line up to the formation of tetrads, then degeneration occurred because of non-separation of tetrads. The tapetum was found to be intact, whereas, in normal cells it disintegrated as meiosis advanced. In the male sterile line identified by Wallis *et al.* (1981) which is designated ms_2, the stamens are brown, shrivelled and arrowhead shaped. Meiotic failure of this source of male sterility occurs earlier than it does in ms_1. Pollen mother cells degenerate at the tetrad stage with the rupture of the nuclear membrane. The anther morphology of the third source of male sterility is similar to that found by Wallis *et al.* (1981). Meiotic failure occurred at the pachytene stage i.e. earlier than the other two male sterile types (Dundas *et al.*, 1982). Krishnamurthy and Gnanam (1987) studied that in male sterile translucent (MST) anthers, the tapetum appears abnormal from the early tetrad stage, the enlarging cells encroaching into anther locule, the microspore tetrad lose their viability and shape and eventually degenerate. Pandey *et al.* (1996) observed male sterility associated with obcordate leaf shape and had widely opened free and thread like keel petals of the flowers, which may encourage cross-pollination.

II. Genetics

Saxena *et al.* (1981,b) reported that male sterility was controlled by a single recessive gene. In *Cajanus volubilis* x *Cajanus cajan* crosses monogenic recessive behaviour of the male sterility with reduced anther type was confirmed (Patel *et al.*, 1998). Male sterility shown by translucent anthers is controlled by single recessive gene ms_1. Another source characterized by brown arrow-head shaped anthers is also controlled by a single recessive gene ms_2. Both of these are controlled by different independent genetic systems (Saxena *et al.*, 1983).

III. Induction of male sterility

A. Through crosses

In pigeonpea male sterility coupled with natural outcrossing can be utilized to improve populations and develop high yielding hybrids. The male sterile Prabhat DT line, bred at ICRISAT is most popular and commercially used in development of short duration hybrids. Govil *et al.* (1994) developed a short duration ms Pusa 33. QMS-1, ms-ICP 3783, HUA-7 are some other male sterile lines of long duration group (Rajni Raina *et al.*, 1996). Pandey and Singh (1998) developed a ms-DAMS1, which might be a good source for hybrid breeding programme of Northern part of the country. Apart from these PMS-1 and IMS-1 are also being used in hybrid development. Patel *et al.* (1998) obtained stable ms in crosses from *C. volubilis* x *C. cajan* cultivars. The conversion into male sterility is in progress in BDN 31, MA 97, ICPL 83024, ICPL 86023, AL 201, AL 230, AL 688, AL 83015, Manak, Paras, ICPL 87051, BDN 7, HYD 185, ICPL 8863, P 869, P853, AKT6, ICPL 83027, Bahar, NDA 88-2, DA 11, Pusa 9, T7, ICP 8860 and PDA 85-1 (Srivastava *et al.*, 1997).

Variability of four types of male sterility was expressed in crosses with *C. volubilis* x *C. cajan* at PKV, Akola ((Srivastava *et al.*, 1997). The cross, (*C. volubilis* x ICPL 83024) x AKMS 7B, showed small anthers, purplish in colour, irregular in shape and non dehiscent type without pollen powder. The cross (*C. volubilis* x ICPL 83024) x DA 6B showed normal anthers, blackish white, non- dehiscent and without pollen grain. The cross, DA 6A x (*C. volubilis* x ICPL 83024) showed unstable male sterility, pale yellow anthers with normal dehiscence. Another cross, AKMS-7 x (*C. volubilis* x ICPL 83024) showed insensitive male sterility with yellow dehiscent anthers, where pollen powder was sterile in all the seasons.

B. Through chemicals

Pandey *et al.* (1996) induced male sterility in long duration pigeonpea varieties *viz.*, Bahar, DA11 and Pusa 9 by chemical mutagen using streptomycin sulfate (SS) and sodium azide (SA). In other studies, chemical mutagens *viz.*, Streptomycin and Terramycin by IIPR, Kanpur, Sodium azide, EMS by IARI, EMS and DES by GAU, S.K. Nagar, Streptomycin, Sulphate and Sodium azide by RAU Dholi have been used to transfer male sterility in diverse pigeonpea genotypes (Srivastava *et al.*, 1997). Complete male sterility to varying degree of pollen sterility was observed in these cases. Using GMS, many male sterile lines *viz.*, ms Prabhat NDT, ms Prabhat DT, IMS-1, QMS-1, msT 21, ms 288, ms 3783, ms 7035, ms Co-5, ms BDN-1, ms C11, ms BWR 370, AK MS-2, -5, -6,.-8, -9, -10 etc have been developed in past by various breeders.

C. Through physical mutagen

Plants with varying degree of male sterility/pollen sterility were isolated through induced physical mutagen as Gamma ray by scientists at IIPR, Kanpur, IARI, New Delhi, HAU, Hissar, GAU, SK. Nagar, TNAU, Coimbatore, NDUA&T, Faizabad and BARC, Trombay. Verulkar and Singh (1997) obtained spontaneously a male sterile UPAS 120 plant, which had white translucent anthers with complete pollen sterility. Inheritance study suggested that the male sterility was genetic and controlled by a recessive gene.

Cytoplasmic genetic male sterility

I. Mechanism

Male sterility, the inability of a bisexual flower to produce functional male gamete or viable zygotes result from one or two gene control systems and is of nuclear genomic origin, often designated ms and is cytoplasm-nondependent for its expression and designated as genic male sterility (g mst-Ariyanayagam *et al.*, 1993). The second less prevalent system results from the interaction of nuclear and cytoplasmic factors. It is generally accepted that specific genes of sterile cytoplasm interact with the fertility restorer gene (fr.) of the nuclear genome to produce male sterile phenotypes. The inheritance is non-mendelian as transference of the sterile cytoplasm is through the maternal parent. This system is designated as gene cytoplasmic male sterility (g-c-mst).

II. Genetics of cytoplasmic genetic male sterility

The genetic factors associated with g-c-mst are highly variable. More than one control system may exist in the same crop. Single and double recessive gene controls have been reported in a large number of monocots and dicots. Control by three, four, five and many recessive genes though less frequent, has also been reported in crops such as sorghum, pearl millet, sugarbeet, flax, alfalfa. Dominant gene action has been found in wheat carrot, potato, red clover whereas, polygene action noted in sunflower, flax, alfalfa, pearlmillet and interaction of dominant and recessive genes in carrot and redclover was noted (Kaul, 1988). Different cytoplasm types of are known in onion, rice, petunia, sorghum and wheat. The existence of non allelic 'fr' genes and different cytoplasm types contribute to complex genetic control of g-c-mst (Kaul, 1988). Genic male sterile line QMS-1 when treated with sodium azide at 0.025% for 48 hours or streptomycin sulfate at 500 mg kg^{-1} for 24 hours appeared to undergo mutational change from the gametophytic type of sterility maintenance to sporophytic maintenance. The sterility was maternally inherited and resembled to g-c-mst (Ariyanayagam, 1993). The maintainer was a heterozygous sib. Fertility restoration occurred with many normal genotypes. In another study sterility resulted from interactions of genomic and cytoplasmic genetic factors of cells, the late appearance of sterility symptoms suggested that either the interaction did not begin until the pollen grains differentiated or that the time lapse for the interaction to take effect was long (Ariyanayagam *et al.*, 1994). In *Cajanus sericeus* x *Cajanus cajan* hybrids, Wanjari *et al.* (1998) observed monogenic recessive male sterility in two progenies, whereas, another three progenies expressed dominant sterility. Thus, male sterility mechanism was governed by recessive as well as dominant genes. Pod and seed set was studied in c-ms lines by Rao *et al.* (1996), he observed that c-ms plants were female fertile and were capable of an acceptable level of pod set under natural pollination. Thus, these should pose no problem in developing commercial hybrids when cms lines are fully developed. Wanjari and Patel (2001) suspected apomixis in second backcross progeny on recurrent parent ICPL 85030 to develop cytoplasmic male sterility. In BC4 generation, plant to plant backcrosses developed by mechanical pollination with the pollen from same recurrent parent, revealed 5 progenies with apomictic seed development without any sexual reproduction while four progenies showed 33.3 to 52.2% sexual seeds.

III. Induction of cytoplasmic genetic male sterility

(A) Through crosses

Ariyanayagam *et al.* (1993) have indicated the prevalence of differences among species, and among accessions within species, for the occurrence of male sterility as well as the level of male sterility in successive generations, for instance, *C. sericeus, C. scarabaeoides* and *C. acutifolius* as female parents in crosses gave a higher frequency of sterile progeny than *C. albicans.* Even accessions within the three promising species responded differently to selection for the trait. Among the *C. scarabaeoides* accessions, PR 4562, was promising and among the *C. sericeus* accessions, EC 121208 gave good response in triple and backcrosses. However, a combination of triple and backcrosses was found to be effective in overcoming the apparent antagonistic effect between the cytoplasm and genome of the parent. The female sterility noticed with direct backcrossing with pigeonpea parent was less prominent when several pigeonpea parents were introduced. This strategy was effective in inducing genetic-cytoplasmic male sterility in *C. sericeus* x *C. cajan* crosses.

In a another search for sources of CMS, 5 species of Atylosia, 5 of Rhynchosia and 2 of Flemingia were crossed with 9 varieties of *Cajanus cajan* (Rajni Raina *et al.*, 1993), however, only one plant from the cross *C. cajan* cv. T.21 x *A. mollis* was found male sterile. Analysis of PMC meiosis showed no separation of tetrads, as well as pollen grains were also not formed. The plant was maintained by backcrossing with T21.

Hybridization with *Cajanus sericeus* indicated possibilities of cytoplasmic genetic male sterility (Wanjari *et al.*, 1998). The hybrids of *C. sericeus* x *C. cajan* showed 44% pollen fertility. Laggards and unequal distribution of chromosomes were seen at Anaphase I. On the basis of pairing behaviour, seven chromosome pairs are seen to be common to both the parents and two pairs had been in the translocation in the course of evolution. Rathnaswamy *et al.* (1989) developed a c-g-mst by crossing two wild species, *Cajanus cajanifolius* and *C. acutifolius* with genic male sterile lines of *C. cajan* (ms Co5). Interspecific crosses between *Cajanus scarabaeoides and C. cajan* has resulted in isolation of progenies having 100 per cent pollen sterility. From the results it is evident that a stable CMS system as a line (288A) and its maintainer B line (288B) is now available (Srivastava *et al.*, 1997). There is a definite interaction of nuclear genome derived from recombination between *C. sericeus* and *C. cajan,* use of this source in isolation of CMS line is in progress at BARC, Trombay and ICRISAT, Patancheru. In addition, four types of male sterile plants were isolated in derivatives of *Cajanus volubilis* x *Cajanus cajan.* The isolated male steriles also showed heteromorphic variation of filament length in relation to length of style, CMS progenies identified at GTS$_5$ stage in *C. sericeus* (EC 121208) x ICP 88027 and 90-100% male sterility developed. In search for CMS, various sources of male sterility using alien germplasm as *C. cajanifolius, C. albicans, C. scarabaeoides, C. sericeus, C. platycarpus, R. bracteata* at IIPR, Kanpur, *C. volubilis, C. platycarpus, R. bracteata, C. lineatus* at IARI, New Delhi, *C. cajanifolius, C. lanceolata, C. volubils, C. acutifolius, C. platycarpus, Flemingea similata* at PAU, Ludhiana; *C. cajanifolius, C. volubilis, C. sericeus, C. lineatus, C. lanceolatus, C. scarabaeoides* at PKV, Akola, *S. scarabaeoides, C. sericeus, C. cajanifolius* at GAU, S.K. Nagar, *C. cajanifolius* at TNAU, Coimbatore, *C. mollis* at BHU, Varanasi were used in crosses with *C. cajan* (Srivastava *et al.*, 1997). Variable sterility (10% to 99%) to complete sterility were noticed in F$_1$ and different segregating populations. Though, barrier in crossability was noticed with *C. volubilis* and *C. platycarpus.* The work at ICRISAT confirmed the stability of male sterility in GT 288A across the location and environment (Annual Report, IIPR, 2001-2002).

B. Through mutation

In a study at NDUA&T, Faizabad a cytoplasmic male sterile source was isolated as a spontaneous mutant (ms ICP 6042 and ms ICP 1024). In ms ICP 6042 (A line) male sterility was maintained by Bahar i.e. B line and sterility was restored by Pusa 9 (R line). Similarly other male sterile line ms ICP 1024 (A line) was maintained by ICP 6622, Bahar, T7 and NDA 88-2. The male sterility of ms ICP 1024 was restored by NDA-93-1, Pusa 9, and ICP 2905, R-line (Srivastava *et al.*, 1997). Another spontaneous mutant in Bahar (DAMS-1) was found less sensitive to low temperature under Dholi condition. The anther colour of this mutant was white (Srivastava *et al.*, 1997).

In hybrid of *C. cajan* x *A. platicarpus* application of gibberellic acid, NAA and kinetin prevented early embryo abortion, later embryos were cultured and hybrid pollen showed 41.5% sterility. In a another study Dundas *et al.* (1987) studied hybridization between pigeonpea and two native Australian species, *Atylosia acutifolia* and *Atylosia pluriflora*. The hybrids showed high level of sterility, thus have potential for use in pigeonpea hybrid improvement.

Role of wide hybridization

Jaswinder *et al.* (1993) studied wide crosses of *C. cajan* with the wild relatives *C. platycarpus*, *C. cajanifolius* and *Rhynchosia aurea*. They observed that application of the growth regulators *viz.*, gibberellic acid and kinetin helped to maintain developing hybrid pods upto 19 days after pollination, whereas, untreated controls survived for only 5 days. Embryo age was found critical for plant regeneration, with embryos less than 11 days old fail to develop. In a search for CMS, one plant from the cross, *C. cajan* cv. T-21 x *A. mollis* was found male sterile. The analysis of PMC meiosis showed no separation of tetrads and no pollen grains were formed. The plant was maintained by backcrossing with T-21 (Rajni-Raina *et al.*, 1993).

Dodia *et al.* (1996) studied growth and development of pod borer, *Helicoverpa armigera* on pigeonpea varieties T151 and the wild relatives *viz.*, *C. scarabaeoides*, *C. cajanifolius*, *C. reticulatus*, *C. sericeus* and F_1 generation of the cross *C. scarabaeoides* ´ *C. cajan*. Larval and pupal mass, developmental period and pupal length were all lower for larvae fed on wild flowers as compared to cultivated pigeonpea. Growth and development of *H. armigera* was adversely affected on flowers of all wild species and few larvae survived to maturity.

Hybrids between 13 accessions of *C. platycarpus* with ICPL 88014 and ICPL 85030 as pollen donors failed to give fertile hybrids (Saxena *et al.*, 1996). IPCW 64 and IPCW 70 produced hybrid plants with both pigeonpea lines but hybrid seeds were undeveloped and failed to germinate. Reciprocal pollination using *C. platycarpus* as male parent was unsuccessful in a study done at ICRISAT.

IV. Molecular analysis

Several distinct lines of evidence suggest that genes which control staminal sterility in maize, sorghum, sugarbeet and wheat are located on mitochondrial (mt DNA) and not on chloroplast (ct DNA). Observations on DNA sequencing of unique genes of the plant mitochondrial system provide convincing evidence for alteration of mitochondrial genome to be the major cause of CMS. Plasmid DNA's are natural components of mitochondrial genome and they can be activated for transposition by genomic stress (Srivastava, 1985). CMS is a maternally inherited trait with the plant remaining female fertile, while the pollen formation is abnormal. CMS was manifested as a result of the incompatibility of the nuclear mitochondrial interaction and the changes were mainly encoded in the mitochondrial genome.

The differences in the restriction fragment patterns among the various pigeonpea cultivars could be the result of inter and intra molecular rearrangements within the mitochondrial genome, which is a common phenomenon in higher plant mitochondria. The studies on another morphology also clearly indicated the differences between cytoplasmic male sterile lines and the genetic male sterile lines.

RFLP analysis of total genomic DNA from three putative CMS progenies derived from crosses between the wild species *C. sericeus* and cultivated pigeonpea was studied by Sivaramakrishnan *et al.* (1996). Results also suggested that male sterile lines derived from these crosses had mitochondria of female wild species parent. The results presented by Sivaramakrishnan *et al.* (1996) on the crosses between the wild species *C. sericeus* and the cultivated species *C. cajan* produced male sterile lines having the mitochondria of the later. Souframanien *et al.* (2001) used randomly amplified polymorphic DNA (RAPD) markers for the identification of two pigeonpea cytoplasmic genic male sterile lines, 288A and 67A derived from crosses between the wild species *Cajanus scarabaeoides* and *C. sericeus* and the cultivated species *C. cajan*, respectively. The RAPD analysis of the male sterile line and maintainer line can be of practical application and also in establishing the genomic stability of the male sterile lines. The identified putative male sterile marker OPC 11600 may be useful in hybrid pogeonpea breeding programme.

Hybrid vigour in pigeonpea and hybrid evaluation

Solomon *et al.* (1957) was the first to report hybrid vigour in pigepnea. To realize a high level of hybrid vigour for yield Shrivastava *et al.* (1976), Reddy *et al.* (1979) and Venkateswarlu *et al.* (1981) suggested selection of parental lines belonging to diverse maturity groups.

Singh *et al.* (1983) reported upto 22.1% mid parent heterosis in a cross Mukta x UPAS-120. Some experimental hybrids out yielded the best control cultivar by over 100% (Saxena *et al.*, 1989). Anand Kumar (1990) evaluated ICPH-8 along with ICPH-11 and seven other hybrids and observed yield increase upto 22% over best control, Pusa 33. Hybrids had more branches and pods as compared to the controls. In another study, heterosis under irrigated conditions ranged between 17% to 67% as compared to 0 to 45% under non-irrigated conditions. Based on it, it appears that hybrids adapted to specific situations may have to achieve high yield. Jain and Saxena (1990) observed that 11 medium duration hybrids from crosses between ms 3783 and advanced breeding lines had significantly higher yield than control, C11 variety. All hybrids also exhibited positive heterosis for plant height, seeds/pods and seed yield. Patel *et al.* (1993) studied 60 pigeonpea hybrids involving three genetic male sterile lines and respectively, eleven and nine medium and short duration pollinators, these hybrids significantly exceeded their parents for harvest index. Identification of stable genetic male sterility aroused the interest in the development of F_1 hybrids in pigeonpea (Sandhu *et al.*, 1994). In the experimental hybrids numerical superiority over best check, over the years ranged from 1 to 39%. In the experimental hybrids yield gain upto 50% over best check have been reported by various workers. Shrivastava and Khan (1994) studied eight hybrids of *Cajanus cajan* and their pollen parents and seed parent (ms3783) for seedling morphology upto 6 days after germination. An analysis of variance showed significant differences between the hybrids and their parents for radicle length on the 2nd day but not for root length on days 4 and 6, plumule length or epicotyl length. Heterotic response for root characteristics was highest on the 2nd day, decreasing gradually on the 4th and 6th days. Heterosis for epicotyl length and plumule length was poor compared to that for radicle and root length based on mid-parental values. A positive heterotic response was noted for radicle, root, plumule and epicotyl length.

Gowda *et al.* (1996) noted significant positive heterosis for grain yield in hybrids viz., AKPH 9071 (181.79%), AKPH 4186 (151.03%) and KBPH1 (119.46%). Superiority of early pigeonpea hybrids was due to significant and positive heterosis for number of pods per plant. So higher yield could be harvested from early pigeonpea hybrids. Twenty four pigeonpea hybrids, derived from crosses between 3 genetic male sterile lines (AKMS2, AKMS 11 and AKMS 21) and 8 diverse testers (ICP 8863, ICPL 87119, BSMR 175, BSMR 736, BWR 171, AKT 9221,C11 and BDN2) were studied by Khorgade *et al.* (2000), significant heterosis was observed in all traits studied. Significant heterosis over the mid-parent and control cultivar was recorded for seed yield per plant in the hybrids, AKMS 11 x AKT 9221, AKMS 11 x C11 and AKMS 21 x C11.

Out of seventy one the highest grain yield of 2314 kg and 3981 kg. ha^{-1} was recorded in the main crop from the hybrid, NDPH 94-20 and RAUPH 9507, respectively. However, from of ratoon crop, the highest grain yield of 1413 kg and 1300 kg ha^{-1} was recorded from the hybrid RAUPH 9001 and RAUPH 9501, respectively while the check variety, Bahar produced 1326 kg and 1285 kg ha^{-1}, respectively in main and ratoon harvest. Thus, raising of ratoon crop in long duration pigeonea hybrids in the northern part of India may not be profitable (Pandey, 2000). Pathak and Sidhu (2001) noted as high as 5 t ha^{-1} yield from some of the hybrids which signify a break through in yield of the hybrids. Sidhu *et al.* (2001) observed more than 25% heterosis over the check hybrid PPH-4 with regard to grain yield. An analysis of these top 10 hybrids further revealed that high heterosis for yield appeared to be related with high heterosis for some of the yield components.

Component analysis of hybrids

Component analysis of hybrids have shown high yield in the heterotic crosses to be closely associated with heterosis for pods per plant, number of primary branches, plant height that all contribute to increased total biomass (Reddy *et al.*, 1979, Marekar, 1981, Venkateswarlu *et al.*, 1981, Saxena *et al.*, 1986, Cheralu *et al.*, 1989). Compton (1977) suggested that inbreeding depression is better evidence of dominance than heterosis. With the discovery of genetic male sterility in pigeonpea (Reddy *et al.*, 1978; Saxena *et al.*, 1983) and the presence of natural outcrossing, it has been possible to breed hybrid pigeonpea varieties. In order to justify a major thrust in a breeding porgramme on F_1 hybrid development, a large dominance variance is essential. Heterosis, which can result from all types of non-additive gene action, such as additive x additive, need not necessarily indicate a high level of dominance. In pigeonpea inbreeding depression does not seem to be significant (Nene *et al.*, 1990). Therefore, in all theoretical probabilities, it is possible to select pure lines equal in performance to F_1 hybrid i.e. may be possible to fix a considerable part of the observed heterosis.

In a study of about, 60 medium maturing hybrids, as a result of high heterosis for pods, plant height and branches, many hybrids showed significant heterosis for seed yield/plant (Patel *et al.*, 1991). Heterosis for seed yield over better parent was highest in crosses, MS3A x ICPL 78-1 and MS Prabhat x ICPL 384 (80 and 78%, respectively) when compared with the standard variety BDN-2. Omanga *et al.* (1992) estimated high GCA variance than SCA for yield, pods, seeds/pod, seed size and days to flowering in hybrids using MS-3A, MS-4A and MS-Prabhat, male sterile lines. MS-Prabhat appeared to be a good general combiner for dwarfness, earliness and seeds/pod. Tester, C11 appeared to be the best general combiner for yield. Patel and Patel (1992) observed high SCA effect for seed yield in the hybrid MS Prabhat x HY3A. Patel and Patel (1992) noticed predominance of additive gene effects for days to maturity and 100-seed weight and of non-additive effects for yield, branches, pods and seeds per plant in hybrid ms Prabhat x HY3A. They further revealed major role of additive genetic variance for days to maturity and 100-seed weight and that of non-additive genetic portion for seed yield per plant, branches, pods and seeds/pod.

Sidhu *et al.* (1992) recorded information on reciprocal cross effects (RCE). Significant GCA, SCA and RCE differences were observed for all characters except seed weight, where, only GCA effects were significant. Narladkar and Khapre (1994) accounted significant heterosis in hybrid MSHY9 x BDN 2 over the better parent, standard hybrid ICPH-8 and standard variety BDN 2 for grain yield. Patel *et al.* (1993) studied 60 pigeonpea hybrids involving three genetic male sterile lines and revealed importance of both additive and non-additive components of genetic variance in the inheritance of harvest index, days to flowering, plant height and reproductive period. The non-additive portion was also pre dominant for all the traits except days to flower where additive genetic variance played a major role. Singh *et al.* (1995) revealed that the maximum weight should be given to pods and primary branches during selection. In general, cross combinations involving parents of different growth habit expressed high heterosis and low inbreeding depression, whilst cross combinations involving parents of similar growth habit exhibited low heterosis and high inbreeding depression for most of the traits (Gumber *et al.*, 1996). Narladkar and Khapre (1996) studied that hybrids exhibiting more heterosis for grain yield was high in crosses involving male sterile line MSHY-9 as the female parent rather than male sterile Prabhat. Manifestation of heterosis for grain yield was due to days to maturity, lower height of first effective fruiting branch and increased number of primary branches and pods/plant.

A study involving three male sterile lines, CMS Prabhat, PMS-1 IMS-1 and 11 diverse pollen donor lines of pigeonpea exhibited preponderance of additive genetic effects for plant height, primary branches, secondary branches and pods/plant. Non-additive gene effects were noted for flowering, maturity, seeds/pod and 100-seed weight, while both additive and non-additive gene effects were present for pod bearing length of main stem and seed yield/plant (Sidhu *et al.*, 1996). Three top yielding hybrids, PMS 1 x AL688, MS Prabhat x AL 101 and MS Prabhat x AL 259, gave the highest SCA effects for seed yield and out yielded the control hybrid PPH-4 by a margin of 67.9, 34.9 and 17.5%, respectively (Sidhu *et al.*, 1996). Dhedhi *et al.* (1997) observed a significant role of additive and non-additive gene action in a combining ability study of 50 hybrids based on 5 GMS lines and 10 short duration lines. In general, hybrids having high heterotic estimates for seed yield included both or at least one good combiner parent. In a line x tester study, Ajay Kumar and Srivastava (1998) found 77.91% to 110.07% heterosis over better parent for seed yield in hybrids involving three male sterile lines and twelve male fertile (Pollen parents) of long duration. Gene action was predominating non-additive for the characters studied.

Chandirakala and Raveendran (1998) observed significance of both gca and sca variances for yield and yield contributing traits, Two hybrids MS CO5 x ICPL 87 and MS CO5 x ICPL 89020 were also identified as superior hybrids. Significant heterosis over better parent was observed in all traits except pod/cluster (Manivel *et al.*, 1998). The analysis revealed that both additive as well as non-additive gene effects were important for all the traits. Male sterile line MS Prabhat NDT was the best combiner for yield/plant. Most of the crosses exhibiting high sca effects involved one good and other medium or negative combiners. Thus, crosses involving diverse parents and showing high sca effects for yield/plant could be successfully utilized for exploitation in pigeonpea improvement. Wanjari *et al.* (1998) studied combining ability using 4 male steriles and 6 diverse pollinators. The cross MSP3 x AK22 was highest yielder and involved both the parents having high gca effects. It was likely to be an additive x additive combination, while second hybrid MSP9 x AK 31 was produced from the parents each of which had negative gca. It had expressed high heterosis (58.82%)

over the better parents. Singh *et al.* (1999) studied twelve male sterile hybrids and noted pods/plant as the most important yield contributing trait was number of pods/plant. Studies carried over by Hooda *et al.* (2000) on forty hybrids indicated that heterosis and epistasis were independent of each other. Anyone or both parameters can be exploited for the improvement of yield and its components in pigeopnea. A study involving three genetic male sterile lines and eight testers of pigeonpea indicated the predominant role of additive gene effects for yield and yield attributes except plant height (Khorgade *et al.*, 2000). AKMS 21 was best general combiner for number of clusters per plant, protein content, 100-seed weight and number of seeds per pod. In a line x tester study using male sterile lines, additive gene effects were predominant for inheritance of plant height, pods per plant, seed size, whereas, non additive gene effect appeared to be more important for other characters (Sidhu *et al.*, 2000). Among females, ms Prabhat (DT) was a good combiner for early maturity, plant height, primary branches, seeds/pod, seed size and grain yield. Ajaykumar *et al.* (2001) studied three genetic male sterile lines and nine diverse testers of early duration and revealed that non-additive genetic variance chiefly controlled the expression of yield/plant and attributes such as primary branches, pods/plant, seed/pod, 100-seed weight, whereas, additive genetic variance predominantly governed the expression of days to 50% flowering and plant height. Among male sterile lines ms Prabhat DT and ms Prabhat NDT were good general combiners and among testers ICPL 88001 was best general combiner for yield.

Stability of hybrids

The first pigeonpea hybrid ICPH 8 was released during 1991 by ICRISAT in collaboration with All India Coordinated Pulses Improvement Project of ICAR and is recommended for cultivation in central zone comprising Maharashtra, Madhya Pradesh and Gujrat. The hybrid matures in 115-135 days giving a yield advantage of 41-52% over other varieties in cultivation (Srivastava *et al.*, 1994). However, a significant impact is yet to be noticed on farmers field. Thus, much remains to be done even after selecting a good heterotic combinations. The factors such as stable performance, environmental factors, improved seed and pollen parents, resistance to prevalent diseases and pests, seed production research and on farm research have to be given due emphasis in future research. Vanniarajan *et al.* (1997) noted that hybrids with high mean values for plant height, branches/plant, 100-seed weight and seed yield/plant were more responsive to favourable environments but unstable in changing environments.

Manivel *et al.* (1998) studied phenotypic stability of 40 hybrids and 14 parents grown over three environments. The hybrids, MS Prabhat NDT x Pant A2, MS Prabhat NDT x ICPL 161 and MS Prabhat NDT x DM1-5 were found stable under three fertility levels as they had high mean and regression coefficient not deviated from unity and non-significant, minimum deviation from regression. Pandey and Singh (1998) noted significant hybrid x year interaction for seed yield. Both linear and non linear components of H x Y interaction played important role in the expression of seed yield It was observed that RAUPH 9117 and RAUPH 9003 were adaptable to all environments, while the hybrid RAUPH 9122 and RAUPH 9127 were suitable for rich environments. Primary branches and pods were the prime contributing characters to seed yield in short duration pigeonpea hybrids.

Genotype x environment interaction, effects were also assessed by Saxena *et al.* (2001) for seed weight and grain yield of 12 pigeonpea pea hybrids and lines *viz.*, (ICPH 8,

ICPH 11, ICPH 13, ICPH 15, ICPH 16, ICPH 22, ICPH 149,ICPH 328, UPAS 120, Manak, Pusa 33 and Co 5 tested in 11 environments distributed in Andhra Pradesh, Maharashtra and Haryana. Pattern analysis was applied to identify the grouping of hybrids and environments. For seed weight, the hybrid grouping was based on the genetic make-up of the hybrid or pure line. The environment did not reflect any specific pattern. For grain yield, hybrids and pure lines responded differently as separate groups, and hierarchical separations reflected the mean performance of genotypes. Environmental and hybrid groupings revealed a distinct pattern of GE interaction based on soil types. Black and non-black soil environments emerged as two distinct groups discriminating hybrids differently. Hybrids and controls showed specific adaptation to particular environments, emphasizing the need to breed for location-specific hybrids.

Management of biotic and abiotic stress in hybrids

The major effort so far on management of pigeonpea diseases has been in the area of utilization of host plant resistance mechanism in cultivars. Though, good progress has been made in the development of cultivars with resistance to major diseases such as ICP 8863 for wilt, Bahar for sterility mosaic and ICPL 87119 (Asha), DA11 with multiple disease resistance. In all the three major pathogens affecting pigeonpea, i.e. *Fusarium udum*, SM pathogen/mite vector and *Phytophthora drechsleri* f. sp. cajani (pdc), physiological specialization exists and this aspect needs to be taken care in future research programmes in order to sustain the benefits of the presently available disease resistant cultivars. In short duration hybrids, phytophthora blight is a serious problem and resistance for this disease needs to be incorporated in the background of wilt and SM resistance. Gradual increase in the incidence of macrophomina stem canker in late types neccessitates adequate attention on this disease. Rathnaswamy *et al.* (1998) observed that no hybrid was resistant either to pod borer or pod fly. It was also noticed that the hybrids exhibiting pronounced incidence of pod borer recorded lesser infestation of pod fly. Govil *et al.* (2001) recorded genes for wilt and sterility mosaic disease resistance besides male sterility in two early maturing breeding lines *viz.*, ICPL 83024 (DT) x ICPL 86023 (IDT). These lines were used as one of the parents in hybrid breeding programme in order to provide resistance in the hybrids besides yielding capacity.

Hybrid should also be tolerant to water logged conditions. Results revealed that tolerance was controlled by a major gene or genes, but the variation in the diversity and the length of adventitious roots and hypertrophied lenticals indicated that the tolerant reaction was also influenced by major gene complexes (Perera *et al.*, 1998). Pigeonpea hybrid COH-1 was tested with eight treatments *viz.*, inorganic N and P, enrich, FYM, rhizobium seed treatment foliar application of DAP, NAA, KCL and various combinations of these. Results revealed that the highest grain yield (970 kg/ha) was recorded when 25 + 50 kg N + P was applied alongwith FYM @ 6t/ha (basal) coupled with 750 kg of enriched FYM apart from Rhizobium seed treatment and foliar spray of 25 kg DAP/ha, twice.

In a study gypsum, Pyrite, phosphogypsum, elemental sulphur and single super phosphate as sources were applied on hybrids (Rajendra *et al.*, 1998). The results revealed that, gypsum registered maximum plant dry matter production, leaf area index, plant height, pods/plant and grain yield.

In our efforts to bring stability in hybrid production, we have to incorporate multiple resistance to these adversities such as fusarium wilt, sterility mosaic, phytophthora blight as for as disease are concerned and pod borer, *Helicoverpa armigera,* Maruca, pod fly are the major insect-pest. Abiotic factors also play a major role in limiting production such as excess moisture in rainy season and low temperature at podding stage. Excess of salts in soil or water also affects the growth of plants. Long term programmes are necessary for the incorporation of genetic resistance to various factors as for as possible by Pyramiding the genes. Biotic and abiotic stresses affect the yielding ability of hybrids as well as depending upon the crop stages at which the crop is subjected to these stresses. In depth physiological information on control mechanism(s) for these multi adversities varieties can help in reducing their adverse effects in target environments. Genetical approach based on physiological traits along with empirical selection for yield is feasible for improving the yield structure of hybrids in targeted environment.

Released hybrid in pigeonpea

ICPH-8 is a first high yielding short duration hybrid maturing in about 140 days. It is indeterminate in growth habit and produces profuse primary and secondary branches. ICPH-8 has also been found to perform well under drought conditions. It was developed by heterosis breeding in the cross MS Prabhat-DT x ICPL 169 at ICRISAT.

Another hybrid PPH-4 is released by Punjab Agriculture University, Ludhiana in 1994 by using heterosis breeding in the cross MS Prabhat DT x AL 688. Hybrid plants show profuse branching, 2.5 to 2.75 m. tall and disease resistant. It matures in 145-147 days. Hybrid, IPH-732 is released by Tamil Nadu Agriculture University, Coimbatore. It is developed from the cross MST-21 x ICPL 87109. The hybrid is of indeterminate growth habit and matures in 115-120 days. It has good cooking quality and 22% around protein. AKPH-4101, a short duration hybrid has been identified for central zone of the country. It is a F_1 hybrid of AKMS-4 x AK-101. The hybrid has been found to have 64% superiority over UPAS 120 and 25% over ICPH-8. It has indeterminate flowering, semi spreading branches, medium bold, reddish brown seeds and matures in 140-145 days. The seeds have around 21% protein and 70% dhal recovery. Its average 100-seed mass is 8.3 g.

Hybrid seed production in pigeonpea

Mass transfer of pollen grains from pollinator to male sterile line in pigeonpea is caused by insects. In most places in India the extent of natural out crossing is sufficient to produce abundance of hybrid seeds on the male sterile plants. A distance of 300-400 meters is very safe for producing seeds of hybrids as well as of male sterile lines. The recommended planting ratio is 1 pollinator to 6 female rows (Saxena and Ariyanayagam, 1991). Plant the first row with the pollinator parent, thereafter, repeat planting, 60 cm apart, the pollinator at every 7th row. The intra-row spacing should be 10 cm. The rows between the pollinator rows should be planted with the male sterile parent at a spacing of 10 cm. Start roguing in the male sterile rows, as sterile plants will have white anthers and no pollen grains, while the fertile plants will have yellow anthers with abundance of pollen grains. The flowering in the male sterile lines is spread over a 15-20 days period. Roguing is an expensive operation and about 200 mandays will be required to rogue one hectare land young pods developed in the pollinator rows should be removed periodically to ensure continuous supply of pollen grains for effective hybridization. Pick mature hybrid pods from the male sterile rows only. Besides the main crop, within a year, 2-3 ratoon crops can be harvested at the interval of 45-50 days. Verma *et al.* (1993) observed that removal of fertile plants from rows designated as females and MS ones from rows designated as males at flowering ensured better control of seed quality. The seed for maintenance of the control of the MS line was harvested only from the maternal (MS) plants. Ravikesavan *et al.*, 1995 worked out cost of hybrid seed as Rs 67.9/kg. However, he visualized that cost of producing hybrid pigeonpea seed could be brought down by increasing the yield of hybrid seed.

Seedling markers in hybrid seed production

Hybrids based on GMS have been developed and released in India for cultivation. The effective hybrid seed production needs clear identifying dominant characters with each parents. Efforts were, therefore, made to isolate different seedling markers. Some of them were derived from interspecific crosses, while others were from germplasm derived spontaneous mutations. Seven seedling markers *viz.*, Green (I) Epicotyl (II) Broad long pair of plumule covering leaves (III) Broad short pair of plumule covering leaves (IV) Narrow short pair of plumule covering leaves (V) unifoliate first leaf after the pair of plumule covering leaves (VI) Dark pigmented (brown) stem (VII) complete green stem. These seedling markers have been fixed and their genetic behaviour and linkage with sterility gene is in progress (Patil, 1998). These seedling markers may be useful for field test of hybrids and parents in future.

Ideal plant type concept in hybrid pigeonpea

Cytoplasmic male sterile derived hybrids of determinate and indeterminate habit with few branches having small leaves with open canopy, small pods and seed size around 9-10 g/100 grains may be an ideal plant type in future hybrid. The immense genetic variability available makes it possible to evolve hybrids with very early to extreme late, dwarf compact to spreading plant type in future. Extra early and early hybrids could find a niche as a sole crop in areas with a seasonal rainfall of 500-800 mm. The expected yield is 1 t-2 t ha^{-1}. The early types need about 1400°C d and 750°C temperature during vegetative and reproductive phases, respectively. The hybrid crop, could, therefore, fit into regions, where medium duration pigeonpeas are not grown and replace crops such as maize, which have similar agroclimatic requirements.

Role of hybrids and its impact on socio-economic aspects

India is the land of agriculturists and that 80 per cent of its population is agriculturally occupied. The fundamental function of an agricultural department is to enable the farmer to produce food for people and raw material for industry from the soil as economically as possible. In recent decades, India has fortunately relied more on increasing the yield potential of crop plants by development of hybrids or improving the plant structure than on expansion of cropped area to feed their populations. Therefore, some important points of socio-economic aspects may be useful in adoption of pigeonpea hybrids.

- The response of hybrids to non-monetary inputs *viz.*, improved hybrid adoption, timely sowing, timely weeding, ridge planting etc. requires only the knowledge on the utilization of the material inputs at the right time and place and organization skill of the growers.
- Human labour is the highest single cost item in present day pigeonpea hybrid cultivation.
- The high annual fluctuations in prices of pulses indicating a higher risk might have turned the farmers away from pulses and in favour of other competing crops like oilseeds and cereals, which exhibit less price fluctuations.
- The non-availability of seeds of high yielding varieties and hybrids in desired quantity is the major constraint in the expansion of pulses like pigeonpea.
- In pulses there are a number of diseases

and insect pests, which cause heavy losses resulting in poor production even in hybrids.

- The area, production and productivity can be increased to manifold, if the improved technology, essential inputs and credit are made available at proper time to the farmers.
- Various constraints experienced by pulse growers are the major cause of sharp declination of production, productivity and acreage of pigeonpea. Hence, there is an urgent need to channelize our efforts to popularize pulse crops among farmers.

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