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Commercial pigeonpea hybrids are just a few steps away

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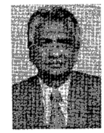
ABSTRACT

The long cherished goal of pigeonpea (*Cajanus cajan* (L.) Millsp.) breeders has been to break the yield barrier in the crop. This indeed is a difficult task, as the productivity has remained low in spite of releasing over 100 varieties. Therefore, the alternative breeding approach such as hybrids, which has been effectively used in many crop species, was attempted for enhancing yield. This is because pigeonpea is a unique legume with partial insect-aided natural out-crossing. ICRISAT began research on this breeding approach in pigeonpea and in 1991, ICRISAT along with Indian Council of Agricultural Research (ICAR) released the world's first genetic male-sterility (GMS) based pigeonpea hybrid ICPH 8. This was followed by the releases of five additional GMS-based hybrids. These hybrids performed well and in spite of their 25 – 40% superiority in yield they could not be commercialized because of their tedious and inefficient seed production technology. These developments, however, encouraged ICRISAT to breed a more efficient cytoplasmic-nuclear male-sterility (CMS) system that would overcome the seed production bottlenecks of GMS-based hybrids. In the last 14 years ICRISAT and ICAR have made a significant progress in developing five CMS systems using the cytoplasm of the wild relatives of pigeonpea. Among these, A_2 and A_4 CMS systems are being used in developing the new generation of pigeonpea hybrids. A number of new experimental hybrids have exhibited over 50% hybrid vigour for seed yield. The CMS-based hybrid pigeonpea technology is new and intensive efforts are needed to (i) identify heterotic hybrid combinations, (ii) diversify nuclear base of parental lines, (iii) train human resources, and (iv) expand seed production and marketing systems. So far the progress in the mission of breeding high-yielding CMS-based pigeonpea hybrids has been tremendous and we believe that the reality of commercial hybrids is just a few years away from now.

Key words: Pigeonpea, Hybrid, Fertility restorer, cytoplasmic-nuclear male-sterility, male-sterility maintainer



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At present, Dr. Saxena is leading a global project on hybrid pigeonpea. Besides this, he is actively involved in promoting pigeonpea in China, Nepal, India, Africa, and the Philippines.

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is a short-lived perennial shrub but traditionally it is cultivated as an annual crop in Asia, Africa, Caribbean region, and Latin America. Considering the vast natural genetic variability in pigeonpea and presence of its wild relatives in the region, it has been postulated that India is the primary centre of origin of pigeonpea (31). It is a hardy, widely adapted, and drought tolerant crop. The short-duration (100 – 140 d) cultivars are cultivated as sole crop while the medium (160 – 180 d) and long-duration (> 200 d) landraces and cultivars are invariably grown as intercrop or mixed crop with other short-duration crops. Besides its main use as *dhal* (dehulled split peas), its immature green seeds and pods are consumed as vegetable. The crushed dry seeds are fed to animals while green leaves form a quality fodder. The dry stems of pigeonpea make an excellent fuel wood. Pigeonpea is also grown on mountain slopes to reduce soil erosion (15).

Globally, pigeonpea is cultivated on 4.58 million hectares of land with an annual production of 3.27 million tonnes and productivity of 714 kg ha^{-1}. India is the major pigeonpea growing country and it accounts for 3.5 million hectares area and 2.4 million tonnes of production. The pigeonpea area, production, and productivity trends in India in last five decades show that there was about 2% increase in the area per year but the yield levels were stagnated around 600 –700 kg ha^{-1}.

PRIMARY PRODUCTION CONSTRAINTS

The per capita availability of pigeonpea in India is gradually declining and one of the main reasons for this is widening of demand and supply gap due to mismatch in the growth of human population and production of protein-rich pulses. Though India ranks first in area and production of pigeonpea, the average productivity of the crop is low at around 650 kg ha^{-1}. Some of the reasons identified for the low productivity are (i) non-availability of quality seeds of improved varieties in adequate quantities, (ii) biotic stresses such as sterility mosaic and wilt diseases and insects like podfly and pod borers, (iii) abiotic stresses such as drought, water-logging, and salinity, (iv) low inputs and poor crop management, (v) disadvantageous and inappropriate row ratios of pigeonpea component in various intercropping combinations, and (vi) inappropriate selection of variety with respect to maturity. Besides these, there are some socio-economic factors also, which contribute to low productivity of the crop. These are, low profitability relative to competing crops or companion crops in the intercropping situations, high inter- and intra-year variation in market prices, lack of information on quality standards affecting pigeonpea production at the farm level, and lack of resources for cultivating improved varieties in small rainfed farms.

The subsidiary status of pigeonpea given by farmers and the government is another important factor. In general, farmers tend to allocate pigeonpea to more marginal areas since it can adapt well to resource deficient situations. Research efforts are in progress to overcome these production constraints of pigeonpea by incorporating genetic resistances, breeding of better varieties, and developing better resource management technologies. To achieve the benefit of these technologies, it is essential that significant emphasis be given to extension, input pricing policies, and marketing opportunities. Among abiotic stresses, water-logging during vegetative stage, cold sensitivity during flowering stage, drought during grain filling stage, and salinity/alkalinity through out the crop growth period may inflict losses in yield, stability in its production because the genetic resistance is lacking. Some of the inherent physiological factors such as low initial crop growth and low harvest index also limit its realized seed yield. In pigeonpea so far about 100 varieties have been released for cultivation in different areas but the adoption of new varieties seem to be limited and greater efforts are needed in future to popularize new varieties and support their seed production and distribution systems.

HYBRIDS FOR QUANTUM YIELD GAINS IN CROP PLANTS

In order to maintain self-sufficiency in food production for the increasing population, a proportionate increase in its production is essential. In this endeavour, the use of hybrid technology in a number of cereals, fruits, and vegetable crops has provided the needed respite. Koelreuter was the first to report the advantage of hybrids. Since then many researchers have reported hybrid vigour in a number of plant species. Most of our understanding on heterosis comes from the research on maize. It has been observed for the first time that certain F_1 hybrids yielded > 40 % grain than its parental varieties (4). Since then many commercial hybrids have been bred and cultivated in a number of crop species. At present, the hybrid technology is well established and is being commercially exploited in a number of field (cotton, pearl millet, sorghum, castor, rice, *etc.*) and vegetable crops.

Among field crops, the phenomenon of heterosis has been predominantly exploited in the cross-pollinated crops by developing open-pollinated synthetics, composites, and/or hybrid varieties. Since dominant genes in natural random mating populations have evolutionary advantage (8), the heterosis was initially considered a discernible phenomenon of only cross-pollinated crops but subsequently, the commercial exploitation of hybrid vigour in some other cereal and vegetable crops established its utility in the self-pollinated group of crops also. It was also reported that besides over-dominance and dominance gene actions for yield in both self- as well as cross-pollinated crops, the additive gene action and the additive x additive inter-allelic and inter-genic interactions also play an important role in the expression of hybrid vigour. The inherent pollination system of a crop, therefore, does not pose any restriction in the manifestation of heterosis. Since pigeonpea is a partially cross-pollinated crop and significant levels of both additive and non-additive gene actions for yield and yield components are available (20), a good scope for breeding commercial hybrids exists.

HYBRID VIGOUR IN PIGEONPEA

Considerable hybrid vigour over the mid-parent and better-parent has been reported for grain yield and other economic characters in a number of legume crops. To break the yield barriers in pigeonpea, one of the ways is to exploit the phenomenon of heterosis. The critical information on the occurrence and magnitude of additive and non-additive genetic variances, playing an important role in the manifestation of heterosis, is limited in pigeonpea. Solomon (27) was the first to report hybrid vigour in 10 inter-varietal crosses of pigeonpea. In some crosses they observed up to 24.5% heterobeltiosis for grain yield together with that of various agronomic characters like plant height, number of fruiting branches etc. A number of reports have been published on hybrid vigour for yield and yield components (20) and most of these reports are from experiments conducted in a single environment, and such estimates could suffer from considerable bias due to genotype x environment interaction and may give an impression of 'pseudo-heterosis'. This bias is considerably accentuated if a particular phenological group is better adapted to the test environment (16). The development of a three-line system of hybrid breeding in pigeonpea is helping in the production of high yielding hybrids. The primary data from the experiments conducted at ICRISAT and various ICAR centres show that now the technology for exploiting heterosis at commercial level is available, which could be exploited effectively to breed heterotic hybrids.

EARLY RESEARCH IN BREEDING PIGEONPEA HYBRIDS

A perfect male-sterility in the female parents in conjunction with natural out-crossing make the hybrid seed production easy and affordable. In pigeonpea, the first systematic effort to search a stable male-sterile system that could be used in hybrid breeding technology was made by Reddy and coworkers (13). They identified a translucent anther type male-sterile that is controlled by a single recessive gene. Later, Saxena and his associates (26) also reported another source of stable GMS system, characterized by brown, shriveled and arrowhead anthers. Soon after identifying these GMS systems, studies were conducted to assess the (i) effectiveness of natural cross-pollination in setting pods on the male-sterile plants, (ii) extents of heterosis in different maturity groups, and (iii) seed production cost of hybrids and their parents. The results of these studies indicated that under field conditions sufficient level of cross-fertilization occurs, and large quantities of hybrid seed could be produced using the male-sterile populations. Further, to identify productive hybrids, over 10,000 experimental hybrids were produced by hand-pollinations and evaluated at a number of locations and some of the hybrids exhibited standard heterosis (superiority over the control) of over 100% or more. The evaluation of early-stage experimental hybrids demonstrated that in pigeonpea sufficient level of heterosis is available for yield that could be exploited through commercial hybrid breeding. The experience at ICRISAT suggested that a row ratio of 6 female : 1 male rows and an isolation distance of 400 m would be ideal for the production of quality hybrid pigeonpea seeds. The detailed seed production studies indicated that the estimated cost of hybrid seed was Rs 6.25 kg^{-1} in Coimbatore (11) and Rs 13.8 kg^{-1} in Ludhiana (32). These studies also showed that the cost of producing hybrid seed could be reduced further under good agronomic management (17).

In the initial efforts, the GMS lines of different maturity were used to develop commercial hybrids. Since in any pulse crop no commercial hybrid was available, the release of the world's first pigeonpea hybrid ICPH 8 jointly by ICRISAT and ICAR in 1991 (22) is considered a milestone in the history of breeding food legumes. Evaluation of hybrid ICPH 8 in multilocation trials showed that the hybrid was superior to the control UPAS 120 by a margin of 41% (Table 1). In 1993, the Punjab Agricultural University (PAU), Ludhiana identified another short-duration pigeonpea hybrid PPH 4 and it out yielded the control variety by 14% (32). In 1994, another short-duration hybrid CoH 1 was released by the Tamil Nadu Agricultural University (TNAU), Coimbatore, and it recorded 32% higher yield over the control (10). In 1997, TNAU released another pigeonpea hybrid CoH 2, which out yielded the control by 35%. Two more pigeonpea hybrids were released by Dr Punjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola. The hybrid AKPH 4104 was 64% superior to control while AKPH 2022 recorded 35% superiority over the respective controls.

Table 1. Genetic male-sterility based pigeonpea hybrids released in India

Hybrid	Year released	Days to maturity	Grain yield (kg ha^{-1})	Superiority over control
ICPH 8	1991	125	1780	41 % over UPAS 120
PPH 4	1994	137	1930	14 %over UPAS 120
CoH 1	1994	117	1210	32 %over Vamban 1
CoH 2	1997	120-130	1050	35 %over Co 5
AKPH 4104	1997	130-140	NA	64 %over UPAS 120
AKPH 2022	1998	180-200	NA	35 %over BDN 2

NA = Data not available
Source: Compiled from various reports and publications.

ADVANTAGES OF HYBRIDS

Enhanced biomass and yield

Inherently, pigeonpea is known to be a slow starter, which makes it a poor competitor, particularly in the early stages of growth. In farmers' fields it generally encounters tough competition with rainy season weeds and companion crops during the first 50-60 days, which results in poor canopy development and low yields. In comparison to pure line cultivars, the pigeonpea hybrids have more plant vigour (22). The differences in the plant vigour between hybrids and pure line varieties begin to appear during early seedling stage and they become more pronounced with time. This attribute of pigeonpea hybrids will make them more suitable under the competitive situations described above. The hybrid plants establish themselves firmly and utilize sunlight, soil moisture and other resources more efficiently. In an experiment conducted at ICRISAT the one-month-old seedlings of hybrids produced 44% more shoot mass and 43% more root mass than pure line cultivars (6). The pigeonpea hybrids also exhibited high crop growth rates while maintaining their partitioning at least at the same level as that of varieties. Thus the hybrids are capable of producing large plants (Fig. 1) as well as more grain yield.

Reduced seed rate

Limited agronomy studies conducted at ICRISAT (6) indicated that the hybrid plants exhibit greater plasticity at plant populations ranging from 16 to 66 plants m^{-2} without adversely affecting their grain yield advantage. This implies that in comparison to the commonly grown varieties the seed

Fig 1: Comparision of seedling vigor in hybrid and control

requirements of the hybrids could be reduced by a significant margin. This is an important attribute of hybrids as the hybrid seed input cost to the farmers will remain within affordable limits of resource poor pigeonpea farmers. The detailed studies with recently developed CMS-based hybrids in different maturity groups are needed to develop an efficient hybrid production package.

Greater disease resistance

Fusarium wilt and sterility mosaic are two important diseases of pigeonpea in India. Together, they cause tremendous yield losses every year. In general, medium- and long-duration types are more prone to these biotic stresses. Our limited experience has shown that pigeonpea hybrids encounter the menace of diseases more efficiently than pure line cultivars. Evaluation of some wilt and sterility mosaic resistant pigeonpea hybrids and pure line cultivars in disease-free as well as disease-sick fields indicated that in the hybrids as well as varieties the level of disease resistance expressed in the disease-sick field was expectedly high with <1.0% incidence. However, hybrid vigour for yield under disease-free and sick conditions differed grossly. Under disease-free conditions the hybrids on average were 19.7% superior to the varieties. On the contrary, in the disease sick field, the level of yield superiority enhanced to 60%. It is, therefore, concluded that in addition to specific anti-fungal/viral resistance mechanisms of the genotypes, the hybrids have an extra degree of resilience that enables the plants to tolerate and produce more yield under severe disease pressure than non-hybrids.

Cytoplasmic - nuclear male-sterility systems

In spite of releasing six high-yielding pigeonpea hybrids at the national level and establishing their superiority in multi-location trials the GMS-based hybrids were not adopted neither by public nor by private seed sector. Niranjan and coworkers (12) assessed the reasons for this failure and identified constraints faced by the researchers, seed companies, and seed growers in the adoption of hybrid technology. They concluded that cost of the hybrid pigeonpea seed was within the affordable limits and the hybrid advantage was salable but the technology itself suffer with major bottleneck when it comes to large-scale seed production of female parents and hybrids. This important constraint, inherent with GMS-based hybrid technology, could be overcome if an efficient CMS-based hybrid seed production technology is evolved.

Considering the limitations in large-scale hybrid seed production encountered due to genetic nature of male-sterility and the prospects of hybrids in yield enhancement through breeding, the development of an efficient CMS system became necessary. The first attempt to develop a stable CMS system was made by crossing a wild relative of pigeonpea (*Cajanus scarabaeoides*) with a cultivated type (14). The male-sterile plants derived from this cross were found to have female-sterility also. Ariyanayagam and coworkers (3) crossed another wild relative of pigeonpea (*Cajanus sericeus)* with a short-duration advanced breeding line of pigeonpea. The F_1 was partially male-sterile and the backcross populations were found segregating for male-sterility. The reversion of some male-sterile plants to male-fertility or partial male-fertility further complicated the selection and stabilization of this trait. Intensive selection in the five subsequent backcross generations, however, resulted in the identification of a promising CMS line (25). At this time, various ICAR research centres also joined the efforts to develop CMS systems.

So far five primary CMS systems derived from various inter-specific crosses have been reported in pigeonpea. These are designated as (i) A_1 cytoplasm, derived from *C. sericeus* (25); (ii) A_2 cytoplasm, derived from *C. scarabaeoides* (30; 19); (iii) A_3 cytoplasm, derived from *C. volubilis* (33), (iv) A_4 cytoplasm derived from *C. cajanifolius* (24), and (v) A_5 cytoplasm derived from cultivated pigeonpea (9). Of these, the CMS systems with A_2 and A_4 cytoplasms have been found to be stable and are being used in the hybrid breeding programmes in India.

A_4 Cytoplasm – A boon to the hybrid breeding programmes

The recently developed CMS system at ICRISAT (24) has the cytoplasm of *Cajanus cajanifolius*, another wild relative of pigeonpea. This CMS system (Table 2) is designated as A_4 cytoplasm. This wild species is reported to be genetically closest to the cultivated type and differs only by a single gene (7). The male-sterile plants in this material show no morphological deformity and produce plenty of pollen grains in hybrid combinations with fertility restoring lines. This male-sterile source has been reported to be stable at Coimbatore (15°N), Hyderabad (17°N), Jalna (18°N), and Ludhiana (28°N) and it is capable of producing high-yielding hybrids. It was

Table 2. Segregation for male-sterility in F_1 of cross *Cajanus cajanifolius* × *C. cajan* and various backcross generations at Patancheru

Generation	Year	Environment	Number of plants		
			Total	Male-sterile	Male-sterility (%)
F_1	2000	Field	12	12[1]	–
BC_1F_1	2001	Glasshouse	8	8	100
BC_2F_1	2002	Glasshouse	5	4+1[1]	80
BC_3F_1	2002	Glasshouse	165	165	100
BC_4F_1	2003	Glasshouse	7	7	100
BC_5F_1	2003	Glasshouse	67	67	100
BC_6F_1	2004	Field	1133	1133	100
BC_7F_1	2005	Field	17286	17286	100

[1] Partial male-fertile.
Source: Saxena et al., (2005)

also observed at ICRISAT that the frequency of fertility restorers in this CMS source is higher than those of others. Therefore, A_4 CMS has a great potential for use in commercial hybrid pigeonpea breeding programmes.

SEED PRODUCTION TECHNOLOGY

Isolation distance

Pigeonpea is an often cross-pollinated crop. The extent of natural out-crossing in the crop is determined by insect activity, which varies from one place to another, therefore, the isolation distances should be specified for different agro-ecological areas. However, at present some safe and standard guidelines are essential to maintain the purity standards of the hybrids and their parents. Isolation distances for the seed production of pure line varieties recommended by various scientists range from 100 to 400 m. With a view to avoid the chances of out-crossing and produce high quality seed, it is suggested that specific studies be conducted using recently developed CMS lines. In the mean time, we continue to produce seeds of hybrids and their parents at the isolation distance of 300 – 400 m (17).

Seed production of hybrid parents

Nucleus seed production of parental lines constitutes an important part of hybrid seed production, since it determines their purity and quality. The details of seed production technology of hybrid and their parents are outlined by Saxena (18).

A-line: At the initial stage the nucleus seed of A-line is produced by growing both A- and B- lines inside an insect proof cage. Single plants of A- and B- lines, confirming to the standards of the lines are selected, and paired crosses made between single plants of A- and B- lines. The crossed seed set on the A-line plants and selfed seed on the B-line plants are harvested separately. For the production of breeder/foundation seed of A-line in large quantities, a field with appropriate isolation distance is selected and A- and B-lines are grown with recommended agronomic package. At ICRISAT, a planting ratio of 4 rows of A-line: 1 row of B-line has been found effective in producing pure seed of A-line. In the short-duration A-line, the mature pods on the male-sterile and fertile plants can be harvested by pod picking or by cutting the top pod-bearing portions of the plants. The perennial nature of species will force the plants to re-generate to produce a second flush of flowers and pods. In the seed multiplication of ICPA 2039 at ICRISAT we harvested 1100 kg ha^{-1} seed. Small quantities of B-lines seed can also be harvested from the same isolation.

B-line and R-line: For producing nucleus seed of B- and R-lines, pure seed lots of B- and R-lines are sown in separate isolations. About 100 plants should be harvested from the central portion of the seed production plot and their progenies be grown in the subsequent season. After assessing their purity aspects, the selected progenies should be bulked to serve as nucleus seed. For breeders and foundation seed production, the lines should be multiplied in separate isolations. Always sufficient care should be taken to rogue off-types as and when such plants are identified in any seed production plot.

Certified seed production of hybrid

The foundation seed of A- and R-lines is the source seed for producing hybrid seed. A- and R-lines should be grown in 4: 1 ratio in an isolated block. Some additional rows of pollen parent can also be sown on each side of the plot (Fig. 2). The main objective here is to establish the desired population of male parent to achieve the maximum crossed pod set and yield of hybrid seed. The pollinating insects visit

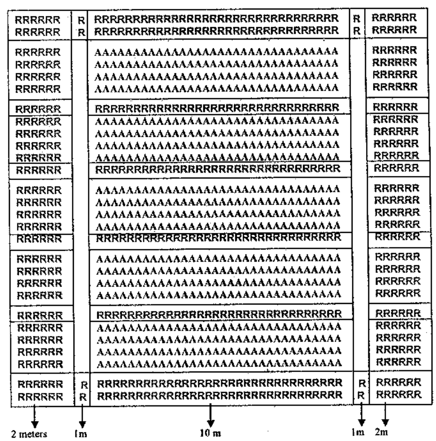

Fig 2: A standard field layout for hybrid seed production
A: CMS line R: Restorer line

the male and female flowers in a random fashion and in the process collect pollen from fertile plants and carry out hybridization on the male-sterile plants. At Patancheru, we harvested 1250 kg ha^{-1} seed of hybrid ICPH 2671 with a row ratio of 1 male: 4 female. This ratio, however, cannot be recommended for all the environments and depending on the insect activity and time of sowing, it should be modified.

Economics of hybrid pigeonpea seed production

So far no study has been conducted to determine the production cost of CMS-based hybrids and their parents. However, the studies on the economic feasibility of GMS-based hybrids showed that the hybrid pigeonpea seed could be produced with affordable costs (17). Experiments at ICRISAT have also demonstrated that adoption of multiple harvest system could reduce the hybrid seed production costs significantly.

Yield of new CMS-based pigeonpea hybrids

Hybrids involving A$_1$ *cytoplasm*

Sixteen long-duration hybrids based on A_1 cytoplasm were evaluated at Patancheru, during 2004 rainy season. Among these, hybrid ICPH 2319 (3017 kg ha^{-1}) was the best with standard heterosis of 61.3% over the best check ICPL 366 (Table 3). In the multi-location trial of medium-duration hybrids ICPH 2899 produced 3040 kg ha^{-1} grain ha^{-1} (Table 4). The other promising hybrids identified were ICPH 2307 (2727 kg ha^{-1}), ICPH 2900 (2514 kg ha^{-1}), and ICPH 2305 (2491 kg ha^{-1}).

Hybrids involving A_2 cytoplasm

During 2005 rainy season, experimental hybrids based on A_2 cytoplasm were evaluated at Patancheru. Among these, ICPH 3172 was found to be the best (Table 5). This hybrid recorded highest yield of 2725 kg ha^{-1} with 33 – 36 % superiority over the controls. The other high-yielding hybrids were ICPH 3176 (2453 kg ha^{-1}, 21% superiority) and ICPH 3184 (2447 kg ha^{-1}, 22% superiority over Maruti). Among the several hybrids tested by ICAR at three locations during 2005 by ICAR, SKNPH 202 was the best with a mean yield of 2479 kg ha^{-1} with 23.8% superiority over the control UPAS 120 (1851 kg ha^{-1}). The other promising hybrids identified by ICAR (Table 6) were SKNPH 309 (2455 kg ha^{-1}, 22.6% superiority), and SKNPH 6 (2269 kg ha^{-1}, 13.3% superiority).

Table 3. Performance of some long-duration pigeonpea experimental hybrids involving A_1 cytoplasm at Patancheru, 2004.

Hybrid	Grain yield (kg ha^{-1})	Days to		Plant height (cm)	100-seed mass (g)	Heterosis (%)
		flower	mature			
ICPH 2319	3017	140	176	233	11.8	61
ICPH 2307	2855	141	175	250	9.1	53
ICPH 2306	2600	141	176	275	10.2	39
ICPH 2896	2579	141	174	258	8.9	38
ICPH 2308	2383	139	179	245	9.4	27
ICPH 2310	2268	141	179	263	9.4	21
ICPL 366 (c)	1870	158	209	253	11.0	-
MAL 13 (c)	1407	164	206	230	10.4	-
SEm (±)	264.5	0.6	1.5	3.3	0.15	
CV (%)	16.4	0.6	1.2	1.9	2.02	

Table 4. Performance of some medium-duration pigeonpea experimental hybrids involving A_1 cytoplasm at JK Seeds, Medchal, 2004.

Hybrid	Grain yield (kg ha^{-1})	Days to		Plant height (cm)	100-seed mass (g)	Heterosis (%)
		flower	mature			
ICPH 2899	3040	122	192	185	11.0	138
ICPH 2307	2727	137	205	190	9.0	114
ICPH 2900	2514	137	192	184	11.0	97
ICPH 2305	2491	132	202	151	9.0	95
ICPH 2337	2117	123	190	188	12.0	66
ICPH 2336	2008	130	206	167	12.0	57
Maruti (c)	1276	111	168	177	9.0	-
SEm (±)	227.6	2.0	2.3	15.6	0.00	
CV (%)	15.1	2.3	1.7	12.7	0.00	

Table 5. Performance of some medium-duration pigeonpea experimental hybrids involving A_2 cytoplasm at Patancheru, 2005 rainy season

Hybrid	Grain yield (kg ha^{-1})	Days to		Plant height (cm)	Seeds pod^{-1}	100-seed mass (g)	Heterosis (%)
		flower	mature				
ICPH 3172	2725	126	162	215	4.1	9.0	36
ICPH 3176	2453	126	162	210	4.0	8.5	21
ICPH 3184	2447	131	168	192	4.0	9.5	22
ICPH 3172	2257	132	169	212	4.0	9.3	12
ICPH 3183	2183	129	162	218	3.7	11.5	9
Maruti (c)	2010	127	164	175	4.0	8.6	-
SEm (±)	374.6	0.9	1.9	14.1	0.11	0.36	
CV (%)	25.3	1.0	1.6	9.6	3.84	5.38	

Table 6. Grain yield (kg ha^{-1}) of pigeonpea experimental hybrids involving A_2 cytoplasm in multi-location trials in Gujrat, 2005

Hybrid	Location			Mean	Heterosis (%)
	SK Nagar	Khedbrahma	Navasari		
SKNPCH-202	2316	2464	2656	2479	24
SKNPCH-309	2825	2510	2031	2455	23
SKNPCH-6	2297	2479	2031	2269	13
UPAS 120 (c)	1851	1642	2031	1841	
SEm (±)	107.5	89.8	115.4		
CV (%)	10.1	8.6	10.8		

Source: Annual Progress Report 2005-06 of IIPR, Kanpur

Hybrids involving A_4 cytoplasm

Seven extra short-duration hybrids involving A_4 cytoplasm were evaluated at five locations, during 2005 rainy season. At Patancheru, ICPH 2438 (3414 kg ha^{-1}) was the best performing hybrid with 161% superiority (Table 7) over the control ICPL 88039 (1306 kg ha^{-1}). At Jalna, ICPH 2363 (3958 kg ha^{-1}, 126% superiority); at Manoharabad, ICPH 2429 (1577 kg ha^{-1}, 51% superiority); at Medchal, ICPH 2438 (2236 kg ha^{-1}, 204% superiority); and at Nagpur ICPH 2438 (3504 kg ha^{-1}, 61% superiority) were outstanding. Considering the overall performance ICPH 2438 ranked first with mean yield of 2893 kg ha^{-1} and mean superiority of 106% over the control ICPL 88039 (1403 kg ha^{-1}). The other promising hybrids were ICPH 2363 (2447 kg ha^{-1}, 74% superiority), and ICPH 2429 (2032 kg ha^{-1}, 45% superiority), and ICPH 2364 (1940 kg ha^{-1}, 38% superiority).

Table 7. Yield (kg ha^{-1}) of some extra-short duration pigeonpea experimental hybrids involving A_4 cytoplasm in Multilocation trial, 2005

Hybrid	Patancheru (ICRISAT)	Jalna (MAHYCO)	Manoharabad (Zuari Seeds)	Medchal (JK Seeds)	Nagpur (Ankur Seeds)	Mean	Superiority over control (%)
ICPH 2438	3414	3792	1518	2236	3504	2893	106
ICPH 2363	2736	3958	1012	2060	2471	2447	74
ICPH 2429	2177	2625	1577	2024	1758	2032	45
ICPH 2364	2375	2300	1101	1696	2229	1940	38
ICPH 2460	2454	2708	1429	1238	1479	1862	33
ICPH 2447	2369	2333	1161	1440	1650	1791	28
ICPL 88039 (c)	1306	1750	1042	736	2179	1403	-
SEm (±)	472.2	NR	149.3	288.5	197.6		
CV (%)	28.2	9.5	16.0	24.4	12.1		

NR- Not reported

Eight short-duration hybrids were evaluated at six locations during 2005 rainy season. The hybrids, ICPH 2432 (3037 kg ha^{-1}, 32% superiority) at Patancheru (Table 8), and ICPH 2433 (3591 kg ha^{-1}, 54% superiority) at Jalna, ICPH 2431 (1795 kg ha^{-1}, 20% superiority) at Manoharabad, ICPH 2433 (2250 kg ha^{-1}, 117% superiority) at Medchal, ICPH 2433 (3929 kg ha^{-1}, 47% superiority) at Jalna (Krishidhan), and ICPH 2432 (5376 kg ha^{-1}, 49% superiority) at Hyderabad were outstanding. On average ICPH 2433 (2996 kg ha^{-1}) and ICPH 2431 (2838 kg ha^{-1}) were the best and they out-yielded the control cultivar UPAS 120 (2245 kg ha^{-1}) by a margin of 33% and 26% respectively.

Twelve hybrids were evaluated at four locations, during 2005 rainy season (Table 9). Among the test entries hybrid

Table 8. Yield (kg ha^{-1}) of some short-duration pigeonpea experimental hybrids involving A_4 cytoplasm in multi- location trial, 2005 rainy season

Hybrid	Patancheru, (ICRISAT)	Jalna (MAHYCO)	Manoharabad (Zuari Seeds)	Medchal (JK Seeds)	Jalna (Krishidhan Seeds)	Hyderabad (Pradham Bio-tech)	Mean	Heterosis (%)
ICPH 2433	2190	3591	1720	2250	3929	4298	2996	33
ICPH 2431	2075	2958	1795	1357	3661	5181	2838	26
ICPH 2448	2442	1896	1304	1488	2810	4695	2439	9
ICPH 2432	3037	1404	1348	1167	1006	5376	2223	-0.9
UPAS 120 (c)	2307	2333	1500	1036	2679	3615	2245	-
SEm (±)	644.7	NR	260	224.6	289.3	574.8		
CV (%)	37.5	NR	28.7	23.1	17.2	18.9		

NR- Not reported

Table 9. Yield (kg ha^{-1}) of some medium-duration experimental pigeonpea hybrids in multi-location trials, 2005

Hybrid	Patancheru, (ICRISAT)	Jalna (MAHYCO)	Manoharabad (Zuari Seeds)	Medchal (JK Seeds)	Mean	Superiority (%)
						Asha
ICPH 2788	2525	4166	3238	3124	3263	64
ICPH 2740	2761	4041	2524	2936	3066	54
ICPH 3331	2216	3791	3476	3185	2917	47
ICPH 2671	2671	3416	2571	2996	2913	46
ICPH 2751	2171	3125	2381	3493	2793	40
ICPH 2744	2790	3146	3000	1901	2709	36
Asha (c)	1927	3124	1333	1570	1989	-
SEm (±)	207.7	NR	540.7	331.0		
CV (%)	13.7	7.3	32.2	21.1		

NR- Not reported

ICPH 2744 (2790 kg ha^{-1}) at Patancheru, ICPH 2788 (4166 kg ha^{-1}) at Jalna, ICPH 3331 (3476 kg ha^{-1}) at Manoharabad, and ICPH 3331 (3185 kg ha^{-1}) at Medchal were found promising. Based on overall performance the promising hybrid combinations were ICPH 2788 (3263 kg ha^{-1}), ICPH 2740 (3066 kg ha^{-1}), and ICPH 3331 (2917 kg ha^{-1}). These hybrids exhibited 47 - 64 % superiority over the control Asha (1989 kg ha^{-1}).

Taking pigeonpea hybrids to the doorsteps of indian farmers

We believe that the CMS-based hybrid technology is more or less ready and minor alteration in its seed production technology could be done to suit local environment. The level of hybrid vigor for yield observed in both GMS- as well as CMS-based hybrids conclusively demonstrated that the hybrids are a definite possibility in pigeonpea. The recent achievement of developing a stable CMS system further substantiates this view. Now, our major responsibility is to take this technology to our clients - the farmers. We expect that both small and large holding farmers will show interest in this product. However, since pigeonpea is predominantly cultivated by small resource-poor farmers, we need to keep the seed costs within the reach of our clients. In India both public and private seed sectors are very strong and they are effectively catering the needs of cereal and vegetable hybrid seeds. We, therefore, have to make use of both the seed channels for pigeonpea as well. Since it would be a new crop to them, we need to work hard in transferring the technology by identifying suitable hybrid combinations, demonstration of the technology, and training of human resources in research and seed production technology. Also, an important aspect of this endeavour should be to provide a range of early and advanced generation breeding materials including A/B lines, R-lines and primary source of germplasm to national agriculture research system and seed companies. This will help in strengthening their hybrid pigeonpea research base.

Selection of hybrid combinations

In India pigeonpea is grown under very diverse environmental conditions and cropping systems. Therefore, to derive maximum benefit of the hybrid technology, it is imperative to select appropriate hybrids. In broad terms, the country has pigeonpea varieties suitable for higher (> 25 ^{0}N), mid (16 - 25 ^{0}N), and lower (< 15 ^{0}N) latitudes. The present pigeonpea production scenarios at these latitudes are quite different. For example in Uttar Pradesh (3,68,800 ha area), traditionally long-duration varieties are grown and the average productivity is more than 1000 kg ha^{-1}. On the contrary in Andhra Pradesh (5,21,000 ha area), the pigeonpea productivity is around 300 kg ha^{-1}. The largest pigeonpea growing state in the country is Maharashtra with 1,046,000 ha planted each year. In this state the mean productivity of pigeonpea ranges around 600 kg ha^{-1}. These large differences in the productivity could be attributed to differences in soil type, evapo-transpiration, temperature, and photoperiod. All these factors together have a very strong influence on the canopy development, flower initiation, and maturity of the crop. In addition to the diversity in selecting the intercrops and their proportions is also extremely high to complicate the system in the farmers' fields. Therefore, to maximize the benefits for hybrid technology and make a strong impact, it is essential to i) identify the potential target environments and ii) select hybrid combinations of appropriate maturity. This will help in reducing the effect of terminal drought. This is more important for the southern and peninsular zones of the country where rainfall is limited and evapo-transpiration is high.

Research issues

For a long-term sustainable hybrid breeding programmes, continuous research inputs are essential. At present we recognize the following research issues, which need attention to cater the needs of the future.

- Search new cytoplasm donors to avoid the cytoplasmic vulnerability to major diseases and insects.
- Diversify the genetic base of parental lines to enhance the magnitude of realized heterosis and stability for yield.
- Trait based parental breeding programme especially for resistance to wilt and sterility mosaic diseases and seed quality traits.
- Study the strategic issues to enhance the efficiency and pace of hybrid pigeonpea research and development. This include identifying criteria for selecting hybrid parents, relationship between the performance of parents and hybrids, combining ability of parents, heterosis, and relationship between genetic / geographical diversity and heterosis.
- Refine the seed production technology to suit different agro-ecological situations.
- Molecular characterization of elite hybrid parents.
- Continue search for new research frontiers like genetic transformation by incorporation of *Bt*-genes to overcome the menace of pod borers.

Conclusions

Pigeonpea still remains a wild plant even after centuries of cultivation as it has retained its unique characteristics such as perenniality, indeterminate growth, low harvest index, and photo-thermal sensitivity. However, its multiple uses and role in sustaining agricultural productivity makes it a favourite crop of small holding rainfed farmers. In the last few decades, a significant progress has been made in domesticating the crop by developing short-duration and determinate types but a large scope for its further genetic improvement still exists.

The promotion of disease resistant pure line varieties has helped in stabilizing the productivity and increasing production at the national level. Unfortunately, this is not enough to meet the demand of pigeonpea in the country.

To achieve quantum jumps in the productivity level, which has remained unchanged and low over decades, a good beginning has been made by ushering in to an era of pigeonpea hybrid. The results obtained so far have clearly demonstrated that in pigeonpea the exploitation of hybrid vigour is feasible and advantageous. This technology has given us hope that the genetic barrier of stagnated yield could be broken. The development of stable CMS system in pigeonpea is a real boon to the breeders. To enhance the pace of research and development of hybrid pigeonpea ICRISAT is actively involved in technology transfer to national research system and public and private seed sector. We believe that a good beginning has already been made with CMS-based hybrid pigeonpea technology and now it is just a few steps more when the commercialization of pigeonpea hybrids would be a reality.

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