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Heterosis Breeding in Pulses – Problems and Prospects

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Abstract

The nature and action of genes determining yield in cereals and pulses are more or less comparable. But the quantum of yield advances made through breeding in cereals such as maize, sorghum, millet etc. is much higher than those of pulses. This distinction of cereals has been primarily due to commercial exploitation of hybrid vigour. The pulses, however, have lagged behind in making use of heterosis breeding mainly due to lack of economic mass-pollen transfer mechanism and non-availability of effective male-sterility system. Although the floral biology of some pulses, permit partial natural-out-crossing but with the exception of pigeonpea, the hybrid vigour for yield has not been exploited commercially in any other crop. The innovative research conducted in the past 25 years in developing hybrid pigeonpea breeding technology has resulted in the release of a few commercial hybrids in India. The adoption of these hybrids, however, is restricted due to seed production limitations posed by genetic nature of male-sterility. This paper, besides reviewing the extent of heterosis available in different pulse crops, discusses scope, challenges, and the latest achievements in the research and development of commercial hybrid breeding in pigeonpea.

The ever-growing population of India with an alarming rate is the root cause of various socio-economic problems of the country. The fractionalization of small rainfed land holdings from one generation to another is increasing dependency rate on the unit cultivable land and production of quality food in sufficient quantity is the prime cause of worry of such farm families. To achieve household nutritional security there appears to be no option except increasing productivity of commonly grown and adaptive cereals and legumes. Since the food production balance both at farmer and country level is always in favour of cereals because of their primary needs, the issue of protein availability especially in rural areas assumes greater significance. The majority of food protein in India is derived from pulses gown invariably under unfavourable and risk prone conditions of marginal lands with no or minimum inputs and this results in low and unstable productivity. Therefore, concerted efforts are needed not only to enhance the productivity but also to sustain the gains made through plant breeding and other research areas.

To increase the production and productivity of pulses in India, Indian Council of Agricultural Research (ICAR) initiated a multidisciplinary crop improvement project in 1967. This project was designed for research and development of 12 pulse crops. These include chickpea, cowpea, horsegram, lentil, lathyrus, mothbean, mungbean, pigeonpea, pea, rajmash, ricebean, and urdbean. A network of 15 research centres covered almost all the important agro-ecological zones of the country. Although over 350 pulses varieties were released under this program and the area under cultivation also witnessed increase, but the productivity of pulses at the national level is yet to record any visible impact and it ranges between 111 kg ha^{-1} (mothbean) to 996 kg ha^{-1} (fieldpea). In these major pulse crops the productivity ranges only between 382 - 735 kg ha^{-1} and these low harvests influence the availability of pulses in the country. Therefore, to break the yield barrier in pulses and to increase their production, some non-conventional scientific approaches in breeding, plant protection, and other important disciplines need to be designed, investigated, and implemented.

The quantum jump in yield potential in the past few decades observed in some cereals, vegetables, and cotton, etc. was primarily due to commercial exploitation of a single genetic phenomenon, commonly known as 'hybrid vigour' or 'heterosis'. In pulses, on the other hand, little gain in yield has been recorded. Arguably, there may be a number of reasons for this yield stagnation, but it is also true that unlike cereals, the pulse breeders were unable to exploit hybrid vigour because of their unique pollination behaviour which does not allow their economic hybrid seed production. In this presentation various issues related to the achievements, prospects, and limitations of hybrid breeding in pulse crops will be discussed with special reference to pigeonpea, where a breakthrough in developing hybrid technology has been achieved in the recent past.

Genetic systems operating in yield determination of hybrids

In the past few decades the phenomenon of heterosis has been extensively investigated and the breeding procedures in cross-pollinated crops have evolved around its exploitation in developing open-pollinated synthetics, composites or hybrid varieties. Basically,

occurs. Among these pigeonpea and faba bean (Table 2) stand out with several reports of out-crossing in a range of environments. Besides this, odd reports of out-crossing are also available in mungbean and common bean. In the remaining pulses either the out-crossing is negligible or not determined so far. In cowpea, common bean, faba bean, guar and pigeonpea efforts have been made to induce male-sterility systems so that hybrid vigour could be used for enhancing their yield potential. Breeders in these crops have attempted breeding methods recommended for open-pollinated crops with limited success. The most successful story, however, comes from pigeonpea where the limited out-crossing and male-sterility system have been used together to develop world's first commercial hybrid, that is know in any pulse crop.

Heterosis breeding for higher yield in pigeonpea

Research on the genetic improvement of pigeonpea started with the selection of disease resistant segregants from landraces in the early part of this century and later some cultivars were also developed from hybridization programmes. However, even today most of the cultivars are landraces or selections from these landraces. There has been a success through breeding in incorporating resistances to major pigeonpea diseases such as *fusarium* wilt and sterility mosaic but the little progress in the genetic improvement of yield potential is also apparent. A review of the quantitative genetic studies in pigeonpea by Saxena and Sharma (1990) shows the presence of a substantial level of additive as well as non-additive genetic variation for yield that can be exploited profitably through heterosis breeding for a possible quantum jump in grain yield. A significant progress has been made in developing a viable hybrid pigeonpea technology. The achievements, problems, and prospects of this endeavour are covered in length in this paper.

Natural cross-pollination

Researchers in India (2 - 70 per cent), Kenya (12 - 50 per cent), Trinidad (26 per cent), Uganda (8 - 22 per cent), and Australia (2 - 40 per cent) have reported a considerable range of natural cross-pollination in pigeonpea. Onim (1981) listed 24 insect species, which are capable of transferring pollen from one flower to another within and across fields. Saxena *et al.*, (1983) while reviewing the subject concluded that in pigeonpea natural cross-pollination is a universal event and its extent varies from one environment to another, depending on activity and availability of pollinating insects. The discovery of male-sterility, however, has changed the scenario and soon after its identification breeding programmes was developed to use the out-crossing for genetic improvement of the crop through hybrid breeding and recurrent selection.

• Genetic male-sterility

With the sole objective of exploiting natural cross-pollination for economic gains, a deliberate search for male-sterility was made in germplasm and in ICP 1596 male-sterility associated with translucent anthers was identified. This form of male-sterility was controlled by a single recessive gene ms_1 (Reddy *et al.*, 1990). Later, a different source of male-sterility, characterized by brown arrow-head shape anthers and controlled by a single recessive gene ms_2, was identified in Australia, (Saxena *et al.*, 1990). Both the male-sterile types have prominent anther morphology, which provides an effective and easy way of identifying male sterile plants in field before anthesis. The male-sterile lines derived from ms_1 sources were used extensively in hybrid breeding programmes at ICRISAT and several other locations in India. The achievements of this endeavour are discussed later in this paper.

Genetic male-sterility based hybrid pigeonpea technology

In the absence of CMS, the available GMS sources were used to develop hybrids and their seed production technology. The chronological details of this development are given (Saxena *et al.*, 1997). Soon after the release of the world's first pigeonpea hybrid ICPH 8, concerted efforts were made by ICRISAT, various ICAR centres, and private sectors to identify new cross combinations. So far, about 10,000 hybrid combinations have been evaluated. These include 6300 crosses made by ICAR (Srivastava *et al.*, 1997), over 3000 by ICRISAT (K.B. Saxena, personal communication), and perhaps over 1000 by Maharashtra Hybrid Seeds Company (MAHYCO). Of these, 182 F_1 hybrids exhibited more than 20 per cent superiority over the best control (Table 3). At ICRISAT also, some hybrids produced exceptionally high yield (Saxena *et al.*, 1997). Considering the performance of hybrids in different maturity groups it was observed that the heterosis was more pronounced in early and medium-duration types than in long-duration hybrids and this could be attributed to the evaluation of few hybrids, lack of genetic diversity, and/or limitation of additional biomass production. In the mid-nineties

Table 3. Heterotic advantage in superior hybrids in multilocation trials from 1990-1991 to 1996-97

	Standard heterosis (%)					
Year	20-40	41-60	61-80	81-100	>100	Total
1990-91	18	21	9	7	11	66
1991-92	7	6	2	2	1	18
1992-93	8	4	2	5	1	20
1993-94	18	5	4	5	3	35
1994-95	16	6	0	0	0	22
1995-96	7	3	2	0	0	12
1996-97	3	1	2	3	0	9
Total	77	46	21	22	16	182
(%)	(42.3)	(25.2)	(11.5)	(12.0)	(8.7)	

ICRISAT discontinued breeding of GMS-based hybrids and the resources were diverted to develop CMS lines and their fertility restorers. ICAR, however, continued this work and six hybrids, exhibiting 14 - 64 per cent superiority in yield over the best-adapted cultivars (Srivastava *et al.*, 1997), were released. A comparison of pigeonpea with other crops such as maize, cotton, rice, millet and sorghum where commercial hybrids are already in cultivation shows that the magnitude of realized heterosis for yield in pigeonpea is more or less similar to those of other crops (Table 4). This phenomenon could be exploited commercially if a grower-friendly mass hybrid seed production technology is developed.

• Commercial pigeonpea hybrids

Since in any pulse crop no commercial hybrid is available, the release of the world's first pigeonpea hybrid ICPH 8 by ICRISAT and ICAR in 1991 is rightly considered a milestone in the history of breeding pulse crops. This hybrid combination was developed by crossing MS Prabhat (DT), a short-duration genetic male-sterile line of determinate growth habit and a non-determinate short-duration fertile inbred line ICPL 161. Evaluations from 100 yield trials showed ICPH 8 to be superior to controls UPAS 120 and Manak by 30.5 and 34.2 per cent, respectively. Increasing spacing from 60 x 20 cm (83,000 plant ha^{-1}) to 75 x 20 cm (66,000 plant ha^{-1}) did not affect the yield and it suggested that lower seed rates could be recommended for hybrids due to higher plant vigour and high plasticity.

• Seed production technology

An efficient seed production system that could provide quality seeds at economically viable costs is the backbone of any hybrid breeding technology. Research on the various aspects of hybrid seed production technology began at ICRISAT as soon as the breeders were able to identify stable male-sterility system that

Table 4. Standard heterosis (%) reported in various field crops in India

Crop	Range of heterosis (%)	Reference
Maize (*Rabi*)	10.0 - 48.0	39
(*Kharif*)	15.0 - 51.0	39
Pearl millet	18.9 - 53.7	13
Sorghum	60.0 - 80.0	7
Cotton	5.3 - 28.4	22
Rice	16.2 - 44.2	1
Tomato	23.8 - 71.7	33
Toria	9.1 - 87.3	8

could set sufficient pods due to natural out-crossing. Since out-crossing in pigeonpea is affected by insects a safe isolation distance is essential to produce quality seed of the parental lines and the hybrids. So far, no isolation distance study has been conducted using male-sterile lines of pigeonpea and it is assumed that the information generated on isolation specifications of inbred cultivars could be utilized safely in producing seeds of pigeonpea hybrids and their parents. Faris (1985) suggested that for quality varietal seed production, two varieties must be separated by at least 100 m, while a distance of 200 m between varieties is essential if the seed is to be used by breeders. In India, the seed certification standards fixed with regard to isolation distance for pigeonpea varieties are 200 m for breeder seed and 100 m for both foundation and certified seed (Tanwar, 1988). Sharma (1993) reported that at 100 m the contamination due to natural out-crossing was 1.41 per cent and less than 1 per cent at the isolation distance of 200 m.

Tests at ICRISAT indicated that full pod set is obtained if one pollinator row is sown after every six male-sterile rows. The ratio of male-sterile and pollinator rows may have to be changed if the recommended 6:1 ratio is not optimal because there are insufficient pollinating insect vectors, and/or plant growth is variable. For example, at ICRISAT six rows of female and one row of male, at S.K. Nagar five female: one male rows, and at Ludhiana four fem... and one male row have been found to be optimum (Srivastava *et al.*, 1993).

• Economics of hybrid seed production

Seed cost plays an important role in the adoption of hybrids. The technology itself and crop management practices are critical in determining the production costs. The feasibility studies jointly conducted by ICRISAT and MAHYCO in 1979-80 showed that the hybrid pigeonpea seed could be produced at a reasonable price (Saxena *et al.*, 1986). Later, in a detailed study undertaken by ICRISAT and TNAU, the estimated cost of hybrid seed was found to be Rs 6.25 kg^{-1}. Roguing was found to be the most critical activity and it accounted for about 45 per cent of the total production cost and to rogue a seed production area of one hectare 15 workers for a fortnight need to be employed (Murugarajendran *et al.*, 1995). Studies conducted by Punjab Agricultural University, Ludhiana showed a large variation in the production costs of male-sterile and hybrid seeds. In 1990, 275 kg ha^{-1} seed of a male-sterile line MS Prabhat (DT) was produced at a cost of Rs 39.4 kg^{-1}. In the subsequent year the estimated production cost of hybrid seed was Rs 13.8 kg^{-1} (Srivastava and Asthana, 1993). In Varanasi, hybrid seed production cost was recorded to be Rs. 45.36 kg^{-1}. Experiments at ICRISAT demonstrated that adopting multiple harvest system could reduce the production costs as there is no need to rogue after the first crop and the same seed production nursery can be used in subsequent years (Saxena *et al.*, 1992). Studies conducted in Ludhiana clearly suggest that under good management the cost of producing hybrid seed is not as high as feared in the initial stages because of the utilization of genetic male-sterility.

• Adoption of GMS-based pigeonpea hybrids

Niranjan *et al.* (1998) evaluated the two-parent hybrid pigeonpea technology by studying its impact on its

Table 5. CMS-based pigeonpea hybrids released in India

Character	ICPH 8	PPH 4	CoH1	CoH2	AKPH 4104	AKPH 2022
Adaptability	Central Zone	Punjab	Tamilnadu	Tamilnadu	Central Zone	Maharashtra
Year	1991	1994	1994	1997	1997	1998
Parentage	MS Prabhat DT x ICPL 161	MS Prabhat DT x AL 688	MS T 21 x ICPL 87109	MS CO 5 x ICPL 83027	NA	NA
Plant type	Indeterminate	Indeterminate	Indeterminate	Indeterminate	Indeterminate	Indeterminate
Days to maturity	125	137	117	120-130	130-140	180-200
Yield (q ha^{-1})	17.8	19.3	12.1	10.5	NA	NA
Superiority over check	30% over TAT 10, 41% over UPAS 120	14% over UPAS 120, 14% over H 82-1	22.3% over Vamban 1, 19.4% over ICPL 87	35% over CO 5	64% over UPAS 120	34.9% over BDN 2, 28.2% over C 11, 25% over ICPL 87119

users and identifying constraints faced by researchers, seed companies, and seed growers in the adoption of this technology. Primary data for this study was gathered through interviews with scientists, officers in public and private seed companies, and seed growers. The secondary set of data was obtained through various research reports. They concluded that the cost of hybrid pigeonpea seed is within the affordable limits and the hybrid advantage is salable but the technology itself suffers with major bottleneck when it comes to large-scale seed production. The other adoption constraints identified were (i) unwillingness of the farmers to remove fertile segregants from seed production plots as they believe it is not good (religiously?) to remove flowering plants and also they will loose yield, (ii) the seed rate of short-duration hybrid was high and it affected farmers' decision to buy the hybrid seed, (iii) shortage of parental seeds, (iv) heavy damage from pod borers, (v) lack of seed production knowledge and inputs, (vi) low price to hybrid seed growers, (vii) problems in grow-out tests for determining genetic purity, (viii) scarcity of labour at the time of roguing, and (ix) competition from other crops with high profit margins.

Recent Developments in Hybrid Pigeonpea Technology

• Cytoplasmic male-sterility

Considering the limitations in large-scale hybrid seed production encountered due to genetic nature of male-sterility and the prospects generated in yield enhancement through hybrid breeding, the development of cytoplasmic male-sterility (CMS) became very important. In order to induce CMS through wide hybridization the main aim was to place pigeonpea genome in foreign (wild) cytoplasm. Two wild species have been successfully used in breeding CMS lines. A brief description of these species is given below:

Cajanus sericeus **(Benth. ex Bak.) van der Maesen comb. nov. :** It is an erect shrub, about 1 m tall, more or less densely branched. It has erect branches. Leaves are trifoliate and leaflets are short coriaceous with lower surface green and thinly pubescent. Racemes are sessile, auxiliary with 1 - 3 flowers. Its pods are small, oblong, 11 - 13 mm long, 5 - 7 mm wide and densely covered with long adpressed silvery hairs, with mostly two seeds. The seeds are orbicular or rectangular-rounded, 4 mm long, 3 - 4 mm wide, gray and black with cream mosaic. Its strophiole is greenish-white and divided (Van der Maesen1986).

Cajanus scarabaeoides **(L.) Thouars (syn: *Atylosia scarabaeoides* [L.] Benth.):** A small, perennial, woody trailing bush found in abundance in the dry areas. This species is reported to have been found in many Asian and African countries (Van der Maesen, 1986). *C. scarabaeoides* can be observed trailing or climbing on grasses, shrubs, and trees. It is a natural host of yellow mosaic virus but tolerates drought. This species also exhibits mechanical resistance and antibiosis to *Helicoverpa* in its pods. *C. scarabaeoides* can easily be crossed with pigeonpea. Some accessions have a significant number of trichomes on their pods. The seed protein content in some accessions is as high as 28 - 30 per cent. The seed coat is hard so it needs to be scarified if it is to germinate rapidly.

• CMS lines developed

The first attempt to develop CMS in pigeonpea using the crossable wild relatives of pigeonpea was made by Reddy and Faris (1981). They crossed these species with fertile F_1 plants of (*Cajanus cajan* x *C. scarabaeoides*). The resulting BC_1F_1 was fertile but in BC_1F_2 generation some male-sterile plants were identified. This male-sterility was found to be associated with female-sterility and therefore was not pursued further. Ariyanayagam *et al.* (1995) crossed *Cajanus sericeus* with a short-duration advanced breeding line of pigeonpea. The F_1 was partially male-sterile and the backcross ($BC_1F_1 - BC_3F_1$) populations (2 - 19 plants) were found segregating for male-sterility. The maternally inherited male-sterility in the BC_3F_1 (15 plants) ranged from 8 - 99 per cent. The segregation for male-sterility observed for four years and their important plant and grain characteristics are given in Table 6 and 7. CMS 85010 is of short-duration with determinate growth habit, CMS 88034 is a non-determinate short-duration type while CMS 13092 has genome from African germplasm and belongs to long-duration group.

Various ICAR centres also joined the efforts of developing CMS lines. Among these, scientists at Gujarat Agricultural University succeeded in developing a CMS line using *Cajanus scarabaeoides* cytoplasm. This source has shown stability in the expression of the trait over locations. The identification of male-sterile plants at Akola in interspecific crosses with *C. cajanifolius* and *C. volublis* are also reported. Similarly, at Varanasi and Trombay some male-sterile plants were found in crosses with *C. mollis* and *C. sericeus.*

Table 6. Segregation for male-sterility in three CMS lines developed at ICRISAT Center, Patancheru

Line/Year	Total plants	Sterile plants	% Sterility
CMS 85010			
1997	16	16	100
1998	1229	1213	99
1999	2769	2636	95
2000	5524	5243	95
CMS 88034			
1997	21	20	95
1998	222	212	95
1999	1700	1653	97
2000	3275	3227	99
CMS 13092			
1997	17	16	94
1998	21	20	95
1999	132	132	100
2000	353	350	99

Recently, scientists at ICRISAT have also succeeded in identifying male-sterile segregants from an inter-specific cross involving *C. scarabaeoides* and a pigeonpea line. A large number of crosses have been made on these selections in 2000-01 season to identify productive and stable maintainers and fertility restorers.

- **Fertility restoration of CMS**

Fertility restoration is a vital component of CMS-based hybrid technology. At ICRISAT, IIPR and other centres based at SAUs during the past 3-4 a number of advanced breeding lines and germplasm of diverse origin have been crossed to study their fertility restoration. The observations on F_1 hybrids indicated that (i) the fertility restorers are available in both germplasm as well as advanced breeding lines but their frequency is low (ii) most lines appear to be heterogeneous for fertility restoration gene(s) and selection within a line is essential to identify pure breeding fertility restorers (iii) some lines produce

Table 7. Plant and seed characteristics of three CMS lines developed at ICRISAT Center, Patancheru

Trait	CMS 85010	CMS 88034	CMS 13092
Days to flower	64.0 ± 0.32	77.9 ± 0.61	135.5 ± 0.38
Plant height (cm)	66.3 ± 0.80	113.8 ± 1.92	182.4 ± 0.73
Primary branches	15.4 ± 0.26	16.5 ± 0.89	12.6 ± 0.47
100-seed mass(g)	9.2 ± 0.11	10.9 ± 0.15	12.6 ± 0.12
Seeds pod^{-1}	3.2 ± 0.03	3.1 ± 0.06	4.9 ± 0.03
Growth habit	determinate	indeterminate	indeterminate
Plant spread	semi-spreading	semi-spreading	compact
Flower colour	yellow with light red streaks	yellow	yellow with red streaks
Stem colour	green	green	purple
Pod colour	green with brown streaks	green with brown streaks	green with purple streaks
Seed colour	brown	brown	white

hybrids with partial fertility restoration (iv) in some cross combination the fertility restoration was found to be influenced by environment.

The intensive search has succeeded in identifying a few fertility restorers (Table 8). Among these, considering its population size, HPL 24 appears to be the most promising. These observations will be reconfirmed to ensure the expression of fertility restoration and their stability analyses and estimation of heterosis will follow it over the standard controls.

• Environment-sensitivity of CMS

Experiments conducted at ICRISAT have revealed that expression of male-sterility in CMS lines derived from *C. sericeus* cytoplasm are influenced by environment. The factors responsible for this sex reversal are still under study. In a recently conducted trial involving environment-sensitive CMS selections it was observed that the CMS lines expressed complete male-sterility in the month of August, when sown in mid June. However, in the month of September when day length and mean temperature started declining, a proportion of the male-sterile plants turned fertile and produced normal pods and seeds. It was also observed that the amount of pollen produced differed grossly from plant to plant but pod set appeared normal. Further, towards mid February when day length and mean temperature increased, these converted fertile plants reverted back to male-sterility. At present these lines are being purified for the sensitivity trait. The seed produced from these plants give rise to male-sterile plants without any abnormality. Similar effects have also been recorded in some crosses made to study their fertility restoration. The detailed investigations will follow soon.

The influence of environment on the expression of CMS and its fertility restoration is not uncommon. Kaul (1988) while reviewing male-sterility in crop plants has quoted a number of such examples from vegetable, cereal and legume crops. Among the environmental factors photoperiod and temperatures are important and they have been reported to influence pollen sterility, microsporogenesis, tapetal development and/or seed set. He also concluded that the stability of expression is not only fertility-restoration and male-sterility gene specific but also depends on the presence or absence of other genes.

Looking Ahead

Pigeonpea remains a wild plant even after centuries of cultivation and it has retained its unique characteristics such as perenniality, indeterminate growth, low harvest index, and photo-thermal sensitivity. However, it's multiple uses and role in sustaining productivity makes it a favourite crop of small holding dry land 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 further improvement still exists.

In recent years, pigeonpea production in India has recorded a significant growth rate that is primarily due to the development of short-duration and medium-duration disease resistant varieties. Since the demand for pigeonpea is ever increasing and the scope for horizontal expansion of area is limited, the attention of researchers need to be focused on increasing its yield potential. The exploitation of heterosis and restructuring of plant type are two sure ways of increasing yielding ability of pigeonpea. To achieve this goal, a complementary approach is needed to knit these two and other important elements together. Earlier some vital breakthroughs in physiological research laid the foundation of green revolution in important food crops. For example, in rice and wheat, it was resistance to lodging while in maize the ability to withstand increase in density (smaller tassel, erect leaves, short anther, and silking period) provided the breakthrough. In soybean, slower declines in

Table 8. Inbred lines and germlasm identified for fertility resotration of CMS at ICRISAT Center, Patancheru

Line/germplasm	Total plants	Fertilie plants	% Restoration
HPL 24	356	332	93
ICPL 129	42	40	95
ICP 10943	57	57	100
ICP 10650	68	66	97
ICPL 89	45	45	100
ICPL 12	27	27	100

photosynthetic rates helped in the genetic enhancement of its yield potential. In pigeonpea this information gap needs to be filled for realizing significant yield increases at genetic level. Restructuring plant is a difficult task and significant input from physiologists is essential. In the sub-tropical environments where plants have plenty of biomass, the inefficient partitioning is the major yield limiting factor. To overcome the physiological limitations to yield some revolutionary brain-storming is needed. In this context, it is postulated that if the intra-plant competition for photosynthates is increased by inducing synchrony in fertilization and pod set in the entire plant, it may help in releasing the stored assimilates from stem, roots, and other plant parts and it may lead to quick grain filling and increased yield. In the tropical environments and post-rainy season pigeonpeas, where restricted biomass is the major production constraint, the hybrids are the answer because hybrids can produce about 25 - 30 per cent additional biomass as a consequence of hybridity.

The experience with genetic male-sterility hybrid technology in the past 25 years has conclusively demonstrated that in pigeonpea the exploitation of hybrid vigour is feasible if the seed production difficulties are addressed adequately. The issues of developing high yielding CMS-based hybrids and their grower-friendly seed production technology also need careful planning. These include diversification and stability of cytoplasmic male-sterility, combining ability analyses, breeding high yielding disease resistant 'A', 'B' and 'R' lines, and identification of heterotic cross combinations. In rice, the first breakthrough in yield was achieved by modifying plant architect and the second breakthrough came with the hybrids. In pigeonpea, the first breakthrough in yield is likely to come from hybrids and the second by modifying the plant type. A very good beginning has already been made both at ICRISAT and some ICAR centres in developing CMS-based hybrid pigeonpea technology. It is not far when Indian farmers will reap the benefits of this technology.

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