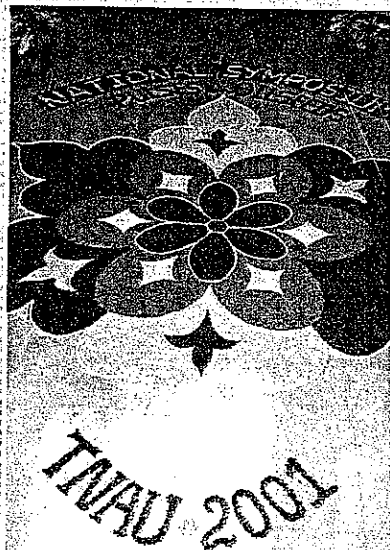
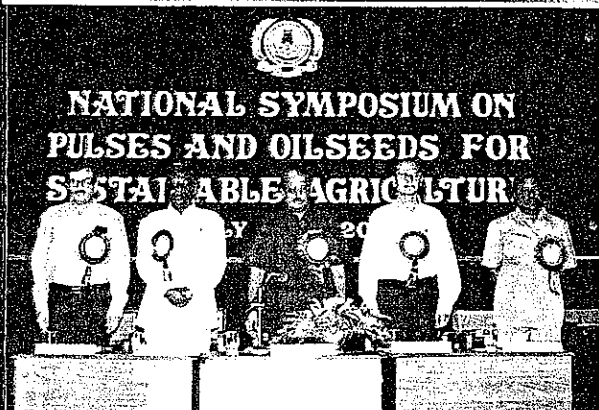
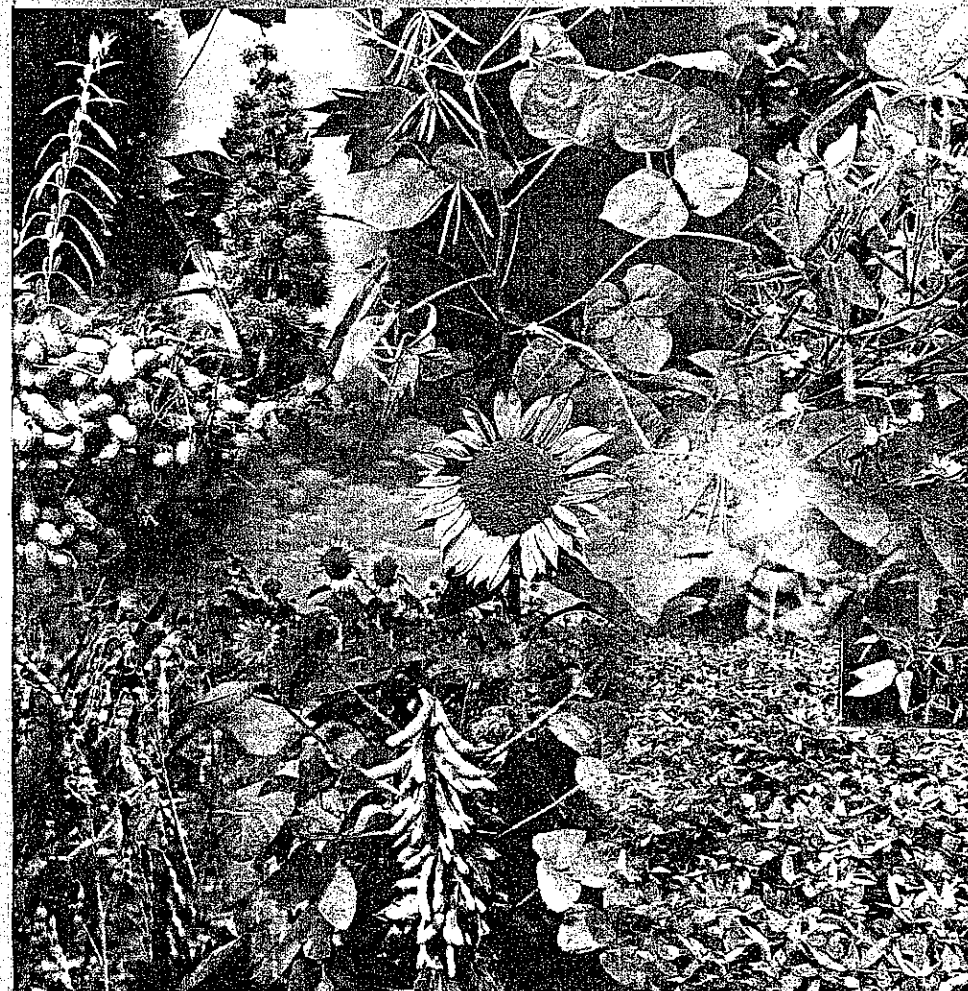


For
Sustainable Agriculture



PULSES AND OILSEEDS PRODUCTION



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PROSPECTS FOR HYBRID PIGEONPEA

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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 is much higher than those of pulses and this distinction may partly be primarily due to commercial exploitation of hybrid vigour in the former. Although floral biology of some pulses permit partial natural-out-crossing but with the exception of pigeonpea, hybrid vigour for yield has not been exploited for commercial use in any other pulse. The adoption of pigeonpea hybrids, however, is restricted due to seed production limitations posed by genetic nature of the male-sterility system. Recently, a significant progress has been made to develop cytoplasmic male-sterility based hybrid pigeonpea technology. This paper discusses scope, challenges, achievements, and prospects for hybrid pigeonpea.

Introduction

The majority of food protein in India is derived from pulses grown invariably under unfavourable and risk prone environments with no or minimum inputs resulting in low and unstable productivity. In India pulses are grown on about 23 m ha but their production (13.0 m tons) as well as productivity (600 kg ha⁻¹) is unacceptably low. Therefore concerted efforts are necessary to enhance the productivity and sustain the research gains.

To accomplish this mission, Indian Council of Agricultural Research (ICAR) initiated a multidisciplinary crop improvement project in 1967 for research and development of pulses. Under this project, so far over 300 varieties have been released and the area also witnessed significant increase, but their productivity remained unchanged and it ranged between 111 kg ha⁻¹ (mothbean) and 996 kg ha⁻¹ (fieldpea). Therefore, to break the yield barrier some non-conventional scientific approaches in breeding, plant protection, and other important disciplines are warranted. The quantum jump in yield potential observed in some crops in the past was primarily due to commercial exploitation of a single genetic phenomenon, commonly known as 'hybrid vigour' or 'heterosis'. In pulses, however, this phenomenon could not be exploited because of their inability to produce their hybrid seed economically. Recently in pigeonpea (*Cajanus cajan* (L.) Millspaugh), a breakthrough has been achieved in developing hybrid technology and in this presentation the problems and prospects of this

technology are reviewed. Globally, pigeonpea is cultivated on 5.25 m ha land in Asia, Africa, and Americas (Table. 1) and it finds an important place in the farming systems adopted by smallholder farmers. Traditional landraces and cultivars are planted at the onset of rainy season and are harvested after 180-280 days. Pigeonpea is used in a wide variety of ways. Its main use in the Indian sub-continent is as human food.

In pigeonpea, Saxena *et al.* (1981) observed the predominance of additive gene action for yield and yield components. Sidhu and Sandhu (1981) reported the importance of both additive and non-additive gene action for yield, while the predominance of non-additive gene action was observed by Dahiya and Brar (1977).

For days to flower, an important yield component, Gupta *et al.* (1981) reported predominance of additive gene effects, while Dahiya and Satija (1978) observed additive genetic variance with partial dominance for earliness. Gupta *et al.* (1981) reported predominance of additive gene action for seed size.

Heterosis

Hybrid vigour over the mid-parent and better parent has been reported by several workers for grain yield and other economic characters. Solomon *et al.* (1957) were the first to report hybrid vigour in pigeonpea in 10 inter-varietal crosses. In some crosses they observed hybrid vigour over the better parent up to a maximum of 24.5% for grain yield together with that of plant height, plant spread, stem girth, number of fruiting branches, and leaf length and width. Component analyses of hybrids have shown high yield in the heterotic crosses to be closely associated with heterosis for pods per plant, number of primary branches, and plant height, that all contribute to increased total biomass (Saxena and Sharma, 1990). Subsequently, a number of reports have been published on hybrid vigour for yield and yield components (Saxena and Sharma, 1990).

Most of the reports on hybrid vigour suffer from considerable bias due to genotype x environment interaction (Jinks, 1983). The studies conducted at ICRISAT conclusively show that a single location suffer from the bias caused by genotype x environment interaction, and may give an impression of "pseudo-heterosis".

Pollination and Male-sterility Systems

Cross-pollination System

The floral biology of pigeonpea flower permits both self as well as cross-pollination. According to Bahadur et al. (1981) the pollen produced by short stamens is used for self-fertilization whereas that produced by long stamens is used for out-crossing. Saxena et al. (1990) described a large variation (0-70%) in natural out-crossing in pigeonpea and it is known to occur as a result of frequent insect visitation from one flower to other within and across the fields. Out of 24 insect species capable of affecting cross-fertilization in pigeonpea, *Magachile* spp. and *Apis mellifera* are the main pollinating vectors (Onim 1981). According to Bhatia et al. (1981) number of insect pollinators, number of flowers, flowering habit of the varieties, location of field in relation to insect habitat, temperature, humidity, wind velocity and its direction determine the extent of cross-pollination.

Genetic male-sterility systems

For exploiting natural cross-pollination for pigeonpea improvement, a deliberate search for male-sterility was made at ICRISAT 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 *ms₁* (Reddy et al., 1978). Later, a different source of male-sterility, characterized by brown arrowhead shape anthers and controlled by a single recessive gene *ms₂*, was identified in Australia (Saxena et al., 1983). 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 *ms₁* sources were used extensively in hybrid breeding programmes at ICRISAT and other research centres in India.

Cytoplasmic male-sterility systems

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. These are *Cajanus sericeus* (Benth. ex Bak.) van der Maesen comb. nov. and *Cajanus scarabaeoides* (L.) Thouars (syn: *Atylosia scarabaeoides* [L.] Benth.)

The first attempt to develop CMS in pigeonpea using the crossable wild relatives of pigeonpea was made at ICRISAT by crossing *Cajanus sericeus* with an advanced breeding line. The F_1 was partially male-sterile and the backcross populations were found segregating for male-sterility. The maternally inherited male-sterility in BC_3F_1 generation ranged between 8 and 99 per cent. Further breeding of this material using ICPL 85010 as maintainer produced materials that initially varied a lot for the expression of male-sterility. Intensive selection and backcrossing in the segregating populations resulted in the development of the first CMS line and it was designated as CMS 85010. To diversify the genetic base of CMS for developing hybrids in different plant types and maturity groups, CMS 85010 was crossed to a number of advanced breeding lines and germplasm. Keeping in view the ability of lines to maintain cytoplasmic male-sterility, diversity of origin, and major plant and seed characters a few CMS lines were identified. At present ICRISAT maintains three CMS lines. 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 it belongs to long-duration group.

Various ICAR centres also joined this endeavour and 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. volubilis* is also reported. Similarly, at Varanasi and Trombay some male-sterile plants were found in crosses involving *C. mollis* and *C. sericeus*.

Genetics of male-sterility and hybrid Pigeonpea

Elite pigeonpea hybrids

ICRISAT achieved a major breakthrough in hybrid breeding technology in pigeonpea. 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 by 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. Of these, 182 F₁ hybrids exhibited more than 20 per cent superiority over the best control. Considering the performance of hybrids in different maturity groups it was concluded 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 hybrid combinations, lack of genetic diversity, and/or limitation of additional biomass production. In the mid-nineties ICRISAT discontinued breeding of GMS-based hybrids and the resources were diverted to develop CMS lines and their fertility restorers.

The following genetic male-sterility based pigeonpea hybrids were released in India (Table 2)

ICPH 8: The world's first pigeonpea hybrid ICPH 8 was released by ICRISAT and ICAR in 1991. ICPH 8 was superior to controls UPAS 120 and Manak by 30.5 and 34.2 per cent respectively. In Maharashtra State, ICPH 8 was 20 per cent better than ICPL 87 and 30 per cent better than TAT-10. In Gujarat state, ICPH 8 recorded 26 per cent superiority over control ICPL 87 in on farm trials.

PPH 4: It was released in 1993 by Punjab Agricultural University (PAU), Ludhiana (Verma and Sidhu, 1995). This short duration hybrid out-yielded the check variety T 21 by a margin of 47.4 per cent in MLTs. PPH 4 recorded 32.1 per cent higher yield than the best national check UPAS 120. PPH 4 also out-yielded the control AL 201 by a margin of 20 per cent in OFTs (Verma *et al.*, 1994). This early maturing pigeonpea hybrids with high yield potential is highly suitable for pigeonpea-wheat cropping system in the irrigated areas of northern India.

COPH 1 and COPH 2: In 1994 a short-duration hybrid IPH 732 was released by Tamil Nadu Agricultural University (TNAU), Coimbatore as COPH 1. COPH 1 recorded 32 per cent higher yield over control VBN 1 in OFTs (Murugarajendran *et al.*, 1995). In 1997, TNAU released another pigeonpea hybrid COPH 2. Which out-yielded COPH 1 and CO 5 by 13 and 35 per cent respectively.

AKPH 4104 and AKPH 2022: They were released by Punjabrao Krishi Vidyapeeth, Akola. AKPH 4104, released for central Zone, is a short-duration hybrid gave 64 per cent higher yield than control UPAS 120. AKPH 2022 is a medium-duration hybrid released for Maharashtra

state which recorded 34.9 28.2 and 25.2 per cent more yield than controls BDN 2, C 11, and ICPL 87119 respectively.

Seed production technology and its adoption

Research on various aspects of hybrid pigeonpea seed production technology began at ICRISAT as soon as stable male-sterility system was identified. It could set sufficient pods due to natural out-crossing. Since out-crossing in pigeonpea is promoted by insects a safe isolation distance is essential to produce quality seeds of the parental lines and 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, whilst 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 inbred varieties are 200 m for breeder seed and 100 m for both foundation and certified seed (Tunwar and Singh, 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 female and one male row have been found to be optimum (Srivastava *et al.*, 1993).

Cost of 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 Rs. 6.25 kg⁻¹ (Murugarajendran *et al.*, 1995). Studies conducted by PAU showed a large variation in the production costs of male-sterile and hybrid seeds. In 1990, 275 kg seed of

a male-sterile line MS Prabhat (DT) was produced in one hectare 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). Rogueing was found to be the most critical activity and it accounted for about 45 per cent of the total production cost (Niranjan et al., 1998). In tropical environments with warm winters, pigeonpea produces several flushes of pods within a year and its perennial nature can be profitably exploited to produce quality hybrid seed at low cost. Experiments at ICRISAT demonstrated that adoption of multiple harvest system reduced the production costs significantly as there are no need to rogue after the first crop (Saxena et al., 1992). These studies suggest that under good management the cost of producing hybrid seed in pigeonpea is not as high as feared in the initial stages because of the utilization of genetic male-sterility.

Cytoplasmic male-sterility and hybrid Pigeonpea

Fertility restoration of CMS

Fertility restoration is a vital component of CMS-based hybrid technology. At ICRISAT during the past three years over 200 advanced breeding lines and germplasm of diverse origin have been crossed to CMS lines to study their fertility restoration. The observations on F₁ 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 hybrids with partial fertility restoration, and (iv) in some cross combinations the fertility restoration was found to be influenced by environment.

The intensive search has succeeded in identifying a few fertility restorers (Table 3). Among these HPL 24 appears to be the most promising. These observations will be reconfirmed to ensure the expression of fertility restoration.

Seed production technology

Environmental effects on CMS: Experiments conducted at ICRISAT have revealed that expression of male-sterility in CMS lines derived from *C. sericeus* cytoplasm is influenced by environment. The

factors responsible for this sex reversal are still unclear. 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 by these plants differed grossly from plant to plant. Further, towards mid February when day length and mean temperature increased, these "converted fertiles" reverted back to male-sterility. At present these lines are being purified for the sensitivity trait. The seeds produced from such 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.

Methodology and its adoption: Various aspects of hybrid seed production technology have already been studied and standardized using genetic male-sterile lines. The seed production technology using CMS is simpler and economical than that of using genetic male-sterility based hybrid technology because it will eliminate rogueing of fertile segregants and which accounts for about 45% of total production cost. Therefore, adoption of the seed production technology by private sector and grower-farmer is expected to pose no difficulty.

Prospects for hybrid Pigeonpea

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. In the recent past vital breakthroughs in physiological research laid the foundation of green revolution in important food crops like rice wheat and maize. Restructuring plant is a difficult task and significant input from physiologists is essential. To overcome the physiological limitations to yield some revolutionary brainstorming 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 consequently, 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 likely answer because they can produce about 25 - 30 per cent additional biomass as a consequence of hybridity.

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. This phenomenon could be exploited commercially if a grower-friendly mass hybrid seed production technology is developed. The experience with genetic male-sterility based 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. Various issues related to the development of 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 diseases resistant 'A', 'B' and 'R' lines, and identification of heterotic cross combinations. In pigeonpea, the first breakthrough in yield is likely to come from hybrids. A very good beginning has already been made both at ICRISAT some ICAR and SLS 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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Table 1. Area and production of pigeonpea

Country	Area (ha)	Production (t)
India	4,600,000	2,500,000
Myanmar	251,700	162,500
Kenya*	164,000	Na
Malawi	143,000	98,000
Uganda	72,000	59,000
Tanzania	55,000	35,000
Nepal	25,000	19,300
Dominical Republic	23,000	23,150
Venezuela	11,000	6,000
Haita	7,500	3,000
Bangladesh	6,000	3,000
Australia*	5,000	Na
Panama	4,200	1,900
Jamaica	2,800	1,510
Barundi	2,100	2,100
Trinidad & Tobago	1,100	3,308
Pakistan	1,100	700
Thailand*	1,000	Na
Others**	2,470	1,039
Total	5,377,970	2,919,507

*Nene and Shield (1990). Source: FAO (1997)

Table 2. Pigeonpea hybrids released in India

Character	ICPH 8	PPH 4	COPH 1	COPH 2	AKPH 4104	AKPH 2022
Adaptability	Central Zone	Punjab	Tamil-nadu	Tamil-nadu	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

Table 3. Inbred lines and germplasm identified for fertility restoration of CMS lines at ICRISAT Center, Patancheru

Line/ germplasm	Total plants	Fertile plants	% Restoration
HPL 24	356	332	93
ICPL 129	42	40	95
ICP 10934	57	57	100
ICP 10650	68	66	97
ICPL 89	45	45	100
ICPL 12	27	27	100