Cytoplasmic Genic Male-Sterility in Pigeonpea and its Utilization in Hybrid Breeding Programme

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Abstract

For commercial exploitation of heterosis in any crop, it is necessary to develop an economically viable mass pollen transfer mechanism. The natural out-crossing in pigeonpea occurs primarily due to insect visitations. A wide range of natural out-crossing is reported to be due to a number of factors, and the number and types of pollinating vectors being the most important one. The discovery of stable male sterility systems, availability of natural out-crossing and evidence of heterotic yield advantage have set a perfect stage for breaking the persisting yield plateau in pigeonpea through hybrid breeding. In spite of releasing six genic male sterility based pigeonpea hybrids at the national level this technology was not adopted by seed sector. The second breakthrough came with the development of cytoplasmic genic male sterile lines in pigeonpea. To broaden the genetic base of newly established cytoplasmic genic male sterility systems in pigeonpea, twelve agronomically superior and good combiner lines were selected. These were Pusa 33, ICPL 87, GT 100, SKNP 289, SKPN 290, BDN 2, SKNP 88-3, SKNP 9523, T 15-15, T 21, UPAS 120 and ICPL 84023. These genotypes were converted into CMS lines through simple backcross breeding method. To study the stability of fertility restoration, 41 experimental hybrids were evaluated at Kanpur, Akola, SK Nagar and Faizabad. It was observed that the hybrids developed at SK Nagar and Faizabad expressed high pollen fertility at both SK Nagar and Faizabad. However, at Kanpur, a large variation for pollen fertility was recorded while at Akola, these hybrids were almost male sterile with pollen fertility ranging from 0 to 35%. This data indicated a significant role of environment in the expression of fertility restorer genes. Therefore, an attempt should be made to breed high yielding hybrid specifically adapted to region rather than aiming for widely adapted hybrids.

1. Introduction

Providing appropriate quantity of quality food to the growing population with limited resources is a big challenge before the country. Stretching the agricultural areas horizontally, increasing cropping intensity, and increased use of inputs have their definite social and economic boundaries and therefore, for producing additional food we have no option except to sincerely look for opportunities of increasing productivity of the commonly grown food crops. Since the food production balance in the country favours cereals because of their vast primary food needs, the issue of protein availability, specially in the rural areas assumes great significance. The majority of the food proteins in India come from legumes, which are invariably grown under unfavourable marginal lands with low productivity and consequently short in supply. It appears that this scenario is not likely to change in the near future and the shortage of food protein would continue to affect the under-privileged rural and urban masses. The young children, expecting and nursing mothers, and elders are the most vulnerable lots. The animal protein being out of their reach, the problem of malnutrition is assuming a serious dimension in the country. To meet this challenge, a concerted effort is needed to increase production and productivity of protein-rich legume crops which can be grown well under subsistence level of farming. Among these, pigeonpea (*Cajanus cajan* (L.) Millsp.) stands out primarily due to its drought tolerance, minimum input requirement, and the ability to produce reasonable quantity of food under unfavourable environmental conditions. Its seeds contain about 20 - 22% protein and reasonable amounts of essential amino acids. The genetic enhancement efforts at the national level have succeeded in developing pigeonpea varieties resistant/tolerant to various biotic stresses. The other areas where significant progress has been registered through breeding is the improvement of seed quality (size) and reduction of crop maturity duration. The new varieties are attracting more and more cultivators each year and for this reason pigeonpea area in the country has witnessed a phenomenal increase from 2.8 m ha in 1950 to 3.8 m ha in 1996 with an average annual growth rate of 2% (Ryan, 1997). Unfortunately, such an increase has not been witnessed in the productivity and the average national pigeonpea yield (600-700 kg ha^{-1}) has not changed over the last few decades.

The issue of plateaueing productivity has been discussed at the national level in several 'brain-storming' sessions and conferences but the success is yet to be witnessed. The recent efforts to exploit hybrid vigour in pigeonpea offer optimism for a breakthrough in the yield potential as it has been witnessed in a number of field crops. This effort began in 1974 with the identification of a stable genetic male-sterility system (GMS) at ICRISAT (Reddy *et al.*, 1977) which when coupled with natural out-crossing offered scope for developing high yielding commercial hybrids in pigeonpea.

2. Theoretical Considerations

Soon after establishment of the phenomenon of heterosis by Shull (1908), the breeders in almost all the cross-pollinated crops attempted to exploit hybrid vigour by developing open-pollinated synthetics, composites or hybrid varieties. Since dominant genes in the population have evolutionary advantage (Fisher, 1930), the heterosis was initially considered a discernible phenomenon of the cross-pollinated crops but subsequent successful exploitation of hybrid vigour in cereal and vegetable crops established its utility in the self-pollinating crops also. Sharma and Dwivedi (1995) argued that since over-dominance and dominance gene actions are not very prominent for yield in both self as well as cross-pollinated crops, the additive gene action and the additive x additive interallelic and intergenomic interactions are likely to play an important role in the expression of hybrid vigour. Therefore, the manifestation of heterosis is independent of pollination system of the crop and in the past few decades enough literature has been published in different crops to support this view. The likelihood of obtaining a heterotic combination, however, is relatively high in the cross-pollinated crops and low in the self-pollinated crops because the former can carry a considerable hidden genetic load of undesirable recessive genes while in the self-pollinated group such traits stabilize rapidly.

Pigeonpea belongs to partially out-breeding category and several useful dominant genes have been preserved in the open-pollinated landraces and cultivars while the useful recessives have been fixed by breeders in pure lines through pedigree selection. Perhaps with little efforts pigeonpea breeders can make use of such gene combinations in exploiting hybrid vigour in this crop. Scanning of literature on gene action and heterosis (Saxena and Sharma, 1990) in pigeonpea clearly shows that important economic traits such as yield, pods plant^{-1}, plant height, seed size, and seeds pod^{-1} are controlled by both additive as well as non-additive gene action and that the level for hybrid vigour for yield is comparable with other crops where successful commercial hybrids have been established. The discovery of stable male-sterility systems, availability of natural out-crossing, and evidence of heterotic yield advantage have set a perfect stage for breaking the persisting yield plateau in pigeonpea through hybrid breeding.

3. Mass Pollination Mechanism

For commercial exploitation of heterosis in any crop it is necessary to develop an economically viable mass pollen transfer mechanism. In pigeonpea, the phenomenon of natural out-crossing was known in the early part of the 20th century when Howard *et al.* (1919) reported 14% natural out-crossing at Imperial Agricultural Research Institute, Pusa. Since then, several studies have reported a large variation (Table 1) in the extent of natural out-crossing (Saxena *et al.*, 1990).

The natural out-crossing in pigeonpea occurs primarily due to insect visitations. Pathak (1970) reported *Apis mellifera* and *A. dorsata* as the main pollinating vectors. Brar *et al.* (1992) recorded five insect species namely, *A. mellifera*, *A. dorsata*, *Xylocopa* spp., *Megachile lanata* and *Ceratina binghami* visiting pigeonpea flowers in Ludhiana. They further reported that *A. mellifera* did not prefer pigeonpea flowers and among the insect species visiting pigeonpea flowers were *M. lanata* and *A. dorsata* which played an important role in affecting cross-pollination in pigeonpea.

Table 1: Natural out-crossing recorded in pigeonpea at various locations in India

Place	Range of out-crossing
Pusa	2.3 - 12.0
Pusa	1.6 - 3.4
Nagpur	3.0 - 48.0
Niphad	11.6 - 20.8
Ranchi	3.8 - 26.7
Varanasi	10.3 - 41.4
Badnapur	0.0 - 8.0
Coimbatore	10.0 - 70.0
Hyderabad	0.0 - 42.1

Source: Saxena *et al.* (1990)

Verma and Sidhu (1995) reported that *M. lanata* and *Xylocopa* spp. were active in promoting cross-pollination in pigeonpea. The wide range of natural out-crossing is reported to be due to a number of factors and the number and type of pollinating vectors being the most important one.

4. The First Breakthrough

Development of stable genetic male-sterility system at ICRISAT (Reddy *et al.*, 1978) is considered an important breakthrough in hybrid pigeonpea breeding programme. This was followed by a series of feasibility studies related to the presence of hybrid vigour and hybrid seed production technology. The initially bred medium-duration pigeonpea hybrids recorded 20 - 32% yield advantage over the standard variety and this encouraged to allocate substantial resources in this project primarily for diversifying male-sterile lines and to produce high yielding hybrids in different maturity groups. This endeavour led to the release of first pigeonpea hybrid ICPH 8 in 1991 (Saxena *et al.*, 1992) jointly by ICRISAT and ICAR. This event is considered a milestone in the history of breeding legume crops. This ICRISAT-bred hybrid was superior to checks, UPAS 120 and Manak by a margin of 30.5 to 34.2%. In the on-farm trials also, this hybrid out-yielded the control by 20 - 26%. This was followed by the release of five additional hybrids by ICAR. All the hybrids recorded significant gains in yield over the best available pure line varieties (Table 2).

Table 2: Pigeonpea hybrids released in India

Character	ICPH 8	PPH 4	CoH1	CoH2	AKPH 4104	AKPH 2022
Adaptability	Central Zone	Punjab	Tamil Nadu	Tamil Nadu	Central Zone	Maharashtra
Year of release	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
Days to maturity	125	137	117	120-130	130-140	180-200
Yield (tons ha^{-1})	1.78	1.93	1.21	1.05	NA	NA
Superiority over check	30% over TAT 10, 41% over UPAS 120	14% over UPAS 120, 14% over H 82-1	22% over Vamban 1, 19% over ICPL 87	35% over CO 5	64% over UPAS 120	35% over BDN 2, 28% over C 11, 25% over ICPL 87119

5. Adoption Failure of GMS-Based Hybrids

In spite of releasing six pigeonpea hybrids at the national level this technology was not adopted by seed sector. Niranjan *et al.* (1998) evaluated this technology by studying its impact on its users and identifying constraints faced by researchers, seed companies, and seed growers in the adoption of the hybrids. 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 major adoption constraints identified by them were (i) unwillingness of the farmers to remove fertile segregants from seed production plots as they believe it is not good 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 seed of ICPH 8, (iii) shortage of parental seed stocks, (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. These production constraints could be overcome if an efficient cytoplasmic nuclear male-sterility (CMS) based hybrid seed production technology is developed. They further concluded that this will make technology transfer easy since many seed growers are trained in CMS-based hybrid seed production in maize, sorghum and millet.

6. The Second Breakthrough

6.1 Development of Cytoplasmic Nuclear Male-Sterility System

6.1.1 Research at ICRISAT: The development of pure breeding cytoplasmic genic male-sterile lines in pigeonpea would effectively overcome the seed production inefficiencies of genetic male-sterility based hybrids and their parents. The first attempt to develop CMS in pigeonpea using the crossable wild relatives was made by Reddy and Faris (1981). They crossed *Cajanus scarabaeoides*, a wild species with fertile F_1 plants of *Cajanus cajan* x *C. scarabaeoides* cross. The resulting BC_1F_1 plants were fertile but in BC_1F_2 generation some male-sterile segregants were identified. This male-sterility was linked with female-sterility and, therefore, it was not pursued further. Ariyanayagam *et al.* (1995) crossed *Cajanus sericeus* with a short-duration advanced breeding line of pigeonpea. The F_1 progeny 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 between 8 and 99%. Saxena and Kumar (2003) reported a stable CMS system derived from a cross involving *Cajanus scarabaeoides* and pigeonpea. Recently, Saxena and Kumar (unpublished) also reported the development of CMS lines by using *Cajanus sericeus* as a female parent. From this material some temperature sensitive CMS lines were also derived (Table 3).

6.1.2 Research at ICAR centres: Encouraged with the initial success in developing CMS at ICRISAT, six ICAR centres, Indian Institute of Pulses Research (9 species), Indian Agricultural Research Institute (1 species), Gujarat Agricultural University (2 species), Punjabrao Krishi Vidyapeeth (2 species), Tamil Nadu Agricultural University (1 species), and Punjab Agricultural University (2 species) also joined the efforts to develop CMS lines through intra-specific crosses. Among these, scientists at Gujarat Agricultural University succeeded in developing CMS lines with *Cajanus scarabaeoides* cytoplasm (Tikka *et al.*, 1997). They selected 14 male-sterile plants from an F_2 population of cross *C. scarabaeoides* x *C. cajan*. For maintaining this male-sterility a number of lines were crossed and the progeny of MS 288(F) produced all male-sterile plants. This male-sterile line, designated as GT 288A, was found stable over environments (Table 4). The identification of male-sterile plants was reported at Punjabrao Krishi Vidyapeeth in an interspecific cross with *C. volubilis* (Srivastava *et al.*, 1997). Similarly, at Varanasi and Trombay some male-sterile plants were also found in crosses involving *C. mollis* and *C. sericeus*.

Table 3: Changes in the fertility status of some environment-sensitive plants identified in the population of ICPA 85010 grown at Patancheru (17^0 N)

Line/ Selection no.	Season		Frequency of male-sterile (S) and fertile (F) plants						Pods/ plant (range)*
	1# 2	No. of plants	7 Sept 4 Sept	28 Sept 22 Sept	25 Oct 17 Oct	11 Nov 14 Nov	20 Feb 16 Feb	10 Mar 14 Mar	
			S:F	S:F	S:F	S:F	S:F	S:F	
82	1	8	**8 : 0**	5 : 3	5 : 3	5 : 3	**8 : 0**	8 : 0	62 – 131
Sel. 82-6	2	23	**22 : 1**	18 : 5	4 : 19	4 : 19	**22 : 1**	22 : 1	76 – 201
77	1	7	**7 : 0**	6 : 1	6 : 1	5 : 2	**7 : 0**	7 : 0	106 – 190
Sel. 77-4	2	26	**24 : 2**	10 : 16	6 : 20	2 : 24	**22 : 4**	22 : 3	111 – 218
83	1	6	**6 : 0**	6 : 0	5 : 1	6 : 0	**6 : 0**	6 : 0	81 – 231
Sel. 83-5	2	21	**21 : 0**	6 : 15	1 : 20	2 : 19	**21 : 0**	21 : 0	97 – 188
149	1	7	**7 : 0**	7 : 0	5 : 2	5 : 2	**7 : 0**	7 : 0	42 – 98
Sel. 149-4	2	20	**20 : 0**	11 : 9	2 : 18	2 : 18	**20 : 0**	19 : 0	126 – 209
86	1	5	**5 : 0**	4 : 1	4 : 1	3 : 2	**5 : 0**	5 : 0	48 – 115
Sel. 86-5	2	26	**21: 5**	0 : 26	0 : 26	0 : 26	**19 : 5**	19 : 4	87 – 191
90	1	8	**8 : 0**	5 : 3	5 : 3	4 : 4	**8 : 0**	8 : 0	123 – 220
Sel. 90-7	2	23	**23 : 0**	4 : 19	2 : 21	2 : 21	**23 : 0**	23 : 0	147 – 260
150	1	8	**8 : 0**	3 : 5	3 : 5	3 : 5	**8 : 0**	8 : 0	38 – 90
Sel. 150-7	2	31	**29 : 2**	12 : 19	10 : 21	17 : 14	**26 : 2**	26 : 2	79 – 158
Control	1								180 ± 14.2
(ICPL 85010)	2								222 ± 41.2

Season 1 = 1999/00, sowing June 22; # Season 2 = 2000/01, sowing June 20; * = recorded in the converted fertile plants in late November

Source: Saxena and Kumar (unpublished)

6.2 Genetic Diversification of Cytoplasmic Nuclear Male-Sterile Lines

6.2.1 C. scarabaeoides derived CMS lines: To broaden the genetic base of newly established cytoplasmic-genic male sterility systems in pigeonpea twelve agronomically superior and good combiner lines were selected. These were PUSA 33, ICPL 87, GT 100, SKNP 289, SKNP 290, BDN 2, SKNP 88-3, SKNP 9523, T 15-15, T 21, UPAS 120 and ICPL 84023. These genotypes were converted into CMS lines through simple backcross breeding programme. These lines were respectively designated as GT 33A, GT 87A, GT 100A, GT 289A, GT 290A, GT 301A, GT 302A,

Table 4: Evaluation of GT 288 A line for stability of pollen sterility in different agroclimatic situations across the locations

Location	Year of testing		
	1997	1998	1999
Bombay	100	-	-
Varanasi	-	98	-
S.K.Nagar	100	100	100
Bangalore	-	100	-
Vadodara	99.60	-	-
New Delhi	-	99.0	100
Kanpur	100	100	100
Faizabad	100	100	100
Akola	100	100	100
Coimbatore	100	100	-

GT 303A, GT 304A, GT 305A, UPAS 120 A, and ICPL 84023 A. Amongst these, three lines *viz*., GT 100A, GT 289A, GT 290A, JCPL 84023 are determinate types, GT 87A is semi-determinate and the rest are non-determinate types. White seeded lines are GT 100A, GT 301A, GT 302A, GT 303A and GT 304A. Early maturing lines include GT 33A, GT 87A, GT 100A, GT 289A, GT 290A, GT 302A, GT 303A, GT 305A, and ICP 84023 (Table 5). At ICRISAT also over 50 lines were found maintaining CMS but only a few with desirable agronomic traits are being maintained (Saxena and Kumar, 2003).

6.2.2 C. sericeus derived CMS lines: CMS 85010A, a male-sterile line with *C. sericeus* cytoplasm was used as a female parent for diversifying the nuclear base of CMS lines. Using a classical backcrossing programme one short-duration non-determinate line ICPL 88034 and another long-duration non-determinate line of African origin ICP 13092 were converted into male-sterility and these were respectively designated as ICPA 88034 and ICPA 13092 (Saxena and Kumar, unpublished).

6.3 Fertility Restoration

6.3.1 Research at ICAR centres: The utilization of diverse germplasm may lead to identification of fertility restorer lines (Pattanashetii *et al.*, 2002). During 1997 and onwards, 1908 hybrids were synthesized using CMS segregants from an F_5 population of cross *Cajanus scarabaeoides* x *Cajanus cajan* and pigeonpea germplasm lines for identification of fertility restoring lines. From these hybrids 18 restorer lines were identified and characterized (Table 5). Out of 18 restorers, eight were of medium

Table 5: Characterization of GT 288A restorer lines identified in Gujarat

Restorer	Characters									
	DF	DM	PH	PP	SP	PL	TW	PT	PC	SC
GTR-1	99	142	155	195	4.1	4.2	10.0	NDT	BSM	Orange
GTR-2	118	172	137	176	4.2	4.6	9.5	NDT	GBS	Brown
GTR-3	102	138	146	165	4.3	4.3	10.2	NDT	Green	White
GTR-4	100	138	143	153	5.1	5.2	10.5	NDT	Green	Red
GTR-5	113	170	146	176	4.2	4.3	10.3	NDT	GBS	Red
GTR-6	111	155	172	188	4.3	4.2	8.5	NDT	GDBS	White
GTR-7	130	210	185	136	3.5	4.0	9.4	NDT	Green	White
GTR-8	97	145	127	143	3.4	4.1	9.2	NDT	BSM	White
GTR-9	92	137	139	162	4.2	4.2	9.5	NDT	GBS	White
GTR-10	103	148	153	207	3.7	4.0	10.1	NDT	Green	Orange
GTR-11	95	145	90	130	3.9	4.1	10.1	DT	GBS	White
GTR-12	110	165	100	122	3.5	4.2	9.7	NDT	GBS	Orange
GTR-13	88	142	110	140	3.6	3.9	9.7	NDT	GBS	Orange
GTR-14	89	146	125	123	3.3	4.3	10.1	NDT	GBS	Orange
GTR-15	105	159	125	130	3.6	4.2	10.2	NDT	GBS	Orange
GTR-16	100	156	110	160	3.8	4.1	9.9	NDT	GBS	Orange
GTR-17	115	167	165	180	3.5	3.6	9.8	NDT	GBS	Orange
GTR-18	100	158	150	155	3.9	4.0	10.2	NDT	GBS	White

DF=Days to flower, DM=Days to mature, PH=Plant height (cm), PP=Pods plant^{-1}, SP=Seeds pod^{-1}, PL=Pod length (cm), TW=Test weight (g), PT=Plant type, PC= Pod colour, SC=Seed colour

maturity (135-150 days) while 10 lines were of medium-late (150-175 days) maturity group. Only one restorer (GTR-11) had determinate growth habit and the remaining were non-determinate types.

So far, a total of 2425 hybrids have been evaluated at Kanpur (700), Akola (350), SK Nagar (950) and Faizabad (425). Of these, 223 combinations were found to restore pollen fertility of different degrees (Anonymous, 2003).

To study the stability of fertility restoration 41 experimental hybrids were evaluated at Kanpur, Akola, SK Nagar and Faizabad (Table 6). It was observed that the hybrids developed at SK Nagar, Kanpur and Faizabad expressed high pollen fertility at both SK Nagar and Faizabad. However in Kanpur, a large variation for pollen fertility was recorded while in Akola these hybrids were almost male-sterile with pollen fertility ranging from 0 to 35%. This data indicated a significant role of environment in the expression of fertility restorer genes. Therefore at present, rather than aiming for widely adapted hybrids, an attempt should be made to breed high-yielding hybrids specifically adapted to region.

Table 6: Fertility status of F_1's grown at different locations during 2002

Hybrid	Percent Fertility			
	IIPR	Akola	SK Nagar	Faizabad
SKNPCH 1	25 – 80	0 – 10	97	100
SKNPCH 5	20 – 85	0 – 35	88	93
SKNPCH 6	20 – 80	0 – 12	100	100
SKNPCH 10	40 – 80	0 – 10	100	100
NDPH 1	28 – 60	0 – 20	99	98
NDPH 2	20 – 60	0 – 10	85	100
NDPH 4	15 – 96	0 – 15	99	100
NDPH 5	15 – 93	0 – 12	95	100
NDPH 7	20 – 85	0 – 20	99	98
IPH 01 – 08	30 – 60	0 – 50	73	64
IPH 01 – 10	20 – 50	0 – 8	29	88
IPH 01 – 11	10 – 30	0 – 5	100	100
IPH 01 – 12	50 – 70	0 – 30	-	100
IPH 01 – 13	30 – 60	0 – 10	80	93
IPH 01 – 14	30 – 60	0 – 8	57	-
IPH 01 – 16	25 – 60	–	-	92
IPH 01 – 18	40 – 85	0	100	100
IPH 01 – 19	60 – 90	–	93	-
IPH 01 – 20	10 – 40	–	40	42
IPH 01 – 21	20 – 40	–	58	-
IPH 01 – 24	10 – 40	0	100	-
IPH 01 – 25	30 – 75	0	25	100
IPH 01 – 26	40 – 70	–	-	61
IPH 01 – 29	20 – 30	0 – 5	100	100
IPH 01 – 30	30 – 70	0 – 10	14	100
IPH 01 – 31	15 – 25	0	00	46
IPH 01 – 32	40 – 70	0 – 10	91	100
IPH 01 – 36	10 – 30	0 – 20	46	54
IPH 01 – 37	20 – 50	0	100	100
IPH 01 – 38	60 – 80	0 – 5	89	94
IPH 01 – 40	30 – 85	0 – 4	100	98
IPH 01 – 41	60 – 80	–	100	100
IPH 01 - 42	40 – 90	–	100	-
NDPH 8	25 – 80	–	85	92
NDPH 9	30 – 70	–	100	100
NDPH 10	40 – 90	–	100	100
NDPH 33	25 – 80	–	00	00
NDPH 34	22 – 60	–	91	100
NDPH 39	20 – 75	–	100	100
NDPH 64	0 – 20	–	00	00
NDPH 65	40 – 80	–	100	100

6.3.2 Research at ICRISAT: Studies on the fertility restoration of CMS lines derived from *C. sericeus* were carried out at ICRISAT and over 200 lines of diverse origin were crossed. Over 50 fertility restorers with varying degrees of restoration were identified (Saxena and Kumar, unpublished). Some of the important selected restorers are listed in Table 7. The fertility restoration of ICPL 129, ICPL 89, and HPL 24 was confirmed in the last three seasons. ICPL 89 is a non-determinate line with few branches. Although it restored a high level of pollen fertility, its crosses were low yielding, suggesting its poor combining ability. On the other, HPL 24, a medium-duration line, produced hybrids with good branching and canopy development. ICPL 129 is a short-duration determinate restorer and it has been used in only one combination with high level of fertility restoration. Fertile hybrids were also found in crosses involving *C. scarabaeoides* CMS lines. Out of 14 hybrids evaluated, eight restored the fertility (Table 8).

At present, a number of fertility restorers have been identified in different genetic backgrounds and these could also be used to develop base populations for the identification of high combining restorer lines.

6.4 Adaptability of CGMS based Pigeonpea Hybrids

Eight CMS based pigeonpea hybrids were evaluated for their yield performance over eight environments (two locations in 2001 and six locations in 2002) in Gujarat state. Highly significant differences were observed for genotypes, environment, and genotype x environment interaction for yield, pods plant^{-1}, seeds pod^{-1}, pod length, branches plant^{-1}, plant height, 100-seed weight, days to flowering and days to maturity. These results suggested differential response of genotypes to environmental changes. The stability analysis showed significance of linear component of variation for all the traits except number of seeds pod^{-1} and 100-seed weight, indicating significant differences among genotypes for 'b_i' component. Significant differences due to pooled deviation for all the traits indicated the importance of non-linear component in the experimental material.

Hybrid SKNPCH-10 (yield = 1763 kg ha^{-1}, $b_i = 1.23$, $S^2d_i = 0.09$) followed by SKNPCH-3 (yield = 1698 kg ha^{-1}, $b_i = 1.16$, $S^2 d_i = 0.09$) and SKNPCH-6 (yield = 1548 kg ha^{-1}, $b_i = 0.98$, $S^2d_i = 0.06$) produced high grain yield with high stability. Hybrid SKNPCH-5 ($X = 1644$ kg h^{-1}, $b_i = 1.36$, $S^2d_i = 0.02$) gave better performance in good environment indicating its responsiveness to specific environment. SKNPCH-2 was found unstable for yield, pods plant^{-1}, pod length, and plant height.

Table 7: Fertility restoration of ICPA 85010 in crosses involving various pollen parents

Pollen parent	Fertile plants (%)		
	2000	2001	2002
ICPL 129	95 (42)	72 (442)	95 (321)
ICPL 89	100 (45)	91 (97)	95 (128)
ICPL 131	100 (15)	80 (45)	100 (29)
HPL 21	-	100 (34)	97 (61)
HPL 24	89 (122)	92 (226)	100 (35)
ICPL 10650	-	100 (29)	-
ICP 11912	79 (14)	83 (12)	-
ICPL 20	-	85 (85)	-
ICPL 205	-	-	100 (5)
ICPL 12	-	-	80 (10)
ICPL 118	-	-	91 (32)
ICPL 83006	-	-	100 (32)
ICPL 86009	-	-	100 (4)
ICPL 90001	-	-	100 (9)
ICPL 90004	-	-	94 (18)
ICPL 90011	-	-	100 (54)
ICPL 91016	-	-	100 (20)

( ) number of plants
Source: Saxena and Kumar (unpublished)

7. 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, its multiple uses and role in sustaining productivity make it a favourite crop of small holding dryland 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.

Since the demand for pigeonpea is ever increasing, the attention of researchers needs to be focused on increasing its yield potential. The exploitation of heterosis and restructuring of plant type are two potential 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.

Table 8: Frequency (%) of fertile plants and average pod number in F_1 hybrids between three *C. scarabaeoides* CMS lines and 14 locally adapted cultivars

Pollen parent	ICMA 88039		ICPA 88034		ICPA 81	
	Fertile plants (%)	Pods/ plant	Fertile plants (%)	Pods/ plant	Fertile plants (%)	Pods/ plant
FRS 1	99 (96)	333.3 ±23.45	95 (21)	480.0 ±22.04	100 (8)	418.3 ±14.65
FRS 2	94 (49)	356.0 ±21.81	100 (4)	550.0 ±13.68	-	-
FRS 3	100 (29)	371.0 ±22.64	100 (4)	585 0 ±7.83	-	-
FRS 4	100 (45)	421.3 ±17.89	-	-	-	-
FRS 5	100 (53)	677.3 ±30.76	-	-	-	-
FRS 6	81 (43)	285.3 ±14.50	86 (36)	377.5 ±23.90	-	-
FRS 7	77 (44)	275.0 ±12 47	56 (16)	210.0 ±4.10	50 (22)	301.0 ±8.89
FRS 8	68 (34)	297.1 ±7.12	-	-	-	-
FRS 9	0 (69)	0	-	-	0 (11)	0
FRS 10	0 (44)	0	0 (9)	0	0 (5)	0
FRS 11	0 (14)	0	0 (24)	0	0 (17)	0
FRS 12	0 (14)	0	-	-	0 (21)	0
FRS 13	0 (13)	0	0 (3)	0	0 (3)	0
FRS 14	0 (21)	0	-	-	-	-
ICPL 87119 (control)		487.4 ±23.02				

( ) Number of plants
Source· Saxena and Kumar (2003)

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 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 (Y. S. Chauhan, personal communication). 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% 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 diseases 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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