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Challenges and opportunities of breeding early maturing pigeonpea hybrids

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ABSTRACT

Recently, a hybrid breeding technology has been successfully developed in pigeonpea and three high yielding hybrids were released. This technology is based on cytoplasmic - nuclear male-sterility (CMS) and insect-aided natural out – crossing systems. These hybrids produced 25-40% more yield over the local cultivars in farmers' fields. The seed production technology of hybrids and their male and female parents has also now been perfected. These hybrids mature in 6-7 months hence have limited adaptation; to register greater impact of this technology early maturing (4-5 months) group hybrid breeding programme was initiated. This paper, besides reviewing the performance of some early maturing hybrids, discusses their prospects in enhancing productivity in the existing and new potential niches.

Key words: Cytoplasmic nuclear male-sterility (CGMS), Early maturity hybrids, Pigeonpea

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Majority of the food proteins in India are derived from pulses that are invariably grown under risk - prone rainfed environments. Among the pulses, pigeonpea [*Cajanus cajan* (L.) Millsp.] occupies an important place in the rainfed cropping systems with an estimated area of 4.04 million ha (IIPR 2013). To enhance pigeonpea productivity multi-disciplinary crop improvement projects were undertaken at various research institutions and more than 100 pure line cultivars were released. The adoption of new cultivars did help in enhancing the total cropped area and production (IIPR 2013) but its productivity did not register any significant improvement; and over the decades it has remained unacceptably low at around 700 kg/ha. This has been a matter of concern since the per capita protein availability in the country is declining steadily from 27.30 kg/year in 1950 to 10 kg/year in 2000 (www.commodityonline.com 2009). This is mainly due to ever growing population, stagnation of pulse production, and escalating prices. At present the national harvest accounts for about 2.56 million tonnes of pigeonpea grains. However this quantity is not sufficient to meet the domestic needs and about 500,000 tonnes of pigeonpea is imported annually. This situation is not likely to improve and considering 2% annual growth in population, additional pulses will be required. Soon after the development of CMS systems in pigeonpea (Saxena *et al*. 2005, Tikka *et al*. 1997), a strong research programme was launched to breed high yielding hybrids. In this endeavour a breakthrough was achieved when a hybrid breeding technology was successfully developed and tested on a large scale. The concept of commercial hybrids in pigeonpea was developed at ICRISAT and a genetic male-sterility based hybrid ICPH 8 was released in 1991 in India (Saxena *et al.* 1992). This hybrid failed to meet the expectations of seed producers due to the concerns arising from its production cost and quality. This attempt, however, confirmed the presence of exploitable hybrid vigour in the crop and demonstrated the effectiveness of partial natural out-crossing in pod setting on the male-sterile plants. Subsequently, to overcome the production issues, it was decided to breed cytoplasmic nuclear male-sterility based hybrids. Hence, deliberate efforts were made in this direction and A_2 from *C. scarabaeoides* (Tikka *et al.* 1997) and A_4 from *C. cajanifolius* (Saxena *et al.* 2005) CMS systems were developed.

In India, majority of the pigeonpea comes from the states of Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Andhra Pradesh, and Uttar Pradesh. In these states medium and long duration pigeonpea cultivars are grown as inter-crop and it is unlikely that the cultivated pigeonpea area will increase by any significant extent to meet the entire needs of the country. Hence, new production niches with early-maturing cultivars were explored. As a follow-up pigeonpea - wheat rotation was successfully introduced in the states of Punjab, Haryana and western Uttar Pradesh. The pigeonpea area in these states has also been stabilized over years. The next best alternative is to enhance the productivity in the unit area and the recent efforts through hybrid breeding look very encouraging (Saxena 2006, Saxena *et al.* 2013) and the development of hybrids in early maturity was given priority. This paper, besides reviewing the performance of some early maturing hybrids, also discusses their prospects in enhancing per se crop productivity through the introduction of early maturing hybrids in the existing and potential niches.

BREEDING EARLY MATURING HYBRID PARENT

Development of early maturing CMS lines: The male–sterile lines carrying A_4 cytoplasm from *C. cajanifolius* (Saxena *et al.* 2005) exhibits perfect male-sterility with absolutely no pollen production. This system has been reported to be highly stable under diverse environments (Dalvi *et al.* 2008a, Sawargaonkar *et al.* 2012). In order to widen the genetic base of hybrids A_4cytoplasm was transferred to 11 diverse early maturing inbred lines through backcrossing (Table 1). Of these, seven were determinate and the remaining were non-determinate. These lines have a considerable range for flowering (60 - 81 days), maturity (105 - 128 days), plant height (71 – 157 cm), and seed weight (8.1 - 12.5 g/100 seeds). Another male-sterile line GT 288A, bred with *C. scarabaeoides* cytoplasm was developed by Tikka *et al.* (1997), and designated as A_2 cytoplasm. The anthers of this male-sterile were translucent with no pollen grains. None of the early maturing CMS lines had resistance to wilt and sterility mosaic diseases and this issue needs to be given importance in the future hybrid parent breeding programmes. In this context the incorporation of dominant gene conferring resistance to fusarium wilt (Saxena *et al.* 2012) should be given serious attention. This gene when incorporated in the female parents, will allow development of more number of wilt resistant hybrids since both resistant x resistant and resistant x susceptible crosses will produce resistant hybrids. On the contrary, the resistance to sterility mosaic is controlled by recessive genes and hence both the parents need to have resistance.

Genetics of fertility restoration: There are certain nuclear genes which have the capability of repairing mitochondrial genome that primarily determines the expression of male-sterility. In most cases the fertility restoring genes have been identified from primary gene pool. However, in certain cases fertility restorer lines have also been derived from the populations involving cytoplasm donor species (Kaul 1988). For breeding fully fertile stable pigeonpea hybrids it is essential that sufficient knowledge about the inheritance of fertility restoring genes and their stability is available to the breeders. The fertility restoration of A_4 cytoplasm has been studied by Sawargaonkar *et al.* (2012), Kyu and Saxena (2011), and Dalvi *et al.* (2008). In all the cases two genes were found to control fertility restoration of hybrids. However their mode of expression was inconsistent. In some reports duplicate dominant (15:1) gene action was observed, while in others it was found to be controlled by complementary gene action (9:7) and recessive epistasis (9:3:4). Saxena *et al.* (2011) reported two genes for controlling fertility restoration in A_4 cytoplasm. They found that for stability of fertility restoration across the locations, the presence of both the dominant genes was essential. On the contrary, the hybrids with a single fertility restoring gene were inconsistent with respect to their fertility restoration. The inheritance of fertility restoration of

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Table 1. List of identified early maturing maintainers and restorers of A_4 cytoplasm

Genotypes	Growth habit*	Days to flower	Days to mature	Plant height (cm)	100- seed weight (g)	Grain yield (kg/ha)	Seed colour	Wilt %	SM %
Maintainers									
Pusa Ageti	DT	81	128	127	10.2	627	B	74	26
ICPL 20171	DT	66	106	76	8.3	724	B	87	60
ICPL 87093	DT	80	120	148	11.3	1107	C	73	7
ICPL 85012	DT	62	110	69	10.0	460	B	92	33
ICPL 86012	DT	72	115	115	12.3	591	C	29	0
ICPL 87102	DT	68	110	86	12.5	760	C	30	60
ICPL 93093	DT	64	110	71	9.2	340	C	55	35
ICPL 20172	NDT	60	105	90	8.3	310	B	57	79
ICPL 91030	NDT	66	113	145	8.1	778	B	71	7
ICP 14425	NDT	76	119	157	9.9	795	C	78	67
ICPL 98011	NDT	67	110	145	8.7	730	B	57	43
UPAS 120 (Check)	NDT	86	129	185	9.8	1541	B	28	67
Restorers									
ICPL 81-3	NDT	77	117	167	7.5	510	B	80	20
ICPL 149	NDT	90	132	162	7.0	1269	B	83	17
ICPL 161	NDT	89	134	180	7.8	1754	B	75	25
ICPL 88034	NDT	78	121	158	9.4	890	B	65	35
ICPL 88039	NDT	66	112	125	9.1	564	B	80	20
ICPL 86022	NDT	65	120	135	11.7	855	B	78	22
ICPL 90048	NDT	70	114	143	9.9	1590	C	50	50
ICPL 92047	NDT	74	118	163	9.0	791	B	77	18
ICPL 89	NDT	72	110	135	8.8	718	C	77	25
ICPL 92045	NDT	71	110	145	8.3	518	B	61	72
ICPL 93103	NDT	62	110	109	9.0	623	B	86	57
ICPL 150	NDT	88	134	198	9.1	1563	B	100	0
ICPL 93107	NDT	72	113	140	7.9	823	B	85	37
ICPL 93101	NDT	71	110	130	9.9	862	C	72	11
ICPL 90030	NDT	67	115	127	8.4	479	C	80	25
ICPL 151	DT	67	120	145	10.5	2087	C	79	0
ICP 11378	NDT	90	133	178	7.6	927	B	68	61
ICP 8744	NDT	90	129	198	8.7	1125	B	100	66
ICP 10907	NDT	77	115	102	10.3	642	B	32	72

*****Growth habit: DT=Determinate; NDT= Non-determinate; SM-Sterility mosaic; C= Cream; B= Brown

A_2 cytoplasm was studied in four crosses and based on F_1 and F_2 data it was reported that the pollen fertility in this system was controlled by a single dominant gene.

Selection of early maturing fertility restoring lines: Stable fertility restoration is an important factor in determining the acceptability of any hybrid combination. During the past few years a total of 19 fertility restorers in early maturity group were identified among advanced breeding lines and germplasm (Table 1). Each line was studied for its fertility restoration for three seasons ; and each hybrid yielded > 90% pollen fertility (data not reported).This set of early maturing restorers was found to have significant variation for flowering (62 - 90 days), maturity (110- 134 days), plant height (102 – 198 cm), and seed weight (7.00 – 11.70 g/100 seeds). None of the restorers was found to have resistance to wilt but, two lines ICPL 150, ICPL 151 recorded no incidence of sterility mosaic disease in the disease sick nursery.

PERFORMANCE OF EARLY MATURING HYBRIDS

Soon after the development of stable CMS system, several experimental hybrids were developed and evaluated (Saxena *et al*. 2006). The first early maturing CMS line with A_4 cytoplasm was ICPA 2039. In 2006, this line was crossed to eight fertility restorers and the first multi-location trial was conducted in 2007; and their evaluation was continued for the next three years (Table 2). All these hybrids matured between 106 - 117 days and compared well with the controls (UPAS 120 and ICPL 88039). A total of 25 yield trials were conducted during four years; and based on the mean performance ICPH 2433, ICPH 2438, and ICPH 2363 were found promising with respectively, 54%, 42%, and 36% superiority over the control UPAS 120. The highest mean yield of 2306 kg/ha was recorded by hybrid ICPH 2433. On average, six hybrids were >20% superior to the control UPAS 120 (1502 kg/ha). According to Saxena and Nadarajan (2010), A_2 CMS based hybrid GTH 1 was developed at SK Nagar, Gujarat and released by ICAR in 2004 for cultivation in Gujarat State. Based on yield trials conducted during 2000 to 2003, GTH 1 (1830 kg/ha) gave 57% yield advantage over the best GMS hybrid AKPH 4101 (1183 kg/ha) and 32% superiority over the best local variety GT 101 (1330 kg/ha). In multi-location trials (IHT and AHT) conducted during 2005-2006, this hybrid recorded the highest yield with >40% standard heterosis. In front line demonstrations GTH 1 recorded 25.3% more yield over the best control. These data demonstrated that the level of hybrid vigour in early maturity group is high. (Saxena and Nadarajan 2010).

The estimates of per day productivity (Table 2) showed that high-yielding hybrids such as ICPH 2433 (22.2 kg/ha/day) and ICPH 2438 (18.5 kg/ha/day) were far superior to the control UPAS 120 (12.50 kg/ha/day) and ICPL88039 (8.4 kg/ha/day), suggesting that the hybrids were more efficient in dry matter production and/or its accumulation in the grains. In this context, studies are needed to understand the physiological aspects of yield determination and its relationship with parents on dry matter production and its partitioning, harvest index and role of yield contributing traits.

SEED PRODUCTION OF HYBRIDS AND THEIR PARENTS

Seed production technology: The commercial seed production of pigeonpea hybrids involves large scale seed production of their female line (A/B), restorer line (R) and hybrid (A x R) combination. Each set of material requires isolation of at least 500 m from other pigeonpea. For seed production of A/B lines, breeder seed of both A- and B- lines are planted using a row ratio ranging from 3:1 to 8:1 (female : male), depending upon the extent of insect activity (Saxena and Kumar 2013). In case of higher insect activity 8:1 ratio also gives good seed yield. In general, 4:1 row ratio gives optimum seed yield at most locations. At maturity, the B-line should be harvested first and followed by pods set on the A-line. For the hybrid seed production (A x R) also, the row ratios, as in case of A/B seed multiplication, may be variable. In this programme also, the R-line should be harvested first to ensure seed purity. Roguing and strict crop monitoring are critical aspects of hybrid seed production. The roguing should be done at seedling, flowering, and pre-harvesting stages. Our experience has shown that the hybrid seed can be produced easily by growers, if the pollinators are present in sufficient number.

Table 2. Performance of early maturing hybrids (A_4) in multi-location trials

ICPH No	Days to		100-seed mass(g)	2007 (n=7)	2008 (n=4)	2009 (n=8)	2010 (n=6)	Mean (n=25)	% Gain over UPAS120	Yield (kg/ha/day)
	Flower	Mature								
2433	87	114	6.9	2538	1864	2331	2489	2306	54	22.22
2438	86	115	7.8	2722	1570	2238	1979	2127	42	18.50
2363	86	115	7.7	2292	1763	2131	2005	2048	36	17.81
2429	83	114	6.9	1825	1907	2015	2037	1946	30	17.07
2431	89	117	6.9	2186	1400	1925	2165	1919	28	16.40
2447	72	114	8.2	1959	1456	2045	1782	1811	21	15.89
2364	74	114	9.6	1909	1294	2018	1883	1776	18	15.58
3310	69	106	9.1	1540	1344	1731	1546	1540	3	14.53
UPAS 120 (Check)	73	120	8.0	1502	1204	1545	1758	1502	-	12.52
ICPL 88039 (Check)	56	112	8.8	1288	554	983	940	942	-	8.41

n = number of trials

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Unlike most pulses, the flowers of pigeonpea contain nectar and its large yellow petals attract honey bees (*Megachile* spp.) and other pollinating insects (Williams 1977, Onim 1981). The cross-pollination takes place when these insects forage on the flowers. It has also been confirmed that wind does not play any role in cross-pollination (Kumar and Saxena 2010). Hence, the success in seed set on the male-sterile plants entirely depends on the availability of pollinating insects in the seed production plots (Saxena 2006). The seed production of an early maturing hybrid ICPH 2433 was attempted in isolated plots using 4 female and 1 male row ratio during 2008 and 2009 at Patancheru and on average, 425 kg/ha hybrid seed was obtained in a single harvest. Since early maturity group of plants offer multiple harvests, their productivity can be enhanced significantly (Saxena *et al.* 1992). In this system the plants at the time of harvest are ratooned and a second crop is harvested after two months from the regenerated growth only in the sterility mosaic virus free locations. Further, it was observed that the row spacing (60 cm) used in these seed production plots was not optimum, due to small biomass production. Hence, to optimize hybrid yields in early maturing group, determination of optimum agronomy is essential (Mula *et al.* 2010 a, b).

Seed quality considerations: In order to ensure consistency in the performance of hybrids, it is important that a high level of genetic purity is maintained year-after-year while producing large seed quantities of hybrids and their parents. During the last three years, it has been observed that the assessment of seed quality is a serious concern in pigeonpea due to its long generation turn-over time that may extend from six to nine months. The inherent photo-sensitivity of the crop further adds to this problem. In most field crops seed quality is ensured by assessing the quality of freshly harvested seed of hybrids and parents through standard grow-out tests. To maintain physical as well as genetic quality of hybrids, grow-out tests are performed using prominent morphological marker(s). This involves collection of representative hybrid seed samples, growing them in the field or glass house, and determining quality using observations related to the absence or presence of the markers. In pigeonpea such tests usually take more time due to the long duration and photo-sensitive nature of the crop. Therefore a simple, rapid, and cost effective seed quality testing is warranted. Saxena *et al.* (2010) proposed a purity test that is based on molecular approach involving simple sequence repeat (SSR) markers. They reported a set of two SSR markers for the hybridity detection in hybrid ICPH 2438. Simultaneously, Bohra *et al.* (2011) used 3,072 SSR markers for polymorphism estimation in various parental lines of hybrids and mapping populations. From the identified polymorphic SSRs two sets of 42 SSR markers were selected for hybridity testing one each in ICPH 2438 and ICPH 2671. These developed sets could be used in multiplexes for assessing the hybridity in pigeonpea hybrids (Fig 1). This approach can be used in commercial seed production for reliable detection of seed purity within the commercial hybrid seed lots.

***Economics of seed production*:** To determine the cost and economic benefits of hybrid seed production of pigeonpea row ratios of 4:1 and 3:1 for female: male parental lines with seven planting treatments were used to analyze economic returns. The study revealed that productivity of hybrid differed significantly among planting distances, row spacing and row ratios. The cost of producing one kilogram of hybrid seeds at this spacing was estimated at ₹ 7.37 (Mula *et al.* 2010a). Likewise, planting distance at 75cm x 30cm and row ratio of 4:1 gave the highest net returns (₹ 224,614 / ha) and with cost - benefit ratio (₹ 6.32). In a study on cost of hybrid seed production using a row ratio of 4: 1 conducted at SK Nagar, the cost of one kilogram of hybrid seed was estimated @₹8.13.

ADVANTAGES OF HYBRIDS

Enhanced germination: Experiments at ICRISAT have shown that in comparison to pure line cultivars the seeds harvested from hybrid plants had faster germination suggesting that the expression of heterotic effect at early growth stages. According to Bharathi and Saxena (2012) and Thakare *et al.* (2013) all the hybrids had longer radical length (20-40%) and greater seedling vigour index (7-14%). These traits give an initial boost for seedling establishment and development allowing them to compete well with weeds or companion crop. The long roots of the hybrid seedlings help them to survive under short spells of droughts, often encountered in early rainy season sowing. The pure line cultivars are known to have slow growth for the

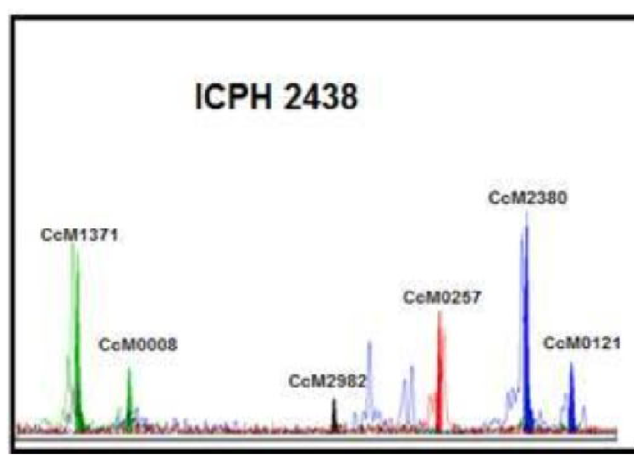

Fig 1. A representative of the multiplexes developed for ICPH 2438 SSR markers labeled with the same fluorescence dye are analyzed in individual panels. Green (VIC) labeled: two SSR markers in each multiplex (CcM1371 and CcM0008 in ICPH 2438; black (NED) labeled: one SSR marker (CcM2982) in ICPH 2438: one SSR marker (CcM0257) in ICPH 2438, and blue (FAM) labeled: two SSR markers in each multiplex (CcM2380 and CcM0121in ICPH 2438

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first 3-4 weeks and fail to produce good yields due to tough competition for resources (Saxena et al. 1992). Hence, this may be a good reason for good performance of hybrids under intercrops (Kumar *et al.* 2012).

Increased vigour and yield: The hybrid pigeonpea plants produce substantially greater biomass than those of pure line varieties of the comparable duration. Saxena *et al.* (1992) postulated that the hybrids utilize inputs such as sunlight, moisture, and nutrients more efficiently, while maintaining their partitioning at par with the pure lines; and this result in higher grain yield. In an experiment conducted at ICRISAT, 30-days old seedlings of hybrids produced 44% more shoot mass and 43% more root mass as compared to the pure line cultivars (Saxena *et al.* 1992). Pigeonpea hybrids are more plastic in nature and produce more number of primary and secondary branches along with large canopy when planted at wide spacing or under long days. This suggests that seed rate of hybrids can be reduced by 40 - 50% without losing productivity of the unit area. The reduced seed rate of hybrids will help in offsetting the high seed cost.

Tolerance to biotic stresses: Results of limited experiments have shown that hybrids offer more resistance to fungal disease attack than pure lines by virtue of their greater resilience (Saxena *et al.* 1992). Evaluation of a few wilt and sterility mosaic resistant pigeonpea hybrids and pure line cultivars indicated that the hybrids exhibited an average of 19.70% superiority over pure line cultivars under disease free conditions; on the other hand, the level of superiority of the same hybrids over pure line cultivars was >60% under disease sick conditions (Saxena *et al.* 1992). The hybrids, therefore, appears to have an extra degree of resilience which helps them to tolerate and produce higher yields under stress conditions as compared to the pure line cultivars. Hence, the cultivation of hybrids is likely to help in arresting the yield fluctuations generally brought about by various biotic and abiotic stresses and bring more stability in the production.

Tolerance to abiotic stresses: In pigeonpea water stress, water-logging and soil salinity are important abiotic stresses. The hybrid pigeonpea plants, by virtue of their greater root mass and depth, have greater ability to draw water from deep soil profiles. This also helps them to tide over intermittent drought conditions prevailing during different phases of crop growth. In recent years water-logging is also emerging as a pressing concern at the backdrop of climate change. A global report on climate change has projected 0.5-1.2°C rise in temperatures by 2020, might result in unpredictable and excessive rains. It is estimated that each year more than 30% of the pigeonpea growing areas are threatened with water-logging and annual losses of pigeonpea crops are estimated at 0.32 m tonnes (Sultana *et al.* 2013). Incorporation of genetic resistance to water-logging tolerance will bring a long-term solution to this problem and help in promoting pigeonpea in high rainfall areas and thus finding new niches for this crop. To identify tolerant pigeonpea cultivars, a number of genotypes were screened at germination, early and late seedling stages. It was found that pigeonpea hybrids exhibited greater tolerance to eight days of continuous water-logging (Sultana *et al.* 2013). It has also been recognized that the risk of crop failure or yield reduction due to water-logging is quite high in early maturing varieties because they get less time to recover from this stress as compared to medium and long duration varieties (Matsunaga *et al.* 1991). In addition to hybrids, some medium maturing pure line genotypes also have shown high levels of resistance to water-logging. We are planning to transfer the water- logging resistance to early maturing hybrid parents. In pigeonpea the water-logging tolerance is controlled by a single dominant gene (Sarode *et al.* 2007, Perera *et al.* 2001), and hence it can be transferred to elite hybrid parents easily by backcrossing.

PROSPECTS FOR EARLY MATURING HYBRIDS IN POTENTIAL NICHES

Early maturing hybrids for water-deficit areas: The crop diversification is one approach that can reduce vulnerability to drought, increasing the resilience of harvests and reducing risks for resource-poor farmers. Drought is a major factor limiting the realization of high yields in pulses. In the areas characterized by less rainfall (<300 – 400 mm) raising the traditional pulse crops is a challenge. For these situations crop diversification is the key that can reduce vulnerability to water scarcity or drought, this will increase the resilience of harvests and reducing risks for resource-poor farmers. Pigeonpea is known as a crop that can tolerate long-term water-stress conditions during its growth cycle (Sinclair 2004) and produce reasonable yield. In contrast to other pulses, which rapidly close their stomata under moisture stress, pigeonpea plants have capacity to adjust their stomata activity in response to variable water stress conditions, and adjust osmosis to a critical internal water status (Flower and Ludlow 1986). In addition, the solutes and other compounds in pigeonpea help in maintaining integrity of cells, preventing protein denaturation (Subbarao *et al.* 1995, Subbarao *et al.* 2000). In addition, a substantial amount of carbohydrates conserved in the stem, root and other parts of the plant helps the plant to recover from unfavorable stress conditions. Introduction of early maturing hybrids with these characteristics will facilitate growing of pigeonpea in water deficient areas of Rajasthan, Gujarat etc. The earliness of such high yielding hybrids will also help in escaping terminal drought and therefore will have good adaptation to environments with a short growing season (3-4 months). The early maturing (140-150 days) hybrid technology would provide an opportunity to increase the grain productivity of the region.

Early maturing hybrids for pigeonpea-wheat rotation: With the advent of green revolution in India the high yielding dwarf wheat and rice varieties became very popular throughout the country and vast area came under the cultivation of these two food crops. The farmers of Punjab and Haryana adopted both these water demanding crops and earned huge profits from rice-wheat cropping system. Over a period of time it was observed that due to excess and continuous use of water and chemical fertilizers for decades, the soils developed drainage and salinity related problems. In order to rejuvenate soil health a need for crop diversification was felt. Among various crops tried to replace the rice crop, pigeonpea was found the best due to its good adaptation in the system and with reasonably good returns. For this system early maturing pigeonpea varieties were required that will allow sowing of a subsequent crop of wheat in the same field. This endeavour began with the introduction of early maturing varieties of pigeonpea that would allow a normal crop of wheat. Nadarajan and Chaturvedi (2010) while reviewing this system, concluded that early maturing varieties are not very profitable due to their low yield. It is therefore expected that pigeonpea hybrids with early maturity and 20-30% yield advantage would be ideal for this system. Research in this direction has already been started and now early maturing CMS lines and their restorers are available. Soon high yielding hybrids will be available for pigeonpea –wheat cropping system.

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Early maturing hybrids for rice-fallows: The potential of early maturing pigeonpea has been demonstrated in the rice-fallow cropping system. In India, where a total 42.4 million hectares is devoted into rice production, an estimated 20.40 million hectares are in the rainfed areas (Directorate of Rice Development 2002) and more than 8 million hectares are classified as Vertisols. At present majority of the rainfed Vertisols are left fallow after harvesting rice, but potentially some crops can be grown in the post-rainy season on stored moisture that is good enough to trigger the growth and development of early maturing pigeonpea genotypes. This type of technology does not require intensive land preparation. It follows the concept of zero tillage and the seeds are dibbled to raise the crop. In low latitude areas pigeonpea performs well after the crop of rice. Seed yields obtain from early duration type (ICPL 88039) after rice ranged between 729 – 924 kg/ha in India (Mula and Saxena 2013) and 875 kg/ha in the Philippines (Saxena and Mula *et al.* 2010), and 1000 kg/ha in Sri Lanka (Saxena 1999). Although the early maturing pigeonpea hybrid have not been tried in such situations the probability of their success in this type of technology is high due to their deep root and drought tolerance.

Early maturing hybrids for eroded-rocky soils: There is a vast area in the country that is characterized by red laterite shallow soils with top soil layers containing a fair proportion of pebbles and small rocks. The water holding capacity of such soils is very less and a large proportion of rain water is lost through run-off. Traditionally, in these areas early maturing varieties of pulses and minor millet are cultivated in the rainy season only. This production system is less profitable. Since the hybrids have more and deep root mass than varieties, they encounter intermittent and terminal droughts much better than pure line cultivars. Since the hybrids do not require any additional inputs, their adoption in such areas is likely to be easy.

Early maturing hybrids for higher altitudes: In the mid and low ranges of Himalayas, large proportion of sloping lands are left fallow due to poor soil fertility and drought. The soil erosion in the rainy season is a regular phenomenon and each year tons of valuable top soil is washed away. In these soils the shallow rooted pulses and cereals fail to encounter post-rainy season drought and invariably produce 300 - 400 kg/ha grain. Recently with the initiative of ICAR, Almora and ICRISAT have introduced an early maturing variety ICPL 88039 (VL Arhar- 1). In this system farmers sow this variety with the first rain in the months of May and harvest it by October end. On average ICPL 88039 produces around 1000 kg/ha yield with least inputs (Saxena *et al.* 2011). A hybrid developed for this agro-ecological area will not only enhance the productivity and profitability but also improve the soil texture/structure and reduce erosion of the top soil. Although at present no hybrid breeding program for this ecology has been initiated so far, but the hybrids appear to have tremendous potential in the low and mid hills of vast Himalayan range.

Early maturing hybrids for frost affected areas: In parts of Uttar Pradesh, Madhya Pradesh and Bihar traditionally long duration varieties of pigeonpea are grown. These are highly photoperiod-sensitive (McPherson *et al.* 1985) and take about 40 weeks to mature and it exposes them to terminal drought stress at lower latitudes and to frosts at higher latitudes. Almost every year the part of this crop is damaged by frost leading to lower yields and poor quality seeds. Since there is no genetic tolerance to overcome this constraint, the ideal approach will be to grow frost avoiding early maturing varieties and integrate it with wheat or any other *Rabi* season crop. In many areas such as Punjab, Haryana, western Uttar Pradesh, and north Madhya Pradesh early maturing relatively photoperiod-insensitive varieties such Pusa 99, AL 15 etc. have already become popular. To fetch higher yields there is a need to develop early maturing hybrids for such areas and their earliness enables them to escape terminal droughts as well as frost (Patel and Sharma 1989).

RESEARCH AND DEVELOPMENT STRATEGIES FOR EARLY MATURING HYBRIDS

The following areas need to be emphasized in a dynamic early maturing hybrid pigeonpea breeding programmes.

- Expand research and development base involving various national programmes and public and private seed companies.
- Diversify hybrid parents and develop high yielding hybrids for specific agro-ecological regions.
- Incorporate resistances/tolerance to biotic and abiotic

stresses, especially sterility mosaic, Phytophthora blight, wilt and pod borers.

- Fine - tune the hybrid seed production technology for increased efficiency and develop seed certification standards for hybrids and their parents
- Incorporate morphological markers in hybrid parents to ensure the genetic purity tested in parents and hybrids.
- Encourage capacity building in hybrid pigeonpea technology.
- Standardization of agronomic practices for improved hybrids to increase productivity.
- Use genomics tools in breeding hybrid parents and seed quality testing.

CONCLUSION

Unlike most pulse crops, pigeonpea is an often out-crossing species (Howard *et. al*. 1919, Saxena *et al.* 1990) and the development of CMS system has given pigeonpea breeders a chance to transform this constraint into an opportunity for a breakthrough in the stagnant productivity of the crop through breeding high yielding hybrids. Now a good beginning has been made by ushering into an era of hybrid breeding in pigeonpea. The results obtained so far have demonstrated that in pigeonpea commercial exploitation of hybrid vigour is feasible and advantageous. Evidences for this have come from the on-farm trials conducted across India (Saxena *et al.* 2013) and Myanmar (Kyu *et al.* 2011), where some exciting results were obtained. Three farmers in Maharashtra harvested a record yield of over 4000 kg/ha. Also, one of the farmers in Medak district of Andhra Pradesh harvested 3300 kg/ha of grains and it demonstrated that the hybrid technology has potential of breaking the long-standing yield barrier in pigeonpea (Saxena *et al.* 2013).

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It appears that the technological breakthrough has been achieved and now it is just a few steps away from commercialization of pigeonpea hybrids and soon it would be a reality in India. The development of CMS in pigeonpea is a path breaking achievement and it has provided a platform for enhancing the pace of research and development of hybrids in pigeonpea. However, more efforts are required to make pigeonpea hybrids a commercial reality. Since the scope for horizontal expansion of pigeonpea area is limited, the researchers need to focus on increasing its productivity. It has also been observed that, in comparison to other crops where commercial hybrids are in cultivation, the magnitude of realized heterosis in pigeonpea is comparable. Considering the adaptability of hybrids in the stress-prone environments, it is expected that the hybrids will adapt well in various ‘difficult to cultivate’ environments.

Traditionally the phenomenon of heterosis has been exploited in cross-pollinated crops and it was general belief that heterosis in self-pollinated crops is not as high as those of cross-pollinated crops due to fixation of dominant and recessive alleles. For any viable hybrid breeding programme, the large scale commercial seed production channel is considered its life line. In the early maturing pigeonpea group all the important hybrid breeding components are well defined and the hybrid technology is at the verge of commercial exploitation. In summary, the recent developments in hybrid pigeonpea breeding are encouraging and soon the farmers will reap its benefits.

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