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Enhancement of Rural Income and Nutrition by Cultivating Pigeonpea Hybrids

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ABSTRACT

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is a favourite crop of rain-fed farmers due to its high food value, drought tolerance and various soil improving properties. The productivity enhancement of this crop has been a long-term goal at the national level but with a little success. In this context, the advent of hybrid breeding technology with over 30% on-farm yield advantages has provided a much-needed breakthrough. The hybrids in pigeonpea were bred using a stable CMS system and natural outcrossing. It is believed that the adoption of locally adapted hybrids would contribute significantly towards both family income and nutrition.

KEYWORDS

Pigeonpea, stagnant productivity, male sterility, hybrid, heterosis

INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an extremely valuable crop for subsistence agriculture in the tropical and sub-tropical areas. Globally, it is cultivated on about 7.0 m ha with total production of about 5.1 mt. India, with 5.06 m ha of area is the single largest producer and consumer (FAOSTAT, 2018). Pigeonpea is believed to have originated about 3500 years ago in India and over time its landraces found adaptation in subsistence agriculture due to its various soil ameliorating and survival properties. The crop is consumed both as de-hulled splits (*dal*) and fresh immature seeds as vegetable and its by-products are used in a number of ways in villages (Saxena, 2008). Pigeonpea is a very versatile plant as far as its adaptation is concerned. It generally tolerates pH ranging from 4.5 to 8.4, and it grows well in areas that receive mean annual precipitation between 530 to 4000 mm and temperatures from 15 to 40 °C. Pigeonpea is cultivated near sea level to 3,000 m in elevation. It has a vast (85-280 days) maturity range. The early maturing genotypes are photo-insensitive while the long duration types are highly photo-sensitive. The crop is grown under diverse cropping systems including sole crop and intercrop with cereals and legumes (Khan *et al.*, 2019 and Singh *et al.*, 2015).

Role in human nutrition

In spite of tremendous gains in food production in India, the endemic malnutrition and ill health continue to stalk a part of rural society with women and children being the most vulnerable sections. There is a great need to enhance nutrition in the diets. According to NIN (2010), the per capita protein availability in India is about 25% short of the prescribed standard of 42 g protein / head / day. Shalendra *et al.* (2013) opined that the pulse production has registered an impressive growth of 3.47% during 1990-2009; but it was insufficient to take care of the national requirements. Further, the rapid population growth and low crop productivity are considered the two key constraints in meeting the challenges of the national nutritional security (Singh *et al.*, 2015).

Legumes are considered the prime source of digestible protein and vital minerals, and blending these with cereal-based diets improves the nutritional quality of foods (Khan *et al.*, 2019). Among legumes pigeonpea is considered an important food because it contains certain vital phyto-chemicals and bio-active compounds (Talari and Shakappa, 2018). According to Singh *et al.* (1984), besides starch and protein pigeonpea also contains appreciable amounts of crude fibre, fat, and mineral and trace elements such as calcium, phosphorus, potassium, zinc, copper, manganese, and iron. Like other pulses, pigeonpea seeds also contain some anti-nutritional factors such as trypsin, chymotrypsin and amylase inhibitors which adversely affect the effectiveness of digestive enzymes. Further, the rapid population growth and low crop productivity were considered the two key constraints in meeting the challenges of the national nutritional security (Singh *et al.*, 2015). In this context, it is reasonable to assume that a quantum jump in productivity is the only viable solution to meet the nutritional crisis; and hybrid pigeonpea technology offers promise.

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Productivity trends

History of cultivar breeding in pigeonpea is less than a century old; and it started with pure line selection within the heterogeneous landraces for the traits such as disease resistance, plant type and seed yield (Ramanujam and Singh, 1981). Green *et al.* (1981), while reviewing the accomplishments and constraints of pigeonpea breeding efforts, concluded that various breeding methods recommended for self-pollinated crops were tried and over 100 pure line cultivars were released in India and elsewhere. Although the new pigeonpea cultivars exhibited significant genetic advances with respect to earliness, plant type, disease resistance and market-preferred traits such as seed size and colour, but without any marked improvement in the productivity that remained low and unchanged over the past half century**.** It is pity to note that its mean yield levels have remained unacceptably low at about 700 kg/ha, suggesting that the crop improvement efforts had been ineffective in raising the productivity of the crop, and it is always considered the main production constraint.

Pigeonpea Hybrids: A Giant Step towards Developing a New Breeding Technology

In the history of plant breeding, the exploitation of hybrid vigour, especially in maize, has saved the world from malnutrition and hunger. The maize yields in the USA recorded five-fold increases from a meagre 25 bushels/acre in 1930 to 140 bushels/acre in1998 (Trayer, 1991; Crow, 1998). This, beyond doubt, happened due to untiring and continuous efforts of scientists in developing improved hybrids and their production technology. The phenomenal success of hybrid maize led breeders to use this technology in other crops such as cotton, sorghum, pear millet, sunflower, brassica, safflower and various horticultural crops. In legumes, however, only limited efforts were made to develop hybrid technology in faba bean (Bond *et al.*, 1966), soybean (Palmer *et al.*, 2010) and pigeonpea (Saxena, 2015).

To overcome the constraint of persistent yield plateau in pigeonpea, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Indian Council of Agricultural Research (ICAR) launched a joint broad-based genetic enhancement programme. The breeding team, besides using various traditional breeding methods recommended for self-pollinated crops, decided to explore hybrid breeding approaches by converting the constraint of natural outcrossing of the crop into an opportunity.

Pigeonpea Hybrids: Science and Technology

To develop a hybrid breeding technology, it was found imperative to discover its primary components. These included (i) a male sterile female (A-) line, (ii) a maintainer (B-) line, and (iii) a restore (R-) line. These major components of a classical three-parent hybrid technology are briefly discussed in the following text.

Survey of hybrid vigour for seed yield

Although pigeonpea breeding research began in the early part of 20th century, the first report of hybrid vigour was published by Solomon *et al.* (1957). Subsequently, a number of reports were published on hybrid vigour for yield and important yield components. In comparison to other crops relatively few genetic studies have been conducted in pigeonpea. Information on the extent of heterosis showed that sufficient hybrid vigour is available in this crop, and it can be exploited for yield enhancement through hybrid breeding (Sharma and Dwivedi, 1995; Saxena and Sharma, 1990). Earlier in the absence of an CMS system in pigeonpea, an attempt was made to exploit hybrid vigour in genetic male-sterility based hybrids such as ICPH 8, PPH 4, Co H 1, Co H 2 etc. (Saxena *et al.*, 1992). These hybrids exhibited 20 to 40% superiority over the respective best local cultivar in farmers' fields. Kandalkar (2007) reported that CMS-based hybrids exhibited standard heterosis upto 156% for yield, whereas Saxena *et al.* (1992) reported yield advantage of 50 to 100% over the control cultivars.

Survey of outcrossing for mass hybrid seed production

Most pulses are known for their high self-pollinated reproductive system, and their quality seed production is rather easy. Pigeonpea, however, is different in this regard with up to 25-30% cross-pollination. The extent of natural cross-pollination may vary from one environment to the other. There is no wind pollination in pigeonpea, and prime pollinating agents include various insect species which forage on the flowers in search of nectar. In the studies conducted in different countries, over two dozen insect species were found foraging on pigeonpea flowers, but outcrossing was affected by only a few of them. These include *Megachile bicolor*, *M. conjuneta*, *Apis mellifera*, and *Xylocopa* species (Saxena *et al.* 2016).

Zeng-Hong *et al.* (2011) conducted studies on the insect behaviour with respect to cross-pollination in pigeonpea and observed that the pollinating insects were more frequent on male fertile plants with a mean of 4.8 visits /10 minutes as compared to 2.8 visits /10 minutes on the male sterile plants. They attributed such differences to the presence of certain chemicals (flavone and flavonol) and a specific scent that is produced by mature pollen grains in the fertile plants. They further reported that even with 50% less insect visits, the pod set and yield were comparable. These observations indicated that very high insect activity may not be essential to produce reasonably good quantities of hybrid seed. Under an open

Fig. 1: Dr William Dar (right) and Dr KB Saxena (left) appreciating pod set on a CMS line

field, the pod set on the male sterile plants (Fig. 1) was high and produced mean yield of 384 g/plant; and it was on par to the male fertile plants (357g /plant). These observations demonstrated that hybrid seed production in pigeonpea is not an issue.

Breeding of cytoplasmic nuclear male sterility (CMS) system

Mass hybrid seed production is a primary requisite of any hybrid programme and this is facilitated by using a male sterile line. Therefore, as a first step, a programme was launched to breed a stable cytoplasmic-nuclear male sterility (CMS) system. In this system, the male sterility is conditioned by the cytoplasm that contains aberrant mitochondrial DNA and it is designated as 'sterile' (S) cytoplasm. In this case, its extra-nuclear genome interacts with its nuclear genome; and male sterility is expressed when the recessive non-restoring nuclear alleles (*rfrf*) are present. The counterpart maintainer (B-) line carries the same recessive (*rfrf*) nuclear alleles but its cytoplasm is normal 'N'. In case the mate sterile A-line is crossed with its maintainer B-line, the resultant progeny is always male sterile like its female parent.

Since there was no known CMS system in the world pigeonpea germplasm collection, plans were made at ICRISAT to create it through breeding efforts. This was done by integrating the nuclear genome of cultivated type with the cytoplasmic genome of a wild species. After several unsuccessful efforts, the success was achieved by Tikka *et al.* (1997) and Saxena *et al.* (2005) by using the cytoplasm of *Cajanus scarabaeoides* and *C. cajanifolius*, respectively. These accomplishments were followed by selecting the third parent, called fertility restorer (R-line). This genotype contains dominant (*RfRf*) nuclear gene and it has the ability to produce fertile pollen grains when crossed with the male sterile A- line. These CMS sources were used to breed diverse male sterile lines, their maintainers and fertility restorers in early, and medium maturing groups to develop hybrids in these maturity groups.

Breeding of new fertility restorers

In order to develop a range of hybrids, it is important that new fertility resorers which produce stable fertile hybrids are identified. To achieve this, over 3000 testers were examined at ICRISAT and various ICAR centres. From the results it was concluded that i) plenty of fertility restorers were available in the germplasm, ii) the fertility restoring genes were distributed randomly with greater frequency in the medium maturing germplasm, and iii) in early maturity the fertility restoring genes were relatively less frequent (Saxena *et al.*, 2014).

It was also noted that the early maturing restorers were unable to produce hybrids with stable fertility restoration across diverse environments. A perusal of published report on the genetics of fertility restoration of A_4 CMS system showed that in F_1 generation either one or two dominant genes controlled the fertility restoration but with variable gene action. In a significant study, Saxena *et al.* (2011) reported that the fertility restoration was stable across environments only when two dominant genes were present together in a single hybrid; and the hybrid combinations carrying either of the dominant genes were also fertile but not in all the environments.

Breeding of high yielding hybrids

Considering the vast area and variable agro-ecological conditions of the country, it is necessary that a greater number of hybrids are bred in different maturity groups. Efforts in this direction are being made both at ICRISAT and ICAR. In this endeavour a number of early and medium maturing experimental hybrids were synthesised and evaluated for their fertility restoration and productivity.

In the last few years, over 1500 medium duration experimental hybrids were developed. Since in this maturity group disease resistance is important, the hybrids were evaluated in the disease sick nursery and selections were made both on the basis of yield and disease resistance. The performance data of eight medium duration hybrids is given in Table 1**.** These hybrids had high levels of productivity and disease resistance. The standard heterosis in these hybrids ranged from 39% to 62%.

Table 1. Some elite hybrids bred at ICRISAT

Hybrid (ICPH)	Yield (kg/ha)	Adv. (%)	Seed 100 wt (g)	Wilt (%)	SM (%)
3371	3013	62	11.5	0	0
3491	2919	57	13.4	0	0
3497	2686	44	10.9	0	15
3481	2637	41	11.6	0	0
3494	2586	39	12.4	0	9
Check (Asha)	1864	-	11.1	0	0
SEm	±205.7	-	±0.33	-	-
Mean	2448.1	-	11.7	-	-
CV (%)	11.9	-	3.98	-	-

Multi-location evaluation of promising hybrids

From early maturing group, eight promising combinations were advanced to multi-location testing (Table 2). From this

Table 2: Yield (kg/ha) of early maturing hybrids in multi-location trials

Hybrid (ICPH)	Y- 1 (n=7)	Y-2 (n=4)	Y-3 (n=8)	Y-4 (6)	Mean (n=25)	% gain
2433	2538	1864	2331	2489	2306	54
2438	2722	1570	2238	1979	2127	42
2363	2292	1763	2131	2005	2048	36
2429	1825	1907	2015	2037	1946	30
2431	2186	1400	1925	2165	1919	28
2447	1959	1456	2045	1782	1811	21
2364	1909	1294	2018	1883	1776	18
3310	1540	1344	1731	1546	1540	3
Check (Maruti) UPAS-120	1502	1204	1545	1758	1502	-

Source: Annual Pigeonpea Breeding Reports, ICRISAT.
n= number of locations

material, two hybrids ICPH 2433 and ICPH 2438 were found promising with respectively, 50% and 42% superiority over the control 'UPAS 120'. Recently ICPH 2438 has been identified for on-farm trials in Madhya Pradesh (Dr. A N Tikle, personal communication). A perusal of productivity data also showed that in comparison to inbred cultivars (12.5 kg/ha/day), the hybrids were more efficient in dry matter production and/or partitioning into grains (22 kg/ha/day). Most recently, an early maturing pigeonpea hybrid IPH 15-03 has been identified and released for cultivation in the North West Plain Zone.

On-farm evaluation of elite hybrids

Hybrid ICPH 2671 was evaluated in on-farm locations of four provinces (Table 3). In Maharashtra state, a total of 782 on-farm trials were conducted in seven districts and the hybrid produced 35% more grain yield (969 kg/ha) than the control. In Andhra Pradesh (399 trials), the hybrid exhibited 56% superiority over the control (Fig. 3). Similarly, in Madhya Pradesh (360 trials), the hybrid out-yielded the control cultivar by 46%; while in Jharkhand (288 trials) ICPH 2671 demonstrated 69% superiority over the control cultivar. Over all the four states (1829 trials), ICPH 2671 produced 1445 kg/ha average yield, and it was 51% more than the local checks (954 kg/ha). Subsequently two more hybrids were released and their performance was also high (Table 3).

Table 3. On-farm yields (kg/ha) of four pigeonpea hybrids

Hybrid	State	Farmers	Hybrid yield	Control yield	% Gain
GTH 1	Gujarat	04	2673	1996	34
ICPH 2671	Maharashtra	782	969	717	35
	Andhra Pradesh	399	1411	907	56
	Jharkhand	288	1460	864	69
	Madhya Pradesh	360	1940	1326	46
	Total/mean	1829	1445	954	51
ICPH 2740	Madhya Pradesh	13	1814	1217	49
	Andhra Pradesh	47	1999	1439	39
	Gujarat	40	1633	1209	35
	Total/mean	100	1825	1288	41
ICPH 3762	Odisha	144	1726	813	
Others	Andhra Pradesh Maharashtra	360	1940	1326	47

Source: Various reports and publications of ICRISAT

Release of the world's first legume hybrid

ICPH 2671 is the first ever commercial pigeonpea hybrid produced in any grain legume so far. This hybrid was produced by crossing a male sterile line ICPA 2043 with a stable fertility restorer ICPR 2671. The plants of ICPH 2671 are semi-spreading, non-determinate with profuse branching. It grows over two meter in height, matures between 164-184 days and contains 3.7-4.0 seeds/pod. The purple coloured seeds weigh between10.5 to 11.2 g/100 seeds. ICPH 2671 has a high level of resistance to both wilt and sterility mosaic diseases (Saxena *et al.*, 2013). In multi-location trials, its mean performance in different years ranged from 2200 to 3183 kg/ha; and on an average, it recorded 47% superiority over the national check, Maruti. In All India Advanced Hybrid Trials, conducted at six locations, ICPH 2671 recorded 35% yield advantage over the control cultivar. In All India Coordinated Trials, the hybrid (2564 kg/ha) recorded 31% superiority over the control variety, Maruti (1996 kg/ha).

Fig 2: A proud farmer with his hybrid pigeonpea crop in Maharashtra state

Hybrid Breeding: Integrating the Genomics Technologies

Application of genomics in hybrid seed quality control

In order to ensure consistency in performance of hybrids in farmers' fields, it is important that a high level of genetic purity is maintained year-after-year. In most field crops the quality assessment of hybrid is done through the standard Grow-out Test (GoT) of freshly harvested seed. In case of pigeonpea, this procedure is not feasible due to the photo-sensitivity and long generation turn-over time of the crop. This constraint has become a major hurdle in the promotion of hybrids. To overcome this bottleneck, an alternative seed quality testing approach that is based on genomics technology has been developed at ICRISAT and IIPR (Bohra *et al.*, 2020). This approach is simple, rapid, and cost effective. This seed testing protocol is now ready for use by breeders and seed producers.

Since at commercial level, analysis of a large number of seed samples from different locations will be required, a cost-effective genomics-based quality testing approach will be an asset. To achieve this, several single nucleotide polymorphism (SNPs) have also been discovered for genotyping using Kbio Sciences Alleles Specific (KASPar) assays. This would allow assessing genetic purity of large number of seed samples with minimum number of loci.

Application of genomics in hybrid parent breeding

To meet the cultivar requirements in future, new hybrid parents need to be bred on a routine basis. This can be done rapidly and economically using molecular marker technologies. The marker associated with fertility restoration (Saxena *et al.*, 2020), cytoplasmic male sterility (Sinha *et al.*, 2015), disease resistance, quality traits (Obala *et al*., 2019) etc. are now available. These marker genes can now be used to transfer the above-mentioned traits into elite R- and B- lines using marker-assisted back crossing.

The genomics science can also be used to generate accurate information on genetic diversity of hybrid parents. This will eliminate environment effect which may mask the true genetic variability in the traits of interest. This information can be used to develop heterotic groups as well as selection of potential genotypes for developing high yielding hybrids.

Hybrid Pigeonpea: Seed Production Technology

Isolation and crop management practices

Since hybrid pigeonpea technology in pigeonpea is new, the officially prescribed seed production guidelines are awaited. However, according to the information generated by ICRISAT and ICAR centres, a minimum of 500 m of isolation distance was found safe to produce Breeder and Certified Seeds. It has also been observed that if the seed production plot is located near wild bushes, horticultural crops or water bodies, the hybrid yields are high because such habitats encourage harbouring of the pollinating insects.

A well-drained field should be chosen for seed production. The crop should be sown on 75 cm ridges and provided with recommended agronomic practices. Since pigeonpea attracts pod boring insects, it is recommended that the insecticide should be sprayed after the sun set or early in the morning because the pollinators forage on the flowers only in bright day light. Rouging operations in the production plot should be performed at least three times; once each at seedling, pre-flowering and flowering/early podding stages.

Since the maintainer (B-) and restorer(R-) lines are fully male fertile, they are multiplied in isolation like any normal inbred cultivar. The seed multiplication of male sterile A- line is done by growing both A- and B-lines at the same time using a row-ratio of 4: I (Fig. 3). Similarly, for producing hybrid seed also, the ratio of female to male rows should be kept @ 4:1. It should be emphasized that special care should be taken during harvesting. To avoid mixture of seed at harvest from the male and female rows, the male rows should be harvested first and later the female rows with crossed pods should be harvested.

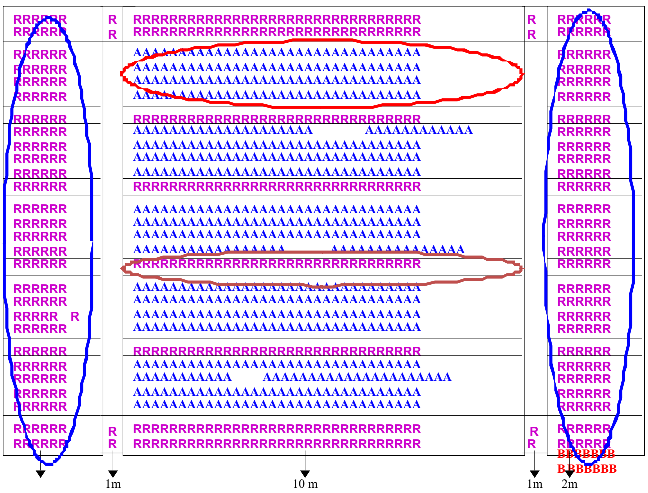

Fig 3: A standard field layout for hybrid seed production
A: CMS line R: Restorer line

Hybrid seed yields

To assess the feasibility of large-scale hybrid seed production using the above-mentioned technology, some known professional seed producers were identified in six states, and the production programmes were undertaken under the direct supervision of experts (Table 4). The results showed that the state of Madhya Pradesh is the best, and it has a great potential to become a hub for the hybrid pigeonpea seed production. The hybrid yields recorded at Indore (2267 kg/ha), Seoni (2500 kg/ha), and Tikamgarh (3040 kg/ha) were highly encouraging

Table 4: Hybrid seed production hot spots identified

Location (Madhya Pradesh)	Yield (kg/ha)	Location (Andhra Pradesh)	Yield (kg/ha)
Tikamgarh	3040	Nizamabad	1750
Seoni	2500	Patancheru	1250
Indore	2267	Medchal	1214
Rewa	1740	Warangal	1063
Katni	1450	Nalgonda	1000

Source: ICRISAT Reports (2014)

Economics of Hybrid Seed Production

Saxena *et al.* (2011) conducted elaborate studies on the economics of hybrid seed production at Indore in Madhya Pradesh. They estimated that the cost of producing of one hectare of hybrid ICPH 2671 seed was Rs 26,395, excluding the rental value of land. The labour accounted for 76.9% of the total cost. This plot produced 1440 kg/ha of hybrid seed and yielded the net profit of Rs 70,000/ha. Using these estimates the hybrid seed cost at the farm gate was Rs.18.85/kg. Further, it was also estimated that with mean hybrid yields of 1000-1500 kg/ha and seed rate of 5 kg/ha, the seed-to-seed ratio for hybrid pigeonpea was high and it varied from 1:200 to 1: 300. This means that to cover 10% of the national pigeonpea area (400,000 ha) with hybrids, only 2000 ha of certified seed production programme would be required and this would add significantly to the national pigeonpea production.

Hybrid Pigeonpea: Advantages over Pure Line Varieties

The pigeonpea hybrids have shown clear advantage over inbred cultivars with respect to yield and adaptation to various stress conditions. The details are available in Saxena *et al.* (1992), Bharathi and Saxena (2012), Lopez *et al.* (1996), (Sultana *et al*., 2013) and Saxena *et al.* (2018). The summary is presented through the following bullet points.

- Hybrids, on the average, produce 30-50% more on-farm yield over the best inbred cultivar.
- Hybrids have high per day productivity. In comparison to inbred cultivars (12.5 kg/ha/day), the hybrids are more efficient in dry matter production and/or their partitioning into grain yield (22 kg/ha/day).
- Hybrid plants have vigorous plant canopy, and therefore require 30% less seed rate when compared to inbred cultivars.

- Hybrid seeds germinate rapidly and have greater seedling vigour index.
- Thirty days old seedlings of hybrids produce about 40% more shoot s and root mass as compared to the pure line cultivars (Fig. 4). This helps in the initial establishment and better survival under adverse conditions including short spells of droughts.
- Hybrids express better environmental buffering as compared to pure line cultivars. Under disease free conditions, the hybrids exhibited only 19.7% yield superiority over inbred lines. The corresponding value under sever disease pressure was >60%.
- Hybrid plants maintain higher water content under adverse conditions, and it contributes to their enhanced drought tolerance.
- Hybrids demonstrate better survival and recovery under water-logged conditions.
- Hybrids show high adaptation both under sole and intercropping.

Hybrid Pigeonpea: Prospects and Opportunities

To fulfil the calorie needs of masses the pulses were pushed on back burners, particularly in the backdrop of green revolution, leading to poor resource allocation to this group of crops. The long term effect has been low crop productivity and deficit of pulses at the national level. At farm level also, the pulses have always received a step-motherly treatment from farmers, and the crops were hardly given the desired inputs. In fact this issue has been discussed in a number of conferences and high level research and management forums; but the situation has remained more or less the same.

Fig. 4: Advantage of hybrid over in bred variety after 60 days

Pigeonpea, the second most important pulse crop of India, also suffered the similar fate and now the unacceptably low productivity has become a serious concern at the national level. It has been observed that in spite of decades of plant breeding efforts, the genetic advances in pigeonpea with respect to yield have been ineffective and it has remained unchanged at around 700 kg/ha. To overcome this bottleneck the joint initiatives taken by ICRISAT and ICAR to breed hybrids were unparrellel and unique since in no other pulse crop this approach was ever tried.

In this context, the release of the first commercial pigeonpea hybrid ICPH 2671, exhibiting 30-50% on-farm yield advantage (Saxena *et al.*, 2013), is considered a milestone in breeding pulses. Besides high yields, the pigeonpea hybrids also demonstrate abilities to encounter various biotic and abiotic stresses and provide greater stability in the productivity.

This technology has now provided a new biological instrument to pigeonpea breeders to realize quantum jumps in the productivity. The extensive on-farm testing of hybrids in the states of Madhya Pradesh, Maharashtra, Gujarat, Telangana, Andhra Pradesh, Odisha, and Jharkhand has given positive signals about the high yield potential of hybrids (Saxena *et al.*, 2019).

At present there is a national drive to increase the production of protein-rich pulses. In this context, efforts are being made to expand the pigeonpea cultivation by introducing the crop in the non-traditional areas and cropping systems and to rehabilitate the eroded soils (Choudhary *et al.*, 2020; Saxena and Kumar, 2020). In such production systems the pigeonpea hybrids could prove a boon because they germinate at a faster rate, tolerate seedling droughts (Saxena *et al.*, 2020) and have rapid growth rate (Saxena *et al.*, 1992). With the release of three high yielding hybrids in the past decade, was estimated that using a conservative estimate of 25% yield advantage and about 10% land area coverage, India can produce enough pigeonpea to meet the domestic needs.

Unfortunately, all is not well at the adoption front and hence the hybrid technology could not reach door-steps of clients - the farmers. There were no apparent issues related to the hybrid yields (around 1000 kg/ha), seed-to-seed ratio (1: 200 to 1: 300), production cost (Rs 20/kg), and profitability (Rs 70,000/ha) as exhibited in the on-farm seed production demonstrations. In this novel endeavour, the major problem arose when the monitoring of seed production plots was found wanting in controlling the genetic purity of hybrid seed. Since the GoT is not feasible in this crop due to long generation turnover time, the hybrid programme suffered and could not meet the expectations of rapid adoption. This bottleneck, however, has now been overcome with the help of new emerging genomics tools.

We believe the revival of hybrid technology is on cards and the institutions involved in this endeavour would be able to achieve the long-awaited breakthrough in the productivity of pigeonpea in India. Pending this, a new technology that is also capable of exploiting heterosis, and called as "sybrids breeding" (Saxena, 2020) can be used by breeders and both the hybrids and sybrids can help in alleviating the nutritional availability in rural areas.

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