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Believe it or not, hybrid technology is the only way to enhance pigeonpea yields

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Abstract- Pigeonpea yields have remainedunacceptably low over the past five decades and efforts to break this plateau through breeding pure line cultivars did not succeed in its mission. Key successes in breeding stable cytoplasmic nuclear male-sterility (CMS) system, its fertility restorers, and development of an efficient hybrid seed production technology have led to the release of the world's first commercial hybrid in pigeonpea [*Cajanus cajan* (L.) Millsp.].This hybrids has demonstrated 40-50% yield advantage over the best locally adapted varieties in different agro-ecological environments, giving a strong indication towards a breakthrough in the stagnant productivity of the crop. This paper discusses various issues related to genetic enhancement of productivity in pigeonpea.

Index Terms- Hybrids, Pigeonpea, Yield plateau

I. Introduction

Pigeonpea or red gram [*Cajanus cajan* (L.) Millsp.]constitute a major protein-rich food supplement for most Indians. The crop is cultivated on 4.04 m ha (IIPR, 2013) mainly at subsistence level as rainfed intercrop since hundreds of years; but its formal genetic improvement began in 1931 with pure line selections within available landraces for simply inherited traits such as plant type, maturity, and wilt resistance. It was in 1965 when Indian Council of Agricultural Research (ICAR) launched a massive crop improvement programme and opened a number of research centres in different agro-ecological regions of the country (Ramanujam and Singh, 1981). However, in spite of serious breeding efforts, the productivity increase did not meet the expectations. This paper summarizes the efforts of a non-conventional breeding approach in enhancing productivity of this pulse crop.

II. The Chronic Problem of Yield Stagnation

Among pulses, pigeonpea *dal* is a staple food across the country and plays an important role in national economic and nutritional security. The annual production of this pulse in India is about three million tonnes; but this quantity is insufficient to meet the domestic needs; and hence a considerable amount (about 100,000 t) of pigeonpea is imported each year (http//www.ipga).To breed high yielding cultivars pigeonpea breeders deployed various methods primarily recommended for self-pollinated crops (Green et al., 1981) and released dozens of varieties but without any marked improvement in its productivity, that remained unchanged over the decades at around 600-800 kg/ha (Fig 1).In the near future also, the issue of yield stagnation is likely to remain more or less the same, until apath breaking technology with exceptionally high yield potential is developed. In this context, the recent success in developing hybrid breeding technology in pigeonpea (Saxena et al., 2013), the first in the world in any grain legume, has generated a lot of optimism and enthusiasm among pigeonpea breeders to break the decades-old productivity barrier. This paper besides giving a brief overview of hybrid technology, discusses the potential role of hybrids in smashing the decades old yield plateau.

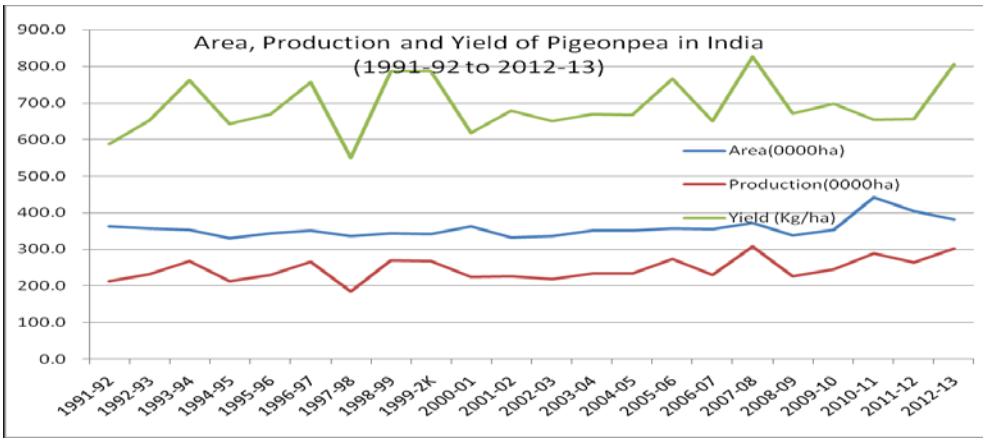

Fig 1: Area, production and productivity of pigeonpea in India

III. The Birth of Hybrid Technology in Pigeonpea

Pigeonpea is known to attract a number of nectar-hunting insects and during the process of foraging cross-pollination takes place (Saxena et al., 1990). Pigeonpea breeders, however never took this phenomenon seriously while breeding cultivars and considered pigeonpea at par with other pulses and followed methods traditionally used in breeding self-pollinated crops. In the mid-seventies ICRISAT planned to convert the constraint of natural out-crossing into an opportunity by using it as a tool for genetic enhancement of yield through hybrids. In this context breeding of a commercially viable cytoplasmic nuclear male sterility (CMS) system using the cytoplasm of *Cajanus cajanifolius* (Fig 2) - a wild relative of pigeonpea, is considered a major breakthrough (Saxena et al., 2005) in achieving the goal of developing world's first legume hybrid.

Fig 2*: C.cajanifolius*, a wild relative of pigeonpea (source: ICRISAT)

IV. Advantages of Hybrids

It is believed that the hybrid plants are naturally programmed at genetic level to produce vigorous plants, greater yields and stability. This is attributed to the interactions among various favourable alleles. It was noted that pigeonpea hybrid plants start showing hybrid vigour right from the early seedling stage. In comparison to pure lines, the hybrids have 18 % longer radical and 15 % greater seedling growth indices (Bharathi and Saxena, 2012; Thakre et al., 2013). According to Saxena et al. (1992) this vigour of the hybrid plants is carried forward throughout its growth period and in comparison to pure lines they produce about 30% more shoot and root mass. The trials conducted at ICRISAT also showed that besides high yields, the hybrids also demonstrated greater tolerance to common root and foliar diseases and drought. The greater biomass of individual plants also allows about 25-30% saving in the seeding rates of the commercial hybrid crops. Saxena and Raina (2001) showed that pigeonpea hybrids were better than pure line cultivars with respect to their stability across environments. The deep root system and dry leaf fall in hybrid plants also help in recycling of valuable soil nutrients lying unused in the deeper soil zones and make them available to the crops with shallow root system.

Evidences of Breakthrough in Productivity

The first commercial hybrid: The first commercial pigeonpea hybrid ICPH 2671 (Fig 3), produced by crossing ICPA 2043 with ICPR 2671, was released in 2010 (Saxena et al., 2013). In 21 multi-location trials it recorded 47%superiority over the check (Table 1a). In All India Coordinated Trials, the hybrid (2564 kg/ha) was 31% superior to the control (Table 1b). In 1829 on-farm trials (Table 2) conducted in states of Maharashtra (782 trials), Andhra Pradesh (399 trials), Madhya Pradesh(360 trials), and Jharkhand (288 trials), ICPH 2671 recorded 30-60% superiority over the best local cultivar. Overall all the five states, ICPH 2671 was 51% better than the control in its productivity. The performance data of the hybrid have shown that in pigeonpea significantly high productivity levels can be achieved by farmers and the persistent yield plateau can be smashed.

Fig 3: ICPH 2671, the world's first commercial pigeonpea hybrid (source: ICRISAT)

Table 1: Yield (kg/ha) of hybrid ICPH 2671and control cultivar in multi-location trials organized by ICRISAT.

Year	Locations	Hybrid Yield	Control yield	Standard heterosis (%)
2005	5	3183	1855	72
2006	4	2410	1589	52
2007	7	2986	2209	35
2008	5	3085	1889	63
Total/Mean	21	2736	1862	47

Source: Saxena et al. (2013)

Table 1b: Grain yield (kg ha^{-1}) of pigeonpea hybrid ICPH 2671 in Central Zone in All India Coordinated trials in 2007 (Mean of Initial & Advanced Hybrid Trial)

Genotype	SDAU, SK Nagar	MPKV Rahuri	ZARS, Khargon	Mean	% Superiority over
ICPH 2671	2936	2479	2278	2564	-
Marurti (C)	1831	2766	1267	1955	31
Asha (C)	1882	2551	1855	1996	28
BSMR 736 (C)	2147	2608	1649	2135	20
CO 6 (C)	2745	2777	1603	2375	8

Table 2. Performance (yield kg/ha) of hybrid ICPH 2671 in the on-farm trials.

State	Farmers (no.)	Hybrid yield	Control yield	Standard heterosis (%)
Maharashtra	782	969	717	35
Andhra Pradesh	399	1411	907	55
Jharkhand	288	1460	864	69
Madhya Pradesh	360	1940	1326	46
Total/mean	1829	1445	954	51

Source: Saxena et al. (2013)

New hybrids: After the success of hybrid ICPH 2671in Madhya Pradesh, two more medium duration hybrids with high yield potential were released in India. In 2012, ICPH 2740 was released for cultivation in Andhra Pradesh (Saxena et al., 2015); while the third hybrid ICPH 3762was released in Odisha in 2014 (Saxena et al., 2014). Like ICPH 2671, the hybrids ICPH 2740 and ICPH 3762 also out-yielded the control by a big (40-50%) margin.

Besides the three releases, a number of new hybrids were also bred to cater the needs of different agronomic niches and cropping systems. This programme began with the development of new male sterile and fertility restoring lines. In the early maturity group, the performance of hybrids was very good (Table 3). In 25 multi-location trials conducted over four years hybrids ICPH 2433, ICPH 2438 and ICPH 2363 respectively produced 54%, 42%, and 36% more yield as compared to the national check (1502 kg/ha). The highest yield of 2722 kg/ha was produced by ICPH2433 in only115 days and

Table 3: Performance of early maturing hybrids in multi-location trials organized by ICRISAT

Hybrid (ICPH)	Maturity (days)	2007 (n=7)	2008 (n=4)	2009 (n=8)	2010 (n=6)	Mean (n=25)	Gain (%)	Yield (kg/ha/day)
2433	114	2538	1864	2331	2489	2306	54	22.22
2438	115	2722	1570	2238	1979	2127	42	18.50
2363	115	2292	1763	2131	2005	2048	36	17.81

2429	114	1825	1907	2015	2037	1946	30	17.07
2431	117	2186	1400	1925	2165	1919	28	16.40
Check	120	1502	1204	1545	1758	1502	-	12.52

Source: ICRISAT

recorded unbelievable daily yield accumulation of 22.22 kg/ha/day, as compared to 12.52 kg/ha/day for the control. This demonstrated 77.5% greater production efficiency in the hybrids as compared to the pure line control cultivar.Among medium maturing hybrids (Table 4), ICPH 3371(3013 kg/ha) and ICPH 3762 (3000 kg/ha) were found as most promising with 62% superiority over the national check Asha (1864 kg /ha). These hybrids were also found to be highly resistant to fusarium wilt and sterility mosaic diseases when evaluated in sick nursery

Table 4. Some promising medium duration pigeonpea hybrids developed at ICRISAT

Hybrid (ICPH)	Yield (kg/ha)	Standard heterosis (%)	100- seed weight (g)	*Wilt (%)	*Sterility mosaic (%)
3371	3013	62	11.50	0	0
3491	2919	57	13.40	0	0
2740	2900	57	12.30	0	0
3762	3000	62	11.90	0	0
Check	1864	-	11.10	0	0
SEm	± 205.7	-	±0.33	-	-
CV (%)	11.9	-	3.98	-	-

*Disease data recorded in sick nursery. Source: ICRISAT

Hybrid records exceptionally high yields: Pigeonpea is notoriously tagged as low yielding pulse but hybrids have shown the way (as described above) with 2500-3000 kg/ha productivity. Some of the farmers in Maharashtra grew the hybrid crop under good management (fertilizer, timely sowing, insect control, weed control, irrigation) and produced about 4000 kg/ha of grains in their fields (Table 5). This data set was encouraging and showed the real yield potential of hybrids. With high market prices and high yields, the pigeonpea hybrid crop can compete with cereals in profitability with added advantage of improving the nutrition and texture of soils.

Table 5: Demonstration of exceptionally high yields (kg/ha) of pigeonpea Hybrid by some farmers in Vidharba (Maharashtra)

Location	Area (m^2)	Hybrid yield	Control yield	Standard heterosis (%)
Salod	450	3956	2044	94
Nimgaon	1012	3951	2469	60
Kothoda	450	4667	3556	31
Tamoli	450	3889	2278	71
Mean	-	4116	2587	59

Source:ICRISAT

Hybrid Seed Production – No More an Issue

In order to get maximum benefits from hybrid vigour, only a single use of true hybrid (A x R) seed is recommended for cultivation. Hence, the large-scale production of hybrid seed is the core activity of any seed business. This will fetch good returns to both the producers as well as farmers. Initially, the hybrid seed production programme faced rounds of ups and downs due to various reasons. However, learning from the failures the hybrid seed production technology was modified over time and it has now been perfected by ICRISAT and their partners. The hybrid yields recorded at many places in the states of Andhra Pradesh, Madhya Pradesh, Gujarat, and Maharashtra has demonstrated that reasonably high yields can be harvested from well managed seed production plots. The on-farm validation at 94 locations, on an average produced 1019 kg/ha of hybrid seed (Table 6); and confirmed that large scale hybrid seed

production is not a difficult task but needs careful selection of sites.

For a successful seed programme the key factors identified were the presence of sufficient number of pollinating insects at flowering and availability of the male flowers for extended periods in the seed production plot. Attempts should be made to select the isolation plots in the areas which are infested with wild bushes, fruit or other trees that generally harbour the insects. It is also observed that if the seed production plots are located near small or large water bodies, it attracts the pollinating insects and helps in enhancing natural out-crossing in the seed production plots to produce good hybrid seed yields (RV Kumar, personal communication). Such seed production 'hot spots' can be identified by organizing a number of small-sized 'pilot seed production plots (Table 7). The pod set under natural conditions will indirectly indicate the presence of pollinating vectors at a particular site; and this will help in identifying suitable locations for large-scale hybrid seed production. A record of such locations and productivity should be maintained and the seed producing agencies should be guided in choosing the favorable production sites.Now it can be said with confidence that hybrid seed production in pigeonpea is not an issue any more.

Table 6. Hybrid seed production (kg/ha) record in six states.

State	Locations	Mean yield	Highest yield
Andhra Pradesh	34 (6)	998	1750
Madhya Pradesh	9 (3)	1674	3040
Gujarat	4 (2)	1179	1669
Maharashtra	5 (2)	603	1017
Odisha	40 (1)	523	1040
Karnataka	2 (2)	1138	1900
Total/Mean	94	1019	3040

( ) number of years. Source: ICRISAT

Table 7. Some hot spots identified for hybrid seed production

Location	Area sown (ha)	Yield (kg/ha)
Madhya Pradesh		
Tikamgarh	5.0	3040
Seoni	1.0.	2500
Indore	1.5	2267
Rewa	1.0	1740
Katni	3.0	1450
Andhra Pradesh		
Nizamabad	1.0	1750
Medak	1.0	1250
Medchal	1.4	1214
Warangal	1.2	1063
Nalgonda	2.0	1000

Source: ICRISAT

V. Promotion of Hybrids-Still a Challenge

The expansion of pigeonpea area under hybrids is important keeping in view the national interest. Since this is a multi-facet issue, several agencies dealing with production, marketing, distribution, and extension need to work together. Hence a strong coordinating unit is a must to develop links with different disciplines. For the promotion of any technology, involvement of experts can help a lot in technology transfer. Since hybrid pigeonpea involves special attention in various seed production activities, a thorough training of seed producers is essential. For increasing the adoption of hybrids the basic requirement is to make available high quality seed at reasonable rates. To achieve this, an efficient seed chain should be developed to cater the needs of breeder, foundation, and certified seeds. Fortunately, the seed-to-seed ratio for pigeonpea hybrids is high (1: 200 to 1: 300) and this will ensure large area coverage. However, a good planning would be required for quality control and timely supply of seed to seed distributors and growers. Initially, it is also important that seed distributors should be given enough information about the product. A set of hand-outs, dealing with

important features of the hybrid and its cultural practices will be helpful.

VI. General Discussion

FAO define food security as "the situation when each group of the population in a country get sufficient calories and essential nutrients in sufficient quantities necessary for a healthy life". With these standards most of the developing countries can be classified as "nutritionally insecure". The scenario of nutritional security in India is quite interesting, as it is self-sufficient in calorie production but lacks in protein and other vital nutrients. In the last half-century the per capita protein availability in India has witnessed a sharp decline from 27.3 kg/year in 1950 to 10 kg/year in 2000 (www.commodityonline.com, 2009).The escalating prices of pulses and other nutrient-filled vegetables, fruits, and milk products have further added to this misery.The averse adverse effects of nutrient deficiency is visible in the mal-nutrition of a major proportion of rural and urban masses, especially children and women.According to National Institute of Nutrition, India (NIN,2010) this is an important national issue and require immediate attention of policy makers. To alleviate this problem perhaps a paradigm shift in the genetic improvement and extension strategies of the nutritive food crops is warranted. In this context the breakthrough in pigeonpea breeding technology has shown a great promise with 30-50% yield advantages in farmers' fields. The promotion of hybrid technology will not only raise the national pigeonpea production but also provide easily digestible quality protein.

The extensive on-farm testing of the hybrids in states of Madhya Pradesh, Maharashtra, Karnataka, Gujarat, Telangana, Andhra, and Jharkhand have given very positive signals to the farmers about the high yields of hybrids. Now the issues related to seed availability need attention from all the corners. Since the hybrid technology in pigeonpea is new, it is essential to convince the public and private seed companies about the financial viability of the hybrid technology.

Pigeonpea hybrids are capable of meeting the challenge of imports by replacing only 10% area of traditional pigeonpea.With hybrid (A x R) seed yields of 1000-1500 kg/ha and seed rate of 5 kg/ha, the seed-to-seed ratio for hybrid pigeonpea is reasonably high (1:200 to 1: 300). This means that to replace the targeted 10% (=400,000 ha) of the national pigeonpea area with hybrids, only 2000 ha of certified seed production programme would be required (Table 8); but it will add about 200,000 tonnes of additional grain to country's production with an estimate of 30 -40% hybrid advantage.

It was observed that harvesting 3000 kg/ha of pigeonpea from commercial hybrids was not uncommon in Maharashtra and some farmers even touched the magic yield mark of 4000 kg/ha. With the yield advantage of 1000-1500 kg/ha and price @ Rs 50/kg, the farmers can fetch additional profit of Rs 50,000-75,000 from one hectare. This level of profitability can easily be compared with any high value field crop; and therefore, pigeonpea can make a grade into "cash crops".

Table 8. Calculations of grain production by replacing 10% pigeonpea area with hybrids

Contents	Units
Estimated annual imports	= 100,000 tons
Total area under pigeonpea	= 40 lakh ha
Area that can be brought under hybrids (10%)	= 400,000 ha
Extra production due to hybrids @ 0.5 t/ha	= 200,000 tons
Certified seed to replace 400,000 ha @ 5 kg/ha	= 2000 tons
Area for producing certified seed @ 1000kg/ha	= 2000 ha.
Breeder Seed needed for 2000 ha @ 5kg/ha	= 10, 000 kg
Area for producing Breeder Seed @ 1000kg/ha	= 10-15 ha

VII. Conclusions

- Yield stagnation in pigeonpea has been a long standing issue
- Pure line cultivars could not enhance yield to desired levels
- Breakthrough in productivity is possible only through hybrids
- On-farm demonstration of hybrids showed a great promise
- Hybrid seed production is no more an issue
- Hybrid seed production is easy and economical
- Seed-to-seed ratio in pigeonpea is high (1: 200 - 1: 300)
- A good hybrid seed chain can now be developed
- Hybrid pigeonpea technology is now established
- To achieve a sustainable breakthrough, a high level of commitment on the part of researchers, research managers, and policy makers is essential.

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