# Development of ‘super-early’ pigeonpeas with good yield potential from early × early crosses

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## Abstract

To enhance the adaptability of pigeonpea at higher latitude and altitude, a breeding program was initiated at ICRISAT involving different sources of early-maturity. A full diallel mating design involving 11 early-maturing lines were used as parents. In $F_2$–$F_5$ generations, selection was followed for early flowering and maturity, grain yield and 100-seed weight by pedigree method. Four brown seeded (ICPX 060064-4-6-10, ICPX 060077-6-5-14, ICPX 060064-4-6-2 and ICPX 060063-11-8-4) and one cream seeded (ICPX 060036-13-4-8) $F_4$/$F_5$ indeterminate super-early progenies that matured, respectively 25 and 23 days earlier than the control cultivar ICPL 88039 were recovered. ICPX 060036-13-4-8 recorded 107% and 34% grain yield advantage over the checks ICPL 86022 and ICPL 88039, respectively. These super-early lines were derived from crosses involving AL 1518-2 × ICPL 85010, AL 1621 × MN 5, AL 1518-2 × MN 8 and MN 8 × AL 1518-2. Other super-early progenies [ICPX 060016-10-8-1 (from MN 1 × AL 1518-2 cross) and ICPX 060017-12-12-20 (from MN 1 × AL 1621 cross)] with greater 100-seed weight were also recovered. Besides serving as excellent donors for earliness, these lines may be photo/thermo insensitive. These super-early pigeonpea lines may open new niches for this crop and help in intensification of farming system.

## Introduction

Pigeonpea (*Cajanus cajan*) is a multipurpose, versatile and hardy food legume grown in more than 20 countries worldwide in an area of 4.5 million ha with an annual production of 3.48 million tons (FAOSTAT 2011). It forms an important component of the cropping systems in Asia, the Caribbean and Latin America.

The majority of pigeonpea-based cropping systems worldwide belong to medium (160–180 days) and long (>180 days) maturity groups (Singh 1996). A small portion also belongs to the early (120–140 days) maturity group. Due to ever increasing pressure on land, there is need for intensification of cropping systems in a sustainable way. The traditional cultivars do not fit into cropping systems such as the intensive wheat (*Triticum aestivum*) based cropping system (Singh 1996). These medium- and long-duration varieties have long vegetative growth phase (120–160 days), mainly attributed to slow initial growth (Saxena 2008). This leads to poor productivity, and less efficient utilization of land and other resources.

To address these issues numerous attempts to breed early pigeonpea were made in the past. Identification of early variety T21 (160 days) in 1961 was a first step in this direction (AICPIP 1986). Ten years later Pusa Ageti (S5) was bred by Indian Agricultural Research Institute (IARI), New Delhi. Subsequently, BS1 was developed as a selection from T21 (Ramanujam and Singh 1981). Other important early varieties developed were UPAS 120, Prabhat, Pant A3, AL 15, AL 201, Pusa 33, Pusa 84, Manak, Paras, ICPL 151 (Jagriti), Co 1, Co 2, Co 3, Co 4, Hy 2, Hy 4, TT 6, TT 10 and ICPL 87 for central and peninsular India. The most recent attempt in this direction was release of ICPL 88039 (VL Arhar 1) in Uttarakhand in 2007. All these cultivars take more than 100 days to mature at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Patancheru (17°45 N, 78°16 E, and 510 m amsl) and may not fit into most of the double cropping systems in India. These types occupy the field not only for longer time but also have low per day productivity. There is need to breed for lines with reduced vegetative growth and higher per day productivity.

Considering these constraints, attempts were made at ICRISAT, Patancheru to breed for high-yielding super-early pigeonpea lines by possibly combining genes for different sources of early maturity. This article describes development of super-early indeterminate (NDT) and determinate (DT) lines with high grain yield and bold seeds.

## Materials and methods

A total of 11 extra-early maturing lines were chosen for hybridization. Five (MN 1, MN 5, MN 8, ICPL 85010, ICPL 88039) of these were breeding lines from ICRISAT, two (AL 1518-2, AL 1621) were breeding lines from Punjab Agricultural University (PAU), Ludhiana, three (ICP 6972, ICP 6973, ICP 6974) were germplasm lines from ICRISAT, and one parent was an early variety (UPAS 120). A set of 110 crosses were made in full diallel mating design, and 109 $F_1$s (ICP 6973 × AL 1621 cross was not successful) along with the parents were planted at a spacing of 75 cm between rows and 20 cm within row in an un-replicated design with two row plots of 4 m length during 2007 rainy season under insect-proof cages to avoid outcrossing. The segregating generations from $F_2$ through $F_5$ were advanced in field protected either in insect proof cages or by large selfing bags, and in glass house by pedigree method of selection during 2008–10. Many of these populations in $F_2$ and $F_3$ generations were affected by Phytophthora blight (*Phytophthora drechsleri* f. sp. *cajani*) leading to seedling mortality. Therefore, rather low selection intensity was applied by rejecting weak progenies to maximize recovery of favorable alleles. These populations were selected on the basis of time to flower and time to maturity, 100-seed weight, number of pods plant$^{-1}$ and general plant vigor. A total of four NDT trials and two DT trials were conducted in 2010 rainy season consisting of selected $F_4$ and $F_5$ entries along with their respective checks (ICPL 88039, ICPL 86022 and ICPL 88034 for NDT trial, and MN 1 and MN 5 for DT trial). The first NDT trial consisted of 15 selected cream seeded NDT super-early entries in $F_4$ generation with three checks (Table 1). The second trial consisted of 29 selected brown seeded entries in $F_4$ generation with ICPL 88039 as check (Table 2). The third trial had selected 39 NDT $F_5$ entries with ICPL 88039 as check, while the fourth trial consisted of 23 NDT entries with ICPL 88039 as check. The first DT trial consisted of selected 11 cream seeded $F_5$ DT entries with MN 1 as check, while the second trial consisted of 11 brown seeded $F_5$ DT entries with MN 5 as check. All these trials with selected homogenous lines were conducted at ICRISAT, Patancheru in alfisols during 2010 rainy season. The test design was RCBD in two replications with three-row plots per entry and 4 m row length at a spacing of 75 cm between rows and 20 cm within row. The crop was given a basal dose of diammonium phosphate (DAP) at 100 kg ha$^{-1}$, and standard agronomic practices were followed to raise a healthy crop.

Data were recorded on time to 50% flower (mean flowering value of all the plants in an entry, in days), time to maturity (mean value of all the plants in an entry when 75% of the pods mature, in days), 100-seed weight (mean weight of 100 random seeds from five competitive random plants, in g), plant height (height in cm from tip of the longest branch of the plant to the base on five competitive random plants) and adjusted grain yield (grain yield in kg from individual plants in an entry, equalized to 54 plants per entry, and converted to kg ha$^{-1}$).

## Results and discussion

Conventionally, plant breeders have tried to increase the value of a trait by crossing phenotypically contrasting parents, and have selected transgressive segregants in the $F_2$ and subsequent segregating generations. In the current study we followed a different approach by attempting to combine all known sources of earliness, by crossing these lines in a full diallel scheme. Such elite × elite crosses were also made in the past to increase values of a trait in other pulse crops, such as improvement of earliness in chickpea (*Cicer arietinum*) (Kumar and Rao 1996). The underlying assumption in the current study was that since most of these lines were unrelated by pedigree and origin, they were expected to carry different genes for earliness that could be stacked together by selections in the segregating generations.

These replicated trials revealed at least four lines with significantly high grain yield advantage and earliness. ICPX 060036-13-4-8 (MN 8 × AL 1518-2), a cream colored line in Trial 1 had 107% and 34% grain yield advantage over extra-early cream seeded check ICPL 86022 and extra-early brown seeded check ICPL 88039, respectively. This line was 20 and 23 days earlier than the checks ICPL 86022 and ICPL 88039, respectively (Table 1). In the same trial, another cream colored line ICPX 060016-4-5-11 (MN 1 × AL 1518-2) had 25% higher yield, and was 13 days earlier than ICPL 86022. Such cream seeded lines command premium price in local markets in some quarters of India, and are strongly preferred by consumers from Gujarat in India, and in

**Table 1. Cream seeded NDT trial conducted at Patancheru, rainy season 2010.**

| Entry name | Time to 50% flower (days) | Time to maturity (days) | Plant height (cm) | Seeds $pod^{-1}$ | 100-seed weight (g) | Seed color[1] | Adjusted yield (kg $ha^{-1}$) | Yield advantage over ICPL 88039 (%) | Yield advantage over ICPL 86022 (%) | Time to maturity advantage over ICPL 88039 (days) | Time to maturity advantage over ICPL 86022 (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ICPX 060036-13-4-8 | 54 | 82 | 95 | 3.7 | 5.9 | C | 1807.6 | 33.89 | 107.32 | 23 | 20 |
| ICPX 060016-4-5-11 | 56 | 89 | 128 | 3.7 | 6.7 | C | 1093.1 | –19.04 | 25.37 | 16 | 13 |
| ICPX 060016-17-4-1 | 51 | 100 | 105 | 2.9 | 8 | C | 917.4 | –32.05 | 5.22 | 5 | 2 |
| ICPX 060016-10-8-13 | 50 | 100 | 98 | 3.6 | 8.3 | C | 875.5 | –35.15 | 0.41 | 5 | 2 |
| ICPX 060063-11-9-7 | 50 | 95 | 98 | 4.2 | 6 | C | 849.8 | –37.06 | –2.53 | 10 | 7 |
| ICPX 060016-17-8-3 | 52 | 97 | 100 | 3.8 | 7.8 | C | 802.4 | –40.57 | –7.97 | 8 | 5 |
| ICPX 060016-13-4-12 | 52 | 90 | 98 | 3.6 | 6.4 | C | 792.2 | –41.32 | –9.14 | 15 | 12 |
| ICPX 060017-6-9-6 | 53 | 100 | 100 | 3.9 | 6.2 | C | 771.0 | –42.89 | –11.57 | 5 | 2 |
| ICPX 060036-7-3-14 | 51 | 90 | 95 | 3.7 | 6.4 | C | 741.2 | –45.10 | –14.99 | 15 | 12 |
| ICPX 060036-7-3-8 | 50 | 86 | 85 | 3.6 | 6.8 | C | 734.0 | –45.63 | –15.82 | 19 | 16 |
| ICPX 060063-11-9-1 | 50 | 82 | 98 | 3.6 | 6.7 | C | 723.7 | –46.40 | –17.00 | 23 | 20 |
| ICPX 060036-13-4-2 | 52 | 88 | 102 | 3.3 | 6.2 | C | 708.3 | –47.54 | –18.76 | 17 | 14 |
| ICPX 060063-11-8-9 | 52 | 95 | 90 | 3.9 | 6.7 | C | 655.9 | –51.42 | –24.77 | 10 | 7 |
| ICPX 060016-4-5-14 | 52 | 90 | 100 | 3.5 | 7.1 | C | 631.5 | –53.23 | –27.57 | 15 | 12 |
| ICPX 060036-12-5-4 | 48 | 88 | 98 | 3.7 | 6.3 | C | 595.0 | –55.93 | –31.76 | 17 | 14 |
| ICPL 88034 (check) | 76 | 120 | 190 | 3.6 | 10 | B | 2283.9 | | | | |
| ICPL 88039 (check) | 59 | 105 | 128 | 3.4 | 9.6 | B | 1350.1 | | | | |
| ICPL 86022 (check) | 58 | 102 | 138 | 3.8 | 9 | C | 871.9 | | | | |
| SEm ± | 1.0 | 4.1 | 3.0 | 0.27 | 0.31 | | 272.3 | | | | |
| Mean | 53.7 | 94.5 | 107.9 | 3.66 | 7.23 | | 955.8 | | | | |
| CV (%) | 2.7 | 6.2 | 3.9 | 10.5 | 6.1 | | 40.3 | | | | |

1. C = Cream seed coat color; B = Brown seed coat color.

**Table 2. Brown-seeded NDT trial conducted at Patancheru, rainy season 2010.**

| Entry name | Time to 50% flower (days) | Time to maturity (days) | Plant height (cm) | Seeds $pod^{-1}$ | 100-seed weight (g) | Seed color[1] | Adjusted yield ($kg\ ha^{-1}$) | Yield advantage over ICPL 88039 (%) | Time to maturity advantage over ICPL 88039 (days) |
|---|---|---|---|---|---|---|---|---|---|
| ICPX 060027-3-4-18 | 51 | 82 | 108 | 3.4 | 7.9 | B | 1159.90 | 19.22 | 20 |
| ICPX 060077-7-4-6 | 50 | 92 | 100 | 3.9 | 7.2 | B | 1097.00 | 12.76 | 10 |
| ICPX 060027-2-1-4 | 51 | 96 | 112 | 3.6 | 7.5 | B | 1048.70 | 7.79 | 6 |
| ICPX 060063-8-9-3 | 50 | 88 | 100 | 3.7 | 7.6 | B | 990.60 | 1.82 | 14 |
| ICPX 060063-8-9-12 | 50 | 86 | 98 | 3.5 | 7.1 | B | 943.20 | −3.05 | 16 |
| ICPX 060036-15-15-1 | 50 | 85 | 85 | 4.0 | 6.6 | B | 921.80 | −5.25 | 17 |
| ICPX 060016-10-8-1 | 48 | 82 | 88 | 4.5 | 8.9 | B | 911.60 | −6.30 | 20 |
| ICPX 060063-8-9-4 | 50 | 82 | 98 | 3.5 | 8 | B | 909.00 | −6.57 | 20 |
| ICPX 060063-8-9-8 | 49 | 94 | 105 | 3.5 | 7.8 | B | 875.60 | −10.00 | 8 |
| ICPX 060017-12-12-20 | 50 | 85 | 102 | 4.1 | 9.6 | B | 746.70 | −23.25 | 17 |
| ICPX 060027-2-1-5 | 52 | 88 | 90 | 4 | 8.5 | B | 745.50 | −23.37 | 14 |
| ICPX 060063-8-9-11 | 51 | 85 | 98 | 4.1 | 7.7 | B | 731.00 | −24.86 | 17 |
| ICPX 060077-6-5-16 | 50 | 84 | 98 | 3.5 | 8.4 | B | 728.60 | −25.11 | 18 |
| ICPX 060064-4-6-2 | 53 | 98 | 108 | 4.2 | 7.3 | B | 726.80 | −25.30 | 4 |
| ICPX 060027-12-12-12 | 50 | 85 | 100 | 3.6 | 7.4 | B | 721.20 | −25.87 | 17 |
| ICPX 060063-11-8-2 | 54 | 98 | 98 | 3.6 | 7.2 | B | 721.00 | −25.89 | 4 |
| ICPX 060063-11-6-6 | 50 | 82 | 102 | 4.0 | 5.9 | B | 719.00 | −26.10 | 20 |
| ICPX 060036-5-8-9 | 50 | 86 | 105 | 3.1 | 8.1 | B | 701.70 | −27.88 | 16 |
| ICPX 060036-12-3-2 | 48 | 86 | 102 | 4.5 | 6.6 | B | 691.60 | −28.91 | 16 |
| ICPX 060027-12-12-7 | 50 | 90 | 92 | 3.9 | 6.9 | B | 687.50 | −29.33 | 12 |
| ICPX 060063-11-9-4 | 51 | 91 | 100 | 4.5 | 6.9 | B | 648.60 | −33.33 | 11 |
| ICPX 060077-6-6-4 | 51 | 82 | 102 | 4.4 | 6.8 | B | 612.80 | −37.01 | 20 |
| ICPX 060017-2-1-1 | 50 | 82 | 95 | 3.4 | 7.2 | B | 590.30 | −39.33 | 20 |
| ICPX 060063-8-9-6 | 52 | 89 | 98 | 4.0 | 7.9 | B | 588.10 | −39.55 | 13 |
| ICPX 060063-8-8-14 | 52 | 92 | 102 | 4.1 | 8 | B | 587.30 | −39.63 | 10 |
| ICPX 060063-11-9-12 | 50 | 85 | 95 | 3.8 | 6.5 | B | 569.70 | −41.44 | 17 |
| ICPX 060017-6-14-1 | 51 | 90 | 95 | 3.7 | 7.3 | B | 560.70 | −42.37 | 12 |
| ICPX 060036-12-3-6 | 50 | 88 | 98 | 3.9 | 7.3 | B | 512.90 | −47.28 | 14 |
| ICPX 060066-16-14-9 | 49 | 85 | 95 | 4.1 | 6.6 | B | 407.60 | −58.10 | 17 |
| ICPL 88039 (check) | 58 | 102 | 115 | 3.9 | 8.3 | B | 972.90 | | |
| SEm ± | 1.2 | 2.5 | 2.6 | 0.1 | 0.5 | | 146.3 | | |
| Mean | 50.7 | 88.1 | 99.4 | 3.9 | 7.5 | | 761.0 | | |
| CV (%) | 3.3 | 4.0 | 3.7 | 2.5 | 9.1 | | 27.2 | | |

1. B = Brown seed coat color.

eastern and southern African countries like Kenya, Tanzania, Malawi and Uganda.

Most of the other promising NDT lines identified from these trials belonged to Trial 2. In this trial three lines appeared promising. Brown seeded line ICPX 060027-3-4-18 (MN 5 × AL 1621) had 19% grain yield advantage and was 20 days earlier than ICPL 88039 (Table 2). Another brown seeded line ICPX 060077-7-4-6 (AL 1621 × MN 5) had 13% grain yield advantage and was 10 days earlier than the check ICPL 88039 (Table 2). The third promising brown seeded line ICPX 060027-2-1-4 (MN 5 × AL 1621) had 8% grain yield advantage, and was 6 days earlier than ICPL 88039. ICPX 060016-10-8-1 (MN 1 × AL 1518-2) (Table 2) had 20 days maturity advantage and had comparable or bolder grains (100-seed weight 8.9 g) compared to ICPL 88039 (100-seed weight 8.3 g). ICPX 060017-12-12-20 (MN 1 × AL 1621) from the same trial had 17 days maturity advantage and 15.7% bolder seeds (100-seed weight 9.6 g) than ICPL 88039 (100-seed weight 8.3 g) (Table 2). Such bold-seeded lines are preferred by farmers and fetch premium price in the market. Thus, it appears that it may be possible to recover early maturing bold-seeded lines. The same has been reported earlier by Vange and Moses (2009). However, more extensive replicated multi-environment yield trials are needed to firmly establish linkage breakdown between seed size and earliness. It may be due to simultaneous selection exercised in the segregating generations for earliness and higher number of primary and secondary branches, higher 100-seed weight, higher number of pods plant$^{-1}$ and greater length of fruiting nodes.

In Trial 3 (data not shown) four lines matured 25 days earlier than the check. These were ICPX 060064-4-6-10 (AL 1518-2 × ICPL 85010), ICPX 060077-6-5-14 (AL 1621 × MN 5), ICPX 060064-4-6-2 (AL 1518-2 × ICPL 85010) and ICPX 060063-11-8-4 (AL 1518-2 × MN 8). However, these lines had lower grain yield and 100-seed weight than the check ICPL 88039. ICPX 060036-5-8-9 (MN 8 × AL 1518-2) from the same trial was an exception. It had 100-seed weight (9.3 g) comparable to ICPL 88039 (9.4 g) and was 19 days earlier. Owing to the large maturity differences, these super-early lines probably fell behind photosynthetic harvest process compared to the check and hence yielded low. However, as demonstrated for ICPX 060036-13-4-8 (MN 8 × AL 1518-2) and other high-yielding lines from Trials 1 and 2, it may still be possible to improve grain yield and 100-seed weight of these lines by carrying out simultaneous selection for grain yield, 100-seed weight and time to maturity.

In DT Trial 1 (data not shown), a superior DT, brown seeded line ICPX 060024-7-6-4-9 (MN 5 × ICPL 85010) was recovered. This line had 12.5% grain yield advantage over extra-early check MN 5 with maturity comparable to this check. Another brown seeded line ICPX 060024-9-8-9-16 (MN 5 × ICPL 85010) had 9% grain yield advantage over extra-early check MN 5 with similar maturity duration (data not shown).

The grain yield advantages reported in this study are from single location and season with relatively small plot size. Therefore, these need to be interpreted with caution. More extensive replicated yield trials over years and locations are needed to rule out any over estimation of grain yield advantage, and firmly confirm the initial evidence of grain yield and maturity advantage reported in this study.

Apart from time to maturity advantage, there appears to be significant advantage for time to 50% flower in most of the entries in the present trials; previous generation of this material had even higher advantage for time to 50% flower. Segregants in the previous generation of DT material had flowered in 34 days and matured in 65 days (compared to earliest DT check MN 5 which flowered in 50 days and matured in 82 days). We also had recovered NDT segregant that flowered in 45 days and matured in 78 days (compared to ICPL 88039 that flowered in 65 days and matured in 104 days) (Srivastava et al. 2010).

This suggests that selection for time to flower and maturity is not a straight forward process, as the genetic gains may fluctuate. It also appears that in some of these super-early lines there is rapid grain filling (since the total reproductive period is much compressed), and better partitioning of photosynthates compared to the check cultivars leading to higher grain yield. These super-early lines also exhibited higher harvest index compared to the control cultivars.

Therefore, the present study has successfully demonstrated that diverse elite × elite crosses can be employed to improve traits such as crop maturity, grain yield and 100-seed weight in pigeonpea. It should be possible to recover lines with still greater time to maturity advantage (ie, early lines) with higher grain yield and bolder seeds. This is because the reported trait values in this study are for $F_4$ and $F_5$ family means. These families although largely uniform, may still be having within family variability that could be exploited to enhance these traits simultaneously, aided by broken linkage blocks between these traits. The super-early lines generated in this study may also help address photo/thermo sensitivity associated with this crop, since early pigeonpea lines tend to be less photo/thermo sensitive (Green et al. 1979, Wallis et al. 1981). Apart from re-validation of grain yield and seed size advantages from across locations and years, further studies are needed to firmly establish interaction of super-early lines with temperature and/or photoperiod.

These super-early lines (Fig. 1) are expected to have significance in cropping systems of Asia, Africa and the Americas. This new maturity class will open new niches for pigeonpea such as wheat-based cropping systems, rice (*Oryza sativa*) fallows, high hills and short growing environments affected by terminal drought, or frost, and may help in sustainable intensification of various farming systems worldwide. Limited quantity seeds of some of these super-early lines are available from Pigeonpea Breeding Unit, ICRISAT, Patancheru.

ICPL 88039 Super-early NDT line

**Figure 1.** Super-early NDT line as seen in comparison with popular extra-early variety ICPL 88039.

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