A Short-Cut Approach for Breeding Pigeonpea Hybrids With Tolerance to Biotic and Abiotic Stresses

Science
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K.B. Saxena	Principal Scientist (ICRISAT, Retd.), 17-NMC Housing, Al Ain, Abu Dhabi, UAE
A.J. Hingane	International Crops Research Institute for Semi-Arid Tropics, Patancheru, Telangana. *Corresponding author
A. K. Choudhary	ICAR Research Complex for Eastern Region, Research Centre for Makhana, Darbhanga
M. Bharathi	Ph D. Scholar (ICRISAT), Untereggweg 7, 4147 Aesch, Basel, Switzerland

ABSTRACT

Lack of stability associated with low productivity have remained key production constraints in pigeonpea for decades. In this paper, efforts have been made to address these two issues together by breeding high yielding pigeonpea hybrids carrying resistance/tolerance to some important biotic and abiotic stresses. In normal course, the selection of parental lines and breeding stress tolerant hybrids will take about 15 years. Therefore as an alternative, a short-cut hybrid breeding approach was designed and its salient features are discussed here. It is expected that by following this approach the crop losses caused by diseases, drought, and water-logging can be reduced and at the same time, productivity can be enhanced through the exploitation of hybrid vigour.

Introduction

Red gram or pigeonpea [Cajanuscajan (L.) Millsp.] is a prime pulse crop of Indian rainfed agriculture with an annual production of about 3 m tonnes from over 4 m ha of plantings (IIPR, 2013). Low productivity and lack of stability have remained key production constraints in this crop for over five decades. Besides various genetic and agronomic reasons, some biotic and abiotic stresses are also responsible for this situation (Saxena, 2008). This scenario can now be changed in a positive direction by simultaneously reducing crop losses and enhancing yielding ability of the crop. Recent success in breeding high yielding pigeonpea hybrids and identifying genotypes that are tolerant to important stresses have given good signals for achieving the goal of increasing yield and stability in the near future. In this article, a short-cut strategy has been outlined to bring these two technologies together for enhancing productivity through hybrids and stabilizing yield through genetic resistances.

Materials and Methods

Hybrid technology in pigeonpea is now well established (Saxena et al., 2013) and the next key target for growth of this technology is to breed new high yielding hybrids that would encounter major yield reducing stresses to achieve stability in the production. To achieve this goal in short term, a method for selecting new male and female hybrid parents with desirable traits has been outlined using published information (Table 1). For A_4 CMS system in pigeonpea, Saxena et al. (2014a) identified 26 male sterility maintainers and 179 fertility restorers. This group of genotypes was selected from germplasm and advanced generation breeding materials and it was used as the base material for the present exercise. These genotypes were cross-checked against the list of water-logging tolerant lines identified by Sultana et al. (2013). This allowed selection of water-logging tolerant male sterility maintainers and fertility restorers. In the next stage, this selected group was cross-checked against the list of Fusarium wilt (FW) and sterility mosaic (SM) diseases resistant genotypes reported by Nene et al. (1981). This exercise identified disease and water-logging resistant hybrid parents. This selected list was again cross-checked against the salinity tolerant lines reported by Srivastava et al. (2006). This way male and female hybrid parents with ability to withstand stresses caused by water-logging, FW and SM diseases, and salinity were identified. In addition, data on maturity, seed colour and seed size were used from ICRISAT Pigeonpea Breeding Progress Reports. Finally, the information generated by Mudaraddi and Saxena (2015) was used to classify the hybrid parents on the basis of genetic diversity and heterotic groups. This consolidated information will help breeders in identifying hybrid parents to cater the immediate needs of developing high yielding pigeonpea hybrids and ensuring stability in production.

Results and Discussion

Major stresses influencing pigeonpea productivity

In general, pigeonpea production environments are harsh and unpredictable with significant yield losses and high risk of crop failures. Globally, the most threatening pigeonpea production constraints are pod borers and drought; the other important yield reducers are diseases, water-logging, extremes of temperature, and salinity. For the stability of production, genetic solutions are the best as far as their durability and reliability are concerned. Therefore, incorporation of resistance/ tolerance to these stresses is a step in the right direction.

Biotic stresses: The most important biotic yield reducers are pod borers (*Helicoverpa armigera* and *Maruca testulalis*)and podfly (*Melanagromyza obtusa*) and together they cause heavy yield losses each year; and unfortunately there is no true field level genetic resistance available within the cultivated gene pool (Choudhary et al., 2013) for use in breeding programme. The cultivators over the years, however, have learned to control these insects through chemicals and certain cultural practices. Therefore considering overall situation, the stresses caused by insects have not been considered in this manuscript, but the other important biotic stresses such as FW and SM diseases have been given due consideration. The sources of genetic resistance to these two diseases have been identified (Nene et al., 1981) and successfully used in the past for breeding pure line cultivars (Saxena, 2008).

Abiotic stresses: Water-logging and drought are major abiotic stresses which adversely affect yield in pigeonpea. Drought generally affects the crop at early, intermittent, or terminal growth stages with variable intensities (Lopez et al., 1996), while water-logging is an early growth production constraint. Although some work has been done in pigeonpea to understand the mechanisms underlying drought tolerance, but the seasonal variations in its occurrence and intensity have made it difficult to understand it completely and develop any screening technology.

Temporary water-logging in soils with high water holding capacity poses a serious threat to pigeonpea productivity in India and annually about 1.1 m ha of land is water-logged (Reddy and Virmani, 1981);, inflicting about 25-30% losses in crop productivity (Choudhary et al., 2011). Under water-logged situations, the useful aerobic bacteria become inactive, while their anaerobic counterparts (both facultative/obligate bacteria) become active resulting in reduced oxygen in the soil (Jackson, 1990). Besides this, under anaerobic conditions the soil nutrient balance is severely disturbed which adversely affects general plant growth and development. For water-logging tolerance, a reliable screening technology has been developed by Chauhan et al. (2008) and recently, a number of water-logging tolerant genotypes were also identified (Sultana et al., 2013). This information has been used in this paper to identify water-logging tolerant hybrid parents.

Soil salinity is an ever increasing production constraint in pigeonpea and both low and high concentrations adversely affect flowering and plant growth; and in this context, the information generated by Srivastava et al. (2006) was used to identify tolerant hybrid parents. The Aluminum toxicity and low temperature sensitivity are area-specific abiotic constraints and, therefore, have not been given importance in this paper.

Justifications for breeding stress tolerant pigeonpea hybrids

In India, the per capita availability of protein has declined steadily from 27.3 kg/year in 1950 to 10 kg/year in 2000 (www.commodityonline.com, 2009).This is mainly due to such factors as substantial growth of human population, comparatively slow growth in the production of protein-rich pulses, and their escalating prices (Shailendra et al., 2013). Among pulses, pigeonpea dal is a staple food across the country. The annual production (3 m t) of this pulse is insufficient to meet the domestic needs and hence, a considerable amount of pigeonpea is imported (Saxena, 2008). In an effort to enhance pigeonpea production and productivity, Indian Council of Agricultural Research (ICAR) released over 100 varieties in the past 4-5 decades (Singh et al., 2005). These cultivars exhibited significant genetic advance for such traits as earliness, plant type, resistance to FW and SM diseases, and some market-preferred traits like seed size and colour. The average yield, however, remained consistently low at around 600 - 800 kg/ha. In the near future also, this nutritional situation is not likely to improve due to stagnation of productivity, non-availability of additional agricultural land, and high population growth. To overcome this situation, simultaneous genetic enhancement of both seed yield as well as stability factors are essential. Such issues should receive high priority in research and development, particularly in view of increasing population and decreasing per capita protein availability in the country (NIN, 2010).

A short-cut strategy to breed hybrids with stable performance

To meet the objective of greater productivity and stability, it is essential that the hybrids are adapted to local environment and withstand the ill effects of various yield reducing factors with built-in genetic systems. The grouping of hybrid parents with respect to maturity is the first and foremost activity. Within each maturity group, the tester genotypes should have genes for resistance to locally important stress factors. This should follow their assessment for combining ability and hybrid vigour for seed yield.

In the present exercise, an attempt has been made to flag hybrid parents which, in high probabilities, would produce hybrids with tolerance to stresses like water-logging and diseases along with desired agronomic and market driven traits. A total of 26 male sterility maintainers were identified (Saxena et al., 2014a) and of these, only seven were found to have tolerance for water-logging (Table 2). These maintainers represented early (1), medium (3), and late (3) maturity groups. One maintainer line ICPL 20092 has white seeds. With the exception of ICP 28, all the maintainers are resistant to both FW and SM diseases.

Similarly, among 179 fertility restorers reported by Saxena et al. (2014a), only 27 (15.1%) exhibited tolerance to water-logging (Table 2). Among these, respectively 3, 18, and 6 genotypes represented early, medium, and late maturity groups. Three restorers (ICP 7086, ICPL 89-1, and ICPL 161) were susceptible to both FW and SM diseases and ICPL 20127 was resistant to SM disease only. The remaining 22 fertility restoring genotypes were resistant to both FW and SM diseases. A similar exercise for salinity tolerance was done and only one restorer ICP 227 was found to be tolerant. The other interesting fact which came out of this multi-stage selection exercise, was that among the selections the genetic variability for agronomic traits such as maturity, seed size, pod length and seed colour was high and it provides options to breed hybrids with diverse traits. Based on various traits of interest, a tentative list of hybrid parents was prepared for use in future hybrid breeding programme. A brief hybridization scheme related to different maturity groups has been outlined in Table 3.

Breeding early maturing hybrids: At present this group of pigeonpea is not very popular and occupies a limited area, especially under rice-wheat cropping system in Punjab, Haryana and Indo-Gangetic plains. In this system, pigeonpea is grown by farmers in place of rice in small areas to provide relief to the soil from the heavy water and nutrient-demanding cereals grown year-after-year. Early maturing pigeonpea also has potential in some new production niches. In one such initiative, it was successfully introduced in low and mid hills of Uttarakhand. In these areas, early hybrids are likely to perform well because of their tolerance to early season water-logging and terminal drought stress due to their large and deep root system. Besides high yields, the hybrids will also provide protection against frequent soil erosion (Saxena, et al., 2014b) in the slopping hills. The early pigeonpea has also been very successful in rainfed dry areas of Rajasthan and Bundelkhand region of southern Uttar Pradesh.

In early maturing group of pigeonpea, diseases are not important and the major production stresses are early growth stage water-logging and drought, besides pod borers. In this context, water-logging tolerant hybrids will adapt well. However, at present the scope of breeding such hybrids is not large since only one female parent (ICPA 2039) and three male parents (ICPL 81-9, ICPL 161, and ICPL 90038) are available for exploiting hybrid vigour (Table 3). Therefore, to expand the base of hybrids, it is important to either breed new hybrid parents or screen for new water-logging tolerant germplasm.

Breeding medium maturing hybrids: This group is most important and occupies about 60% of the total pigeonpea areas located in the states of Andhra Pradesh, Maharashtra, Karnataka and parts of Gujarat, Madhya Pradesh, Odisha and Jharkhand. Three pigeonpea hybrids have already been released for this agro-ecological zone, but to harvest high yields more number of hybrids will be required to cover the vast area. In this maturity group, three maintainers with tolerance to water-logging and resistance to FW and SM diseases are available. Besides this, 12 fertility restorers are also available (Tables 2, 3). This number gives an opportunity to develop 36 hybrid combinations with tolerance to water logging and resistance to diseases. The availability of one white seeded male sterile line (ICPA 2048) and four restorers (ICP 7086, ICPL 20108, ICPL 20112, and ICPL 200118) provide an added advantage of breeding white-seeded hybrids, a primary requirement for Gujarat state. Of these, ICP 7086 should be given low priority due to its susceptibility to diseases.

Breeding late maturing hybrids: This group of materials is

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highly prone to both water-logging and diseases because the crop is grown as rainfed in deep soils with plenty of underground water to support a crop for 8-9 months. Such areas are situated in central and eastern Uttar Pradesh, Bihar, parts of Jharkhand, Madhya Pradesh, Gujarat and West Bengal. Among the restorers of this maturity group, MAL 9, MAL 15, ICPL 20120, ICPL 20129, and ICPL 20237 are promising and can be used to develop water-logging tolerant, FW and SM resistant pigeonpea hybrids. Within this group, a choice also exists to breed white seeded hybrids by crossing ICPA 2048 with ICPL 20237 (restorer) for Gujarat state. The other combinations will produce brown seeded hybrids. The maintainers (Table 2) such as ICP 14085, ICPL 20099, and ICPL 20093 can easily be converted to A-lines through back crossing.

Crossing scheme based on heterotic groups: Based on the information published by Mudaraddi and Saxena (2015) the hybrid parents were linked to three heterotic groups. Among the male sterile lines, two heterotic groups were recognized while among restorers, the presence of three heterotic groups (HG) was recorded. A total of four A-lines (HG 1, 2) and 11 restorer lines (HG 1, 2, 3) found places in these heterotic groups (Table 3). Since this grouping is based on genetic diversity, it will facilitate selection of hybrid parents differing in gene frequency at most loci (parents from diverse groups) and eventually production of high yielding hybrids.

Important considerations for breeding hybrids

- The major threat in a hybrid breeding is the maintenance of genetic purity of parental lines due to insect-aided natural out-crossing. Any laps in this activity will adversely affect the pace and quality of hybrid breeding programme.
- For selecting hybrid parents for future programme, the potential germplasm should be classified into different heterotic groups, primarily on the basis of genetic diversity and combining ability.
- A considerable weightage should be given to key market-preferred traits such as seed size, seed colour, uniformity of grains, and preferred milling traits such as high dal recovery.
- An effective and sustainable seed chain should be developed in collaboration with various seed organizations for producing different grades of quality seed.
- Develop quality control parameters to maintain genetic purity of hybrids and their parents.
- Regularly organize hybrid promotional on-farm activities in the target areas.

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Table 1. Publications from which relevant information was used to identify promising hybrid parents

Reference	Brieftitle	Informationused
Saxena et al. (2014a)	Fertility restoration of A_4 CMS	CMS maintainers and restorers
Sultana et al. (2012)	Water-logging in pigeonpea	Wáter-logging tolerant sources
Reddy et al. (1990)	Pigeonpea diseases	Disease resistant sources
Srivastava et al, (2006)	Salinity screening in pigeonpea	Salinity tolerant sources
ICRISAT (different years) Mudaraddi and Saxena (2015)	Pigeonpea Breeding Reports Molecular diversity groups	Morphological data Heterotic groups

Table 2. Promising A-lines, malesterilitymaintainers, and fertility restorers with their important agronomic traits

Genotype	Fertility/ sterility class	Water-logging	Wilt	Sterility mosaic	Pod size	Maturity	Seed size	Seed Colour
Reference	(1)	(2)	(3)	(3)	(4)	(4)	(4)	(4)
ICPA 2047	CMS line	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
ICPA 2048	CMS line	Tol.	Resis.	Resis.	Long	Late	Large	White
ICPL 20093	Maintainer	Tol.	Resis.	Resis.	Long	Medium	Large	Brown
ICPA 2039	CMS line	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
ICPL 20099	Maintainer	Tol.	Resis.	Resis.	Long	Medium	Large	Brown
ICPA 2039	CMS line	Tol.	Susc.	Susc.	Small	Early	Medium	Brown
ICP 14085	Maintainer	Tol.	Resis.	Resis.	Medium	Late	Large	Brown
ICPL 87119	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
MAL 15	Restorer	Tol.	Resis.	Resis.	Medium	Late	Medium	Brown
ICP 7086	Restorer	Tol.	Susc.	Susc.	Medium	Late	Medium	White
ICPL 20093	Restorer	Tol.	Resis.	Resis.	Long	Medium	Large	Brown
ICPL 20096	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
ICPL20108	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Medium	White
ICPL20112	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Small	White
ICPL20116	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
ICPL20117	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Small	Brown
ICPL20118	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Large	White
ICPL20120	Restorer	Tol.	Resis.	Resis.	Medium	Late	Medium	Brown
ICPL20123	Restorer	Tol.	Resis.	Resis.	Long	Medium	Medium	Brown
ICPL20125	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
ICPL20126	Restorer	Tol.	Resis.	Resis.	Long	Medium	Large	Brown
ICPL20127	Restorer	Tol.	Susc.	Resis.	Medium	Medium	Medium	Brown
ICPL20128	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
ICPL20129	Restorer	Tol.	Resis.	Resis.	Long	Late	Large	Brown
ICPL20137	Restorer	Tol.	Resis.	Resis.	Long	Late	Large	White
ICPL 81-9	Restorer	Tol.	Susc.	Susc.	Medium	Early	Medium	Brown
ICPL 90038	Restorer	Tol.	Resis.	Resis.	Medium	Early	Medium	Brown
ICP 11378	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
MAL 9	Restorer	Tol.	Resis.	Resis.	Medium	Late	Medium	Brown
ICPL 93101	Restorer	Tol.	Resis.	Resis.	Medium	Medium	Medium	Brown
ICPL 161	Restorer	Tol.	Susc.	Susc.	Medium	Early	Medium	Brown

References: 1. Saxena et al (2014a); 2. Sultana et al. (2012); 3. Reddy et al. (1990); 4. ICRISAT Reports.

Table 3: Male and female parents identified for breedinghybrids in three maturity groups

Maturity group	Female parent	Male parent (ICPL No.)	Expected phenotype* of hybrid
Early	ICPA2039 $^{HG-1}$	81-9, 161, 90038	water- logging tolerance, highyield, brownseed
Late	ICPA 2048 $^{HG-2}$ ICP 14084	MAL15^{HG-1}, MAL9 $^{HG-1}$	water- logging tolerant, disease resistant, brown/white seed
Medium	ICPA 2043 $^{HG-1}$ ICPA 2047^{HG-2} ICPL 20099	20120^{HG-2}, 20129^{HG-2}, 20116^{HG-2}, 20123^{HG-2} 20128^{HG-2}, 20125^{HG-2}, 20118^{HG-2} 20137^{HG-2}, 87119^{HG-3} 20117, 20129, 149	water-logging tolerant, disease resistant, brown / white seeds vegetable typepods brown / whiteseeds vegetable typepods
		20137, 20108, 20112, 20093, 20126, 20096,	

Based on parentage and reported dominance relationships for different traits; HG (superscript) = heterotic group

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