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Current Status and Way Forward for Scaling up Productivity of Pigeonpea in Madhya Pradesh: A Review

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ABSTRACT

Madhya Pradesh ranks first both in terms of area (25%) and production (32%) of pulses in India. However, it ranks sixth after Uttar Pradesh, Bihar, Haryana, West Bengal and Gujarat in terms of productivity. To realize better yield; recommended production and protection technologies have to be followed. Most of the pigeonpea varieties have been developed by traditional breeding either by pedigree method or selection from landraces or by bi-parental mating. After getting stable male sterile and restorer lines, development of hybrid pigeonpea have been major breeding objectives. Availably of genomic tools by decoding the genome sequence, pigeonpea have been equipped with modern genetic and genomic tools for use in the research programmes. Different approached like mining superior alleles by re-sequencing of wild species, fine mapping for drought tolerance, fertility restoration and developing superior lines by genomic selection, identification of candidate genes which are associated with hybrid vigour by using epi-genomics and mitochondrial genome sequencing and identification of candidate genes and functional markers for water-logging tolerance are already in progress. Transgenic approach has also been initiated to develop resistance against pod borer. Collaborative efforts among ICRISAT, IARI and IIPR-Kanpur are on the way for use of different transgenes and promoter options for developing transgenic plants and their evaluations for effectiveness and bio-safety concerns.

Key words: Genomic tool, Pigeonpea, Production, Pedigree method, Transgenic breeding.

Pigeonpea is a *kharif* season crop and is the second most important pulse crop after chickpea. It is also known as Red gram in English, Arhar in Hindi and Tur in Bengali and used as dry split dhal for consumption purposes. It is diploid (2n = 22) with a genome size of 808 Mbp (Varshney *et al.* 2010). Pigeonpea [*Cajanus cajan* (L.) Millsp.] is cultivated in the semi-arid regions of topics and sub-tropics and provides protein rich food, firewood and income to the small and resource poor farmers. It has ability to fix atmospheric nitrogen in their root system and thereby improves nitrogen content in the soil. It is a deep rooted crop, helps in extracting moisture and nutrients from deeper soil layers hence is suitable for cultivation in rainfed situations. Pigeonpea is largely used as an important source of protein in human diet as its seed contains 20-23% protein, 3.5% minerals, 57.6% carbohydrates (Table 1) and essentials amino acids (Table 2) and provides 335 cal energy per 100 g (Saxena *et al.,* 2010; Sarkar *et al.,* 2020). Besides its consumption in the form of dry split dhal, pigeonpea has multiple uses like green seeds are used as vegetable and the stem and roots as fuel wood, green branches and leafs for forage purpose, and it also improves soil health through its deep rooting system, and leaf drop at maturity. Its cultivation also enrich soil fertility by providing 40-60 kg N/ha to the subsequently grown crop (Sarkar *et al.,* 2020). Hence, pigeonpea is often called as "Biological plough". It also helps in preventing soil erosion by wind and water, helps on infiltration of rain water and smothers the weeds (Kirar *et al.,* 2020). The carbohydrates available in pulses are released slowly as compared to cereals and so a high value for maintaining

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optimal blood sugar levels and thus restoring energy over a long period of time after the meals (Chung *et al.,* 2008).

Being important pulses crop in rainfed agriculture, collaborative research efforts are going on towards genetic enhancement of pigeonpea. For the last five decades, no stable increase has been realized in its productivity and has remained stagnant and a dearth of high yielding cultivars has been observed as one of the major factors causing the yield stagnation (Bohra *et al.* 2010). Occurrence of biotic and abiotic stresses in pigeonpea cultivation is again a serious concern for pigeonpea stakeholders and immediate attention is needed to take up the effective breeding approaches for solving these problems in collaborative manner. The purpose of this article is to highlight the trend of area, production and productivity of pigeonpea in Madhya Pradesh and breeding efforts needed for the development of the superior, short and mid-early duration, high yielding varieties/hybrids with tolerant to wilt and sterility mosaic virus disease.

Crop status in India and Madhya Pradesh

Pigeonpea is the 5th vital legume in the world and ranks 2nd after chickpea in terms of area and production in India (Pratibha *et al.,* 2015). The major pigeonpea growing states are Maharashtra, Madhya Pradesh, Karnataka, Gujarat and Andhra Pradesh. In India, the area under pigeonpea cultivation was approximately 4.82 M. ha. with production of 3.88 M.T. and productivity of 804 kg/ha in 2020-2021 (agrocrop.nic.in) and during same year, area and production was 5.37 lakh ha and 5.87 lakh tones, respectively in Madhya Pradesh. In term of area and production; India rank 1st in the world with 80% and 63% of world's acreage and production, respectively. In productivity, Trinidad ranked first with 2381 Kg/ha followed by Philippines and Jamaica (FAOSTAT 2008). Since its domestication in the Indian subcontinent at least 3,500 years ago, pigeonpea seeds have become a common food ingredient in Asia, Africa, and Latin America. In South Asia, it is consumed on a large scale and is a major source of protein for the population of the Indian subcontinent. It is the primary accompaniment to rice or roti and has the status of staple food throughout the length and breadth of the country. The centre of origin is probably peninsular India, where the closest wild relatives (*Cajanus cajanifolia*) occur in tropical deciduous woodlands (Van der Maeson, 1995). Africa is the secondary centre of diversity and at present it contributes about 21% of global production with 1.05 million tones (Carney and Rosomoff, 2009).

Table 1: Nutritive value of pigeonpea.

Nutritional parameter	Value	Nutritional parameter	Value
Protein	22.3%	Calcium	73 mg/100 g
Fat	1.7%	Phosphorus	304 mg/100 g
Minerals	3.5%	Iron	5.8 mg/100 g
Fiber	1.5%	Moisture	13.4%
Carbohydrate	57.6%	Calorific value	335 Kcal/100 g

Table 2: Nutritional profile of various amino acids in pigeonpea (Bressani *et al.*, 1986).

Essential amino acid	Available mg/g of protein	Min. required mg/g of protein
Tryptophan	9.76	7
Threonine	32.34	27
Isoleucine	36.17	25
Leucine	71.3	55
Lysine	70.09	51
Methionine+Cystine	22.7	25
Phenylalanine+Tyrosine	110.4	47
Valine	43.1	32
Histidine	35.66	18

Trends in area, production and productivity

Out of the total pulses areas (29.0 million hectares), more than 7.3 million hectares is in Madhya Pradesh alone, earning a prime status in pulse production commodity registering a remarkable 25% of the country's pulse area with 33% production, thereby ranking first both in area and production. This is followed by Rajasthan in respect of area (16%) and Maharashtra in case of total production (13%) (DACandFW, 2017-18). Total area, production and productivity of pigeonpea in Madhya Pradesh over last fifteen years in shown in graph as Fig 1.

There is a wide gap between the demand and the supply of pigeonpea in India. This gap is likely to increase further unless more vigorous efforts to increase production and productivity of this crop are made. Pulse farming is still in its initial phase of technological change. Especially, there has not been enough technological break-through in pulses to make pulse farming as remunerative enterprise. Though some recommended varieties like UPAS-120, Rajeshwari, TJT-501, BDN-711, BSMR 736, Asha and Rajeev Lochan (Table 6) have been immensely contributing but there is a still need of promising extra-early/short and medium duration, high yielding varieties which could be a potential substitute for cultivation in the Madhya Pradesh. Saxena *et al.,* (2005) reported that the trends in pigeonpea area, production and yield over the last five decades reveal about 2% annual increase in its area; however, the yield levels have remained low and unchanged at around 700 kg per hectare. Major pigeonpea growing states and their contribution of total pulses area and production are given in Table 3.

Potential yield

About 20% of the Gross Cropped Area (GCA) of Madhya Pradesh is under pulses crop. Though pigeonpea ranked first in terms of area and production, it ranked sixth after Uttar Pradesh, Bihar, Haryana, West Bengal and Gujarat in terms of average yield. It has been noticed that, in general, average potential yield gap between FLD and farmer's field (local check) is about 29%. The level of potential yield could be achieved by applying improved package of practices and technologies. Front Line Demonstration (FLD's) conducted on pigeonpea with improved variety JKM 189, TJT 501, Pusa 992 in Madhya Pradesh, with improved practices yield was 1394 kg/ha while farmers yield was 1078 kg/ha, thus revealing 22.66% increase in yield over check. While comparing with state average yield, improved practices has shown 61% increase in yield over the state average yield (Table 4). States like Bihar, Gujarat, Haryana, Jharkhand, Kerela, Madhya Pradesh, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand and West Bengal has shown yield better performance over the national average while Andra Pradesh, Assam, Himachal Pradesh, Karnataka, Maharashtra, Odisha and shown below the national average (Table 5).

Climatic requirement

Pigeonpea is mainly a crop of tropical areas mostly cultivated in semi-arid regions of India. It can be grown with

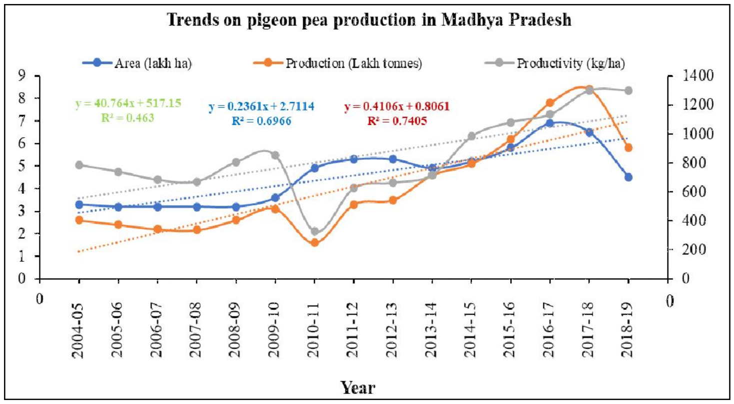

Fig 1: Trends in area, production and productivity of pigeonpea in Madhya Pradesh over last 15 years.

Table 3: Major pigeonpea (Source: DAC and FW).

States	Area (lakh ha)	% Contri.	States	Production (lakh tones)	% Contri
Madhya Pradesh	73.23	25	Madhya Pradesh	80.38	33
Rajasthan	48.19	16	Maharashtra	32.65	13
Maharastra	43.50	15	Rajasthan	29.78	12
Karnataka	31.13	11	Uttar Pradesh	22.34	9
Uttar Pradesh	23.61	8	Karnataka	18.52	8

Table 4: Technological yield gap.

Crop	Yield (kg/ha)			Gap over FP		Gap over SAY	
	IP	FP	SAY	Actual	%	Actual	%
Pigeonpea	1394	1078	863	316	29	531	61

IP = Improved practice, FP = Farmer's production, SAY = State average yield.

a temperature ranging from 26°C to 30°C in the rainy season (June to October) and 17°C to 22°C in the post-rainy (November to March) season (Reddy and Virmani 1981). It is highly susceptible to frost damage at all stages of growth and hence bright sunshine is essentials for higher seed yield. In pigeonpea accessions, there is short day, day neutral and indeterminate types and they will not grow in area which is higher than 1800 m from msl. An average rainfall between 600-100 mm is quite suitable and high yields are obtained when there is enough rainfall during the first and second months of growth followed by a dry spell during the flowering and harvesting stages as it has better drought resistant ability.

Land requirement

The pigeonpea can be grown on a wide range of soil types provided they are not deficient in lime and are well drained. It is favorably grown in well drained, black-cotton soils of Madhya Pradesh and Maharashtra with a pH ranging from 7.0-8.5. Sandy-loam to clay-loam soil is supposed to be best and soil must be very deep, well drained, alluvial and loamy soil for its good cultivation (Chandra *et al.,* 1983). Pigeonpea responds well to properly tilled and well drained seed-bed. A deep ploughing with soil turning plough followed by two to three cross horrowings and proper leveling should be given to ensure uniform irrigation and proper drainage. Being a deep rooted crop, it requires a deep and well pulverized field which is free from weeds and clods. It is vulnerable to deficiencies of phosphorus, zinc and manganese. Wind can be a problem but if crop is planted in double rows, it can survive. Pigeonpea is also sensitive to salty spray from either soils or the sea and do not grow well along the sea. Ridge-furrow or Broad Bed Furrow planting in lower as well as intercropping areas is advised. Raised Bed method of planting by dibbling at 2-4 inches depth is better for uniform germination.

Sowing time

Time of sowing, a non-monetary input however, has a considerable influence on growth and yield of pigeonpea. It makes sure the complete harmony between vegetative and reproductive phases on one hand and climate rhythm on other hand. Sowing time also plays a significant role in dry matter accumulation by the crop. Early sown crop could accumulate more dry matter and cause reduced podding, whereas late sown crop may decrease the biomass accumulation and consequently reduction in economic yield. Delay sowing beyond the optimum time results in low seed yield (Rao *et al.,* 2004; Kumar *et al.,* 2008). Thus, sowing of seed crop in first week of June is recommended for obtaining higher seed yields. Source of seed should be genuine like foundation/certified seed from source approved by seed certification agency.

Seed rate and plant geometry

The seed rate of pigeonpea based on the desired plant population for a genotype (early, medium or late), cropping system (pure crop, mixed crop, or intercrop), germination rate of seed and mass of seed. 18-20 kg seed per hectare

Table 5: Yield gap exhibiting the production related constraints among the states.

Crop season	National yield (kg/ha)	Highest/ lowest. yield (kg/ha)	States > national avg	States < national avg.
Total Pulses	835	HP (1338) J and K (397)	AP, Bihar, Gujarat, HP, Jharkhand, Kerela, MP, Punjab, Telengana, UP, Uttarakhand, WB	Assam, Haryana, J and K, Karnataka, Maharashtra, Odisha, Rajasthan, Tamil Nadu,
Arhar	937	MP (1297) HP (360)	Bihar, Gujarat, Haryana, Jharkhand, Kerela, MP, Rajasthan, TN, UP, Uttarakhand, WB	AP, Assam, HP, Karnataka, Maharashtra, Odisha, Punjab

Table 6: Recommended high yielding varieties of pigeonpea for Central Zone.

Variety	Year of Release Notification	Area of adoption (zones/states)	Maturity (Days)	Yield (q/ha)	Special features
UPAS 120	1976	UttarPradesh	120-150	11-15	Early maturing
Asha (ICPL 87119)	1993	CZ and SZ	160-170	16-18	Resistant to wilt and SMD,Bold seeded, Indeterminate
BSMR 736	1996	Maharashtra	180-185	12-18	Resistant to wilt andSMD. Brown seeded. Indeterminate
Malviya Arhar 13	2004	NEPZ	250-260	20-22	Tolerant to wilt
Pusa 2002	2007 (SVRC)	Central Zone	110-150	16-17	Indeterminate, semi-spreading, early maturing,suitable for pigeonpea-wheat cropping system
IC 550413	2007 (SVRC)	Central Zone	178-180	18-19	Resistant to *Fusarium* Wilt, Sterility Mosaic Virus,and Mod. tolerant to *Helicoverpa. armigera* and Pod Borer
Jawahar Tur JKM 189	2007 (SVRC)	Madhya Pradesh	160-180	19-32	Mode.resistant to *Fusarium* Wilt, SMD and PB.Tolerant to PBcomplex and PF andNematodes.
TJT 501	2008 (CVRC)	CZ (Central)	135-183	18-19	Tolerant to Pod Borer and pod Fly
Phule T 0012 (Rajeshwari)	2012 (CVRC)	CZ	135-150	18-20	Moderately resistant to F*usarium* wilt, SMD and tolerant to Pod borer and Pod fly
BDN 711	2012 (SVRC)	Maharashtra	150-160	15-23	Indeterminate, spreading, Resistant to wilt and sterility mosaic disease, escape terminal drought
Rajeev Lochan	2011 (SVRC)	Chhattisgarh	178	18-19	Resistant to wilt and sterility mosaic disease
ICPH 2671	2013 (SVRC)	Madhya Pradesh	180-190	15-16	Indeterminate, medium maturity, tolerant to wilt and sterility mosaic
IPA 203	2014 (CVRC)	NEPZ	115-120	16-18	Resistannt to sterility mosaic disease, tolerant to *Phytohthora* blight and *Fusarium* wilt.

SVRC- State variety release committee, CVRC-Central variety release committee, CZ- Central zone (MP.,Maharashtra, Chhattisgarh, Gujarat), SZ- South zone (AP, Karnataka, Tamilnadu, Odisha) NEPZ-North eastern plane zone (East Uttar Pradesh, Bihar, Jharkhand, West Bengal). Res.= Resistant,, Tol.= Tolerant, Mod.= Moderately, SMD= Sterility Mosaic Disease

(Source:- Project Coordinator's Report, Annual Group Meet on Pigeonpea, 2016-17, AICRP, ICAR, IIPR, Kanpur).

should be used in early duration varieties and for medium/ late duration varieties it should be 12-15 kg per hectare. If pigeonpea is to be taken with other crop then 5-6 kg seed per hectare should be used, row to row spacing of 45 to 60 cm and plant to plant 10 to 15 cm for early duration varieties and 60 to 75 cm row to row and plant to plant 20 to 30 cm for medium/late duration varieties is suitable for healthy plant growth. Based on growth habit of the varieties, spacing to be adjusted to provide enough space to the planted materials for healthy growth (Mula and Kumar, 2015).

Method of sowing

There are three systems of sowings being practiced for its cultivation. The most common one is flat sowing; the others are broad bed-furrow (BBF) for extra-early group and ridge-and-furrow for the late maturity group (Kaul and Sekhon, 1975). Bund cultivation of pigeonpea in rice-fallow areas is also adopted in Chhattisgarh, Madhya Pradesh and in states of North East region. Last two methods are beneficial when there is poor surface drainage and water logging kind of situations. The raised bed also helps for better aeration and nodulation. A broad bed and furrow method is used for planting extra-early genotypes, and for medium and late duration ridge-and-furrow method is used at ICRISAT.

Seed treatments

Treatment of seeds with Thiram (2 g)+Carbendazim (1 g) or Thiram @ 3 g or *Tricoderma virdie* 5-7 g/kg of seed before sowing is beneficial. Seeds should also be treated with Rhizobium and PSB culture 7-10 g/kg seed (Chandra *et al.,* 1983). This helps in early stand of disease-free seedlings and attains vegetative growth in time.

Manure and fertilizer

The fertilizer should be given based on the results of soil test. All the fertilizers are applied in furrows at a depth of 5-10 cm, along the side of 5 cm, from seed. Apply 25-30 kg N, 40-50 kg P_2O_5, 30 kg K_2O per hectare as basal dose at the time of sowing (Kulkarni and Pawar, 1981). For good yield, application of ten cart loads of farm yard manure (FYM) followed by 25 kg of nitrogen and 50 kg of phosphorus is recommended for better result .

Secondary and micro nutrients

- **Sulphur**

In sandy loam or medium black cotton soils, application of 20 kg Sulphur/ha (equivalent to 154 kg gypsum/phospho-gypsum or 22 kg bentonite sulphur) as basal dose is effective, and if Sulphur deficiency is observed in red sandy loam soils, use 40 kg Sulphur/ha (equivalent to 300 kg gypsum/phospho-gypsum/or 44 kg bentonite sulphur). This quantity would be sufficient for one crop cycle (Tandon, 1987).

- **Zinc**

In sandy soil, use 3 kg Zn per hectare (15 kg zinc sulphate hepta hydrate/ 9 kg zinc sulphate mono hydrate) as basal. If Zinc deficiency is noticed in the standing crop, it can then be sprayed 5 kg Zinc sulphate+Lime 2.5 kg dissolved in 800-1000 liter water per hectare (Saxena and Singh, 1970).

- **Iron**

In light textured soils, foliar application of 0.5% $FeSO_4$ at 60, 90 and 120 days after sowing are beneficial (Saxena and Singh, 1970).

Water management

Pigeonpea being a deep rooted crop has potential to tolerate drought situation (Pandit *et al.,* 2015). However, in prolonged drought situations, there is need of three irrigations, 1^{st} at branching stage (30 days after sowing), 2^{nd} one at flowering stage (70 days after sowing) and 3^{rd} at the time of podding (110 days after sowing) (Rao *et al.,* 1983). Proper drainage is a pre-requisite for the better yield of pigeonpea. Therefore, ridge planting has been found to be effective in areas where sub-surface drainage is poor and this helps in providing enough aeration for the roots during the period of high rainfall (IARI, 1971).

Weed management

The first 60 days of crop growth is very critical and harmful if weeds infestation is taking place. To overcome this problem, Kumar *et al.,* (2020) reported that two hoeing at 40 and 70 days after sowing found to be most effective to control all kind of weeds. However, weeding should be completed before flowering.

Use of pre-emergence herbicide *i.e.*, Pendimethalin @ 0.75 - 1 kg *a.i.* per hectare in 400-600 liter of water destroys the germinating weeds and helps in keeping the field weed free for the first 50 days (Chakravarthy and Manoharan, 2016; Sarkar *et al.,* 2020). If weed found from long time use Fluchloralin 50% EC (Basaline) 1 kg of a.i per hectare in 800-1000 liter, well incorporated in the soil before sowing or Alachlor 50% EC (Laso) 2-2.5 kg a.i. per hectare in 400-500 liter of water as pre-emergence (Chauhan, 1990).

Harvesting and threshing

With 66% to 75% pods maturity judged by changing pod colour to brown is the appropriate harvesting time. The matured plants are mostly cut with a sickle 60 - 80 cm above the ground level and harvested plants are kept in the field for sun-drying for 3-6 days, depending on weather conditions. Threshing is mostly done either by beating the pods with stick or using Pullman Thresher. The clean seeds should be kept for sun-dried for 3-4 days, it would help in bringing down the seed moisture level at 9-10% for safe storage (Balakrishna and Natarajaratnam, 1988).

To check the development of bruchids and other storage pests, it is suggested to fumigate the storage material and godown before onset of monsoon and again after the monsoon with ALP @ 1-2 tablets per tonne. The small quantity of seed can also be preserved by mixing inert matter (ash, soft stone, lime etc.) or through smearing non-edible/ edible oils or by mixing with plant products like neem kernel/ leaf powder at the rate of 1-2% w/w basis.

On-going breeding efforts

History of pigeonpea improvement research in India

In India, the first scientific effort on pigeonpea breeding was initiated by Shaw *et al.,* (1933) who reported morphological and agronomic characters of 86 *elite* collections. Same level of efforts was made by Mehta and Dave in 1931; who identified early and late maturing and high yielding types. The crop improvement activities like field collections and their evaluation were carried out and continued for more than two decades without any considerable improvement in the productivity. Considering the importance of pigeonpea improvement, ICAR initiated All India Coordinated Pigeopea Improvement Project in 1965. Under this mega project, the crop improvement activities were simultaneously launched at 31 research centers in diverse agro-ecological zones (Ramanujam and Singh, 1981) and till now more than 150 varieties have been resealed.

Organized crop improvement work was also initiated at ICRSIAT since its inception in 1972. The main focus was on collection, evaluation, maintenance and sharing of germplasm and yield enhancement research during first decade (1972 to 1980). During 1980 to 2000; ICRISAT research major priorities were development of stable sources of resistance for wilt and Sterility Mosaic Disease which are considered to be highly devastating and endemic in India in nearly all the agro ecological zones of pigeonpea cultivation. Then from 2000 onward, concerted efforts are in progress on cytoplasmic genetic male sterility system (CGMS) based hybrid development. ICRISAT has developed varieties *viz.,* ICP 8863, ICPL 87119, ICPL 85063, ICPL 332, ICPL 84031, ICPL 85010, ICPL 151 and ICPL 88039 which are released by ICAR, NARS partners and are highly popular among all the states of India. ICP 8863 (Maruti) which is first wilt resistant variety, stabilized livelihoods of farmers in central and southern zones. ICPL 87119 (Asha) a wilt and SMD resistant variety, very popular in the country and still today occupies largest area (Kumar *et al.,* 2018).

ICPH 8, a world first genetic male sterility system (GMS) based hybrid in pigeonpea, released by ICRISAT in the year 1991 (ICRISAT, 2007; Saxrna, 2008). The another first Cytoplasmic Male Sterility System (CMS)- based hybrid GTH-1 was released in India in 2004 by ICRISAT in collaboration with their partners. The commercial hybrid of pigeonpea ICPH-2671, developed by crossing ICPA 2043 with ICPR 2671 and released in 2010 (Saxena *et al.,* 2013). In all four states Maharashtra, Andhra Pradesh, Madhya Pradesh and Jharkhand, ICPH-2671 gave 51% better in yield than the control. After better result of ICPH-2671 in Madhya Pradesh, two more medium duration hybrids with high yield potential were released in India. During 2012, ICPH-2740 was released for cultivation in Andra Pradesh (Saxena and Tikle, 2015) and the third hybrid ICPH 3762 was released in 2014 for cultivation in Odisha (Saxena *et al.,* 2014). Two CMS lines MA CMS 32A (Compact plant type, medium plant height, reddish flower with red stripes, pod green with strip, seed colour dark red) and MA CMS 25A (Compact plant type, tall plant height, light reddish flower with red stripes, pod green with strip, whitish seed colour), and one restorer line MA-6 have been identified at Banaras Hindu University which were phenotypically spreading type, tall plant height, yellow flower, dark purple pod, brown seed colour (Saroj *et al.,* 2015). Very recently, IPH-15-03; an early maturing pigeonpea hybrid has been identified and released for cultivation in the North West Plain Zone (NWPZ) (Saxena *et al.,* 2020) and continuous efforts are underway to make hybrid technology commercially profitable and viable. Till now ICRISAT in collaboration with National Food Security Mission of India, Indian Council of Agricultural Research, and State Agricultural Universities has also released hybrids ICPH 2671 and ICPH 2740 for cultivation in India. It is reported that these hybrids have given 30-40% yield advantages over varieties in farmers' fields and still efforts are being made to develop hybrids in different maturity groups, especially mid-early and medium duration group for the central India.

Genetic resources

The genus *Cajanus* comprises 32 species and belongs to the sub-tribe *Cajaninae* (Van der Maesen, 1990; Bohra *et al.* 2010), from which *Cajanus cajan* (2n = 2x = 22) comes as domesticated species (Bohra *et al.* 2010). *Cajanus cajan* belongs to primary gene pool, while the wild progenitors are put in the secondary and the tertiary gene pool, based on their crossing ability with the cultivated species (Bohra *et al.* 2010). A total of 13771 accessions are deposited at gene bank in ICRISAT, Patancheru, India, about 11221 accessions are collected at National Bureau of Plant Genetic Resources (NBPGR), India, 4116 accessions deposited at U.S. Department of Agriculture (USDA), USA and around 1288 accessions maintained at Kenya Agricultural Research Institute's National Genebank of Kenya (KARI-NGBK), Kenya. These germplasms act as reservoirs of genetic resources for the present and future research works. Though utilization of these genetic resources for pigeonpea improvement has been limited and major diversity in the existing germplasm remained unexplored (Majumder and Singh, 2005). An effort has been put to define a core collection of 146 accessions and a mini core collection of 146 accessions at ICRISAT for more utility of germplasm in research work. These collections contribute more than 80% of the existing diversity in the complete germplasm and are considered to be ideal resources for genetic diversity and association mapping (Gowda *et al.* 2013). Many accessions have been characterized for high seed protein content, early maturity, large seed size, high pod number/plant, high iron, high zinc, tolerance to water-logging and salinity (Gowda *et al.* 2013). Wild relatives have been identified for desirable traits such as resistance to pests and diseases, tolerance to abiotic stresses, high protein content, photo-insensitivity, cleistogamy and cytoplasmic male sterility. The wild species are gradually decreasing from their habitat and could extinct if not protected. Though late, but the importance of these landraces and wild accessions has been realized and efforts has been put to conserve them.

Approaches to improve pigeonpea production and productivity

Breeding approaches in pigeonpea have been more challenging and difficult than other legumes due to various crop specific characters. It is a often cross pollinated crop, with an insect-aided natural out-crossing which ranges from 20 to 70% and this has limited the application of effective selection and crossing designs, which is possible in self-pollinated crops (Saxena *et al.* 1990). Lot of genetic resources have lost high yield potential traits during the process of domestication in pigeonpea like other legume crops and this lost variability which need to be regenerated, conserved and used in the breeding programme (Singh *et al.* 2014). Mostly plant breeding efforts for developing high yielding varieties in pigeonpea targets on defect elimination/ correction *viz*., development of resistant/tolerant varieties for abiotic (high or cold temperature, moisture stress) and biotic (*Fusarium* wilt, Sterility mosaic disease, *Phytophthora* blight, Pod borer and Pod fly) stresses. Presently available plant type of pigeonpea is like a semi-tree in habit and hardy plant which survives under the adverse environment conditions. This pant also has more vegetative growth and woody growth with low sink capacity. Therefore, a planned research to rebuild the new plant type to improve the genetic yield potential of pigeonpea is required to meet the demand of the nation. On this backdrop, the following approaches are under progress for genetic improvement of this crop.

Traditional breeding

Conventional breeding techniques for pigeonpea improvement have been in application for many decades but have shown limited improvement/success in overcoming hurdle of these biotic and abiotic stresses for better and stable crop production (Varshney *et al.* 2007; Saxena, 2008). Among conventional breeding, pedigree method has been a potent breeding approaches for the improvement of yield in the past, despite occurrence of natural out-crossing. Most breeders approached to pedigree breeding without pollination control mechanisms and out of 87 varieties released in India, 82 were bred by pedigree method. Interestingly, 55% of these were evolved through selections from the populations derived by bi-parental crossings, and the remaining were selections from heterogeneous landraces (Saxena *et al.* 2016). Saxena *et al.,* (2020) also reported by using pedigree breeding method, a total of 89 pigeonpea varieties were released since 1960 and 455 advanced breeding lines were also nominated for their evaluation in the National Coordinated Trials organized by Indian Council of Agricultural Research (ICAR). These facts underline the extensive use of pedigree breeding method in pigeonpea.

Genomic tools for developing varieties/hybrids with resistance to biotic and abiotic stresses

On availably of genomic tools by decoding the genome sequence of the crop during the year 2012 (Varshney *et al.* 2012) pigeonpea have been equipped with modern genetic and genomic tools for use in the research programme. On diversity analysis of released cultivars of pigeonpea, it has shown very limited genetic diversity contrast to the high diversity available in landraces and wild relatives. This genetic diversity must be exploited for rapid crop improvement programme. Different approaches like mining superior alleles by re-sequencing of wild species, fine mapping for drought tolerance and fertility restoration, developing superior lines by genomic selection, identification of candidate genes which are associated with hybrid vigour by using epi-genomics and mitochondrial genome sequencing and identification of candidate genes and functional markers for water-logging tolerance are already in progress.

Breeding for development of varieties/hybrids with disease and insect resistance

Pigeonpea is grown in many states in India in different agro-ecological situation, along with diversified cropping patterns and crop durations. Due to climate change, there are erratic rainfall patterns and its distribution, varietal requirement scenario is changing for different locations. Therefore, it is necessary to breed adaptable lines which could fit for those particulars zones with changing climate conditions. Crop improvement efforts which led to development of cytoplasmic and genetic male sterile lines for different agro-ecology and seed production technology have also been standardized for large scale commercial seed production (Saxena *et al.* 2014). There is an urgent need for exploitation of hybrid vigour through breeding heterotic hybrids for different agro-ecological zones in the country to improve productivity and production of pigeonpea (Saxena *et al.* 2013). Approaches like development of mid-early and medium duration varieties/hybrids with wilt and SMD resistant for central zones, breeding for development of extra-early genotypes with 120 days maturity which could fit into pigeonpea and wheat cropping systems in North Western Plain Zone with water logging tolerance and development of varieties with more than 180 days maturity along with frost resistance for North Eastern Plain Zone is under progress.

Breeding for super early genotypes for different cropping patterns

Because of the photo and thermo sensitivity and mostly indeterminate growth habit of the medium and long duration of the pigeonpea crop, it could not be spread for different cropping systems and patterns. However, with the advancement of the current research, complete day-neutral and photo in-sensitive varieties have been evolved which could be grown in any part of the year and offer opportunities for horizontal spread in the crop to different cropping systems (Vales *et al.* 2012). Some of the feasible areas of expansion is rice-fallows (about 10 million ha) available in eastern India *viz*., Jharkhand, Bihar, Chhattisgarh, Odisha and West Bengal) provide opportunities for expansion of pigeonpea areas. Therefore, there is a need to develop the kinds of varieties which could adapt to different niches by collaborative breeding works.

Induced variation through mutation

Through mutation breeding, eight commercial pigeonpea varieties has produced. By the use of Ethyl methane sulphonate (EMS) treatment (0.6% solution) a high yielding pigeonpea variety CO 3 was developed, while 16 kr of gamma rays helped in the development of another high yielding variety CO 5. Two other high performing varieties, TT 5 and TT 6, were developed for rainfed areas of central zone by using fast neutrons (Reddy *et al.,* 1996). The variety TT 6 has 25% larger seeds and higher yield than its parental cultivar T 2. Through mating two mutant inbreds (derived from fast neutrons) another important pigeonpea variety TAT 10 has been developed. The cultivar TAT 10 has high yielding ability and it matures one month earlier than the control (Pawar *et al.* 1982).

Transgenic technology

Insect like pod borer (*Helicoverpa armigera*) is still a major challenge for the pigeonpea growers in the country and till date a line with high degree of resistance to pod borer has not been found in the available germplasm. Though some wild species have been observed with high level of resistance and efforts are under way to tap these wild species in improving resistance to pod borer. Transgenic approach has been initiated to develop resistance against pod borer in pigeonpea as well. Collaborative efforts between ICRISAT, IARI and IIPR-Kanpur is going on for use of different transgenes and promoter options for developing transgenic plants and their evaluations for effectiveness and bio-safety concerns.

Breeding constraints-Pigeonpea

Availability of limited genetic variability

Pigeonpea shows large phenotypic variation within primary gene pool for most of the economically important characters. However, in contradiction, in molecular genetics study shows limited genetic variability in the germplasm and could be a reason for limited genetic gain in the productivity. Singh *et al.* (2016) while studying diversity among parents used in breeding the released varieties reported that that 50% of varieties had 10 parents in common. They observed that more than 1/3rd of the released varieties evolved directly from landraces and these examples explain how a limited parental diversity was used for improving yield of this crop.

Knowledge of genetic inheritance

Understanding of genetic inheritance for yield and yield attributing traits plays significant role in deciding breeding approaches and strategies for pigeonpea improvement. Compare to other economically important crops, limited efforts have been made to understand the genetics of important traits in pigeonpea. Saxena and Sharma, (1990) have reported importance of both kind of additive and non-additive gene effects for determining yield, plant height and protein content. Byth *et al.* (1981) reported pleiotropic effects of genes, physiological changes and very sensitive nature of this crop towards the environmental changes; which make it difficult to explain the inheritance of yield and yield attributing traits.

Abiotic and biotic stresses

Under field conditions, a numbers of stresses considerably affect pigeonpea growth, yield and performance stability. Biotic stresses like insects *viz*., pod borer and pod fly and diseases *viz*., wilt and sterility mosaic disease (SMD) are the most devastating, and, in general, genetic resistance against the insect is either still lacking or very weak which could make any impact on improving genetic gain in breeding lines. Even, no reliable information is available on the genetic control mechanism of the insect tolerance/ resistance (Saxena *et al.* 2016). Genetics of wilt resistance is well documented and inheritance patters are quite known. In different lines, 1 or 2 genes with dominance recessive action have been observed for controlling wilt resistance/ tolerance (Saxena *et al.* 2014). But still, enough information has to be generated on account of the biotypes of *Fusarium udum* and inheritance of their resistance and this would help in breeding widely wilt resistant varieties. The resistance of SMD is governed by recessive genes but its mode of inheritance is still uncertain (Saxena and Sharma, 1990). Many varieties with significant level of stable resistance against wilt and SMD have been evolved through breeding and these occupy nearly 60-75% of the growing area. Two varieties Maruti and Asha have played a vital role in suppression of wilt and SMD in parts of Karnataka, Maharashtra, Madhya Pradesh and Telangana states in India (Saxena *et al.* 2016). Drought is again a widely known limitation in pigeonpea; but unfortunately, no clear information is available on physiological traits which might directly or indirectly have influence on the incidence and degree of drought conditions in the different growing regions. Water-logging is another abiotic stress which occurs temporarily in the fields; where drainage facility is very poor. Generally, water-logging have more impact on the yield performance of the early types as compared to those taking 6-9 months to mature (medium and long duration group); because medium and long duration crop could recover from this stress. Hingane *et al.* (2015) described that in water-logging tolerant genotypes; some new morphological characters like aerenchyma cells, lenticels, and/or adventitious roots developed in water-logged situations and these traits might helps in respiration to stressed plants through supply of oxygen from stems to roots.

Seed purity contamination issues

Contrary to most pulses, in pigeonpea the maintenance of genetic purity is a bit difficult and resource-intensive, mainly due to occurrence of insect-aided natural outcrossing (Saxena *et al.* 2016a). In these situations, the specific feature for which a variety was released could lose its identity in short period and this process of quality deterioration is very quick when it is governed by recessive genes. There is report that in absence of proper seed production management, varieties with good disease resistance have become highly susceptible over a period of a few years. For example; variety "Bahar", a high yielding and widely adapted variety, well known for its high degree of resistance against SMD became a mixture of resistance and susceptible plants over a period of few years and further, it lost its yield potential, adaptation and popularity. Another key prospect is maintenance of maturity duration for which variety was recognized; this happens due to increase in number of indeterminateness of the plants (within a variety) which lead in shifting their duration; for example, still a very popular variety "UPAS 120" generally mature in around 120 days but its maturity period extended for almost a month and thereby adversely affecting cultivation practice of Pigeonpea-Wheat rotation crop. Hence, for maintaining identity of a particular variety, an efficient seed production, storage and quality control mechanism need to be given top priority (Saxena *et al.* 2016).

Way forward for scaling up the production and productivity of pigeonpea

Horizontal expansion

By bringing additional area under pigeonpea cultivation and introducing diversification of rice-wheat cropping system in plains by recommendation of popular early and mid-early duration varieties of pigeonpea. Intercropping of the pigeonpea with other existing *kharif* season crops of that area *viz*., promoting early or mid-early, thermo-insensitive varieties of pigeonpea with soybean/groundnut/millets cultivation as these could be an alternative to boost up the area and production of this crop.

Vertical expansion

By improving productivity of the pigeonpea and bridging the yield gaps between research station yield and farmers field performance by timely availability of the quality seed and adoption of the recommended cultivation practices to boost up productivity. Development of super-early or early and mid-early duration, high yielding and insect-pest resistant/tolerant varieties for that particular ecology would be a better solution for increasing productivity. Efforts have been paid by the earlier researchers and have developed popular high yielding varieties but those varieties performance have been either stagnated or became susceptible to the new races of the pathogens. Therefore, continuous breeding efforts should be given either to improve the one or two weakness of the existing popular high yielding varieties or by developing new and efficient plant types genotypes which would have more input use efficiencies. Popularization of the hybrid pigeonpea would be another option to exploit the hybrid vigour of this crop to great extent. Development of super hybrids and to achieve this development of potential parental lines is a pre-requisite.

Conflict of interest: None.

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