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Research Review Article

Varietal improvement of pulse crops in India: Introspection and prospectives

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ABSTRACT

The work on crop improvement in India started in the beginning of the 20th century by the Imperial Agricultural Research Institute at Pusa, Bihar where germplasm samples of different pulse crops were collected, purified and evaluated. Some of the pure lines were released for cultivation. This work continued for several years. However, systematic efforts were made by Indian Council of Agricultural Research in collaboration with All India Coordinated Pulses Improvement Project (AICPIP) centres of State Agricultural Universities (SAUs). National Bureau of Plant Genetics Resources (NBPGR) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) also made significant contributions in collection of germplasm as well as their evaluation. The resistant donors were identified and used to transfer gene (s) for several biotic stresses. As a result, several high yielding varieties were developed in major pulses crops through intra-specific hybridization. Large numbers of these varieties are resistant to one or more major diseases of the zone. Six varieties in mungbean, two in blackgram and one in chickpea were developed through inter-specific hybridization which had new plant type and resistance to prevailant diseases. However, limited success has been achieved for the development of varieties with resistance to insect-pests and abiotic stresses. There is a need to intensify research in these areas through introgression of desirable alleles from secondary and tertiary genpool into the cultivated type for photo period and temperature insensivity and insect pest tolerance. The support of genomic resources may also be used in this endeavour.

Key words: Biotic and abiotic stresses, Genotyping, Genomic resources, Grain legumes, Interspecific hybridization, Phenotyping, Pre-breeding, Re-arrange

The grain legumes belong to the family leguminosae. The plants of this species have a group of bacteria, *Rhizobium* in their roots which are able to utilize atmospheric nitrogen by a process called symbiosis, which occurs in the root hairs. The dry seeds (whole or split) of some grain legumes are called pulse. The pulse crops occupy a unique position in the world agriculture by virtue of their higher (2 to 3 times) protein content (20 to 25%) than cereals and their capacity to fix atmospheric nitrogen. In the developed countries, grain legumes are important indirect source of protein being animal feeds of good biological value. However, for many developing countries, pulses constitute the cheap and readily available source of dietary protein.

In India, more than a dozen pulse crops are grown, which are integral part of cropping system and are of great significance in sustainability of largely cereal based agriculture. These are grown in pure culture as well as in mixed culture not only with cereals but with oilseeds and other crops. Pulses are important for the nutritional security of the cereal based vegetarian diet of large population. The leaves and green seeds/pods of some of the pulse crops are used as vegetable. Dry seed (whole or split) are consumed as *dahl* or used as flour (*besan*) for various food preparations. The stalks both green and dry are used as fodder. The seed coat and broken cotyledons are used as animal feed.

Production trends

Globally, pulse crops are grown in area of >76 m ha with a production of about 68 m tonnes. In India, the total pulse area is about 25 m ha which produces about 18 m tonnes. The average productivity at the global level is about 800 kg/ha and of India is >750 kg/ha. In 2013-14, the total area, production and average productivity of all pulse crops was 25.2 m ha, 19.3 m tonnes and 764 kg/ha respectively. The area of pulse crops has not increased much during the past 60-65 years, except in 2010s comprising the years 2010-11, 2011-12 and 2012-13 it showed an increase of 1.5 to 2.0 m ha (Fig 1). The total production of all the pulse crops has remained between 10 to 13 m tonnes. However, during the past 6 to 7 years, a significant increase in total production is observed. During this period, the average productivity has increased from 598 kg in 2005-06 to 789 kg/ha in 2012-13.

Among the pulse crops, chickpea, pigeonpea, mungbean, blackgram, lentil and field pea are considered as major pulse crops as these are widely grown. In 2013-

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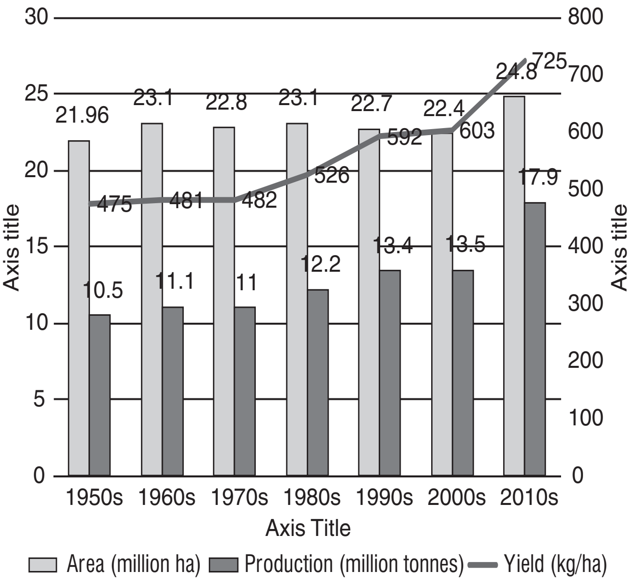

Fig 1 Decade wise area, production and yield of pulses in India

14, these crops were grown in an area of 22.5 m ha with the production of 18.0 m tonnes. The average productivity per ha was 800 kg. However, the other pulse crops including grass pea (lathyrus), moth bean, horsegram, rajmash, rice bean and adzuki bean contribute to 2.7 m ha area and about 1.3 m tonnes of production. The average productivity in 2013-14 was 481 kg/ha. These crops are not grown widely through out the country, however, are grown in some regions and in particular niches.

Chickpea (*Cicer arietinum* L.) also called Bengal gram is the most important and is grown in 11.55 m ha area with the production of 10.46 m tonnes (FAO 2010) in 45 countries of the Indian sub-continent, the Mediterranean region in West Asia and Nort Africa, East Africa and Latin America. Of these, a dozen countries, viz. India, Turkey, Pakistan, Iran, Mexico, Myanmar, Ethiopia, Australia, Spain, Canada, Syria and Morocco contribute to about 96% of the global production. In India, at present it is grown in all the states in 9.9 m ha which produces 9.5 m tonnes. The average yield is about 960 kg/ha. India is the largest producer of chickpea in the world: The states in order of their contribution to total chickpea production of the country are Madhya Pradesh> Rajasthan>Maharashtra> Andhra Pradesh> Uttar Pradesh. Between 1960s to 2010, the productivity has shown a linear increase which is due to the development of high yielding varieties with shorter duration and resistance to major diseases.

Field pea (*Pisum sativum* L.) is one of the earliest human foods. Its production ranks second amongst the cool season pulses in the world. It is grown in places with cool climate; hence it is grown in almost all the temperate regions of the world. In India, it is grown in the plains during winter months and in the hills during most part of the year except summer. It is grown to be used as dry seeds all over country for *dahl* and flour (*besan*) and also for green seeds used as fresh, frozen or canned vegetables mainly in northern parts of the country. Vegetative parts of garden pea types are used as green fodder and haulm of pulse types of fodder. It is grown on a wide variety of soil types ranging from light sandy to heavy clayey soils. In India, in 2013-14, field pea was grown in an area of 0.96 m ha with a production of 0.92 m tonne. The average yield of field pea was about 960 kg/ha. Between 1970s to 2010 there was a slow increase in both area and production of pea except in 1980s; a decrease was noted in area and production. However, the productivity in 1970s was only 634 kg/ha which has shown an increase of 210 kg/ha in 2010s. This increase could be ascribed to the development of disease resistant varieties with dwarf plant type. Important states which contribute to field pea area in the country are Uttar Pradesh, Madhya Pradesh and Jharkhand.

Lentil (*Lens culinaris* Medikus) is considered to be the oldest and most widely adapted pulse crop in the world and is grown on an area of about 4 m ha. Lentil is used primarily as human food and consumed in the form of whole/split seeds. In India in 2013-14, it was grown in an area of 1.34 m ha with a production of about 1.02 m tonnes. Its average productivity is 759 kg/ha. A significant increase in area, production and productivity of lentil is achieved. This is due to release of superior varieties with stable productivity. Important states of India which has made significant contribution to lentil area of the country are; Madhya Pradesh> Uttar Pradesh> Bihar > West Bengal and for production, important states in that order are; Uttar Pradesh > Madhya Pradesh > Bihar > West Bengal.

Pigeonpea or red gram (*Cajanus cajan* (L.) Millsp.) is very widely grown in the tropical and subtropical regions. Globally, it is grown on 4.5 m ha land in more than 20 countries with a production of 3 m tonnes (FAO 2011). It is grown in India and Myanmar in Asia, Uganda and Kenya in Africa, the West Indies, Puerto Rico and in the Dominican Republic in the Caribbean region, which are the major pigeonpea producing countries. Pigeonpea is consumed as human food in various forms but is mainly used as split *dahl*. Between 1970s and 2010s, the pigeonpea area and production has increased but the productivity has not increased. This trend is due to decrease in area of pigeonpea in Uttar Pradesh. This was occupied by long duration varieties which were also higher yielding. In 2013-13, it was grown in an area of about 4.0 m ha with an annual production of 3.17 m tonnes. The average productivity of this crop is 813 kg/ha. It appears to be better adapted to marginal climatic conditions than many other pulse crops.

Mungbean [*Vigna radiata* (L.) Wilczek] which is also known as green gram is cultivated most extensively in South East Asia, although production is found in Australia, Peru, Ecuador, USA, Kenya and Malawi and in local areas of many other Caribbean, African and Middle Eastern countries. However, about 85% of mungbean production is consumed in several countries of Asia and a variety of moisture in *rabi* in eastern and southern parts and in irrigated condition in spring/summer in food products is prepared. In India it is grown in different seasons; in rainfed condition in *kharif,* on residual north India. The area, production and yielding ability of mungbean has increased during the past 40 to 45 years which is due to the availability of early maturing varieties with resistance to diseases. India is the largest producer and consumer of mungbean. In 2013-14, it was grown in an area of 3.38 m ha with a production of 1.61 m tonnes. The average productivity of mungbean is 474 kg/ha. Important states that contribute to the total area and production of mungbean are; Rajasthan > Maharashtra > Andhra Pradesh.

Black gram or urdbean [*Vigna mungo* (L.) Hepper] is cultivated in different seasons in India. As a mixture it is grown in rainfed condition with cereals, pigeonpea etc. in *kharif* season, in irrigated condtion in *rabi* and spring/summer as pure crop. It is also grown on residual moisture in *rabi* in eastern and southern parts of country. Between 1970s and 2010s, in this crop an increase of >1.0 m ha area and > 1.0 m/tonnes of total production with an increase of 210 kg/ha in average productivity was achieved. In 2013-14, it was grown in 3.1 m ha area with a production of 1.7 m tonnes. Its average productivity is 556 kg/ha. Important states that contribute to the total area and production of blackgram are; Madhya Pradesh > Uttar Pradesh > Andhra Pradesh > Maharashtra.

The grass pea or *khesari* (*Lathyrus sativus* L) grows well on drought prone, poor soils where lentil and chickpea are not expected to give dependable yields. It is cultivated in central, south and east Europe. It is widely grown in India, Middle east and South America. In India, it is grown mainly as a *paira* crop in standing paddy, where it is sown as broadcast. In 2013-14, it was cultivated in an area of 0.40 m ha with a production of 0.29 m tonnes and average productivity is 707 kg/ha. Chattisgarh and Bihar are most important in area and production of *khesari*. Other states of lesser importance are Madhya Pradesh, West Bengal and Maharashtra.

Horse gram [*Macrotyloma uniflorum* (Lam.) Verdc.] is adapted in dryland areas of India, Australia, Myanmar, Sri Lanka, Malaya, Mauritius, Transvaal and West Indies. In India, it is grown in northern hills and in several central and southern states as pure crop as well as intercrop with cereals, groundnut and sesamum etc. in a small area of 0.21 m ha with a production of 0.12 m tonnes and the average productivity is 580 kg/ha. In *kharif* season Karnataka > Odisha > Maharashtra > Madhya Pradesh are important states both for total area and production. In *rabi* season, Karnataka, Tamil Nadu and Andhra Pradesh are important states for total acreage and production of this crop.

Moth bean [*Vigna aconitifolia* (Jacq.) Marechel] is grown in arid and semi-arid regions of India. It is a drought resistant crop. In India, it was grown in an area of 0.96 m ha in 2013-14. It is largely cultivated in *kharif* season in mixture with cereals like pearl-millet or sorghum. Rajasthan occupies most of the area of moth bean and also produces most. Two other states which also have some area are Gujarat and Maharashtra. The area, production and productivity of other minor pulses [like; rajmash (*Phaseolus vulgaris* L.), cowpea [*V. unguiculata* (L.) Walp.], rice bean [*V. umbellata* (Thunb.) Ohwi and Ohashi], adzuki bean [*V. angularis* (Willd.) Ohwi and Ohashi] and dolichos bean or field bean [*Lablab purpureus* (L.) Sweet] is together 0.87 m ha, 0.51 m tonnes and 491 kg/ha, respectively. In general, the area, production and productivity of all the minor pulse crops have shown a decreasing trend in past five years.

Search of useful genes and their deployment in pulse varieties

Collection of germplasm and their evaluation: In India, the work on collection of germplasm of pulse crops was taken up in the beginning of 20th century by Botanical Section of the Imperial Agricultural Research Institute at Pusa (Bihar). The germplasm of various types in different pulse crops were collected and purified as pure lines. This work continued for several years and resulted in the selection of superior genotypes in different crops. Some of the accessions were also lost during the evaluation process and remaining were tested over the years for various characteristics and some of these were released for commercial cultivation. Subsequently, the collection of land races and their purification work was taken up by economic botanists in different parts of country. However, systematic efforts were made after the establishment of the All India Coordinated Pulses Improvement Project (AICPIP) with its headquarter at IARI in 1966-67, later on, it was shifted to Kanpur. In 1970s, NBPGR and ICRISAT alongwith SAUs collected germpasm of various pulse crops. Prior to this, the germplasm explorations were taken up by IARI with the support of PL-480 project. The current status of global and national holding at NBPGR is presented in Table 1.

Table 1 Current status of germplasm resources at global and national level

Crop	Global holdings	National holdings at NBPGR (2014)		
		Indigenous	Exotic	Total
Chickpea	81000	11444	3133	14577
Pigeonpea	13777	10781^{+}(10)	309	11100
Mungbean	24918	3567	537	4104
Black gram	3767	3127 + (13)	6	3146
Lentil	10500	2076	613 (63)	2752
Peas	58266*	2677	1060	3737
Lathyrus	21652	2550	91	2641
Common bean	36016*	2130	1372	3502
Cowpea		2681	1094	3775
Cluster bean		4273	37	4310
Horse gram		3007 + (1)	11	3019
Rice bean		1883	179	2062
Lablab bean		1660	5	1665
Moth bean		1445	33	1488
Faba bean		508	367	875
Wild Vigna		490		490
Atylosia		20		20
Other pulses		326 + (6)		

Figures in parenthesis are number of accessions of wild species/relatives of indigenous germplasm. *Also includes vegetable types.

Some collections are also held at different AICPIP centres at SAUs in the country. IIPR, Kanpur has been identified as National site for maintenance of active/working collection of pulses.

Identification of donors against biotic stresses: An array of diseases (wilts, root rots, stem rots, downy mildews, powdery mildews, leaf spots, blights, rusts, mosaics and stunted growth resulting from attack by root knot nematodes) caused by fungi, bacteria, viruses and nematodes adversely affect the yielding potential of the pulse crops (Table 2). Some of these diseases, like Fusarium wilt (FW) in chickpea and pigeonpea, MYMV in mungbean and black gram are damaging these crops throughout the country. Similarly, the insect-pests like pod-borers damage chickpea and pigeonpea in the entire country. Storage grain pests cause damage to the grains of all pulse crops during storage. During the past, efforts were made for the morphological characterization of causal agents, understanding of the racial differences and stardardization of efficient and reliable screening techniques and identification of donors in pulse crops.

First published record on screening of pigeonpea genotypes in plots severely infected by the wilt fungus is by Butler in 1908 at Pusa. McRae and Shaw (1926) used susceptible variety as an indicator line after every test entry for selecting wilt resistant lines in wilt sick area. The diseased debris collected from the previous crop was buried between each row for creating the disease. Vaheeduddin and Nanjundiha (1956) created wilt sick plot for screening pigeonpea genotypes by spreading compost made of wilted plants. Later on these techniques were refined (Nene *et al*. 1981, Nene and Haware 1980). At ICRISAT, the greenhouse techniques were developed (Nene and Kannaiyan, 1982) and field screening methodology for SMD were also developed. The screening techniques to diseases of chickpea and pigeonpea have also been described in various publications of ICRISAT. The screening techniques of other crops have been developed by SAUs. Disease scoring system for foliar diseases has been standardized by pulse scientists in Annual Group Meetings of pulse crops and a scale of 1 to 9 (where =1 is free from disease and 9 is most susceptible) has been agreed and followed for scoring the disease reactions.At the hot spot natural screening (Table 3) was very effective and useful for screening large number of germplasm lines/cultivars including exotic and indigenous types. Exotic types including wild species/wild relatives have also been evaluated against important biotic stresses. At ICRISAT, chickpea and pigeonpea germplasm lines were screened. The percentage of pod damage was scored on 1-9 scale. Verulkar *et al*. (1997) used dual choice arena test to assess antixenosis mechanism of resistance in pigeonpea to *H. armigera.* The IIPR has screened large collections of pigeonpea to pod-fly. At PAU, entire indigenous collections of mungbean were screened to white fly. Other SAUs have made sporadic attempts to screen germplasm lines of pulse crops against insect-pests important in their area of jurisdiction. Sources of resistance to important insect-pest like; pod-borers, bruchids and root knot nematodes in chickpea; pod-borers, pulse beetle, reniform nematode and cyst nematodes in pigeonpea, leaf miners in peas; pod borers, bruchids and aphids in lentil and white fly in mungbean have been reported by various workers and have been compiled by Singh (2014).

Table 2 Some of the important biotic stresses identified in major pulse crops of India

Crop	Season(s)/niches	Stress
Chickpea	Timely sown	Fusarium wilt (FW), root rot, chickpea stunt, botrytis gray mould, pod-borer
	Late sown	FW, root rot, *Ascochyta* blight or chickpea stunt, pod borer
Lentil		FW, root rot, rust
Pea		Powdery mildew (PM), rust, leaf miner, stem fly
Pigeonpea	*Kharif*: Early Medium/late	FW, *Phytophthora* blight, pod-borers
	Pre-*rabi*	FW, sterility mosaic disease, pod-borers
		FW, Alternaria leaf blight, pod-fly
Mungbean	*Kharif*	Mungbean yellow mosaic virus (MYMV), cercospora leaf spot (CLS), web blight, defoliators, sucking insect-pests.
	Zaid (spring/ summer)	MYMV, root and stem rot
	Rabi	PM, rust, CLS
Blackgram	*Kharif*	MYMV, anthracnose, web blight, leaf crinkle virus, sucking insect-pests and defoliators
	Zaid (spring/ summer)	MYMV, root and stem rot, stem agromyza
	Rabi/rice fallow	PM, rust, Corynespora leaf spot

After such evaluations, the donors were identified and used for transferring the gene(s) to the biotic stresses. Donors were also identified to have genes for resistance to two or more biotic stresses (Singh 1981, NBPGR 1987, Nene 1988, Singh 1995, 2000, 2014; Ahlawat *et al.* 2005, Tickoo *et al*. 2005 and Pande *et al.* 2013) in indigenous and wild type and have been used to develop varieties with multiple resistances to biotic stresses.

Identification of germplasm against abiotic stresses: Pulse crops are grown on marginal lands under rainfed agriculture, hence are prone to abiotic stresses. The abiotic stresses are required to be tackled together with biotic stresses. Some of these stresses have been identified crop-wise for different seasons/niches (Table 4). The pulse crops are sensitive to temperature stress especially at full bloom stage and exposure to high temperature and moisture stresses which are responsible to heavy yield reductions. Winter pulses; like chickpea, lentil and fieldpea are often prone to two types of drought, i.e. intermittent and terminal. Pigeonpea is very sensitive to waterlogging at seedling stage in all maturity groups (early, medium and late) and to

Table 3 AICPIP centres used as hot spots for the screening of germplasm against important diseases of major pulse crops

Crop/Disease	Hot spots used for screening
Chickpea	IIPR (Kanpur), IARI (Delhi), ICRISAT (Hyderabad), MPKV (Rahuri)
Fusarium wilt	JNKVV (Jabalpur), UAS (Bangalore), SKRAU (Durgapura)
Dry root rot	JNKVV (Jabalpur)
Collor rot	GBPUAT (Pantnagar)
Botrytis gray mould	PAU (Ludhiana)
Ascochyta blight	
Pigeonpea	
Fusarim wilt	IIPR (Kanpur), UAS (Raichur), RAS Badnapur (MPAU, Parbhani), ICRISAT (Hyderabad), CSAUT (Kanpur)
Phytophthora blight	GBPUAT (Pantnagar)
Sterility mosaic disease	IIPR (Kanpur), NDUAT (Faizabad), BHU (Varanasi), RAU (Pusa), ICRISAT (Hyderabad)
Mungbean and blackgram	GBPUAT (Pantnagar), CCS HAU (Hisar)
	IARI (New Delhi), IIPR (Kanpur)
Mungbean yellow mosaic virus	HPKVV (Dhaulakuan), TNAU (Coimbatore), ANGARU (Hyderabad)
Powdery mildew	ANGARU (Lam centre), IGKV (Raipur), BARC (Trombay), UAS (Dharwar), TNAU (Coimbatore)
Lentil	RSKVV (Sehore), IARI (New Delhi)
Fusarium wilt	
Rust	GBPUAT (Pantnagar), IIPR (Kanpur)
	BHU (Varanasi), NDUAT (Faizabad), HPKVV (Dhaulakuan)
Peas	
Powdery mildew	CSAUT (Kanpur), IARI (New Delhi), GBPUAT (Pantnagar), BHU (Varanasi)
Rust	GBPUAT (Pantnagar), BHU (Varanasi), HPKVV (Dhalakuan)

Table 4 Some of the important abiotic stresses identified in major pulse crops (after, Singh 2000)

Crop	Season/niches	Abiotic stress identified
Chickpea	Timely sown	Low temperature
	Late sown	Terminal drought, salt stress,high temperature
Lentil		Terminal drought, heat stress
Pea		Terminal drought, heat stress
Pigeonpea	*Kharif*-Early medium and late	Water logging, sensitivity to photo-period and temperature
	Pre-*rabi*	Cold stress, terminal drought
		Cold stress, terminal drought
Mungbean	*Kharif*	Pre-harvest sprouting, terminal drought
	Zaid (spring/summer)	Pre-harvest sprouting, temperature stress and drought stress, sensitivity to photoperiod and temperature, terminal drought
	Rabi	
Blackgram	*Kharif*	Terminal drought, sensitivity to photoperiod and temperature,
	*Zaid (*spring/summer*)*	pre-harvest sprouting
	Rabi	Temperature stress, drought stress
	Rice fallows	Terminal drought

low or high temperature stress at reproductive stage in medium and late maturity groups. Low temperature is detrimental for germination of mungbean and blackgram in spring season in north India where as heat and drought stresses cause adverse effect at reproductive stage.High sensitivity to photoperiod and temperature is another major bottleneck in realizing the yield potential and predicting desired harvest index in most of the legumes

Long term field observations on pulses, indicated that reproductive parts and grain filling process are extremely sensitive to temperature extremities. When high temperature is superimposed with drought, the productivity further goes down (Basu *et al.* 2009). Pigeonpea, in particular, is highly sensitive to temperature fluctuations, causing massive flower drop, forced drying and bending of apical leaves when subjected to cold stress (<5^0C) (Basu *et al.* 2009). In mungbean, temperature > 42^0C during summer, causes seed hardening due to incomplete sink development. Lentil and chickpea showed retarded growth at <7^0C. Day time maximum temperature at > 40^0C during reproductive phase in winter pulses results in complete failure of anthesis, pod setting and induces hardening of seeds. Pollen germination, stigma receptivity, pollen load on stigma and ovule viability starts decreasing above 35^0C (Basu *et al.* 2009). Fieldpea is even more sensitive to high temperature than chickpea and lentil. While, short duration varieties growing in central and south zones do not encounter such contrasting temperatures. Short duration large seeded chickpea genotypes, e.g. ICC 4958, Phule G-5 bred at warmer south zone have high biomass and deep root system compared to the medium to late maturing chickpea genotypes; KWR 108, C235 and Pant G 114 bred in the northern plains (Basu *et al*. 2014). The studies conducted at IIPR, Kanpur on chickpea revealed differences in photosynthesis and damage of photosynthetic system in intact leaves of contrasting genotypes. The fluorescence images of heat sensitive genotype ICC-10685 showed complete inhibition of photosynthesis at 43^{0}C. The heat tolerant genotype, ICCV 92944 showed reduced photosynthesis but leaf remained photosynthetically active even at 43^{0}C. Similarly, the heat tolerant genotype ICCV 92944 showed the lowest membrane injury when subjected to high temperature. The pollen of heat tolerant genotype, (ICCV 92944) was viable at 35/20^{0}C (41% fertile) and at 40/25^{0}C (13% fertile), however the pollen of heat sensitive genotype (ICC 5912) was completely sterile at 35/20^{0}C with no in vitro germination and no germination on the stigma. The stigma of the sensitive genotype (ICC 5912) remained receptive at 35/ 20^{0}C and non-stressed pollen (27/16^{0}C) germinated on it during reciprocal crossing. This data indicated that the pollen grains were more sensitive to high temperature than the stigma in chickpea. Both anthers and pollen showed more structural abnormalities under stress including changes in anther locule number, anther epidermis wall thickening and pollen sterility, rather than function (e.g. *in vivo* pollen tube growth).

Delayed sowing synchronizing with the reproductive phase of the crop with the occurrence of higher temperature (>35^{0}C) was proposed for heat tolerance screening in chickpea (Gaur *et al.* 2007). A screening of 180 genotypes at ICRISAT and IIPR during 2007 showed significant variations for heat tolerance index (HTI) in chickpea (Krishnamurthy *et al.* 2011). The genotypes that showed high heat tolerance over best check cultivar, ICCV 92944 included; ICCV 07104, ICCV 07105, ICCV 07110 and ICCV 07115. A heat tolerant variety, JG 14 has been released for late sown condition of central India (Gaur *et al*. 2010). Based on delayed sowing in order to expose reproductive phase to high temperature under irrigated conditions in field at > 37^{0}C, three genotypes of lentil, IG 4258, FLIP 2009-55L and IG 2507 were identified as heat tolerant (Kumar *et al.* 2014).

High degree of pollen sterility was observed in pigeonpea at temperature >38^{0}C. Similarly frost and low temperature cause significant damage to the pigeonpea crop. One hundred fifty minicore collections of pigeonpea including, 85 medium and long duration lines and 35 early duration lines were tested at different hot spots (Ludhiana, Kanpur, Badnapur, Khargone and Gulbarga) under NICRA project. Phenotyping for high temperature tolerance was developed based upon variable fluorescence and imaging. These tolerant genotypes were WRP 1, JKM 7, ICP 8700, JKM 189, MAL 13, ICP 995, BSMR 736 and NDA 1. The derivatives of *C. scarabaeoides* which flowered and set pods at 40/20^{0}C max/min temperature and low soil moisture were identified. Therefore, combined tolerance such as foliar resistance based upon variable fluorescence and reproductive tolerance, e.g. pollen viability and *insitu* germination proved useful criteria for selection. Photo-insensitive and thermotolerance mungbean genotypes setting pods at 43/25^{0}C max/min temperature and 11 and 16h daylength were identified. These genotypes IPM 02-3, MH 3-18, Ganga 8, ML 1257, Copergaon, HUM 1 were superopr in comparison to sensitive line LM 95. *Vigna* accessions were evaluated and characterized based on 37 morpho-physiological traits. Two extra early genotypes; IPM 409-4 (INGR 11044) and IPM 205-7 (INGR 11043) of mungbean have been developed. These genotypes are useful for summer cultivation and ideal for intercropping in crops like sugarcane that can avoid terminal heat stress (Pratap *et al*. 2013).

Biomass has been found to be the most sensitive to water stress. The leaf expansion is affected even under mild water stress with a leaf water potential declined to < 1.2 MPa. The biomass showed a linear relationship with yield under rainfed indicating source (leaves and stems) are the major limiting factor for low yield. Field screening for drought tolerance is largely based upon drought susceptibility index and was utilized in the AICPIP for identification of drought tolerance. The genotypes which showed low yield relative to its rainfed counter part, had higher drought susceptibility index (DSI). The lower the DSI, the greater was the drought tolerance of the line. Matching phenology and early biomass accumulation, dehydration postponement, root characteristic, osmotic adjustment, lethal leaf water potential, membrance stability, proline accumulation, water use efficiency are some of the potential traits identified for selecting drought tolerant lines in pulse crops.

The degree of osmotic adjustment (OA) has also been shown to be correlated with yield under dry land conditions in pulses. The OA maintains stomatal conductance and photosynthesis at low leaf water potential, delays leaf senescence, reduces flower abortion and improves root growth and water extraction from the soil (Basu *et al*. 2007).

The development of mungbean genotypes with drought and salinity tolerance, can retain large number of flowers with productive pods during high temperature (>40^{0}C) are prerequisite to increase mungbean production in India (Singh and Singh 2011). Under ICAR sponsored programme on National Initiative on Climate Resilient Agriculture (NICRA) funded projects, a large number of genotypes of pulse crops have been identified based upon multilocation trials and controlled environments showing tolerance to drought, heat, water-logging, frost and insensitive to photo-thermo periods. The drought tolerant genotypes identified in chickpea are; RSG 888, Phule G 5, BGD 72, Vijay, PG 96006, ICC 4958, Tyson, Katila, and K 850 (Basu *et al*. 2007).

Similarly, thermotolerant and photoinsensitive genotypes identified in blackgram are; PGRU 95016, IPU 99-89, IPU 94-1, IPU 99-79, BGP-247, Pant Urd 31 and thermotolerant genotypes in greengram are; IPM 02-3, IPM 02-10 and Pant M -5. Some accessions of *C. scarabaeoides.* Out of 50 pigeonpea genotypes from ICRISAT evaluated at Ludhiana, Kanpur, Khargone, Badnapur and Gulberga, the cultivars/lines, BDN 2008-1, Bennur Local, ICP 1156, BDN -2008-12, TJT 501, GRG 2009, ICP 995, ICP 4575 and ICP 14832 appeared superior at pod filling stage under rainfed condition .

Pigeonpea cultivar ICPL 84023 and Asha are reported to be tolerant to waterlogging and this was due to development of lenticel and more root biomass and adventitious roots (Sarode *et al.* 2007, whereas LRG 30, ICPL 85063 and ICPL 332 showed tolerance to drought due to high RWC, pods/plant and HI, osmotic adjustment (Reddy 2011). At low temperature, pigeonpea cultivar IPA 7-2, Bahar, MAL 19 and Narendra Arhar 1 showed ability to flower and pod set (Singh *et al.* 1997, Singh and Singh 2010). C 11, ICPL 227, WRP 1, GS 1, TS 3, UPAS 120 and ICPL 151 showed tolerance to salinity due to reduced translocation of Na and Cl from root to shoot (Chauhan, 1987, Subbarao *et al.* 1991) and cv. IPA7-10, Type 7, 67 B and GT 101 E showed tolerance to Al-toxicity throught Al exclusion.

Waterlogging affects plant growth by reducing oxygen diffusion rate between soil and atmosphere and by changing physical and chemical properties of soil. Five pigeonpea lines, namely , IPAC 79, Narendra Arhar 1, IPAC 42, IPAC 76 and LRG 30 showed relative tolerance against waterlogging in the initial growth stage as compared to sensitive genotype ICPL 7035 (NICRA 2013).

Selection of useful genes from the germplasm

Selection from germplasm (indigenous and exotic) as well as from land races has played an important role in the development of superior cultivars of pulse crops. Before 1950, virtually all the varieties were developed by selection of superior genotypes from the samples of local cultivar. Some of the varieties were also developed from the exotic materials. From the indigenous cultivars as well as from the exotic cultivars (introduced through NBPGR) the desirable plants were selected and after their progeny testing, the superior pure lines were establised. The pure lines were evaluated for yield, yield traits and for reaction to diseases and the best pure line was released for cultivation. This practice has continued even after the establishment of AICPIP in 1966-67 (Table 5).

Table 5 Methods of breeding used for the development of higher yielding varieties in different pulse crops between years 1967 to 2013 in India

Crop	Variety developed			Total
	Selection	Hybridization	Mutation	
Chickpea	40	134	15	189
Pigeonpea	54	62	5	121
Mungbean	37	69	12	118
Blackgram	35	36	7	78
Lentil	14	24	2	40
Fieldpea	11	34	1	46
Grasspea	3	2	-	5
Mothbean	8	1	6	15
Cowpea	8	2	3	13
Horsegram	12	3	1	16
Total	222	367	52	641

Some of the important chickpea varieties developed through selection and released for cultivation are C 235, G 24, S 26, C 104, Type 1, Type 2, Type 3, Gwalior, Ujjain 21, Chaffa, Annegeri 1, Co 1, RS 10, ST 4, BR 75, BR 77, GNG 146, Jyoti and JG 315. Some of these were cultivated for several years, as they possessed genes for tolerance to important biotic and abiotic stresses. JG 315 was resistant to wilt, GNG 146 was resistant to root rot, C 104 and Annegiri were resistant to *Fusarium* wilt. C 104 was also resistant to root rot. RS 10 and CO 1 were drought tolerant. C 235 was widely adapted. A bruchid resistant variety, G 109 1 was selected from an exotic material from Turkey (Saxena and Raina 1970).

The earliest work on selection in pigeonpea for wilt resistance in India was started in 1905 at Pune (Maharashtra) (Butler 1908); in 1917 at Hebbal (Karnataka) and in 1932 at Kanpur. Subsequently, superior selections were made from land races as well as from exotic materials introduced through NBPGR. Some of the very old varieties of pigeonpea developed in different states of India are; Type 7, Type 66 K (UP), RG 37, RG 72 (AP), SA 1 (TN), Type 16, Type 41, and Type 51 (Karnataka), Vijayapa 49 (Gujarat) and B 7 (WB). Of these, Type 7 was widely cultivated in UP, Bihar and MP Later on several other varieties were released. Some of these were not only high yielding but were widely adapted like; UPAS 120, Type 7 and Narendra Arhar 1 as they had genes for resistance to atleast one of major diseases of pigeonpea like; Narendra Arhar 1 was resistant to sterility mosaic and *Fusarium* wilt, BDN 1 and BDN 2 from Maharashtra and C 11 from Andhra Pradesh were resistant to Fusarium wilt. Bahar from Bihar was resistant to sterility mosaic. It was of medium maturity duration variety. UPAS 120 developed for arhar-wheat rotation. It was very popular in Haryana and western UP.

The breeding work on mungbean started in India through selection in early part of 20th century at Pusa (Bihar). Selection from local and exotic germplasm/cultivars has made notable contributions in mungbean improvement from 1930 to 1970. Several pure lines were released from different states of India. Some of the old varieties which were popular with the farmers and were used by plant breeders as a base material for further improvement through crossing. Type 1 was a selection from Muzaffarpur (Bihar). It was released in 1936 in UP. Moong 54 and Moong 305 were the product of selection from local mixtures in Punjab and released in 1947. Co 1, a selection from local germplasm was released in Tamil Nadu in 1952. In Maharashtra, Kopergaon, a selection from local germplam was released in 1956 and Jalgaon 781 a selection from China Mung was released in 1957. In Madhya Pradesh, Khargone 1, a selection from UP local, K 119-56 and Krishna 11 selections from local materials of Gwalior were released in 1961. Gujarat 1 and Gujarat 2 were important pure lines released in Gujarat State. Shining Mung 1 and PS 16 were developed through selection from the materials introduced from China and Iran, respectively. Pusa Baisakhi was a selection from a popular variety, Type 44, already released in UP. All of these varieties were of early duration and had genes for wide adaptation and desirable seed traits. Some of these pure lines were also tolerant to diseases for instance, Gujarat 1 is tolerant to cercospora leaf spot (CLS) and PS 16 was resistant to both MYMV and powdery mildew (PM). Several cultivars were introduced through NBPGR from AVRDC, Taiwan and some these, after selections were released as varieties. These are Pusa 9531, Pusa Vishal, Pusa 101, Pusa 105, SML 668, SML 134 and Pant Mung 5. All of these varieties are large seeded.

In case of black gram, systematic collection of land races followed by selection of pure lines was taken up in the early part of 20th century. Several varieties developed through pure line selection were released in different states for cultivation. For example, Type 9 was selected from Bareilly local and was released in 1948. It had maturity duration of 80-90 days and had semi-spreading growth habit and medium seed size. This was preferred by farmers due to these traits. Other notable varieties developed through selection from local materials were, Type 27, Type 65, Type 77, BR 68, BR 76 and Gwalior 2. These were indeterminate and spreading type suitable for intercropping. Type 65, Type 77 and BR 76 had green seeds.

The earliest varieties of lentil developed through selection from local germplasm are; Type 8, Type 36, BR 35, BR 77, NP 11, NP 47 and were cultivated in UP, Bihar and West Bengal. After the establishment of AICPIP in 1966-67, selection of pure lines from land races continued and some of the important varieties are; Pant L 406 and K 75 (Malika) developed in UP and released in 1979 and 1986, respectively and L 9-12 developed in Punjab. These varieties were widely cultivated in all the lentil growing areas. This was because these varieties had genes for wide adaptation. Pant L 406 was selected from P 495. It was small seeded variety with resistance to rust and wilt diseases. K 75 (Malika), a selection from local material of Bundelkhand was preferred due to its seed size (2.7 g/100 seeds). In some lentil growing areas, VL Masoor 1 a selection from Almora land race was tolerant to rust and wilt diseases. It was a popular variety in the hill region of Uttarakhand, due to its small black seeds. These seed traits are preferred in this region.

Several high yielding varieties of field pea in India have been developed by pure line selection from land races. Type 163, a high yielding variety with large white seeds was selected from a sample of Bulandshahr in UP, which was a ruling variety of field pea for several years in the country. In Bihar, BR-2, a purple flowered type was selected from local germplasm was suitable for hilly areas of that state. In Maharashtra, Khaparkheda No. 23 and No. 43, the white seeded types were selected from local germplasm. In West Bengal, BR-22 and in Rajasthan, RP-3 and in Himachal Pradesh Kinnauri were selected from local germplasm/land race(s). Harbhajan is a selection made at IARI from an exotic material. Between year 1967-2013, 11 higher yielding varieties were released from local materials. These varieties had characteristics required by the local farmers.

Selection of superior pure lines from indigenous germplasm as well as from exotic materials have also been used by plant breeders to develop superior varieties in minor pulse crops, viz. grass pea, moth bean, cowpea and horse gram etc (Table 5). A grass pea variety Bio L 212 is a somaclone of P 24. It has low ODAP content. Of the 14 varieties of moth bean released so far eight are selections from local germplasm. Similarly of the 16 varieties of horse gram released so far 12 are developed through selection. Some of these are resistant to anthracnose disease. VLG 8 is moderately resistant to yellow mosaic virus and powdery mildew diseases. VL Rajmash 63 is an old variety of Rajmash released for cultivation in the hills of Uttarakhand in 1978 for *kharif* season. Five other varieties of Rajmash were also developed through selection for *rabi* season. All of these are tolerant to bean common mosaic virus (BCMV). In cowpea also eight of the 13 varieties were produced using selection as a method of breeding. Some of these varieties were resistant to foliar diseases and were also tolerant to drought.

Genetic studies

Genetics of morphological characters: The available information pertaining to the inheritance of various morphological characters in the pulse crops cultivated in India have been compiled in several reviews in the form of books published by IIPR, Kanpur and ICRISAT, Hyderabad and by Singh (2014) in his recent book "Genetics and Breeding of Pulse Crops". Shaw and Khan (1931) were the first to study on inheritance of flowers per pedical in chickpea. Inheritance studies have been conducted on morphological traits including; plumule emergence, growth habit, thick stem, branching habit, fasciation of stem, leaf types, foliage colour, flowers colour, flowers/pedical, seed type, seed surface, seed coat colour and root nodulation in chickpea. In general, these characters are governed by a recessive/dominant gene. Seed type (*desi* and *kabuli*) was controlled by few major genes; *desi* is dominant over *kabuli* type. There are few reports on the linkage relationships of morphological traits.

Shaw (1933) was the first to report inheritance of inflorescence (condensed or scattered) in pigeonpea. The characters were governed by a single dominant gene. Since then several reports have been published on the inheritance of morphological traits, which are compiled by ICRISAT and IIPR. Singh (2014) in his book compiled inheritance of qualitative traits including, plant height, stem colour, leaf shape and size, inflorescence type, flower colour, pod pubescence, pod colour, seed coat colour and seed strophiole. The inheritance of these traits was monogenic recessive or dominant except of flower, pod and seed colour which are due to digenic interactions. Linkage studies showed tight linkage between flower and seed colour traits.

In case of mung bean and black gram, several research papers have been published. However, first cross was made in 1932 at Pusa to study inheritance of colour of ripe pods and seed coat surface in mungbean (Bose 1939). He reported that colour of unripe pod is due to the same gene responsible for flower colour. Since then attempts were made to compile the inheritance of morphological traits including plant type , plant colour, leaf type, flower colour, inflorescence type, pod pubescence, pod shape, pod colour, shattering habit, seed coat colour, seed coat surface, hard-seededness in these crops (Singh 1982, Singh 2014). In general, these characters were governed by a single gene except seed colour which was conditioned by two independent genes. Linkage of seed coat colour and pod colour were established in both the crops.

In India, hybridization was attempted in lentil crop in 1970s. This was due to difficulty in making crosses as the flowers are small and fragile. The published information on inheritance studies was compiled by Singh (1991), Tickko *et al.* (2005) and Singh (2014). These publications reported inheritance of growth habit, cotyledon colour, leaves vs tendrils, fasciation of stem and branches, flower colour, flowers/inflorescence, peduncle length, pod dehiscence, pod size, seed size, seed coat colour and coloration pattern and globe mutant. All these traits are inherited as monogenic, except flower colour which showed dihybrid segregation (9: 3: 3: 1). The cytoplasmic male sterility was governed by a single recessive gene.

In India, only few studies on inheritance of morphological traits have been conducted including those on plant and leaf surface, leaf shape and size, flower colour, pod surface, pod shape, seed surface, hilum colour and male sterility in field pea (Singh 2014). All of these traits are governed by a single gene (dominant or recessive or incompletely dominant).

Genetics of quantitative characters: A major aspect of genetic studies of quantitative traits in pulse crops has been an analysis of the genetics of economically important characters such as grain yield, yield traits and protein content etc. As expected these characters have largely been handled as polygenically controlled characters and analysed using various biometrical approaches (Ramanujam 1983). The major approaches used in the genetic analyses have been the diallel crosses. Limited use has also been made of the line x tester approach. In some cases first degree statistics such as generation mean analysis have also been used. Many of these studies have been based on limited number of parents usually adapted varieties selected for grain yield and materials were often grown out in single year environment (Singh 2014). Therefore, the results of such studies have limitations. Broadly however, the analyses generally indicated that characters such as seed yield, pod/plant and branches/plant, bunches/plant etc had either predominantly non-additive or in predominance of additive effects or equal contribution of both additive and non-additive genetic effects. Based on combining ability studies, good general combiners were identified for different yield traits. The studies of heterosis, inbreeding depression as well as association analysis attempts were made to identify parents (Singh 2014). The donors/parents were used in the on-going hybridization programme which has helped in genetic enhancement of the old varieties and the release of newer varieties with high yielding ability as well as with stable yields.

Genetics of resistance to diseases: The inheritance of resistance to important pathogens in major pulse crops of India has been studied. The first report on inheritance of resistance was published in wilt of pigeonpea by Pal (1934) followed by a report in wilt of chickpea by Ayyar and Iyer (1936). After the publication of these reports in thirties, virtually very little work on this aspect was carried forward. However, several studies have been conducted in 1970s onward (Singh 2014). The inheritance studies conducted on fungal diseases, viz *Fusarium* wilt, dry root rot, botrytis gray mould and Ascochyta blight in chickpea, *Fusarium* wilt, *Phytophthora* blight and *Alternaria* blight in pigeonpea; rust and powdery mildew in field pea; *Fusarium* wilt and rust in lentil, anthracnose in black gram and *Cercospora* leaf spot in mungbean (Table 6). In general, resistance is governed by a single gene, dominant/recessive or incompletely dominant. However, resistance to wilt of chickpea was also due to digenic recessive or digenic interaction (Upadhyaya *et al.* 1983 b). The wilt of pigenopea is also reported to be due to under multiple genetic controls (Pal 1934). The inheritances of resistance to viral diseases have been presented in (Table 7). The inheritance studies have been conducted on viral diseases like MYMV in blackgram and mungbeen and SMD in pigeonpea and on bacterial pustule in mungbean. Resistance to viral diseases, MYMV in *Vigna* species and SMD in pigeonpea are governed by two recessive genes, however, in few cases resistance is also due to a single dominant/recessive gene. The bacterial pustule in mungbean is due to a dominant gene. The discordance in the nature of inheritance could be ascribed to racial differences in these studies. The allelic relationships have been studied in case of MYMV and SMD only.

Resistance lines of mungbean, Tarai local, L 80, LM 214 and LM 294-1 had non-allelic genes for resistance to MYMV (Shukla and Pandya 1985). The resistance donors to MYMV in black gram (Pant U 84 and UPU 2) had the same gene(s) for resistance (Verma and Singh 1986). P 7, P 27, P 103 and P 115 carried a single dominant non-allelic resistance gene to leaf spot (*C. truncatum*) (Kaushal and Singh 1988). Resistance to Fusarium wilt of chickpea in CPS-1 and WR 315 was conferred by a single recessive allele at the same locus (Kumar and Haware 1982). K 850 also carried a recessive allele for resistance but a locus

Table 6 Inheritance of resistance to fungal diseases in pulse crops (after, Singh 1995)

Crop/Disease	Inheritance	Reference(s)
Chickpea	Monogenic incomplete dominant	Ayyar and Iyer (1936)
Fusarium wilt	Monogenic recessive	
(*F. oxysiporum* f. sp. *ciceri*)	Early wilting dominant to late wilting	Pathak *et al.* (1975), Kumar and Hwaare (1982)
	Digenic recessive	Singh *et al.* (1987)
	Late wilting monogenic recessive (h_1 or h_2)	Upadhyaya *et al.* (1983a)
	Monogenic dominant	Upadhyaya *et al.*(1983 b)
		Smithson *et al.* (1983)
Dry root rot	Monogenic dominant and gene for resistance	Ananda Rao and Haware (1987)
(*Rhizoctonia bataticola)*	in ICCL 87322 and ICC 10302 is different	Singh and Singh (2007)
Botrytis gray mould	from gene in ICC 1069	
(*B. cinerea*)		
Ascochyta blight	Monogenic dominant (Rar 2)/ recessive (rar 1)	Hafiz and Ashraf (1953),
(*A. rabiei*)		Grewal and Gupta (1975),
		Singh and Reddy (1983)
Pigeonpea		
Fusarium wilt	Multiple genetic control	Pal (1934)
(F. udum)	Digenic complementary	Shaw (1936 a; b),
	Monogenic dominant	Pathak (1970)
	One dominant and one recessive gene	Joshi (1957)
		Saxena *et al*. (2012)
Phytophthora blight	Monogenic dominant (Pd 1)	Sharma *et al.* (1982),
(P. cajani)	Two homozygous recessive genes	Ahlawat *et al.* (2005)
	(pdr_1 pdr_1 pdr_2 pdr_2) in KPBR 80-1-1 and	
	KPBR 80-2-2 while in Hyb 3 C and BDN 1	
	it is a monogenic recessive (pdr_1 pdr_1)	
	Monogenic recessive (al 1)	
Alternaria leaf spot	Monogenic dominant	Singh *et al.* (1988),
(*A. tenuissima*)		Ojha *et al*.(1993)
Pea	Tolerance was governed by a single	Pal *et al.* (1979), Katiyar and Ram (1987),
Rust *(Urornycis fabac)*	recessive gene.	Chawda and Singh (2006)
Powdery mildew *(Erysiphe pisi)*	Monogenic recessive	Saxena *et al.* (1975), Narsinghani *et al.* (1979)
	Digenic recessive	Ram *et al.* (1981), Kumar and Singh (1981),
		Sohi *et al.* (1974),
Lentil	Two complementary genes (9:7)	Kannaiyan and Nene (1976)
Fusarium wilt		
(F. oxysporum f. sp. *Lentis)*	Monogenic dominant	Sinha and Yadav (1989), Singh and Singh
(Uromyces fabae)		(1990), Lal *et al.* (1996)
Blackgram	Monogenic dominant	Kaushal and Singh (1988)
Anthracnose	Digenic interaction	Kaushal and Singh (1988)
(Colletotrichum truncatum)		
Mungbean		
Cercospora leaf spot	Monogenic dominant	Thakur *et al.* (1977 a; b),
(Cereospora spp.*)*	Monogenic recessive	Thakur *et al.* (1980), Mishra *et al.* (1988),
		Singh *et al.* (2008)

different from and independent of that carried by C 104. The recessive alleles at both loci together confer complete resistance (Smithsom *et al.* 1983). It will be desirable to conduct more studies on the allelic relationships of resistant genes in pulse crops.

The studies on linkage of resistant gene(s) with other morphological characters are helpful in the selection of desirable segregants. The wilt reaction segregated independently of flower colour and number of flowers/fruiting node in chickpea (Singh *et al.* 1988). Resistance to wilt in pigeonpea was inherited independently of vegetative and reproductive morphology (Shaw 1936 a, b). A gene for corcospora leaf spot was independently inherited with that of pigmentation (Thakur *et al*. 1977a).

Genetics of resistance to insect-pests: Several insect-pests cause severe damage to pulse crops, however, less attention is given to investigate the mode of inheritance of resistance to the insect pests (Table 8). Pod borer

Table 7 Inheritance of resistance to viral and bacterial diseases in pulse crops (Singh 1995)

Crop disease	Inheritance	References
Blackgram	Digenic recessive	Singh (1980), Solanki *et al.* (1982), Verma and Singh (1989)
Mungbean yellow mosaic	Digenic recessive (ymv_1 ymv_2)	Dwivedi and Singh (1985)
virus (MYMV)	Non- allelic genes of resistance	Verma *et al.* (1978)
Mungbean		
MYMV	Tolerance : Monogenic recessive (v)	Singh and Patel (1975)
	one gene, F_1 intermediate	Singh and Patel (1977)
	Resistance : Digenic recessive with	Thakur *et al.* (1977a)
	epistatic effects	Shukla *et al.* (1978)
	Digenic recessive	
Bacterial pustute	Monogenic dominant (B)	Thakur *et al.* (1977a),
(*Xanthomonas phaseoli)*	redesignated as Bls	Singh and Patel (1975)
Pigeonpea		
Sterility mosaic disease (SM)	More than two recessive alleles at two loci	Sharma *et al.* (1984)
	Resistance was governed by either one or both of the two genes in homozygous recessive form.	Singh *et al.* (1991)
	Digenic complementary genes	Srinivas *et al.* (1997), Singh *et al.* (1984),
	Monogenic ecessive/dominant	Singh *et al.* (2003)
	Non-allelic genes are reported to SMD	Singh and Singh (1997), Singh and Dhar (1997)

(*Helicoverpa armigera*) is a very destructive and pod fly (*Melanagromyza obtusa*) also causes considerable losses in pigeonpea. Both of these insects damage the pods of pigeonpea. The wild species, *Cajanus scarabaeoides* is resistant to both of these insects. The antibiosis (*antixenosis*) to pod borer in JM 4147 accession of the wild species is governed by a single dominant gene and the resistance to pod fly in this accession is due to two recessive, genes (Verulkar *et al.* 1997). The bruchids (*Callosobruchus chinensis*) damage the pulse crops. Resistance to bruchids in mungbean is dominant and is governed by few major genes (probably two) with some modifiers (Sarkar and Bhattacharya 2014).

Genetics of resistance to abiotic stresses: Several abiotic stresses cause negative effect on the yielding ability of pulse crops (Singh 2000). Sources of resistance have been identified in major crops; however, no detailed genetic study is reported. Some preliminary observations have been made. For ready reference the important stress (es) in chickpea are; temperature and/or salt stress; in lentil moisture/temperature stress, in peas shattering stress; in pigeonpea water logging, cold and terminal drought, in blackgram and mungbean pre-harvest sprouting in *kharif* as well as in spring/summer season, whereas terminal drought is important in *rabi* season in both of these crops.

Deployment of useful genes for genetic enhancement

Hybridization involving one adapted cultivar of the area/region and the other parent is the donor for specific trait(s) of interest like biotic or abiotic stress or quality and/or yield trait has been used for developing superior varieties of pulse crops. In general, intraspecific hybridization has been used and rarely interspecific hybridization is used for genetic enhancement. Largely single crosses have been attempted and the segregating generations were handled using pedigree method or its modifications. Before 1970, hybridization was used less frequently. This was due to shortage of trained scientific manpower, availability of limited genetic diversity and also scarcity of funds. However, crosses were made at some of

Table 8 Inheritance of resistance to some of the major insect pests of pulse crops

Crop/Insect-pest	Inheritance of resistance	Reference (s)
Pigeonpea Pod borer (*Helicoverpa armigera)*	Antixenosis (antibiosis) was governed by a single dominant gene.	Verulkar *et al.* (1997)
Pod fly (*Melanagromyza obtusa)*	Resistance to pod-fly in *C. scarabaeoides* was governed by two recessive genes.	Verulkar *et al.* (1997)
	Two genes govern the resistance with interaction between recessive and dominant alleles.	Singh and Lal (2002)
Mungbean Bruchids *(Callosobruchus chinensis)*	Resistance is dominant and governed by few major genes (probably two) with some modifiers.	Sarkar and Bhattacharya (2014)

the research stations funded by State Department of Agriculture and also by Central Government and superior varieties were developed by these stations/centres using recombination breeding.

Intraspecific hybridization: In case of mungbean, the first releases using hybridization were; Type 44 in UP, Kanke in Bihar and *Kharif* Sona in West Bengal from Type 2 × Type 49, Type 1 × China Mung 781 and Type 1 × Sona Mung crosses, respectively. In black gram, the first varieties developed through hybridization were; KM 1 released in 1977 and ADT 2 released in 1979 at Coimbatore (TN) from (G 31 × Khargone-3) × G 31 and AB 1-33 × ADT 1 crosses, respectively. C 235 was the first variety of chickpea developed using hybridization, from a cross of IP 58 × C 2134 at Ludhiana and was released in 1960 for cultivation in Punjab. It has small brown seeds and tolerance to *Ascochyta* blight and was widely adapted to rainfed areas. Pant Lentil 639 was the first variety of lentil developed using hybridization. It was produced from a cross of L 9-12 × Type 8 at GBPUAT, Pantnagar and was released in 1981 for NWPZ and NEPZ. This was resistant to rust and tolerant to wilt diseases.

The AICPIP was started in 1966-67. This project made access to genetic resources easy. During 1970, 15 main and 13 sub-centres were established under the AICPIP which provided required man-power for research. The exchange of germplasm among pulse breeders was followed by evaluation for yield and yield traits as well as for biotic and abiotic stresses. The establishment of International Crop Research Institute for Semi-Arid Tropics in 1972 and elevation of Plant Introduction Division of IARI as National Bureau of Plant Genetic Resources in 1976 has helped the Indian Pulse Breeders to the access of exotic germplasm resources. Some of the exotic lines/cultivars were selected by Indian breeders from International Nurseries of chickpea and lentil provided by ICARDA and of mungbean provided by AVRDC, which were used for the hybridization purposes to transfer the desirable genes to the indigenous pure line/ cultivars and also into the cross bred cultivars. This has helped in the development of new cultivars with improved traits like; seed size, early maturity and plant types etc (Singh 1997).

Among the major pulse crops, largest numbers of varieties from recombination breeding have been developed in chickpea (134) followed by mungbean (69), pigeon pea (62), blackgram (36), field pea (34) and lentil (24) (Table 5). Of these, one variety in chickpea, six in mungbean and two in black gram are produced from interspecific hybridization and the rest of the varieties are the result of intra-specific hybridization. In the minor pulse crops, only few varieties have been developed through hybridization, which could be primarily due to limited variability available.

Some of the important features of genetic enhancement in pulse crops using intra-specific crosses are described cropwise as follows.

In case of chickpea, the varieties of both *desi* and *kabuli* types have been developed from *desi* × *desi* and *kabuli* × *kabuli* crosses, respectively. However, in some cases, both *desi* and *kabuli* type of varieties were developed from *desi* × *kabuli* or *kabuli* × *desi* crosses for, eg. C 104, L 144, L 550 (*kabuli* type) and S 33 (*desi* type) were developed from *desi* × *kabuli* crosses. Better success was achieved when *desi* type of cultivars were used as female parent. The donors of both indigenous and exotic types have been used to transfer desirable traits. Varieties have also been developed for specific niches. For late sown condition after the harvest of rice crop in north-east zone of the country, KPG 59 (Udai), Pant G 186, Pusa, 372, Pusa 547, Adhar and Sangam (GNG 1488) have been developed. Large seeded and extra large seeded varieties of *kabuli* type with short duration have been released for irrigated conditions of central and Southern regions of the country. These are KAK 2, Virat, IPCK 2002-29, PKV Kabuli 4 and MNK 1. NBeG 3 is drought tolerant and CSG 8962 (Karnal Chana 1) is tolerant to moderate soil salinity condition. In all the varieties of chickpea developed through hybridization, resistance gene (s) for atleast one and/or two important diseases of the zone have been incorporated.

Superior varieties have been developed in all the three maturity groups (i.e. early medium and late types) in pigeonpea. Sharda is the first variety developed through hybridization in pigeonpea. It is of medium maturity duration. In early group the varieties with both determinate and indeterminate plant types have been released for cultivation. Notable among these are; Pusa Ageti, Pusa 33, Type 21, Prabhat and Manak released for northern India, Sagar for Haryana, AL 201 for Punjab, Vishaka 1 (TAT 6) and AK 8811 for Maharashtra, ICPL 84031 for AP and ICPL 87 (Pragati) for entire country. Of these, ICPL 87 (Pragati) is resistant to wilt and Pusa 33 is tolerant to wilt and SMD. Among the prominent medium maturing varieties of pigeonpea developed using hybridization are; Sharda (S 8) released for Delhi and Karnataka in 1971 from a cross of Brazil 1 × NP (WR) 15; JA 3 and JA 4 for MP developed from a cross of No. 148 × C 11 in 1975 and 1991, respectively, WB 20 (105) for WB from a cross of Prabhat × B 157 in 1983; BSMR 175 and BSMR 87-119 (Asha) for Maharashtra from a cross of (PA 3 × ICP 7035) × BDN 2 in 1991 and C 11 × ICPL 6 in 1993, respectively, ICPL 85063 (Laxmi) for AP from a cross of (T 21 × BDN 1) × JA 275 and TS 3 for Karnataka from a cross of ICP 87051 × PT 221 in 2001, MA 6 for UP from a cross of MA 2 × Bahar in 2002. Most of these are resistant to wilt disease. WB 20 (105) is resistant to alternaria blight. Among the late maturing varieties of pigeonpea developed through hybridization, the prominent ones are, DA 11 (Sharad) for Bihar from a cross of Bahar × NP (WR) 15 in 1993; Pusa 9 for UP, Bihar and WB from a cross of UPAS 120 × 3673, K 91-25 (Azad) for UP, Bihar, WB from a cross of (MA 2 × MA166) × Bahar in 2004. All of these varieties are resistant to sterility mosaic disease which is the most important disease for NEPZ. Sharad is suitable for pre-*rabi* sowing.

Out of 69 mungbean varieties released through hybridization 63 were developed using intra-specific hybridization whereas six were developed from inter-specific crosses. Only five varieties were released through hybridization before the establishement of AICPIP which were susceptible to diseases and were low yielding. From the list of remaining varieties >30 were resistant to MYMV, 9 were tolerant/resistant to PM, three varieties (JM 721, PDM 84-178 and BM 4) were tolerant/resistant to both MYMV and PM and two were resistant to three diseases. Pusa 105 was reported to be resistant to MYMV, PM and Macrophomina blight and was released for C Z and NWPZ in 1987. ML 613 was reported to be resistant to MYMV, bacterial leaf spot and pod leaf spot and was released for Punjab state in 1996. Some of the varieties have developed from indigenous × exotic (from AVRDC) crosses. Earliness and large seed size have been transferred from exotic lines/cultivars.

Traditional varieties of blackgram were spreading type and late maturing, selected from indigenous materials. So far 35 varieties have been developed through hybridization. After the start of AICPIP, intensive hybridization between pure lines was taken up. During 1970s four varieties were developed and released for Tamil Nadu. These varieties and their pedigree are; KM 1 (G 31 × Khargone 3) × G 31, KM 2 (19 × 164), ADT 2 and TMV 1 (AB1 33 × ADT 1). Of these, KM 1 was recommended for multiple cropping and KM 2 for delta regions of TN KM 2 was reported to be tolerant to MYMV. In northern India, Type 9 and its selections were frequently used as parents in hybridization programme. Pant U 19 and Pant U 30, released in 1981 were developed at GBPUAT, Pantnagar from a cross of UPU 1 × UPU 2. Of these, UPU 1 was a MYMV tolerant selection from Type 9 and UPU 2 (a MYMV resistant selection from D 6-7), a variety of Maharashtra. Pant U 19 was recommended for cultivation in NEPZ and Pant U 30 was recommended for cultivation in CZ and PZ. Both of these varieties were similar to Type 9 (UPU 1) in morphological traits and maturity duration. However, these varieties were resistant to MYMV. The two recessive genes for MYMV resistance were transferred from UPU 2. Subsequently, Pant U 35 was developed from a cross of UPU 3 × Pant U 19. It was an improvement in seed size over Pant U 19 and was released in 1985 for cultivation in UP Pant U 19 and Pant U 35 were cultivated over large acreage in *kharif* as well as in spring/summer season in northern India where as Pant U 30 was cultivated in central and southern parts of the country. Resistance to MYMV in these varieties was stable across the years/locations and seasons. These varieties have frequently been used as parents for further improvement of released cultivars. Later on several other MYMV resistant varieties have been developed and released for *kharif* season. Shekhar 1 (KU 301), TU 94-2 were released in 1998 for cultivation during *rabi* season in SZ and were developed, respectively from G 31 × Type 9 cross at CSAUAT, Kanpur and from TPU 3 × TAU 3 cross at BARC Trombay. Both of these were resistant to MYMV and powdery mildew. Rashmi (LBG 625) is suitable for rice fallows. Pant U 31 and Pant U 40 are suitable for pure culture as well as for mixed culture with cereals. At present, Pant U 31 is the most widely cultivated variety in India. In Andhra Pradesh alone, it is grown in >30 thousand ha area. Pant U-31 is a dwarf, indeterminate, photo-thermo-resistant early maturing (70 days) with medium black seeds. Its resistance to MYMV is stable across the states and seasons in the country. It is also released in HP as Himachal Mash 1 and is also cultivated in Jharkhand and Odisha.

Twenty four varieties of lentil of both small seeded, (*microsperma*) and large seeded (*macrosperma*) type have been developed through hybridization. In India, the seed size of <2.5 g/100 seed is classified as *microsperma* type and above it, as *macrosperma*. Accordingly, 12 released varieties are small seeded and other 12 are large seeded type. Of these, 11 are resistant to rust, seven are resistant to wilt and rust, two are resistant to wilt and root rot (VL Masoor -125 and -129) and one is resistant to rust and blight (LL 129). Three varieties (Pant L-5, Pant L-6 and Pant L-7) are resistant to wilt, rust and blight diseases. In general, the small seeded varieties are grown in northern states after the harvest of rice crop and large seeded are confined to Bundelkhand region of UP and MP Some of the exotic cultivars (eg Precoz from Argentina) have been used in hybridization programme for transferring earliness, resistance to biotic and abiotic stresses and traits related to plant type. The crosses between indigenous and exotic lines/cultivars are reported to produce transgressive segregation with an increase in pod bearing length of the branches (Kumar *et al.* 1996).

The indigenous land races/cultivars of field pea were tall, trailing type (indeterminate) and were low yielding. These were largely grown in mixture with cereals and other crops. The exotic dwarf types are determinate to semi-determinate with better standing ability (Singh 1997). The first important tall field pea varieties developed through hybridization are; Rachna from CSAU, Kanpur and Pant Pea-5 from GBPUAT, Pantnagar. Rachna was a product of Type 163 × Type 10 and Pant Pea-5 were from its reciprocal cross. Both of these varieties were resistant to powdery mildew disease. Some of the exotic lines were leafless type (with af gene that converts all the leaflets to tendrils) and semi-leafless type (with st gene for reduced stipule size). These types were crossed with indigenous improved varieties and several varieties with dwarf/semi-dwarf (determinate to semi-determinate growth habit) with resistance to powdery mildew disease were developed. First dwarf variety Aparna (HFP 4) was developed at CCS HAU from a cross of Type 163 × EC 109196 and was released in 1988. It is about 45 cm tall with leafless plants and resistance to powdery mildew (*Erysiphe polygoni*). It can be grown at a density of 44 plants/m2 compared to 33 plants/m2 for tall varieties. After the establishment of AICPIP, 34 varieties have been developed from hybridization. Of these, 10 are tall type and 24 are dwarf and semi-dwarf type. All of these are resistant to powdery mildew (PM) and eight varieties are resistant to PM and tolerant/resistant to rust disease.

In minor pulse crops, few varieties have been

Table 8 Usefulness of wild species/relatives in pulse crops

Wild species/relative	Used to transfer useful trait(s) in pulse crop
Cicer reticulatum	Cold and AB tolerance, early maturity, higher yield and for desirable plant type in chickpea
Cajanus scarabaeoides	Tolerance/resistance to pod borers and for increasing clusters/plant in pigeonpea
Cajanus sericeus, C.scarabaeoides, C. volubilis and C.cajanifolius	Sources of cytoplasmic genetic male sterility; A_1, A_2, A_3 and A_4, respectively in pigeonpea
Vigna radiata var. *sublobata*	Early maturity, plant type and MYMV resistance, tolerance to bruchids in mungbean
V. mungo var. *sylvestris*	Early maturity, MYMV resistance, plant type and tolerance to bruchids in black gram

A_2 and A_4 are being used to develop hybrids of pigeonpea.

developed using hybridization. Two varieties, Prateek and Mahatora have been developed using hybridization in grass pea. Both of these varieties are low in neurotoxin content BOAA (beta-N-oxalyl-L-alpha-beta-diamino-propionic acid). It is also called ODAP. Similarly in cowpea two varieties; RC 101 and RC 19 have been developed with cross breeding in Rajasthan. Three anthracnose tolerant varieties of horse gram; VLG 10, VLG 15 and VLG 19 were developed using hybridization between 2006 and 2010 at VPKAS, Almora. Only one variety of Rajmash, HUR 137 (Malviya Rajmash 137) was developed through recombination breeding at BHU, Varanasi. It is erect, semi-dwarf with deep pink seeds. In moth bean, only one variety CAZRI Moth-2 has been developed from a cross of Jadia × RMO 40 for all the moth bean growing areas of India.

Inter-specific hybridization

The wide crosses were made to increase variation beyond parental limits and for developing CMS system and to transfer gene(s) for biotic and abiotic stresses and rarely have been used for the improvement of yield traits. The usefulness of wild species/relatives has been highlighted recently by Singh (2014). There are several wild species of chickpea and pigeonpea. Some of these are reported to possess useful genes for biotic and abiotic stresses, however, only few have been exploited for practical significance (Table 9).

Early flowering and maturing plants were selected in the early segregating generations of *C. arietinum* (ICC 8923, *kabuli* type) × *C. reticulatum* (JM 2106). One of the lines was synchronous in F_4 and was also cold tolerant to 7 to 9^0C temperature (Singh *et al.* 1984). Some of the F_3 progenies showed advantage over *C. arietinum* parent for yield traits as well as for yield/plant. At Pantnagar University, we have crossed an elite line of *kabuli* chickpea, PG 92-97 as female and *C. reticulatum* (JM 2100 from Turkey) as male. One of the progenies, PG 063 was superior to female parent as well as to the check cultivars. It was registered with NBPGR (INGR 09108) as superior germplasm in 2009 for high yield/plant and bushy and dwarf plant type. A cross (Pusa 256 × *C. reticulatum*) × Pusa 362) made at IARI has resulted in the development of a variety, Pusa 1103 which was released in 2004 for cultivation.

Deodikar and Thakar (1956) for the first time suggested the possibility of hybridization between pigeonpea and its wild species. The wild species/relatives possess genes for resistance to diseases, insect-pest, high protein content and a source of CMS systems. However, *C. scarabaeoides*, the wild progenitor of pigeonpea is reported as resistant to all the major diseases and to pod borers of pigeonpea. The resistance to pod-borers of pigeonpea and to pod-fly has been transferred from this wild relative to pigeonpea at ICRISAT and at GBPUAT, Pantnagar. The CMS systems have been developed by integrating the cytoplasm of wild species with the genomes of cultivars of cultivated pigeonpea through interspecific hybridization followed by selection and back crossing (Saxena *et al.* 2010)

Interspecific crosses have been attempted between mungbean (*Vigna radiata*) and black gram (*V. mungo*) to improve both the species simultaneously. In general, the success has been achieved when black gram was used as male parent. Six varieties have been released from such crosses (Table 9). Pant Mung 4 is the first variety developed

Table 9 Varieties of mungbean and urdbean developed through interspecific hybridization involving mungbean as female and black gram as male

Variety	Pedigree	Year of release	Area of adaptation	Developed by
Pant Mung 4	T 44 × UPU 2	1997	NEPZ	GBPUAT, Pantnagar
Malviya Jyoti (HUM 1)	BHUM 1 × Pant U-30	1999	CZ & SZ	BHU, Varanasi
Meha	Pant Mung 2 × AMP 36	2004	NEPZ	IIPR, Kanpur
Pant Mung 6	Pant Mung 2 × AMP 36	2007	NHZ	GBPUAT, Pantnagar
IPM02 3	IPM 99-125 × Pusa Bold 2	2009	NWPZ	IIPR, Kanpur
IPM 02-14	IPM 99-125 × Pusa Bold 2	2010	SZ	IIPR, Kanpur
Vamban 7	Vamban 3 × *Vigna mungo* var. *sylvestris*	2011	SZ	TNAU, Coimbatore
TU 40	TU 94-2 × *V. mungo* var. *sylvestris*	2011	SZ	BARC, Trombay

UPU 2 and Pant U 30 are black gram cultivars. AMP 36 is a derivative of K 851 × MCK 2. IPM 99-125 is derivative of Pant Mung 2 × AMP 36.

from interspecific hybridization. Subsequently, five more varieties have been released. All of these have inherited MYMV resistance genes from blackgram. IPM 02-14 is recommended for cultivation in spring/summer season and other five varieties are recommended for cultivation in *kharif* season.

At Pantnagar, we have recovered several lines of both mungbean and blackgram type from an interspecific cross of mungbean *V. radiata* cv. BDYR 7 × black gram (cv. DPU 88-31). BDYR 1, is a large seeded exotic cultivar susceptible to foliar diseases. DPU 88-31 is an elite cultivar, of blackgram which is free of foliar diseases of mungbean. The recovery of black gram type of progenies from such a cross is the first report. Earlier workers reported recovery of mungbean type of progenies as the black gram type of plants did not survive in the early segregating (F_2/F_3) generations. Other successful crosses reported in genus *Vigna* are; V. *radiata* × *V. radiata* var. *sublobata* (Ahuja and Singh 1977) and *V. mungo* × *V. mungo* var. *sylvestris* (Singh 1982), which have been used for the genetic enhancement of the respective cultivated species, (Singh 1990, Reddy and Singh 1989 and Parida and Singh 1985). Two varieties of black gram; Vamban 7 and TU 40 have been developed, respectively from Vamban 3 × *V. mungo* var. *sylvestris* and TU 94-2 × *V. mungo* var *sylvestris* and released in 2011 for SZ of the country (Table 11). Vamban 7 is resistant to MYMV and PM and recommended for cultivation in *kharif* season and TU 40 is resistant to PM and recommended for cultivation in *rabi* season.

Exploitation of heterosis: In India, BP Pal in 1945 published the first research paper on heterosis in chickpea involving 6 crosses. Number of pods/plant was the only character which showed marked hybrid vigour. The first paper on heterosis in pigeonpea was published by Solomon and coworkers in 1957. The best yielding hybrid gave a lower yield than the best parental type. In between 1960 and 1990, several research papers were published in different pulse crops and very high magnitude of heterosis, both BP and SP were reported (Singh 2014). The presence of considerable non-additive effects for yield components have raised the prospects for exploitation of hybrid vigour in pigeonpea; which is often cross-pollinated crop. The out-crossing of 15 to 20% is mediated by insects mostly bees (*Megachile lanita* and *Apis florea*). Therefore, during 1980s serious efforts were made to develop pigeonpea hybrids using genetic male sterility (GMS). The GMS is governed by a single recessive gene. The male sterile lines are propagated by crossing with heterozygous fertile lines, Msms. In the F_1 one half of the heterozygous fertile plants have to be removed. For hybrid seed production GMS and fertile plants are grown in alternate rows in an ideal ratio. F_1 seeds are harvested from GMS lines.The pigeonpea hybrids using GMS tested in multilocation trials. As a result of these trials, ICPH 8 developed by ICRISAT was identified and released in 1991. Subsequently more pigeonpea hybrids of early and extra early duration were released by the State Agriculture Universities. These are PPH 4 from Punjab, CoPH 1 and CoPH 2 from TNAU and AKPH 4101 from Maharashtra.

The GSM hybrids are labour intensive and due to high cost for hybrid seed production had limited adoption among the farmers. Therefore, efforts were made to develop CMS based hybrids. In this approach the cytoplasm of wild species (used as female) was integrated with the genome of cultivated pigeonpea cultivars (used as male) through interspecific hybridization followed by selection and backcrossing. The cytoplasm of wild species has been used to integrate into the genome of different pigeonpea cultivars to develop CMS lines. However, only A2 and A4 are being used in hybrid pigeonpea breeding. Some CMS lines have also been developed using other wild species like; *C acutifolius* (Saxena *et al*. 2010).

An early maturing Gujarat Tur Hybrid 1 (GTH 1) using CMS line has been released in 2010 for central zone of India. It is developed from a cross of GT 288 A × GTR 01. It yields on an average 25 to 30 q/ha with a maturity of 140-160 days. It is resistant to wilt and sterility mosaic disease. Patel and Tikka (2014) studied 72 CMS based hybrids of 3 maturity groups, early medium and late alongwith standard parent GTH 1. Eight best hybrids showed better parent heterosis from 140.62 to 307.54% and standard check heterosis from 80.44 to 116.4%. These hybrids also gave high mean seed yield/plant. This study suggested the possibility of developing still higher yielding pigeonpea hybrids.

Mutation breeding: Induced mutations have been found useful in creating useful variability for yield traits, plant type and resistance to various stresses. So far 52 varieties have been developed through mutation breeding in different pulse crops (Table 5). Most of these have been developed from already released and adapted varieties. In general, gamma-irradiation has ben used and rarely chemical mutagens have been used. Sharma and Sharma (1984, 1986) used gamma-rays and NMU to induce genetic variability in lentil. The mutant varieties are improvement over their maternal parent and/or standard check for character(s) such as plant type, seed size, seed colour, maturity duration and resistance to disease (s).

Pant Mung 2 is a mutant of ML 2. It is moderately resistant to MYMV and has shining green seeds. It was higher yielding to the parental cultivar and was released in 1982. This variety is very popular in central UP and is grown after harvest of potato. LGG 450 (Puskara) is mutant of Pant Mung 2 for tolerance to pre-harvest sprouting. Blackgram variety Vamban 2 is a mutant of Type 9 and it tolerant to drought and resistant to MYMV. Prasad (B 3-8-8) and Ujala (OBG 17) varieties of blackgram are mutant of Type 9 and B 3-8-8, respectively. Both of these were released in 2005 for *kharif* and *rabi* season and were resistant to MYMV. Fifteen varieties of chickpea and 5 of pigeonpea have been developed through induced mutations. Two important varieties of lentil; Arun and HUL 57 are mutant of BR 25 and HUL 11, respectively. Arun is tolerant to wilt and HUL 57 is tolerant to rust disease of lentil. Both of

Table 10 Current status of transgenic pulses development

Crops	Trait	Explants	Stages	Institutes/Universities/SAU
Chickpea	cry2Aa	Cotyledon with half embryonic axis	T1	AAU, Jorhat
	cry1Ab and cry1Ac	Cotyledonary node	T1	NBRI, Lucknow
	DREB1A	Axillary meristem	T6	ICRISAT, Hyderabad
	cry1Ab/Ac	Embryonic axis	T2	Kolkata University
	cry1Aabc	Axillary meristem	T4	IIPR, Kanpur
	Cry1Ac	Axillary meristem	T3	IIPR, Kanpur
Pigeonpea	Pod borer resistance	Embryonic axis	T0	NRCPB, New Delhi
		Axillary meristem	T2	ICRISAT, Hyderabad
	cry1Aabc	Axillary meristem	T5	IIPR, Kanpur
	cry1Ac	Axillary meristem	T3	IIPR, Kanpur
	P5CSF129A	Embryonic axis	T1	GITAM University, Vishakhapatnam
Mungbean	*Callosobruchus* spp	Cotyledonary node	T1	Rohtak University
Blackgram	Enhanced drought tolerance	Cotyledonary node	T1	JNU, New Delhi
Pea	Nematode resistance	Thin embryonic slices	T0	IIPR, Kanpur

these are popular in the state of Bihar.

Transgenic development: The momentum for development of transgenic pulses is quite slow because of constraints like recalcitrance of pulse crops for regeneration, low competency of regenerating cells for transformation and lack of reproducible system. Efforts have been made to make chickpea and pigeonpea transgenics for podborer resistance using cry1Aabc and cry1Ac. Two other gene constructs like cry2Aa and cry1Ab were also used for developing transformants for incorporating resistance in Chickpea. This work has been undertaken in several laboratories but transforming events are still in primary stages. Besides podborer resistance, drought tolerance in chickpea and blackgram using DREB1A and nematode tolerance in pea using RNA_i techniques are underway at ICRISAT and JNU, respectively. At present in India, 10 centres are actively working for development of transgenic pulses for different traits (Table 10).

Genomics enabled improvement: Genomic resources help to understand the genetics of traits of interest. It leads to identify the markers linked to genes/QTL controlling a trait or a group of traits of interest. Hence, genetic manipulation of traits can be done more precisely and effectively through marker assisted back-cross breeding (MABC), marker assisted recurrent selection (MARS) and advanced backcross (AB) breeding. During the last two decades, powerful genetic and genomic tools such as establishment of genetic and physical maps, expressed sequence tags (ESTs), bioinformatic tools, genome-wide sequence data, genomic and metabolomic platforms have been developed for many legume species. Despite of considerable variations in genome size of different pulses (Table 11), the efforts are underway to enrich the available database and development of overall genetics of crops. Most recently, draft genome sequence has been made available in pigeonpea (Singh *et al.* 2012, Varshney *et al.* 2012), chickpea (Varshney *et al.* 2013a) and Mungbean (Kang *et al.* 2014) and similar efforts are currently underway in lentil.

Table 11 Variation in basic chromosome number and genome size among puilse crops

Species	Basic chromosome number (X)	Genome size (Mb)
Common bean (*Phaseolus vulgaris*)	11	637
Cowpea (*Vigna unguiculata*)	11	620
Pigeonpea (*Cajanus cajan*)	11	858
Pea (*P. sativum*)	7	4,400
Lentil (*L. culinaris*)	7	4,063
Chickpea (*C. arietinum*)	8	740

Source: Pratap *et al.* (2014).

Various DNA-based marker systems are widely available in legume crops. However, breeders prefer PCR (Polymerase Chain Reaction) based SSR and SNP markers because these are highly reproducible and generate high level of polymorphism and can easily be employed in genotyping of large segregating populations in a cost-effective manner and with minimum infrastructure facilities (Pratap *et al.* 2014). SSR markers have the advantage of being multi-allelic and co-dominant (Gupta and Varshney 2000). These makers have been extensively utilized, in other crops but in pulses their use is still limited to only a few crops like chickpea and pigeonpea (Varshney *et al.* 2009a). In chickpea, 2000 SSR markers have been developed from genomic DNA libraries (Varshney *et al.* 2007, Nayak *et al.* 2010), ESTs (Varshney *et al.* 2009b), 454/FLX transcript reads (Garg *et al.* 2011). A large number of SSR markers have been developed from BESs and 454/FLX sequences in pigeonpea. For instance, after mining 88860 BESs, a set of 3,072 SSR markers were developed (Bohra *et al.* 2011a). In addition, 3583 SSRs have been identified from ESTs (Raju *et al.* 2010) and 454/FLX sequences (Dubey *et al.* 2011, Dutta *et al.* 2011). Furthermore, by scanning the draft genome sequence of pigeonpea (see later), 309,052 SSRs

Table 12 Molecular markers linked to desirable genes/QTL for MAS in pulses

Crops	Traits	QTL/genes	Type of markers	Laboratories
Blackgram	Yellow mosaic virus resistance	Monogenic	STS-RGA	Bose Institute, India
		Monogenic	ISSR, SCAR	BARC, India
		Monogenic	SSR	IIPR, India
Chickpea	*Ascochyta* blight resistance	Ar19	RAPD	IIPR, Kanpur
	Double podding, seeds/pod, mean seed weight	QTL	RAPD, ISSR, RGA,SSR, ASAP	NCL, Pune, India
Pea	Powdery mildewresistance (pisi)	er-1	SCAR, RFLP	IARI, India

have been identified (Varshney *et al.* 2012). Compared to other marker systems used in pulses and other crop plants, SNP markers are high throughput and cost effective (Varshney *et al.* 2012).

Using EST database, candidate genes controlling defence mechanism against *Ascochyta* blight have been isolated in chickpea. Microarray or DNA chips have also been used similarly in study of functional genomics of model and other legume species legumes like *M. trunccatula*, pea, Chickpea and lentil. These have been developed from ESTs or cDNA libraries and can be used to identify the network of genes underlying the expression of agronomically important traits. In chickpea, transcriptional change in genes responsible for different abiotic stress was observed leading to identification of 2, 15 and 30 genes differentiating between tolerant and susceptible genotypes for drought, cold and high-salinity respectively.

Several new generations sequencing (NGS) and genotyping platforms have revolutionized plant genomic research. These developments led to generation of millions of ESTs per run. In *M. truncatula*, ~75 million ESTs have been generated using an Illumina/Solexa resulting in quantitative expression data complement and extend Affymetrix Gene Chip data. NGS helped to accelerate linkage mapping, whole genome association (WGA) studies (Varshney *et al.* 2009a, b), and transcriptomics of non model species where DNA arrays are unavailable. In chickpea, 2496 ESTs were generated and utilized in for the development of 487 functional markers such as EST-SSRs, intron targeted primers, EST polymorphisms (ESTP) and SNPs (Choudhary *et al.* 2012b). The WGA, helped to to identify 26082 SNPs in chickpea (Hiremath *et al.* 2011), 28104 novel SNPs in pigeonpea (Varshney *et al.* 2012). Similarly, KASPar assays from another next generation SNP genotyping technology have also been developed for 2005 SNPs in chickpea and 1,616 in pigeonpea.

Use of molecular markers in improvement of pulses: The impressive progress has been made in transferring major genes for improvement of pulse crops through conventional breeding. With the development of whole genome sequencing information in chickpea and pigeonpea, the marker assisted breeding is now being routinely used in chickpea as all India network project funded by Department of Biotechnology, Government of India. MAS is advantageous for traits with low heritability where traditional selection is difficult, expensive, or lacks accuracy or precision (Varshney *et al.* 2010), whereas MARS is used to estimate the markers effect from genotyping F2 or F3 population and phenotyping F2 derived F4 or F5 progenies, followed by two or three recombinant cycles based on the presence of markers alleles. Efforts have also initiated to use MAS in chickpea for disease resistance, pathogen resistance and resistance to several biotic and abiotic stresses. Another approach is to identify markers linked to desirable genes/ QTLs for marker assisted selection or marker assisted recurrent selection for complex trait controlled by many genes. Once favourable QTL alleles are identified, MAS can help deploy them in existing agronomic base. The summary of all markers linked to different traits has been given in Table 12.

Linkage map is another pre-requisite for undertaking marker assisted breeding programmes. However, a good progress has been made in developing linkage maps in lentil, pea and cowpea. These molecular maps have been prepared mostly using more than one type of marker, such as restriction fragment length polymorphism (RFLP), amplified fragment length polymorphism (AFLP), random amplified polymorphic DNA (RAPD) and SSR. Dense molecular maps consisting of more than 400 loci have been developed in a few legume crops including azuki bean Vigna angularis. Both inter- and intraspecific mapping populations have been used for preparation of molecular maps: the former is more commonly used because of the low level of polymorphism in the cultivated gene pool. For example, in lentil, use of divergent parents (wild × cultivated) in development of molecular maps often results in lower recombination rates and smaller map sizes (Tadmor *et al.* 1987). As a result, molecular maps developed from these populations cannot be used as reference maps. Intervarietal maps, which have more practical utility in tagging desirable gene(s), have not yet been developed, mainly due to limited availability of polymorphic molecular markers. There have been efforts to develop dense intervarietal molecular maps based on highly polymorphic SSRs, single nucleotide polymorphism (SNP) and gene-based markers in chickpea (Nayak *et al.* 2010).The availability of high-throughput and cost effective genotyping platforms, combined with automation in phenotyping methodologies, will increase the use of genomic tools in breeding programmes.

The germplasm collections of various pulses crops in India have been done fairly well. However the systematic evaluation is limited to major pulse crops only. India has so far released 641 varieties of pulse crops out of which 222 were selections from available germplasm and land races, 367 through hybridization (mainly in major pulse crops), 9 adopted pure lines and donors for resistance to diseases and 52 through mutation breeding. Interspecific hybridization has also been used for genetic enhancement in pulse crops and nine varieties have been released. Six varieties of mungbean have been produced using mungbean as female and blackgram as male parent whereas two varieties of blackgram have been developed using blackgram as female parent and its wild progenitor, *Vigna mungo* var *sylvestris* as male parent. In chickepea, one variety was developed using chickpea as female parent and its wild progenitor*, Cicer reticulatum* as male parent. Heterosis has been exploited at commercial scale in Pigeonpea using GMS and five hybrids of early maturity duration were released for cultivation. The wild species of Pigeonpea have been used to develop CMS system by combining the cytoplasm of wild species with the genome of cultivated Pigeonpea. An early maturing Gujarat Tur Hybrid 1 has been developed using CMS line and was released for the central zone of India.

In general, the released varieties of major pulse crops are superior in at least one or more important traits like, early maturity, plant type, large seed size, resistance to one or more highly prevalant diseases (rarely more than two diseases) with at least 10% increase in grain yield. However, very few varieties have been developed for specific niches. In spite of very impressive achievements like availability of donors for most of the desired traits, their use in breeding superior varieties and exploitation of heterosis atleast in early pigeonpea, the gains in genetic enhancement of pulse crops are not up to the expectation. This could be due to certain pitfalls in the breeding approaches for the existing environmental conditions in the farmers' field. In general, the experimental stations are located in favourable environments and are well equipped with modern facilities for crop husbandry. The pulse varieties have been developed under such conditions. This has resulted in selection of traits having better expression under those conditions. However, the released varieties when cultivated by the farmers under harsh and variable environments are at a disadvantage. For instance, varieties of determinate plant type with large pods and bigger seeds do not perform well under the rainfed conditions (usually sown on residual moisture) with minimal plant protection measures. The cost of cultivation of such varieties is higher (due to higher seed rate) and risk of damage of crop due to the insect-pests is very high (e.g. determinate Pigeonpea and large seeded chickpea).

It is suggested that the pulse varieties should be developed for the conditions which are representative of farmers' field. The pulse crops are generally grown as mixed crop (e.g. pigeonpea, mungbean and blackgram) with cereals in *kharif* season or after the harvest of rice in northern India in *rabi* season (e.g. chickpea, fieldpea, and lentil) or in rice fallows (e.g. blackgram and mungbean in southern parts). The segregating generations and the fixed lines at the research stations need to be evaluated under such situations and superior lines for respective conditions may be selected. The breeders may focus developing varieties with semi-determinate growth habit with small and medium size of seeds. Such varieties have shown wider adaptation. The varieties with small and medium seed-size have advantage in germination (on residual moisture and in undulated field), also show less damage to insect-pests and give higher yield. In India the seed is consumed largely as split *dahl* or *besan* (ground flour in chickpea and fieldpea). The varieties with small to medium size of seed are preferred by the millers since they give high dahl recovery. The cooking quality of small and medium seeded varieties is also better. The emphasis may also be given to incorporate tolerance to major insect-pests(s) and abiotic stresses. The varieties with semi-determinate plant type with small and medium seed size with tolerance/resistance to major biotic and abiotic stresses would give higher and stable yield and would always be less prone to environmental hazards. There have been spectacular advances in demonstrating alleles from wild relatives of crops to have potential to improve the performance of crops. This is likely to provide a major stimulus for the use of diverse genetic material of crop relatives for incorporation into new crop cultivars.The application of marker technologies to the re-domestication of crops by exploiting the potential gold mine of favourable alleles existing in the wild relatives of crops provides an excellent opportunity for achieving necessary advances in pulse improvement.

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