Pulses research and development strategies for india

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I. Introduction

The world population is projected to grow from the current ~7.3 billion (in 2015) to ~8.9 billion by 2050 (United Nations Report 2004). Therefore, increasing food production to provide food and nutritional security is a challenge. Food and nutritional security becomes all the more important with the certainty of climate change scenario and ever increasing human population. These twin challenges can be addressed to by diversifying the global cropping pattern and by promoting food/grain legume crops, generally called Pulses in India. Legumes include ~750 genera and ~18000 species (Graham and Vance 2003; Polhill et al. 1981). The Legume family consists of important food grain, oilseed, forage, and agroforestry species. The domestication of legumes by humans dates back to Neolithic times. Chickpea (Cicerarietinum) is one of the seven Neolithic founder crops of the near East (Lev-Yadun et al. 2000). Some of the earliest domesticated legumes include: lentil (Lens culinaris; ~9000 yrs; Cohen 1977),beans (Phaseolus vulgaris) and soybean (Glycine max; ~3000 year;Hymowitzand Singh, 1987; Kaplan and Lynch, 1999). Legumes form an important part of human daily diet especially in several developing and some developed countries and therefore sometimes legumes are considered as poor man's meat.

Pulses are produced on ~12-15% of global arable land and their contribution to total human dietary protein nitrogen requirement is ~30% (Graham and Vance 2003). Most important dietary pulses include chickpea, beans, lentil, green gram(mungbean), black gram (urdbean) field peas, pigeonpea, and cow pea. Soybean and groundnut are important oilseed legumes meeting ~35% of the global vegetable oil requirement (Graham and Vance 2003), and are also used as protein supplements. The global legume/pulse production, area and yield during 2013 was ~73 million tonnes (MT), ~80.8 million ha (m ha) and ~904 kg ha-1respectively (FAOSTAT 2015). Legume/pulse production, area and yield during the same period was ~18.3 MT (~25% of the global production), 28.2 m ha (~35% of global area) and 650 kg ha-1respectively. Further, Africa and Asia together contribute ~49 MT, i.e., 67% of the global pulse production. India's production of different legumes during 2013 was: chickpea (~13.1 MT), pigeonpea (~4.74 MT), lentils (~1.13 MT), dry peas (0.6 MT), groundnut with shell (9.4 MT) and soybean (11.95 MT; FAOSTAT 2015). Overall, the global legume production has increased by ~1.7 times between 1961 and 2011 and during the same period cereal production has increased by ~ 3 times. The yield per hectare of legumes has increased only by ~1.4 times to that of ~3.0 times in cereals. All these factors contribute to an overall short-supply of legumes globally, especially pulses in India.

More than a dozen pulses crops are grown in different parts of India. Among them, chickpea (gram or chana), pigeonpea (tur), mungbean (green gram or moong), urdbean (black gram or mash), lentil (masoor) and fieldpea (matar) are most common ones. During 2013-14, India produced 19.27 MT of pulses, and about 3.18 MT of pulses worth more than Rs. 11038 crores (US$1.8 billion) were imported from Canada, Australia, Myanmar, Turkey, Syria, Tanzania, etc. during same year. The results from frontline demonstrations clearly indicated that pulses production can be enhanced to the desired level if appropriate technology transfer efforts are made. India has witnessed an impressive growth in pulses production during last 5 years with the good compound growth rate. The growth rate of pulse production (2.61%) during last one decade was even higher than the growth rate of rice (1.59%), wheat (1.89%) and total cereals (1.88%). This has also had a direct effect on per capita availability of pulses (39.4 g/capita/day from the earlier 36g/capita/day). Among different pulses, the highest growth rate was observed in chickpea production (5.89%) followed by pigeonpea (2.61%). The overall productivity of pulses increased to an impressive 786 kg ha-1 during 2012-13 as compared to 577 kg ha-1during 2004-05. The credit goes to the improved varieties and production of breeder seed, demonstration of pulses production technologies through technology demonstrations, frontline demonstrations, policy support and various schemes like National Food Security Mission (NFSM), RashtriyaKrishiVikasYojana (RKVY), and accelerated pulses production program (A3P) etc. launched by the central government to promote pulses cultivation. In order to ensure self-sufficiency, the requirement for pulses in the country is projected at 39 million tonnes by the year 2050; at an annual growth rate of2.2%. This will require a pragmatic change in research and developmental strategies, beside good policy support from the government.

II. Why Pulses?

Pulses in general are nutritionally enriched as they have high protein content, relative to staple cereals. In addition to their nutritional content, there are several reasons that strongly support legume cultivation and adoption. Important reasons for their cultivation include: (i) suitability for human and animal consumption, (ii) adaptability for inter- or mixed cropping, (iii) agronomic management of legumes is relatively easy, (iv) legumes are relatively hardy crops and grown in some of poorer soils and harsh growing conditions and face lower incidence of pests and diseases, (v) input (especially nitrogen fertilizer) requirement is lower compared to other crops,and (vi) legumes are also considered as cash crops. Though legume cultivation has several advantages they also suffer from some limitations restricting their cultivation, especially limited availability of quality seeds of improved varieties, harvesting is tedious,in addition to labour requirement for value addition, and most importantly volatility of markets.

Grain composition of pulses

'Protein Calorie Malnutrition (PCM)' is a global concern especially in infants, young children and nursing mothers. The protein content of legumes is substantially higher (20-36.0%; Gowda et al 2014) compared to major cereals (6.0-15.0%; Champagne et al 2004; Shewry 1993, 2009; Zuber and Darrah 1987). The protein content of important grain legumes is: pigeonpea [21.7 g 100-g], chickpea [19.3 g 100-g], lentil [25.8 g 100-g], bean [23.4 g 100-g], cowpea [~24.0 g 100-g] and, soybean [36.5 g 100-g] (USDA 2013). Additionally, high variability (60-92%) was observed for in vitro protein digestibility (IVPD) for different legume crops (Gowda et al 2014). Further, the commonly consumed legumes were found to have a relatively balanced amount of all the required essential amino acids.

Minerals are important in human metabolism and mineral deficiencies are often associated with some human diseases/ disorders like cardiovascular disease (CVD), diabetes, cancer, and neurodegenerative disorders (Cabrera et al 2003). Pulses are a good source of different minerals. Consumption of 100-200 mg of legumes can meet the daily requirement of different minerals: e.g. the daily zinc requirement of 3.0mg/day for women and 4.2 mg/day for men (FAO 2002) can be met by consumption of 100-200 mg of lentil, cowpea, and chickpea. Similarly, daily iron requirement (1.46 mg/day for women and 1.05 mg/day for men) can be met by consuming 100 g of most of the food legumes.Further, legumes are good source of different types of Vitamin B, folic acid, and α/γ tocopherol (Gowda et al 2014). Additionally, legumes like chickpea and bean also provide β-carotene and Vitamin-K.

The fat content of many pulses ranges between ~1-6 g/100 g (USDA 2013). Chickpea hasthe highest fat content (~6.0g/100 g) among the grain legumes, almost about 3-4 times higher than others. The range of polyunsaturated, monounsaturated and saturated fatty acids (PUFAs, MUFAs and SFAs) in most of the pulses is 40-60%, 20-25% and 15%,respectively (Gowda et al 2014). Legumes are a good source of health promoting fatty acids like linoleic, linolenic, oleicand palmitic acids. Additionally, most of the legumes are also good source of carbohydrates (30-60%; USDA 2013). The different carbohydrates in legumes include: (i) monosaccharides – glucose, fructose and ribose (ii) disaccharides – maltose and sucrose (iii) oligosaccharides – ciceritol, verbascose, stachyose, and raffinose,(iv) polysaccharides – starch, cellulose and hemicellulose (Chibar et al 2004, 2010; Han and Baik 2006).Higher oligosaccharide content in chickpea leads to higher flatulence (Jaya et al., 1979; Rao and Belavady, 1978). The main carbon reserve in grains of legumes starch and is constituted of amylose and amylopectin (Chibar et al 2010).Grain legumes are a good source of fibre and total dietary fibre (TDF) content in legumes is ~8-27.5% (Guillon and Champ 2002). Several health benefits are associated with increased consumption of dietary fibre including reduced risk of several diseases (cardiovascular disease/diabetes/cancer/ obesity) and also lowers blood cholesterol levels (Tosh and Yada 2010; Marlett et al 2002).

III. Future Strategies for Increasing Pulses Productivity and Production

1. Chickpea

Chickpea (*Cicerarietinum*) has always been the most important pulse crop of India and its global importance has increased considerably during the past three decades. The number of chickpea growing countries has increased from 36 to 52 and importing countries from 30 to 150 during 1981 to 2011. Chickpea reached a record high global area of 13.3 million ha (mha) and production of 11.75 million tons (MT) during 2011. In 2013 the area of chickpea cultivation increased to 13.5 m ha but production remained at 13.1 MT (FAOSTAT 2015). Chickpea is currently the second most important food legume in the world after common bean. During 2013, 89.20% of the chickpea area and 84.47% of production was in Asia, 3.57% and 4.05% in Africa, 4.24% and 6.22% in Oceania, 2.44% and 4.55% in Americas and 0.55% and 0.71% in Europe (FAOSTAT 2015). The major chickpea producing countries,which contributed to about 90% of the global chickpea production during 2013, include India (67.4%), Australia (6.21%), Pakistan (5.73%), Turkey (3.86%), Myanmar (3.74%), Iran (2.25%)

There has been an impressive growth in area, production and productivity of chickpea in India during the past decade. The year 2011 was particularly rewarding as the chickpea production exceeded 8 MTfor the first time and the area reached 9.2 m ha, which was~0.4 mha less than the highest chickpea area recorded in 1962 (~9.57 mha). Overall, India's contribution towards global chickpea area and production is about 70%, so the global trend follows the Indian trend in chickpea area and production.

Chickpea is a cool season crop and general perception is that it requires cooler and longer winter season and more suited to northern India. It was probably true for the earlier varieties which were bred for cooler, long-season environments confining the chickpea production to northern and central India. However, the scenario of chickpea cultivation has drastically changed in India during the past five decades, primarily because of two factors:(i) the green revolution that intensified wheat cultivation in northern India replacing post-rainy season pulses, particularly chickpea, and (ii) development of short duration chickpea varieties which are better adapted to warmer, short-season environments ofcentral and southern India. There has been a major shift (about 4.0 million ha) in chickpea area from northern India (cooler, long-season environments) to central and southern India (warm, short-season environments).During the triennium 1965-67 and 2010-12, the chickpea area declined from 4.7 to 0.7 million ha in northern states (Punjab, Haryana and Uttar Pradesh), while it increased from 2.1 to 6.1 million ha in central and southern states (Madhya Pradesh, Maharashtra, Andhra Pradesh and Karnataka).

1.1 Strategies for enhancing chickpea production in India
There are tremendous opportunities for further increasing area and productivity of chickpea in India. The following chickpea improvement strategies are proposed for enhancing chickpea production in India:

Input responsive and non-lodging varieties: The chickpea area has reduced drastically (about 4.0 million ha) in northern India because the existing varieties are not responsive to high input conditions and tend to show excessive vegetative growth and lodging when grown in fertile alluvial and black soil and receive rains or irrigations during crop growth. Re-introducing legumes for crop diversification in cereal-dominated cropping system of northern India is very much needed for enhancing and sustaining cropping system productivity. The chickpea crop can be made more profitable and competitive by developing chickpea varieties which are non-lodging and responsive to high input conditions. This will require long-term investment in research on restructuring the plant type. The other traits need to be combined are resistance to foliar diseases (ascochyta blight and botrytis grey mold), herbicide tolerance and suitability to machine harvesting.

Abiotic Stress Tolerance: Drought and heat are the major abiotic stresses affecting chickpea at reproductive and terminal phases of crop growth especially in central and southern India. The residual nature of soil moisture coupled with progressively receding soil moisture conditions and increasing temperatures towards end of the crop season impact the crop severely. Early maturing and stress tolerant cultivars are required to combat these stress conditions. Excellent progress has been made to develop chickpea breeding lines with improved heat tolerance. Breeding lines with enhanced drought tolerance have been developed through marker-assisted breeding. Thus, breeding lines can be developed which combine both drought and heat tolerance.

Vast rice-fallow areas (~10 million ha) available in eastern India (Jharkhand, Bihar, Chhattisgarh, Odisha and West Bengal) offer opportunities for expanding chickpea area. The earlier experiments clearly demonstrated that chickpea is a very suitable pulse crop for rice-fallows, provided suitable varieties and technologies for crop establishment are available. The most important traits required in chickpea varieties for rice-fallows include early to extra-early maturity and tolerance to reproductive stage heat tolerance. An early maturing heat tolerant chickpea variety JG 14 (ICCV 92944) is already becoming popular in Eastern India. This variety can be further promoted and used as a benchmark for developing better performing varieties.

Biotic Stress Tolerance: Dry root rot (DRR) and Fusarium wilt have emerged as highly devastating root diseases of chickpea in central and southern India. There are many wilt resistant varieties, but there is a need to enhance efforts on identifying sources of resistance to DRRin the germplasm of cultivated and wild species and combine resistance to DRR and wilt in the varieties developed for central and southern India.

Pod borer (Helicoverpaarmigera) continues to remain a major and challenging insect-pest of chickpea.It has not been possible to develop varieties with high levels of resistance to pod borer due to non-availability of sources with high levels of resistance. Higher levels of resistance have observed in some wild species and efforts are being made to exploit these wild species in improving pod borer resistance. Greater chances for development of pod borer resistant cultivars exist through application of transgenic technology. Concerted efforts are needed on using different transgenes and promoter options for developing transgenic events and their evaluations for effectiveness and biosafety.

Chickpea is a poor competitor to weeds especially at early growth stages. Weeds compete with the crop for nutrients, water, sunlight, and space. Therefore, herbicide tolerance in chickpea is another important trait. Chickpea is sensitive to herbicides and manual weeding is currently the only option for weed control. Development of herbicide-tolerant cultivars can help in controlling weeds economically and also facilitate no-till methods, which help preserve topsoil. Presently ICRISAT, IIPR, IARI and four state agriculture universities (SAUs) are working together in a project funded by NFSM for developing machine-harvestable and herbicide tolerant chickpea cultivars.

Extra-large kabuli varieties for domestic and international market:Extra-large kabuli chickpea fetches premium price in domestic and international markets. Thus, there is a substantial area under extra-large kabuli chickpea in Madhya Pradesh, Maharashtra and Andhra Pradesh. Considering the demand of extra-large kabuli chickpea varieties in India, a research project on “Development of extra-large seeded kabuli chickpea” was funded through ISOPOM during 2006-2009. The breeding lines developed under this project have led to release of three extra-large kabuli cultivars. There is a need to enhance adoption of improved extra-large seeded cultivars. Efforts are further needed on development of better varieties which have better plant type, higher yield potential and resistance to fusarium wilt.

Super-early varieties for green grains: The immature green grains of chickpea are used as a vegetable or snack throughout India. Early flowering and low temperature tolerance are needed in a chickpea variety for early podding in northern India. Similarly, a combination of early maturity and heat tolerance is required for staggered planting and continuous supply of green seeds in other parts of India. There is a need to develop super-early chickpea varieties with acceptable seed size, resistance to fusarium wilt, tolerance to cold and heat tolerance at reproductive phase and should harvested in ~60-70 days for green pods.

Machine harvestable and herbicide tolerant varieties: Enhancing mechanization of farm operations for improving efficiency and reducing the cost of cultivation is being widely adopted in India. The farmers are demanding chickpea cultivars which can be directly harvested by combine harvesters. The current chickpea cultivars are not suited to mechanical harvesting because the plant height is not adequate and the branches are close to ground due to semi-spreading growth habit. Development of chickpea cultivars with 30 to 40% more height compared to thepresent cultivars with semi-erect to erect growth habit is essential for mechanical harvesting.

Nutritionally enhanced varieties: Chickpea is the most consumed pulse crop of India and it contains high protein content (20-22%). Though wide variation has been observed for protein content (14 to 30%) in chickpea germplasm, no efforts have been made to breed for high protein varieties. The high protein germplasm accessions already identified can be exploited for development of high protein varieties. An improvement in the protein content by 20-25% appears feasible. The high protein chickpea cultivars will improve protein availability to the people by 20 to 25% from the same amount of chickpea consumed.

Development of chickpea varieties with higher beta-carotene (precursor of Vitamin A) levels and micronutrient contents is highly desired for India where it is the most consumed pulse crop. Limited studies conducted on assessing genetic variability for nutritional quality traits in chickpea germplasm suggest large genetic variation for contents of β-carotene (0.4-0.1 μg per g seed weight), iron (35-150 ppm) and zinc (25-50 ppm). Thus, opportunities exist for developing varieties with enhanced contents of β-carotene, iron and zinc.Raffinose family of oligosaccharides (RFOs), responsible for causing flatulence uponchickpea consumption is an anti-nutritional factor associated with chickpea. A recent study indicates range of RFOs from 1.58 to 5.83 mmol/100 g seed in chickpea germplasm. The low RFO lines already identified can be used for development of low RFO containing chickpea varieties.

2. Pigeonpea

Pigeonpea is an important grain legume mostly being cultivated in Africa, Asia and Americas. The global chickpea area, production and yield (in 2013) was ~6.22 mha, ~4.74 MT and 762.4 kg ha-1respectively (FAOSTAT 2015). During 2013, ~83.09% of global pigeonpea production and ~85.50% of area was in Asia, 14.34% and 12.19% in Africa, 2.57% and 2.31% in Americas (FAOSTAT 2015). The major pigeonpea producing countries include India (63.74% of global production), Myanmar (18.98%), Malawi (6.07%), Tanzania (4.42%) and Uganda 1.98%). In India pigeonpea was cultivated on 4.65 mha with a total production of 3.02 MT and yield of 650.0 kg ha-1during 2013. It is grown as sole crop or intercrop with urdbean, mungbean, castor, sorghum, soybean, cotton, maize and groundnut in different states like Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Uttar Pradesh, Gujarat, Jharkhand, Rajasthan Odisha, Punjab and Haryana.

Pigeonpea is mostly consumed as dry split dhal besides several other uses of various parts of pigeonpea plant. It is an excellent source of protein (20-22%), supplementing energy rich cereal diets in a mainly vegetarian population. Pigeonpea is a multi-purpose crop that fits very well in the context of sustainable agriculture. In addition to food, it can be used as fodder, feed, fuel, functional utility (for making baskets, huts, fences, etc.), fertilizer (fixes atmospheric nitrogen and releases phosphorus), forest use (re-forestation, lac production), and even for pharmaceutical purposes. However, the current production of pigeonpea in India cannot meet the domestic demand leading to a decrease in per capita availability of pigeonpea from 70 gm to 35 gm. Despite the fact that a large number of high yielding varieties and have been released, productivity in the crop remains stagnant around 700 kg ha-1as compared to its potential yield (2500-3000 kg ha-1). This gap may be attributed to several biotic and abiotic factors. Since it is mainly a rainfed crop, unfavorable rainfall (delayed, erratic, improper distribution) leads to terminal drought or heavy down pour. Non adoption of improved management practices and lack of proper research and commercial perspective for the crop influence the low productivity to a greater extent.

2.1 Strategies to enhance production and productivity

Pigeonpea like most other grain legume crops has lost genetic variability during the process of its domestication. Most present day plant breeding efforts in developing high yielding varieties aim at defect elimination i.e., developing resistant varieties to biotic (wilt, SMD, Phytophthora, and pod borer) and abiotic (moisture, high or cold temperature) stresses. Systematic studies to rebuild the plant type to improve the genetic yield potential of pigeonpea are very limited. In view of above, the following strategies are needed for genetic enhancement in the crop:

Development of varieties/hybrids tolerant to wilt, SMD, pod borer and Phytophthora: The major constraints in pigeonpea production are fusarium wilt and sterility mosaic disease (SMD); and in recent times phytophthora blight is emerging as potential threat (due to climate change) to pigeonpea production causing huge yield losses. Considering the need, ICRISAT and its national partners have developed several varieties and hybrids resistant to fusarium wilt and SMD in medium duration, maturity group. Several wilt, and SMD resistant genotypes have been identified and these sources of resistance are used by national program scientists as resistant donors in pigeonpea breeding program. In the recent past efforts are intensified to develop resistant varieties for both Fusarium and Phytophthora. Helicoverpa tolerance/ resistance was identified in wild relatives and pre-breeding is underway transfer the resistant genes to cultivated lines.

Recent crop improvement efforts of ICRISAT and ICAR led to development of stable cytoplasmic and genetic male sterile system in pigeonpea; and hybrids have been developed for different agro-climatic niches. Seed production technology is also standardized for large scale production of commercial seed. There is an immediate need for exploitation of hybrid vigor by breeding heterotic hybrids for different zones in the country to improve productivity and production.

Development of extra-short duration genotypes (< 120 days maturity) to different cropping systems in north western plain zone: Extra-short duration pigeonpea has a potential to becultivated in new niches considering its photo- and thermo-insensitivity. It can grow in diverse range of latitudes (35° N) and altitudes (>1250 msl) like in Uttarakhand, Rajasthan, Odisha and Punjab. The adoption of short duration pigeonpea variety ICPL 88039 in the states of Rajasthan, Uttarakhand and Odisha has helped in improving the livelihoods of poor farmers living in the harsh environment and undulated and hilly regions. In addition to ICPL 88039, extra short duration pigeonpea varieties ICPL 85010 and ICPL 84031 varieties were also released earlier in Himachal Pradesh and Andhra Pradesh allowing farmers to grow pigeonpea in various cropping systems.

Development of genotypes (> 180days maturity) with frost resistance for north eastern plain zone: In parts of Uttar Pradesh, Madhya Pradesh and Bihar traditionally long duration varieties (>200 days) of pigeonpea are grown. These are highly photoperiod-sensitive and take about 40 weeks to mature and it exposes them to terminal drought stress at lower latitudes and to frosts at higher latitudes. Almost every year the crop is damaged by frost leading to lower yields and poor quality seeds. There is need to identify sources of tolerance/ resistance for this constraint and design appropriate breeding strategies to develop suitable varieties.

Development of super-early genotypes (90-100days maturity) for different cropping systems: Photo-and thermo-sensitivity of pigeonpea had restricted its expansion to wider latitudes and altitudes. Considering this, a breeding program was initiated at ICRISAT in 2006 to develop super-early maturing (< 100 days) pigeonpea lines. This resulted in very stable photo- and thermo-insensitive lines in determinate (ICPL 20340, ICPL 20338, ICPL 11255) and non-determinate group (ICPL 20325, ICPL 20326, ICPL 11301). These lines provide number of opportunities like pigeonpea–wheat cropping system since pigeonpea matures by 100 days provides time to prepare the land for the following wheat crop which is not possible with traditional medium duration varieties. It escapes drought, and pod borer attacks if planted early in June and harvested before those stresses occur. Introduction of super-early pigeonpea in rice-fallows not only generates additional income but also improve soil health and productivity.

Integrated Pest and Disease Management: Although pigeonpea is grown on large area, yet the production per unit is very low due to attack of pests and diseases at vegetative growth to pod formation stage. It was observed that the overall cost of cultivation decreased with the increasing adoption of Integrated Pest Management, along with promotion of improved disease resistant varieties of pigeonpea, widely grown in the semi-arid tropics of the Indian subcontinent and South-eastern Africa. Farmers often cultivate pigeonpea as mixed and intercrop. The integrated crop management technologies promoted helps other crops grown simultaneously or in rotation. Similarly, technologies dealing with avoidance of virus inoculum, vector control (for sterility mosaic disease), management of pod borer, and seed processing and storage practices are implemented in farmer participatory approach which also helps in reducing input cost of pigeonpea cultivation.

Pigeonpea, being a drought tolerant crop, is raised as a sole crop or as an inter-crop with cotton, maize, castor, sorghum or greengram. But achieving the higher and more stable yields remains the prime and high priority objective. For pigeonpea the major factors influencing adoption of new varieties are the yield potential, resistance to pests and diseases and seed availability. There are several constraints pertaining to seed availability (quantity, quality, time and prices) which hinder the adoption of improved varieties. The existing seed delivery system of pigeonpea constrains the technology adoption. Incorporation of preferred traits in the pigeonpea crop improvement programs will foster adoption. There is, therefore, no option but to concentrate on increasing the yield potential of pigeonpea by evolving such varieties of pigeonpea that are high yielding and resistant to drought conditions, pests and diseases and are of short duration with bigger sized grains, brighter yellow coloured dhal and higher recovery percentage accompanied by less wastage. Incorporation of these preferred traits would not only foster adoption at a faster rate but would also increase their marketability.

3. Lentil

Lentil (Lens culinarisMedikus), or masoor, is one of the most nutritious amongst cool season legumes, grown throughout the northern and central India for grains, which are used as dal (whole or dehulled) and in various other preparations. Lentil seeds contain 25% protein, 0.7% fat, 2.1% mineral, 0.7% fibre and 59% carbohydrate. It is rich in phosphorus, calcium, iron, zinc and carotene. Due to presence of more protein, calcium and phosphorus it is preferred fodder for animals compared to wheat straw (Gupta etal. 2013). In India, red cotyledon lentil seeds are more preferred over yellow and green cotyledons seeds while in Canada, Syria and Turkey yellow or green cotyledon seeds are preferred.

During the past few years, world production of lentil has increased from 2.76 MT to 3.60 MT. In India, lentil was cultivated on 1.42 m ha area in 2012-13 with a production of 1.13 MT (DoAC 2015). In the last two decades, the area under this crop has increased by 28% and production by 24% with a productivity increase of 6%. Lentil is mainly cultivated in Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Jharkhand, Bihar and West Bengal. It is generally grown as rainfed crop during rabi season after rice, maize, pearl millet orkharif fallow. It is also grown as intercrop with barley, linseed, mustard and occasionally with autumn planted sugarcane. In north-eastern parts of the country, lentil is also cultivated as sequentialcrop after rice, where seeds of lentil are broadcast in the standing crop of rice just before its harvest. Productivity of lentil is also limited by several biotic stresses such as diseases and pests and weeds (Gupta 2014; Kumar et al. 2013), hence breeding strategies need to include development of varieties with multiple resistances.

3.1 Strategies to enhance production and productivity

Lentil is mainly grown under harsh environmental conditions, and realization of yield potential depends on the stored moisture from the previous rainy season and rainfall during crop growth. There is an urgent need to develop climate smart varieties for rainfed conditions and suitable for late sown areas. Some of the strategies to enhance production and yield of lentil are enumerated below.

Germplasm enhancement and pre-breeding: The recent approach on hybridization of diverse genotypes from different agro-climatic zones of India and utilization of exotic lines in hybridization has also helped in broadening the genetic base and several good varieties have been developed both in small- and large-seeded background. Wide hybridization involving closely related species is yet to be explored for germplasm enhancement. Systematic pre-breeding efforts are being made through IIPR and ICARDA collaborations, and are likely to result in identification of new sources of resistance/tolerance to diseases, insect pests, nematodes and post emergence herbicides. The power of genomic resources would enable breeders to effectively go for the transfer of targeted genes for resistance to different diseases and pests and incorporation of traits being controlled by many genes (Chamarthi et al. 2011). The recent efforts on decoding of lentil genome will definitely help in development of more robust genomic resources for practical breeding leading to varieties release.

Early maturing varieties for rice fallow areas: A substantial area of lentil is sown under late sown condition in rice-fallowfields of Indo-Gangetic plains. Early maturing varieties possessing high biomass and tolerance to high temperature at reproductive stage are required. Varieties should have resistance to diseases like stemphylium blight, rust and wilt; tolerance to low temperature at vegetative stage and high temperature at reproductive stage, and terminal soil moisture stress. The rice varieties should be early maturing and have less re-growth; and lentil varieties should have herbicide tolerance.

Nutritionally dense Varieties for culinary and export purpose: Accelerated productivity gains are required for enhancing total production of protein, by enhanced yield and increasing seed protein content. Systematic bio-fortification research has to be given top priority to enhance availability of minerals like Fe and Zn (Gupta et al. 2013). Ample scope exists for development of extra-large seeded lentil varieties for so that farmers can get more money from per unit area of cultivation. The extra-large seed are already being utilized for preparation of snacks.

Restructuring existing plant type: There is need to reduce cost of cultivation. Accordingly, need is being felt to understand vegetative and reproductive components to develop the physiologically efficient plant types so that more solar light interception can be ensured to have proper partitioning of photo-synthates. Lentil varieties amenable for mechanized harvesting can provide a viable option to the farmers to reduce cost of cultivation. Hence tall, erect, non-lodging and non-shattering varieties will be suitable.

Climate smart varieties: Lentil production is limited by lack of proper soil moisture and warm temperatures in major lentil growing areas. Little progress has been made in development of drought tolerant varieties ensuring increased water use efficiency.Genotypic differences for waterlogging have been reported in literature. Genotypes like, ILL 5845, ILL 6451, ILL 6788 and ILL 6793 possess relative tolerance to salinity. Recent efforts have resulted in identification of heat tolerance in lentil. There is need to develop phosphorus acquisition efficient lentil varieties those can extract phosphorus even when soil phosphorus status is low. Efforts needed to combine tolerance against different stresses, so that lentil varieties resilient to climate change can be developed.

There is need to have seed multiplication rolling plan to achieve required seed replacement rate. Results of 6000 technology demonstrations have indicated vast yield gaps which exist between realizable and realized potential in terms of productivity enhancement. Systematic transfer of available technologies have potential to enhance lentil yield by at least 20-25%.

4. Mungbean (Green gram)

Green gram or mungbean (Vignaradiata L. Wilczek) is an important short duration grain legume which can be grown in varying environmental conditions, during all three crop seasons viz., kharif, rabi and spring/summer in different parts of the country, as sole or intercrop for grain and green manure. The major portion is utilized in making dal, curries, soup, sweets and snacks. The germinated seeds have high nutritional value compared with asparagus or mushroom. There is an increase in the thiamine, niacin and ascorbic acid concentrationwith sprouting..Mungbeanhas easily digestible protein. The mungbean seeds contain approximately 25-28% protein, 1.0-1.5% oil, 3.5–4.5% fiber, 4.5–5.5% ash and 62–65% carbohydrates on dry weight basis. The concentration of sulphur containing amino acid methionine and cystine are low. Lysine values are comparatively high, hence the protein of mungbean is an excellent complement to rice in terms of balanced human nutrition.Mungbean seeds also contain isoflavons(Narasinga Rao, 2002), and isoflavons content of pulses has been reported to increase after germination (Sharma 1981), and hence consumption of germinated pulses is preferred by many people.

Mungbean is grown throughout Asia, Australia, West Indies, South and North America, Tropical and subtropical Africa. However, India alone accounts for 65% of the world acreage and 54% of the world production. During 2012-13, 1.19 MT of mungbean was produced from 2.71 m ha area distributed over different seasons. Rajasthan, Andhra Pradesh, Maharashtra, Odisha, Uttar Pradesh, Bihar, Punjab, Tamil Nadu, Karnataka, Gujarat etc. are major mungbean producing states.Mungbean is grown mostly during rainy season, however development of short duration and disease resistant varieties opened doors for its cultivation during spring/summer season (Chaturvedi and Asthana 1999) in almost all parts of country and during rabi season (rice fallows) in peninsular India.

4.1 Strategies for increasing production and productivity

Among various pulse crops grown in India, mungbean offers good potential for bringing additional area and enhancing production and productivity, as varieties with varying maturity groups exist to meet the needs of different cropping systems. Recently, the availability of draft genome sequence of mungbean has opened doors for development of genomic resources for utilization in crop breeding(Nadarajan and Chaturvedi 2010). The following research strategies are being suggested to enhance production and productivity of mungbean in India.

Germplasm enhancement and pre-breeding: Systematic identification of donors possessing traits of economic importance, quality traits, and resistant sources against biotic and abiotic stresses is pre-requisite for any crop improvement programs. Wild relatives of Vigna i.e., V. radiata var.sublobata and V. mungo var. silvestris have resistance to MYMV and bruchids. The gene introgression derivatives have potential for yield contributing traits and disease resistance. These derivatives facilitate further genetic enhancement in mungbean. During recent past, wide hybridization has resulted in development of several high yielding varieties of mungbean and these are being grown by farmers in different parts of the country.

Climate resilient varieties: Mungbean is known to have good tolerance to high temperature. Accordingly, its cultivation during spring and hot summer of northern and north-eastern parts of the country is now reality. Development of photo- and thermo-insensitive varieties will help in developing variety for different seasons and agro-ecologies, and for non-traditional regions and seasons. This will also help in large scale seed production of high yielding varieties as per demand.

Biotic stress resistance: Large numbers of viruses, fungal and bacterial diseases are known to damage mungbean crop at different stages of crop growth and during storage. Pyramiding of genes for resistant to major insect pests (thrips, jassids and pod borer) and diseases (yellow mosaic virus, anthracnose, powdery mildew, Cercospora leaf spot, etc.) for which high level of resistance is not available in cultivated germplasm, and identification of donors from diverse germplasm is of paramount importance. Pyramiding of useful genes to develop multiple stress resistant varieties is needed through deployment of molecular markers in breeding programs. Similarly, incorporation of bruchids resistance will help in minimizing post-harvest losses during storage.

Short duration varieties for crop diversification: Presentlyseveral varieties maturing in 60-65 days are available for large scale adoption. However, most of these do not have distinct vegetative and reproductive phase so that these can fit well in narrow windows of cereal- cereal cropping system. The indeterminate nature of present day varieties do not allow single harvest, and rains at physiological maturity lead to reversal of reproductive to vegetative phase. The incorporation of seed dormancy or pre-harvest sprouting will help in minimizing damage by rains during crop maturity. There is further need to reduce maturity duration at least by another 8-10 days to fit mungbean varieties for sustainability of wheat-rice dominated cropping system. Reduction in maturity duration will also reduce water requirement to the crop ensuring more profit to summer mungbean growers. Similarly additional area of 2.7 m ha under mungbeanis possible in southern and coastal India during rabi season under rice-rice cropping system. Inclusion of mungbean in between rice and wheat and rice-rice cropping systems will provide for long term sustainability and help in protecting the environment from the risk associated with mono-cropping and high input agriculture.

Restructuring plant type: Most of the mungbean varieties are largely photo- and thermo-sensitive, have indeterminate growth habit, low harvest index and low grain yield. Mungbean has to fit in gaps in high input cereal– cereal dominated cropping systems, to remain a commercially competitive crop. There is need to restructure existing plant types so that future varieties with determinate growth habit, photo- and thermo-insensitivity, early maturity, high harvest index and high yield (>2.0 tones ha-1) and resistant to lodging can be released for large scale cultivation. Good seedling vigour with a clear-cut distinction between vegetative and reproductive phases will be essential components of the restructured plant types.

Results of the front-line demonstrations have clearly indicated the scope for enhancing yields at farmers' fields following systematic technology transfer particularly in spring/summer season. Since the crop fits well in small window after harvest of rabi crop (such as wheat and rabi maize) and kharif cereals (such as rice and sorghum) in irrigated conditions, mungbean cultivation will help in sustaining productivity of the cereal based cropping systems in different parts of the country.

5. Urdbean(Black gram)

Urdbean[Vignamungo (L.) Hepper] or black gram is one of the most important cultivated pulse crops of the 'Vigna' group. It is cultivated since prehistoric period in India and considered to be originated from Vignasilvestris. Archeological studies have shown that urdbean was cultivated in the country as far back as 2200 B.C. It is a short day photo-and thermos-sensitive crop. However, completely photoperiod insensitive to highly sensitivegenotypes are known.

Major portion of urdbeanis utilized in making dal, for curries, soup, sweets and snacks. In South India, the most popular Idli and dosa are prepared using mixed proportions of rice and urdbean. The food values of urdbean lie in its high and easily digestible protein. Urdbean seeds are known to contain high protein (25-28%), oil (1.0 -1.5%), fibre (3.5 – 4.5%), ash (4.5 – 5.5%) and carbohydrates (62 – 65%) on dry weight basis. Amino acid analysis indicates that as with most grain legume crops, the concentrations of sulphur containing amino acid (methionine and cystine) are small.

The area, production and productivity of urdbean has increased from 1.87 m ha in 1971–72 to 3.11 m ha during 2012-13 with production level of 1.90 MT. This increase in production has been due to additional area brought under the crop as well as productivity gains (from 0.5 to 1.3 t/ha). Summer cultivation in northern India and winter cultivation in rice fallows in southern and coastal areas of the country also added to additional acreage. In India, Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, Maharashtra, Rajasthan, Odisha, Bihar, Karnataka and West Bengal are major urdbean producing states. Urdbean is grown mostly during rainy season, however, development of short duration and diseases (powdery mildew and yellow mosaic virus) resistant varieties led its cultivation during spring/ summer season in almost all parts of country and during rabi season (in rice fallows) in peninsular India. Since the crop is highly photo-thermo-sensitive, due care is required during seed supply.

5.1 Strategies for increasing production and productivity

Germplasm enhancement and pre-breeding: Narrow genetic base of the present day cultivars as indicated by pedigree analysis of released cultivars in urdbean indicate that a fewer number of parents with high degree of relatedness were repeatedly used in crossing program resulting in low yield gains in new varieties. This clearly indicates the requirement for diverse germplasm lines for development of biotic and abiotic stresses resistant/tolerant varieties(Chaturvedi 2009). The wide hybridization involving wildVigna species is needed to broaden the genetic base so that vulnerability to diseases, insect pests and abiotic stresses can be minimized.

Short-duration varieties for sustainability of cereal-based cropping system: The expansion of cereal –cereal rotation poses a serious threat to the sustainability of production system as indicated by a decline in total factor productivity in high input agriculture of Haryana, Punjab and western Uttar Pradesh(IIPR Vision 2050). Being a short duration and nitrogen fixing crop, urdbean fits well in multiple cropping systems and can provide desired sustainability to cereal based cropping systems. Considerable scope exists to bring additional area under urdbean through inclusion of short duration urdbean varieties between two cereal crops in many parts of the country where irrigation facilities are available. There is further scope for increasing area, hence the need to develop short duration and high yielding varieties with better biomass for spring/summer or rabi seasons.

Varieties with multiple diseases resistance: Crop breeding has contributed significantly in developing varieties with desired traits including disease pest resistance. Varieties developed in past with resistance to single stress may not be a viable solution as new diseases and pests are emerging and incidence of diseases and insect pests is often unpredictable. Therefore varieties having resistance to more than one stress provide greater insurance and stability of crop production. Combining resistance to major diseases in desirable background will help in consolidating the yield level and production.

Development of efficient plant type: The plant type of the present day varieties of urdbean is largely photo- and thermo-sensitive, indeterminate growth habit,with low harvest index and poor grain yield. An efficient plant type would be photo-thermo-insensitive, with determinate growth, early maturing, high yielding (>2000 kg ha-1) with high harvest index. Good seedling vigourwith a clear cut distinction between vegetative and reproductive phages will be essential components. At the same time, insulation of varieties against major diseases and insect pests will be required (Gupta, 2014).

Developing herbicide tolerant varieties: Since urdbean is known to have slow initial growth, weeds pose serious threat to urdbean cultivation during kharif season and under rice-fallow situations. Hence, there is need to incorporate high seedling vigour and post emergence herbicide tolerance in urdbean varieties. A systematic germplasm and wild relatives should be screened to identify sources of herbicide tolerance and introgress in adapted varieties.

Limited work has been done to enhance urdbean production in India during last two decades. Systematic research led to development of several high yielding varieties for cultivation in coastal areas of Andhra Pradesh that helped in enhancing production of urdbean in the 1990s. However, the productivity gains could not be realized due to slow seed replacement rate of improved varieties. There is urgent need to develop climate smart varieties and matching crop production technologies.

6. Fieldpea (Dry pea)

Field pea (Pisumsativum L.) is one of the important rabi pulse crops grown in India that serve as a source for food, feed and vegetable. There are two distinct types of peas grown in India viz., (i) vegetable type characterized by sweet grains when green and become wrinkled on drying, and (ii) dry grain type that generally has white and round seeds. Often pea flour is mixed with chickpea flour to prepare varying types of snacks. The cultivation of grain type is confined to northern and central parts of the country, whereas vegetable types are also grown in cooler parts of southern India. Recently, breeders have also developed intermediate type, green and round seeded or dual purpose varieties with high yield potential.

In India, fieldpea is grown on about 0.76 m ha areas with an annual production of 0.84 MT showing productivity of >1.1 t/ha during 2012-13. Crop is largely cultivated in Uttar Pradesh, Madhya Pradesh, Bihar, Maharashtra, Haryana and Rajasthan. Its cultivation is also confined to the rainfed areas and marginal and sub-marginal lands with poor soil fertility, however, with the development of input responsive dwarf type varieties farmers often irrigate crop to achieve higher yields in central and northern India. Usually tall type varieties without tendrils are preferred for rainfed conditions.

Fieldpea grains are rich in protein (20%), essential amino acids and minerals important those are important for human health. Pea contains 4 mg pro-vitamin A, 300 mg vitamin C, 3 mg B1, 1.5 mg B2 and 1.2 mg pantothenic acid per 1000 g fresh seed weight. Grains also contain 1.1% fat, 2.2% minerals, 4.5% fibre and 56.5% carbohydrate. Green pea and the immature pods of pea have high level of active lipotropic anti-sclerotic substances--choline and inositol. Choline deficiency may lead to the development and growth of malignant tumors. Grains also contain anti-nutritional factors and consumption in large quantity leads to flatulence.

6.1 Strategies for increasing production and productivity

Restructuring plant types for lodging resistance and mechanical harvest: The traditional tall varieties tend to lodge leading to yield penalty. A plant type with strong and thick stem can keep plant standing and erect till maturity and will help in increasing the yield potential. The 'tendril' trait needs to be combined with high biomass so that plant populations per unit area can be increased besides having varieties with lodging resistance. The non-lodging types will also be suitable for mechanical harvesting.

Dual purpose, short duration varieties: The demand for animal feeds and fodder will increase in the years to come and, therefore, a highly productive crop like field pea can play an important role to meet out the demand. Accordingly, development of dual purpose feed-forage varieties possessing high biomass and early maturity would be priority for field pea breeders. Thus, the future needs of pea breeding will be develop dwarf, non-lodging and disease resistant varieties. Early maturing varieties will allow cultivation of late sown wheat (if harvested for green immature pods) or spring season mungbean and urdbean. There is ample scope of bringing more area under extra-early maturing field pea varieties in northern India.Transfer of available technology can bridge the vast gaps which exist between realizable and realized potential in terms of productivity enhancement. However, paradigm shift is required in policies to bring additional under this crop.

7. Use of Genomic resources and approaches in developing improved varieties

Rapid advancements in development of genomic resources have made it possible to use genomics-assisted breeding in legumes improvement, especiallyfor resistance abiotic and biotic stresses. Significant progress in developing legume genomic resources has taken place in the last decade. This has been made possible due to financial support and coordinated efforts of several international (Bill & Melinda Gates Foundation, CGIAR Research Programs, National Science Foundation – USA, American Peanut Council, etc.) and national (Indian Council for Agricultural Organization (ICAR), Department of Biotechnology, Department of Science & Technology, and Ministry of Agriculture, Government of India) level organizations. This strong financial support and efficient team work resulted in developing a huge cache of genomic resources such as molecular markers, genetic and molecular maps, and quantitative trait loci (QTL) for important agronomic characters, and most importantly initiating the marker-assisted breeding. Additionally, whole genome sequencing of some legume crops has been completed (pigeonpea and chickpea) and sequencing efforts are underway in others (ex. Groundnut, lentil, etc.). The latest advances in the field of genomic resources are available on web-based platforms like: (i) International Chickpea Genetics and Genomics Consortium (http:// www.icrisat.org/gt-bt/ICGGC/home.html) (ii) International Peanut Genome Initiative (http:// www.peanutbioscience.com) and (iii) International Initiative on Pigeonpea Genomics (http:// www.icrisat.org/gt-bt/iipg/home.html).

7.1 Genomic Resources

Molecular makers:Among the different DNA-based marker systems available, 'microsatellites' or 'simple sequence repeats [SSRs]' are markers of choice, especially for plant breeding applications. SSRs amplify the unique sequences flanking the repeat units and polymorphism is detected by the differences in number of repeat units amplified. Co-dominant inheritance and multi-allelic nature of these markers makes them suitable for genotyping and detection of allelic variants. Another advantage with these markers is that SSRs developed for a particular species can also be used in related species (cross species utility). SSR development is largely based on size-selected DNA libraries, mining of expressed sequence tags (ESTs) or bacterial artificial chromosome (BAC)-end sequences (BESs). As per Varshney et al (2013) about 3000-6000 SSR markers are available in three legume crops (chickpea, pigeonpea and groundnut).

'Single nucleotide polymorphisms [SNPs]' are another class of markers that indicate single nucleotide (A, T, C, or G) difference in gene/genome between member species. In addition to their higher abundance and amenability to high-throughput, SNPs are the most common type of nucleotide variations either in plants or humans. SNPs can be found either with in a gene or outside. Although they may not be associated with any character/trait, but they certainly act as marker for that trait. In legumes SNPs have been identified using 'Sanger ESTs', allele-specific sequencing of candidate genes, tentative orthologous genes (TOGs) developed based sequence similarity and next generation sequencing (NGS) technologies (454/FLX or Illumina/Solexa). NGS has been utilized in identifying about 26, 082 and 12,141 potential SNPs in chickpea and pigeonpea respectively (Hiremath et al 2011; Dubey et al 2011). Furthermore, 8486 SNPs were identified in groundnut using 454/FLX-sequencing technology (Varshney et al 2013). Genome sequencing efforts of mung bean has additionally yielded several thousands of potential SNPs and SSRs. Appropriate SNP genotyping platforms (Illumina GoldenGate Assay, Illumina GoldenGate SNP array, VeraCode Assay, and KASPar assay) have been developed for different legume crops.

'Diversity array technology [DArT]' is microarray-based hybridization procedure that is used to detect presence versus absence of a particular sequence or fragment in genomic representations. It is mainly used in diversity studies, for detecting genome introgressions from other species and saturating linkage maps. Joint efforts of ICRISAT with DArT Pvt Ltd, Australia were successful in developing DArT arrays with 15,360 features for different legume crops. Both SNPs and DArT systems enables the researchers to analyse genomes without prior knowledge of DNA sequence.

Transcriptome and genome sequencing: Prior to the availability of low-cost next generation sequencing (NGS) technologies for genome sequencing, Sanger sequencing technology was used for transcriptome sequencing to access genes in many legume crops. Utilizing transcriptome sequencing technologies about 20162EST were identified in chickpea and 9888 EST in pigeonpea (Varshney et al 2009; Raju et al 2010). Several research groups have used transcriptome sequencing techniques to identify several thousand additional ESTs in different legumes. Furthermore, more than 250,000 Sanger ESTs are available for groundnut in the public domain (http://www.ncbi.nlm.nih.gov/sites/gquery, as of 2012). Though transcriptome sequencing contributed significantly, genome sequencing is the ultimate approach to identify all the possible genes in a crop species. Genome sequencing helps in understanding the genome structure, identifies genes and provides tools for gene mapping/isolation and molecular breeding. Availability of low-cost NGS technologies has made it feasible to sequence legume crops. Among the important grain legumes, pigeonpea, chickpea, mung bean (Vignaradiata) and common bean (Phaseolus vulgaris) genomes have been sequenced and their draft genomes have been published. The genome size of the sequenced legumes is as follows: (i) desi chickpea – ~520 megabase (MB); kabuli chickpea – ~740 MB (ii) pigeonpea - ~833MB with 48,680 genes (iii) mung bean – ~548 MB with about 22, 427 genes (iv) common bean – 587 MB with 27,197 protein-coding genes.

Genetic maps and QTLs: Development of genetic maps has helped in identification of molecular markers specific for several agronomically important characters. Both inter- and intra-specific mapping populations have been developed and these have been used to generate genetic maps in different legume crops. In chickpea, several workers (Gujaria et al 2011, Thudi et al 2011 and Choudhary et al 2011) have utilized a mapping population developed from a cross between ICC 4958 x PI 489777. Genetic maps integrated with several thousand markers of different types (SSRs, DArT and genic molecular markers [GMMs) have been developed using this population. Additionally, Hiremath et al (2012) have developed a genetic map including 625 'Chickpea KASpar Assay Markers (CKAMs)', 314 TOG-SNPs, and 389 published marker loci. Furthermore, molecular markers associated with several important traits have also been identified like resistance to Fusarium wilt/rust, tolerance to salinity, seed traits and grain yield in chickpea.

In case of pigeonpea, the development of genetic maps has lagged behind compared to others due to lack of sufficient number of DNA markers and less or limited genetic variability. But, due to the development of low cost-NGS platforms large scale SSR and SNP markers have been developed. The availability of these markers facilitated the development of several inter- [ICP 28 (C. cajan) x ICPW 94 (C. scarabaeoides)] and intra-specific genetic maps (TTB 7 x ICP 7035; ICPB 2049 x ICPL 99050; and ICPA 2043 x ICPR 2671). This inter-specific genetic map consists of 239 SSR markers covering a distance of ~930 cM. Additionally, this inter-specific mapping population was used for developing DArT-based maternal- and paternal specific genetic maps. Availability of genetic maps with extensive phenotypic data has helped in identifying of QTLs/ markers for important traits like SMD and fertility restoration in pigeonpea.

Several genetic maps saturated mostly with SSR markers have been developed in groundnut and some of these are trait-specific (drought tolerance related traits and foliar diseases). These individual maps have been used in developing a consensus map for drought traits and foliar diseases separately with 293 and 225 SSR loci respectively. These consensus maps coupled with other dense genetic maps with uniformly distributed markers are very valuable resources for selection, diversity analysis and to develop other genetic maps. These efforts have resulted in identification of several epistatic QTLs for drought tolerance related traits. Similarly, QTL analysis based on phenotyping and genotyping data of two different recombinant inbred line (RIL) populations has resulted in identification of 28 QTLs for late leaf spot (LLS) and 13 QTLs for rust. Further, a major QTL for rust (82.96 PV) and LLS (62.34 PV) have been reported and their associated markers validated. Additionally, QTLs for protein content, oil content, oleic and linoleic acid, and tomato spotted wilt virus have also been identified. These genomic resources complement the groundnut breeding efforts significantly by increasing the efficiency and reducing the time/labour.

A backcross population (BC1)based-molecular map (Florida map) was developed in common bean by Vallejos et al (1992). This mapping population was also used to map a QTL for bacterial blight resistance. This map consisted of 294 molecular markers along with pigmentation gene 'P'. An F2-population derived by crossing parents of two different gene pools ('Middle American' and 'Andean') was used to develop 'Davis map'. 'Davis' and 'CIAT' maps were utilized to localize anthracnose resistance genes and for QTL analysis of tannin content respectively. The 'CIAT' map has also mapped several SSR and SNP markers. Additionally, several RILs have been developed in common bean. Further, a saturated and integrated (physical and genetic) common bean genetic map using BAC-derived microsatellite markers has been developed by Córdoba et al (2010). Yuste-Lisbona et al (2014) have identified QTLs for various key pod traits which could provide opportunities for bean breeding by improving efficiency, selection for improved pod traits.

Several dense molecular map have been developed using different type of markers in few other legumes including blackgram (Vignamungo; Gupta et al 2008), cowpea (Vignaunguiculata; Ouedraogo et al 2002), faba bean (Viciafaba; Roman et al 2002), adzuki bean (Vignaangularis; Han et al 2005) and lentil (Lens culinaris; Tullu et al 2008). An interesting study by Fedoruk et al (2013) reportedQTLs for seed diameter, and plumpi-ness in lentil. Further, the authors developed a genetic map (of 697cM) integrating ~560 markers in seven linkage groups. QTLs identified in several legumes are presented in Table 1.

Genomics-assisted breeding (GAB): Integrating genomic tools with conventional breeding approaches for improvement of trait of importance is often referred to as 'GAB'. The term 'GAB' includes proteomics and transcriptomics along with genomics. The development of efficient 'NGS' platforms and high-throughput genotyping technologies has led to better prediction of phenotype of progenies in breeding programs. Based on these and other emerging technologies several breeding approaches like 'Marker-Assisted Backcrossing (MABC)', 'Marker-Assisted Recurrent Selection (MARS)', 'Genome-Wide Selection/Genome Selection (GWS/GS)', and 'Advanced Back-Cross QTL (AB-QTL)' have been advocated (Varshney et al 2013). These approaches are briefly described below with examples.

MABC involves the use of molecular markers in introgression of a trait of importance from 'donor' parent into a 'recurrent' parent, usually an elite or leading variety/cultivar. This approach leads to developing a cultivar/line with the whole genome of recurrent parent but containing the major gene/QTL for the trait of interest. The only limitation with this approach is that it can used for transfer of limited number of loci including transgenes from donor to recurrent parent. MABC can also be used to develop near-isogenic lines or chromosome substitution lines (CSSLs), which could be used in genetic analysis of QTLs. MABC has already been used in developing an improved groundnut variety 'Tifguard High O/L' containing DNA fragment carrying root-knot nematode resistance. Additionally, several efforts utilizing MABC have been initiated in groundnut (leaf rust QTL introgression) and chickpea (Fusarium wilt, Ascochyta blight resistance and drought tolerance).

MARSis routinely used in cross-pollinated crops, using markers for selection, can increase its efficiency. First, the QTLs are identified in the breeding population and thereafter lines carrying superior alleles are crossed to introgress major alleles in to one genetic background. These improved lines are further evaluated phenotypically and best lines selected for multi-location testing. The advantage with MARS is that it helps to pyramid several minor and major QTLs, genetic gain is higher in MARS compared to MABC. MARS is mostly employed by several multinational corporations (maize and soybean) and few public sector institutes (wheat, sorghum, rice and chickpea).

GS/GWS identifies better performing lines with higher breeding value using genome-wide marker profile data. Since the breeding values are estimated based on genome-wide marker profile data they are referred to as genomic-estimated breeding **values (GEBVs). GS/GWS employs two types of populations:** (i) training population and (ii) candidate population. Phenotyping and genotyping data generated are used for estimating GEBVs of the lines. Similarly GEBVs for progenies of candidate population are estimated and superior lines selected for making crosses. In this way progenies can be selected based on higher GEBVs and these can further be utilized in next breeding cycle or can be field tested and advanced for multi-locations trials. Significant positive attributes of GS/GWS include: (i) phenotyping frequency is reduced leading to an overall decrease in duration and costs (ii) there is no need for QTL mapping (iii) length of selection cycle is reduced. But, availability of appropriate statistical model to estimate GEBV with higher precision is very critical. Several models including 'Best Linear Unbiased Prediction (BLUP)', 'Bayesian Methods (Bayes B)', and 'Weighed Bayesian Shrinkage Regression (wBSR)' are available to estimate GEBVs. Though GS/GWS is not widely used in legumes presently but, it has the potential to be applied in the future.

IV. Creatingthe PulsesRevolution in India

Pulsesare playing a vital role in ensuring the food and nutritional security in India. However, there is a huge gap in supply and demand of many of the pulse crops. There is a huge potential for substantially enhancing production of pulses in India, primarily by increasing productivity and to some extent increasing area. A large gap exists between the average yields received by farmers and the yields obtained in research stations and well managed farmers' fields. The adoption of high yielding cultivars/hybrids and improved crop management practices can increase the yield substantially. There is also a scope of enhancing area in the rice-fallows of eastern India (and possibly other rice-fallow areas, and also in the hilly areas where some of the improved extra- short and short-duration varieties.

Some of the interventions that can bring a pulses revolution in India are listed below:

a. Promoting cultivation of early maturing, heat tolerant varieties for expanding rabi pulses (chickpea, lentil, field pea) cultivation in rice-fallows of eastern India:Vast areas of rice-fallows (about 10 million ha) available in eastern India (Jharkhand, Bihar, Chhattisgarh, Odisha and West Bengal) offer opportunities for expanding area under rabi pulses. The earlier experiments clearly demonstrated that chickpea, lentil and field pea are suitable pulse crops for rice-fallows, provided suitable varieties and technologies for crop establishment in rainfed rice-fallows are available. The most important traits required in the varieties for rice-fallows include early growth vigor, early to extra-early maturity, and tolerance to reproductive stage heat stress. For example, an early maturing and heat tolerant chickpea variety JG 14 (ICCV 92944) released for late sown conditions of Madhya is already becoming popular in Eastern India. This variety and other heat tolerant varieties can be promoted along with suitable sowing equipment and technologies for ensuring better crop establishment and plant stand. . Similarly, early maturing varieties of lentil like Pant L 6, HUL 57, DPL 62, Moitree etc. are getting popularity among farmers of eastern Uttar Pradesh and Bihar as these varieties are suitable for late sown and rice fallow conditions. Recently, short duration field pea varieties viz., Vikas and Prakash are being accepted by the framers of North East Hill states of India as farmers are getting more price when they sale immature pods in market.

b. Promoting early-maturing, drought and heat tolerant and disease resistant varieties for central and southern India:Drought and heat stresses during the reproductive phase and with increasing severity towards the end of the crop season are the major abiotic stresses of chickpea and other rabi pulses as these crops are generally grown rainfed (68%) on residual soil moisture and experiences progressively receding soil moisture conditions and increasing atmospheric temperatures towards end of the crop season. Early maturity is an important trait for escaping these terminal stresses. In addition, we need cultivars with enhanced tolerances to these stresses. For example, some of the promising varieties of chickpea possessing these traits include JG 11, JG 130, JAKI 9218, KAK 2 and Vihar. The adoption of such varieties needs to be enhanced in central and southern India. . Farmers of central India usually have preference for large seeded lentil varieties. Considering the demand several early maturing varieties having large seeds were released for cultivation. Out of these varieties, DPL 62, JL 3, IPL 316 and IPL 526 are getting popularity in Bundelkhand tracts of Uttar Pradesh and Madhya Pradesh. Government of Karnataka has also taken initiative to promote early maturing lentil varieties in state. Similarly, early maturing fieldpea varieties like Adarsh, DDR 23, Ambika, Vikas, Indra, Shikha and Prakash are very popular and have helped in enhancing fieldpea productivity (1100 kg ha-1) in India. During 2013, a early maturing green seeded variety 'IPFD 10-12'has been released for cultivation in central India. This variety has potential to replace some of the area of vegetable type pea. In southern India, fieldpea is a less known crop but have vast potential during kharif season. For example, many farmers in adjoining of Dharwad in Karantaka have already started cultivation of pea during kharif season. These varieties offer ample scope in central and southern India.

c. Extra-short and short-duration pigeonpea in high elevation and rice-fallow cropping system:Early duration pigeonpea varieties have a potential to grow in new niches considering its photo and thermo insensitivity. It can be grown in diverse range of latitudes (30° N) and altitudes (1250 msl) like in Uttarakhand, Rajasthan, Odisha and Punjab. For instance, ICPL 88039, a short duration (140-150 days) pigeonpea variety, can enhance pigeonpea production in the states of Rajasthan, Uttarakhand and Odisha. This variety provides an opportunity to increase crop intensity by growing a post-rainy season crop after harvesting pigeonpea. Since its cultivation does not require any additional inputs and the grains have good market value, its adoption by the farmers will be quick. Similarly,super-early lines (ICPL 11300, ICPL 11285 and ICPL 20325) maturing in 90 days have potential to be adaptive and productive in the rice-fallow cropping system and rainfed hilly areas of India.

d. Expanding pigeonpea hybrid production: During the past 5 decades, pigeonpea productivity in India has remained almost stagnant around 700 kg ha-1. In this context, the hybrids can produce more biomass (more than 50%) and productivity (more than 30-40%) than varieties. ICRISAT and its partners have developed the hybrid technology in pigeonpea. In the past 6 years, several hybrids (ICPH 2671, ICPH 2740, and ICPH 3762) have shown enhanced productivity and adaptability in Maharashtra, Andhra Pradesh, Odisha, Telangana State, Madhya Pradesh, Karnataka and Jharkhand. ICRISAT and partner institutions (Department of Agriculture, State Agriculture Universities, public and private organizations, and farmer organizations) can expand commercial hybrids substantially.

e. Promotion of pulses in intercropping systems and non-traditional areas:Pulse crops are grown as intercrops in many parts of the country during all three crop seasons (rabi, kharif and spring/summer) and forms integral part of rainfed agriculture. Vast potential exists for promotion of pulse crops in intercropping system as an intercrop. For example, chickpea/ lentil + autumn planted sugarcane in western Uttar Pradesh, Terai region of Uttar Pradesh, Maharashtra and Karnataka; mungbean + long/medium duration pigeonpea in Uttar Pradesh, Bihar, Jharkhand, Madhya Pradesh, Maharashtra and Gujarat; chickpea/lentil + mustard in Rajasthan, southern Madhya Pradesh and Uttar Pradesh; pigeonpea + soybean; andpigeonpea + sorghum etc. (see Table below) offers not only scope to enhanced pulses production but also to ensure sustainable agricultural production base.

Table: Details of bringing additional area under pulses

	Potential crop/cropping systems/Niche	Specific area
1	Intercropping	
	Mungbean with ratooned Sugarcane during spring/ summer (irrigated) Mungbeanwithcotton and millets (rainfed uplands)	Uttar Pradesh (excluding Bundelkhand parts), Bihar, Maharashtra, Andhra Pradesh and Tamil Nadu
	Pigeonpea with soybean, sorghum, cotton, millets and groundnut (rainfed upland)	Andhra Pradesh, Malwa region of Madhya Pradesh, Vidarbha of Maharashtra, North Karnataka, Tamil Nadu
	Chickpea as intercrop with barley, mustard, linseed and safflower (rainfed)	South East Rajasthan, Punjab, Haryana, Uttar Pradesh, Bihar, Vidharbha region of Maharashtra
	Chickpea or lentil with autumn planted sugarcane	Maharashtra, Uttar Pradesh, Bihar
2.	Mungbean: sole crop in spring/summer season (irrigated)	Western and Central Uttar Pradesh, Haryana, Punjab, Bihar, West Bengal
3.	Rice fallow areas	
	Chickpea	Eastern Uttar Pradesh, Bihar, Jharkhand, Orissa, Chhattisgarh, West Bengal
	Urdbean/ Mungbean	Andhra Pradesh , Tamil Nadu, Orissa, Karnataka
	Lentil	Eastern U.P., Bihar, West Bengal, Assam, Jharkhand
	Lentil/fieldpea	North-East
3.	Urdbean in Kharif fallow of Bundelkhand	Uttar Pradesh and Madhya Pradesh
4.	Lentil in Diara lands	Uttar Pradesh and Bihar
5.	Pigeonpea in foot hills of Terrain sloping lands	Uttarakhand, North Bihar

f. Knowledge empowerment of farmers and making seeds and other inputs available to farmers:There has been slow adoption of improved cultivars and production technologies by farmers. The major reasons include unawareness of farmers about improved cultivars and technologies or unavailability of seeds and other required inputs. Concerted efforts on training and other awareness activities for farmers, strengthening formal and informal seed systems and increasing access to other inputs are needed for enhancing adoption of improved cultivars and technologies. Considering the huge requirement of quality seed of improved varieties, and limited interest of private players in the pulses seed sector, there is need to encourage 'Seed Village' concept through involvement of farmers in quality seed production. We will also need to develop good linkages between the formal and informal seed system so that the entire seed system chain can be strengthened. It is also a known fact that many tribal and poor farmers of Jharkhand, Chattisgarh, Assam and North East Hill region usually consume or sell green immature pods of chickpea and field pea, therefore proper training and awareness among farmers need to be created for production of quality seeds, and policy support from government is inevitable.

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Table1. QTLs identified in different cultivated legumes

Crop	Scientific Name	Traits	QTL/gene	Marker Type	References
Black gram	*Vignamungo*	Yellow Mosaic Virus (YMV)	Monogenic	STS-RGA	Basak et al 2004
Chickpea	*Cicerarietinum*	*Ascochyta blight*	QTL, AR19	RAPD	Millan et al 2003, Cobos et al 2005; Rakshit et al 2003
			QTL_{AR3}, QTL	SSR	Cho et al 2004, Iruela et al 2007; Flandez-Galvez et al 2003, Anbessa et al 2009
		Fusarium wilt	*foc-4, foc-5*	SSR	Cho et al 2004; Iruela et al 2007
		Seed traits	*Sfl, Spp, QTL*	RAPD, ISSR, SSR, RGA	Radhika et al 2007
Common bean	*Phaseolus vulgaris*	Bean common mosaic virus	*bc-1, bc-2, bc-3*	RAPD, SCAR	Miklas et al 2006
		Fusarium wilt	P_vPR1, P_vPR2	RAPD	Schneider et al 2001
Cowpea	*Vignaunguiculata*	*Strigagesneriodesresistance*	Rsg 1	SCAR	Boukar et al 2004
Mungbean	*Vignaradiata*	Powdery mildew resistance	QTL	AFLP, RFLP	Young et al 1993, Chaitieng et al 2002, Humphry et al 2003
Lentil	*Lens culinaris*	*Ascochyta blight*	Ra/2, QTL	RAPD, SCAR; AFLP	Chowdhery et al 2001, Tar'an et al 2003; Rubeena et al 2006
		Stemphyliumblight	QTLs	SSR, SRAP, RAPD	Saha et al 2010
		Rust resistance	R	STS, SSR, RFLP	Saha et al 2010
Pea	*Pisumsativum*	Ascochyta blight	QTL	SSR, RFLP	Tar'an et al 2003
		Orobanchecrenata	*Ocp 1,Ocp 2*	STS, RAPD	Valderrama et al 2004
Alfalfa	*Medicagosativa*	Aluminium toxicity	-	RFLP	Sledge et al 2002

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