International Research and Development Activities on Chickpea and Pigeonpea

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The global productivity of chickpea has shown an upward trend in the last two decades, but at 0.8 t ha^{-1} it continues to be rather low, and far below the potential (5 t ha^{-1}) or actually realized yields at research stations and farmer managed on-farm trials (2.5 to 3.5 t ha^{-1}). The chickpea demand in 2010 is estimated at 11.1 million t, up from 8.2 million t in 2001-02, an increase of 35%. Approximately 85% of the additional demand would come from India alone. A combination of yield increase and area expansion would be possible options in meeting projected demands.

Exact data and information about global pigeonpea area and production is not available since the statistics from different sources are highly variable. However, information collected form different sources shows that pigeonpea is grown on about 4.69 m ha with annual production of 3.29 m. In many countries pigeonpea does not occupy the status of a commercial crop but its landraces are grown. India, by far is the largest producer of pigeonpea and accounts for about 80% of global area and production. Myanmar and Nepal are other important pigeonpea growing countries. In China, where pigeonpea was introduced in 1999, it is now grown on about 20,000 ha. In Africa, Kenya, Malawi, Tanzania, Uganda and Mozambique are important pigeonpea growing countries; while pigeonpea is grown on significant areas in the Caribbean countries, Dominican Republic, Venezuela and Haiti.

ICRISAT has global responsibility for germplasm collection, conservation and crop improvement of chickpea and pigeonpea. Currently the Rajendra S Paroda Gene Bank at Patancheru holds 17000 accessions of both *Kabuli* and *desi* chickpea from 44 countries; and 13544 pigeonpea accessions acquired from 73 countries. Our research and development activities are carefully designed to cater the needs of almost all the major chickpea and pigeonpea growing areas.

Several environmental, agronomic and biotic factors cause severe yield losses and destabilize chickpea and pigeonpea production. The relative importance of these

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factors, however, varies from region to region because of the diversity in agroecological conditions. ICRISAT works with partners (NARS, NGOs, ARIs and Private Sector) on alleviating production constraints in chickpea and pigeonpea in different regions of semi-arid tropics. A brief description of research accomplishment and future priorities is presented here.

Chickpea

Chickpea yield should be increased from the existing level of 0.8 t ha^{-1} to 1 t ha^{-1} in the next 8 years. There is limited scope for expansion of chickpea area in many regions (*e.g.* southern India, rice-fallows of North-eastern plains of India and high Barind tract of Bangladesh), provided suitable varieties and technologies are made available.

1. Development of efficient and rapid screening techniques and identification of new sources of resistance

Availability of efficient and rapid screening techniques and stable sources of resistance is a pre-requisite for success of any resistance-breeding programme. ICRISAT and partners have developed cost-effective screening techniques for several biotic and abiotic stresses. Efficient field and laboratory screening techniques are now available for resistance to *Fusarium* wilt, *Ascochyta* blight, botrytis gray mold and *Helicoverpa* pod borer. A line-source sprinkler technique has been effectively used to screen for drought tolerance and a pollen screening techniques for chilling tolerance. Visual rating scale for nodulation capacity has been successfully used to identify high N_2-fixing lines. Efforts are being made to optimize a cylinder culture method for root studies (drought tolerance) and further refine the laboratory, greenhouse, and field screening techniques to screen for resistance to pod borer, *Ascochyta* blight and botrytis gray mold.

Sources of resistance to various biotic and abiotic stresses have been identified and many of these have been widely used by ICRISAT and national programmes. For example ICC 4958 for drought tolerance due to high root mass; ICCV 2, ICCV 96029, and ICCV 96030 for drought escape due to earliness; ICCV 88503, ICCV 88506 and ICCV 88510 for cold tolerance; ICC 506 for *Helicoverpa* pod borer resistance; WR 315 for *Fusarium* wilt resistance; and ICCL 87322 for botrytis gray mold resistance. Efforts will be continued and further strengthened to identify stable and diverse sources of resistance from the germplasm of cultivated as well as wild species.

2. Development of diverse breeding lines with enhanced levels of resistance with suitable maturity, plant type and seed characteristics

Drought, particularly terminal drought, is the most important abiotic stress, as chickpea is largely grown in post-rainy season on residual moisture under rainfed conditions. Early maturing cultivars can escape terminal drought. ICRISAT has placed high emphasis on development of short duration varieties such as ICCV 2 and ICCC 37, that have made it possible to extend chickpea cultivation to tropical environments and rice-fallows. Now, super-early chickpea lines (ICCV 96029 and ICCV 96030), which mature in 75 to 80 days, have been developed. These lines also have cold tolerance and can set pods at low temperature. The studies suggest that super-early chickpea can be promoted as a catch crop between early maturing rice and late-sown wheat, the most prevalent cropping system in North-western India. Several short-duration, large-seeded *kabuli* varieties, such as KAK 2, JGK 1 and Vihar, have been developed in India through collaborative efforts of ICRISAT and NARS scientists. These cultivars fetch high premium price in the market and are providing new remunerative options to farmers.

Efforts have also been made to develop drought tolerant lines through trait-based selection for drought tolerance. Large root traits help in greater extraction of the limited water available in the soil, and the smaller leaf area that reduces transpiration losses. Lines with greater degree of drought tolerance have been developed by combing large root traits with fewer pinnules trait.

Chickpea is particularly sensitive to chilling temperature (temperature $<5^0$C) during reproductive growth phase as chilling temperature adversely affects fertilization and pod setting. Considerable yield loss in chickpea can occur from this cold temperature stress in northern India, Canada and some parts of Australia. ICRISAT has developed a number of cold tolerant lines, such as ICCV 88502, 88503, 88506, 88510 which are able to set pods at low temperature.

Excellent progress has been made in development of *Fusarium* wilt resistant varieties. It was possible because sources of high level of resistance and easy and effective field screening methods are available. Similar level of success could not be achieved for resistance to other biotic stresses. *Ascochyta* blight is the major foliar disease of chickpea in West Asia, North Africa, Canada Australia and northern India. Several advanced breeding lines with diverse background and moderate level of resistance to *Ascochyta* blight have been developed.

The wild *Cicer* species possess a wealth of genes for resistance to biotic and abiotic stresses. Evaluation of a large number of accessions of annual wild

Cicer species at ICARDA and ICRISAT indicated that resistance is available for most stresses in wild species and it was of higher level than those found in cultivated species. Resistance for some stresses (*i.e.* bruchids and cyst nematode) is available only in wild species, and several accessions of wild species have resistance to three to five stresses. Efforts are being made to exploit wild species for increasing levels of resistance and to diversify genetic base.

3. Use of biotechnological tools to improve precision, speed and effectiveness of breeding efforts

Successful crosses of the cultivated species with closely related species *C. reticulatum* and *C. echinospermum* were reported a quarter century ago. Despite extensive efforts at several institutions globally, crossing of the cultivated species with the remaining six wild species still remains a challenge. ICRISAT scientists have successfully employed embryo rescue technique to obtain hybrids from *C. arietinum* x *C. pinnatifidum* cross. Efforts are being made to fine-tune the technique to achieve success in other incompatible crosses. Our focus is primarily on the three species: *C. bijugum, C. judaicum* and *C. pinnatifidum*, which are known to be major sources of resistance genes.

Marker-assisted selection (MAS) can improve the precision and accelerate the progress of a breeding programme aimed at improving traits that are difficult or inconvenient to select directly. One such trait is root vigour, which imparts drought tolerance in chickpea. Measuring root traits under field conditions is labour intensive and expensive. Molecular markers can aid detection of the QTLs for such traits. Efforts are on to identify molecular markers associated with root traits, and resistance to *Helicoverpa* pod borer, *Ascochyta* blight and botrytis gray mold.

In an effort to rapidly develop more markers, ICRISAT has adopted a targeted approach for generating expressed sequence tag (EST) markers, specific to the trait of interest. Through a cDNA subtraction technique, differentially expressed sequences from roots of ICC 4958 were isolated. The process resulted in over 6600 cDNA clones, and from which 1000 unique EST sequences have already been generated and fully annotated based on predicted protein structure and a further 1000 are currently being generated.

Development of high-density linkage map of a crop helps in tagging genes of economic importance for MAS and cloning. Interspecific mapping populations have been used so far to develop linkage map of chickpea as the cultivated chickpea has been found to have little polymorphism for most molecular markers. A linkage map developed based on the polymorphic markers in interspecific populations will have limited use in marker assisted chickpea breeding which mainly uses intraspecific crosses. Studies in recent years have revealed high polymorphism for SSR (simple sequence repeats) markers in cultivated chickpea.

ICRISAT is working on development of transgenics for resistance/tolerance to several biotic and abiotic stresses of chickpea including *Helicoverpa* pod borer, botrytis gray mold, *Ascochyta* blight, dry root rot, drought and cold. Protocols for efficient transformation and regeneration of chickpea have been developed.

Transgenics have been successfully produced for resistance to pod borer by using genes derived from the bacterium *Bacillus thuringiensis* (*BtCry1Ab*) and soybeans (soybean trypsin inhibitor). The molecular characterization and insect bioassays are currently ongoing. Under a new collaborative project with CIRAD in France, new constructs with combinations of different *Cry* genes are being developed, besides the artificial synthesis of some of these genes for optimal expressions in plants. Genes with antifungal properties such as chitinases, glucanases and polygalacturinase-inhibiting proteins (PGIP) are being used for fungal resistance. Efforts are also being made to identify and clone tissue specific promoters for more controlled expression of these potential transgenes. A project funded under the Indo-Swiss Collaboration in biotechnology (ISCB) is aimed at developing transgenic chickpea for tolerance to drought and low temperature stresses by using genes with regulatory functions such as Drought Responsive Elements (DREs), and osmoregulation such as *codA* and *P5CSF*.

4. Development and promotion of efficient modules for integrated disease and pest management

The unavailability of strong sources of resistance for some biotic stresses, ineffective and/or expensive chemical control measures, development of insecticide resistance, and adverse effects of pesticides on environment and living beings make it necessary to go for integrated disease and pest management (IDM and IPM). Considerable progress has been made in development of IDM technology for botrytis gray mold and IPM technology for *Helicoverpa* pod borer. The promotion of IDM for botrytis gray mold in Nepal has helped in bringing crop back to cultivation which was once almost out of cultivation due to this disease. Effective IPM technology has been developed for *Helicoverpa* pod borer but there is need to popularize this technology. Efforts will continue on development and refinement of location – specific IDM and IPM technologies and on education and motivation of farmers to adopt these technologies.

5. Promotion of chickpea in cereal dominated cropping systems for crop diversification and improving the sustainability of cropping system

About 14.3 million ha rice area in South Asia remains fallow during the subsequent winter season. These rice-fallows offer a huge potential for expansion of area of chickpea. ICRISAT has worked with Bangladesh Agricultural Research Institute in identification of chickpea cultivars with early maturity and resistance to fusarium wilt that could be cultivated profitably after rice in Barind (Northwestern Bangladesh). This had made it possible to bring more than 10,000 ha of rice-fallows in Barind under chickpea cultivation. Efforts are needed for expansion of chickpea in rice-fallows of India, which has vast potential as nearly 82% of the rice-fallows are located here. Efforts should be made to promote chickpea in rice-wheat systems either as replacement of wheat or as a short duration catch crop for vegetable purpose between early maturing rice and late-sown wheat.

6. Future thrusts

- Further search for resistance genes in the cultivated and wild species germplasm.
- Use of diverse sources of resistance genes in the breeding programmes.
- Development of varieties with multiple resistance.
- Popularization of IPM and IDM technologies using participatory research approaches.
- Refinement and extension of technologies for promotion of chickpea cultivation in rice-fallows.
- Exploitation of wild *Cicer* species for enhancing the genetic base of the cultigen and for introgressing genes for resistance/tolerance to biotic and abiotic stresses.
- Marker-assisted breeding for traits that can not be handled efficiently through conventional breeding methods.
- Exploitation of transgenic technology for resistance to stresses for which high level of resistance is not available, and for improvement of protein and other nutrients.

Pigeonpea

ICRISAT's pigeonpea improvement is primarily focused on important issues common to major pigeonpea growing countries. Yield improvement (including hybrid development), insect, pest and disease management, catalyzing marketing and utilization, and seed systems to tackle natural disasters are major areas of attention. Those countries with high interest in pigeonpea research and development are also priority for our research. We provide advanced breeding lines, varieties and populations to national programmes with good R&D capabilities. We also provide trait-specific advanced lines and observation nurseries to other countries.

1. Research and development in Asia

In Asia, India is the most important research and development partner. Pigeonpea scientists from different ICAR centers visit ICRISAT to select breeding materials for use in their breeding programmes or for direct testing. ICRISAT has also developed a number of bilateral partnership projects with various ICAR institutions. This fruitful cooperation has resulted in the release of 12 pigeonpea pure line and hybrid varieties in India.

In Sri Lanka, China, Indonesia, and Nepal various research and development activities were carried out under special projects and 9 varieties were released in 5 countries. In other Asian countries elite lines have been identified through International Nurseries.

2. Research and development in eastern and southern Africa

The pigeonpea improvement programme for eastern and southern Africa is based at ICRISAT-Kenya, and covers 10 countries - Kenya, Malawi, Mozambique, Namibia, South Africa, Sudan, Swaziland, Tanzania, Zambia, and Zimbabwe. The research and development activities are carried out with active collaboration of national programmes, NGOs and other interest groups. The major production constraints in this region are *Fusarium* wilt, bruchids, sucking bugs, marketing and utilization. National research capacities have been strengthened through training and research partnerships, leading to development and adoption of improved varieties and crop management methods that have sharply increased yields. Private sector firms have begun to work closely with other project partners to identify markets for pigeonpea, and develop varieties targeted at these markets.

Major achievements

- High-yielding, disease-resistant improved varieties, adapted to specific environments have been released in Kenya (2), Malawi (1), and Uganda (1). In addition, 14 varieties are being tested on-farm in different countries preparatory to release.
- A new production package is helping to increase productivity in the widely used maize-pigeonpea intercropping system. In on-farm trials, the package increased pigeonpea yield by 55% with no loss in maize production and no extra labour cost.
- New technologies have been developed to slash pesticide use by two-thirds with no loss of effectiveness in the control of field pests.

3. Pigeonpea research initiatives in west Africa

Drought tolerance and multiple use of pigeonpea have attracted the attention of scientists and administrators in West African countries such as Benin, Niger, Guinea, Ghana, Mali, Nigeria, Sierra Leone, Senegal, and Cape Verde. Advanced lines were evaluated in these countries. However, these initiatives could not be followed due to lack of financial support in many NARS. In countries like Cape Verde, Benin, Niger, and Guinea pigeonpea lines have performed well, indicating very good potential for pigeonpea for human nutrition and rejuvenating degraded lands.

4. New production niches

Pigeonpea for fodder in USA : High-quality forage is often scarce from late July to late November in the Southern Great Plains of USA. Research programmes aim to provide high-quality forage year-round which will reduce the costs associated with harvesting the storing forage and of purchasing feed concentrate for use when green forage can not be grown. ICRISAT and USDA scientists at the Grazinglands Research Laboratory in El Reno, Oklahoma, USA found that the pigeonpea forage yield and nutritive values during the summer equaled those of other forage crops of the region. Potential benefits of pigeonpea to the farmers would include lowered costs of livestock production and improvement in soil fertility. Pigeonpea has the potential to produce large quantities of high quality biomass and three ICRISAT pigeonpea lines produced more than 5 t fodder ha^{-1}. Recently International Livestock Research Institute (ILRI) has also joined this potential endeavor and now we are jointly screening pigeonpea germplasm for high fodder quality at Patancheru and in Ethiopia.

Pigeonpea in the rice-wheat cropping systems in Indo-Gangetic Plains : The introduction of high-yielding cultivars of rice and wheat in the 1960s contributed greatly to increased food production. But, cereal monocropping is showing signs of fatigue leading to concern about the sustainability of rice-wheat systems. Crop diversification has been suggested in the Indo-Gangetic Plains to arrest the decline in productivity, and enhance sustainability of rice-wheat cropping system. A short-duration pigeonpea cultivar ICPL 88039 developed at ICRISAT gave high yields and profits, and enabled timely sowing of subsequent wheat crop. In collaboration with Rice-Wheat Consortium (RWC), on-farm demonstrations were organized in 2002 using different planting systems. In these trials, ICPL 88039 produced 1.7 to 2.1 t ha^{-1} in different planting systems as compared to the 1.2 to 1.4 t ha^{-1} of the control variety UPAS 120, showing 50 % superiority. Plans have been made to popularize this variety in RWC areas because it is remunerative, requires less water, produces much needed fuel wood, and improves soil by adding organic matter.

Pigeonpea for soil conservation in China : It was about 1500 years ago when some adventurous traders carried pigeonpea seeds from India to China where known as "Mu Dou". It did not succeed as a crop due to its long-duration, small seeds, low yield, and bitter taste. Still the crop managed to survive for centuries because the local people discovered the medicinal values of pigeonpea. In 1950s, the Chinese scientists successfully explored the possibility of rearing a lac insect (*Kerria lacca* Kerr.) for the production of lac. Gradually, the cultivation of pigeonpea in China ceased due to loss of international lac market. In 1997, a set of newly developed pigeonpea varieties was sent to China. These varieties were found to have good adaptability in different agro-ecological zones of southern provinces in China. Besides high seed yield potential, these varieties matured early, had resistance to diseases and good quality seeds suitable for dry and green (vegetable) purposes. Some genotypes had high biomass production, and were also found to be suitable for reducing soil erosion and stabilizing hill slopes. New ICRISAT pigeonpea materials have given a hope to green some of the barren lands. The tender leaves and branches of young pigeonpea plants make good fodder for goats and cattle, and successful grazing and stall-feeding trials have been conducted. By 2002, pigeonpea crop has spread to over 20,000 ha of uncultivable hilly lands and it is on the move.

5. Future Thrusts

In the past ICRISAT has successfully interacted with various NARS, NGOs and private sector. This not only has helped in releasing 30 pigeonpea varieties in 12 countries, but also played a major role in understanding local problems and research issues. ICRISAT will continue this activity with more vigour and enthusiasm and extend help in solving various researchable issues through bilateral special projects and networks. It is also proposed to carryout hybrid pigeonpea research involving cytoplasmic male sterility, on large scale with close collaboration with private sector and various ICAR institutions. Besides providing the technology, training of field and scientific staff will be given priority. Special purpose germplasm and breeding materials will continue to be supplied to all national R&D programmes. In brief, the improvement of pigeonpea, particularly in the developing countries, will remain ICRISAT's prime research and development commitment.