Genetic resources enhancement of ICRISAT-mandate crops†

William D. Dar, B. V. S. Reddy, C. L. L. Gowda and S. Ramesh*

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru is a science-based international organization, which conducts research on sorghum, pearl millet, chick-pea, pigeonpea and groundnut crops that support livelihoods of the poor in the semi-arid tropics. ICRISAT's strategy (among others) is to make its mandate crops more productive and nutritious through genetic enhancement approach. In this article, we describe briefly (i) priorities of genetic enhancement research and resultant breeding products, (ii) on-farm impact of these products, (iii) application of biotechnology tools, (iv) capacity building of national research and extension programmes and (v) future research focus.

Keywords: Breeding products, genetic resources, hybrid parents, ICRISAT, on-farm impact.

THE semi-arid tropics (SAT), where the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru operates, includes parts of 55 developing countries: most of India and parts of Southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and a few countries in Latin America. These areas are characterized by unpredictable weather, long dry seasons, inconsistent rainfall and soils that are poor in nutrients. SAT supports over 1.4 billion people, of whom 560 million are classified as poor. Of these, 70% live in rural areas[1].

Challenges of SAT

Poverty, food insecurity, child malnutrition and gender inequalities are widespread in SAT regions, where rainfed agriculture constitutes the source of food security, employment and cash income for the vast majority of rural inhabitants. Therefore, the greatest challenge lies in increasing the productivity of water used for agriculture, leaving more water for other users and the environment – getting more crop per drop[1]. This is possible by improving the productivity of the crops that support livelihoods of the poor through the development of seed-based and natural resource management technologies and technologies for product diversification to broaden utilization options.

Creating wealth in rural SAT and generating science-based agricultural technologies that improve crop yields, increase incomes and reduce degradation of dwindling natural resources such as biodiversity, land and water are vital. ICRISAT is committed to improving the productivity of sorghum, pearl millet, chickpea, pigeonpea and groundnut along with national agricultural research system (NARS) partners through integrated genetic and natural resource management and socio-economic research, since these crops are staple for millions of poor in the SAT.

ICRISAT's genetic enhancement strategies

ICRISAT's dynamic genetic enhancement priorities and strategies are guided by the changing scenario of agriculture. Improved yield potential is its most important breeding objective, followed by improvement of yield-stabilizing traits such as resistance/tolerance to diseases, insect-pests and abiotic stresses, and improvement of adaptation and quality of grain and fodder. It recognizes that traditional germplasm resources are vital to crop improvement; hence its genebank conserves genetic resources of sorghum, pearl millet, chickpea, pigeonpea, groundnut and six small millets; holding 114,870 accessions of these crops from 130 countries. It has been supplying over 40,000 germplasm samples annually to scientists globally, of which about 30% has been shared with scientists involved in the Indian national programme. ICRISAT's global collection also serves the purpose of restoring germplasm to source countries when national collections are lost due to natural and human-induced calamities. A number of germplasm accessions/selections are released as superior varieties through partnership research. Among the germplasm accessions supplied from the ICRISAT's genebank, 66 have been directly released as cultivars in 44 countries. Since some genetic resources are not agronomically acceptable in their original form, their acceptability is improved through genetic enhancement processes. The breeding methods and cultivar options are guided by reproductive and polli-

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The authors are in the International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, India.
*For correspondence. (e-mail: c.gowda@cgiar.org)

nation control in each crop. The end products are guided by the requirements of producers, industry and end-users.

Breeding methods

At ICRISAT, simple recurrent selection is being used to improve ms_3 and ms_7 genetic male sterility-based sorghum populations to develop trait-based gene pools. Pedigree selection in segregating populations derived from planned crosses is the major breeding method to develop pure line varieties in sorghum. With the discovery of a stable and heritable cytoplasm–nuclear male sterility (CMS) mechanism in sorghum[2] and pearl millet[3], enabling large-scale economic hybrid seed production, heterosis exploitation has become a matter of routine commercial application since early 1960s in these crops. Pedigree breeding has been used to develop hybrid parents in sorghum and pearl millet. Various forms of recurrent selection have been used to develop open-pollinated varieties (OPVs) in pearl millet. In the case of groundnut, the pedigree method is most commonly used. A combination of pedigree and bulk method is generally used for selection after hybridization in chickpea. The backcross method is used only occasionally to incorporate one or few traits from a germplasm line, sometimes a wild species, to a well-adapted variety. Rapid generation advancement in greenhouse following a single seed descent method is generally used to develop recombinant inbred lines in all crops.

In pigeonpea, selection to capitalize on tremendous genetic variability within landraces has been effective in developing high-yielding popular varieties. Population breeding, mutation breeding, mass selection and bulk pedigree methods have also been used with limited success. The limited natural outcrossing has also been successfully exploited for increasing yield and stability through development of commercial hybrids using genetic male sterility. Currently, the discovery of a stable and heritable CMS system[4] has enabled the development of commercial pigeonpea hybrids.

Breeding products and impacts

ICRISAT focuses on partnership-based research to develop improved varieties and hybrid parents at its Patancheru campus for Asia, and finished products at other ICRISAT locations in Africa. Partnership efforts by scientists at ICRISAT and in the NARS programmes have led to the release of 474 different cultivars in Africa, Asia and the Americas. These cultivars have improved grain-yield potential, resistance to biotic (diseases and insect pests) and abiotic stresses (soil salinity), micronutrient density and alternative uses.

Grain yield and early maturity

ICRISAT has been successful in developing improved early-maturing sorghum varieties that have been adopted by subsistence farmers. ICSV 111 which is popular among farmers in Ghana, Cameroon, Chad and Nigeria for its tolerance to *Striga*, excellent brewing qualities, short duration and high yield potential; and Macia (SDS 3220) that has greatly benefited farmers in Mozambique and Botswana[5], are examples of ICRISAT's success stories. Several ICRISAT-bred improved sorghum hybrid parents have been extensively used by both public and private sector research organizations to develop and market hybrids in Asia. More than 30 hybrids, based on ICRISAT-bred parents have been released in India and China. The productivity gain from improved cultivars has more than compensated the cost of additional inputs used for their cultivation. The cost–benefit ratio of production of improved sorghum cultivars is estimated at 1 : 1.4 in India[6].

An ICRISAT–private sector hybrid, JKSH 22 known for its high grain-yield potential, bold grain and earliness (5–10 days compared to the most popular hybrid CSH 9) showed remarkable adoption covering 1500 ha in 1994 to 210,000 ha in 2002 (about 0.5% of the total *kharif* sorghum area). During 1994–2002, seed production of JKSH 22 earned farmers, on an average, over US$ 0.31 million $year^{-1}$ in Andhra Pradesh and Karnataka, and US$ 2.7 million $year^{-1}$ from commercial cultivation in Maharashtra and other sorghum-growing states in India. During 2001–02 to 2003–04, a total of 29,800 t of certified hybrid seeds of ICRISAT–private sector hybrids were produced, which fetched a total income of US$ 18.8 million to farmers in Andhra Pradesh and Karnataka[5]. Adoption of another ICRISAT–private sector partnership hybrid, VJH 540, with its high yield potential increased from 650 ha in 1997 to 142,000 ha in 2003 in rainy season in major sorghum-growing states in India, as evidenced[7] from the increased seed sales of this hybrid from 6.5 t in 1997 to 1420 t in 2003. ICTP 8203, the earliest maturing commercial open-pollinated pearl millet variety developed by recombining five progenies selected from a landrace from northern Togo[8], was rapidly adopted in Maharashtra and is cultivated on a limited scale in Karnataka, Andhra Pradesh and Rajasthan.

The application of a panicle harvest index selection procedure in the bold-seeded early composite led to the development of an OPV in pearl millet, ICMV 88904 (released as ICMV 221) that outyielded the popular OPV ICTP 8203 by 15% across 21 trials in nine locations[9]. The success of the *iniari* group of materials led to a targetted collection of this germplasm, followed by intensive evaluation that led to the constitution of an extra early-maturing B-composite (EEBC), making it the earliest maturing pearl millet population developed to date. Its selected version (ICMP 94001) has been shown[10] to outyield EEBC unselected bulk by 12%, with only 13% less grain yield than the commercial HHB 67. The development of hybrid HHB 67, however, remains the greatest landmark in breeding early-maturing pearl millet cultivars.

In groundnut, several short-duration cultivars have been developed with multiple tolerance/resistance. ICGV

86015 has wide adaptability and was released in Pakistan as BARD 92, in Vietnam as HL 25, in Nepal as Jayanthi and in Sri Lanka as Tikiri. ICGV 91114 is gaining popularity with farmers in drought-prone areas of Anantapur in Andhra Pradesh and Saurashtra in Gujarat[11], while ICGV 89104 has resistance to seed infection by *Aspergillus flavus*.

Reduction in time to flowering and maturity has substantially contributed towards increasing and stabilizing chickpea productivity in the tropics. This was done by identifying a major gene *efl-1* for earliness. More than 50 short-duration and *Fusarium* wilt-resistant cultivars have been released so far through national programmes in several countries with the help of ICRISAT. History was made when kabuli chickpea adaptation was extended for the first time to the tropics with the release of ICCV 2 as Swetha[12] (and desi variety, Kranthi) in Andhra Pradesh in 1989, increasing chickpea area in Andhra Pradesh fivefold and production thirteenfold during 1993–2002. Another kabuli chickpea variety, KAK 2 (PKV 2)[13] is popular among the farmers in Maharashtra, Andhra Pradesh and Madhya Pradesh states because of its early maturity, high-yielding ability and extra large grains.

Through ICRISAT's development of the first hybrid (ICPH 8) pigeonpea variety and hybrid seed production technology, private and public sectors in India have been able to develop hybrid cultivars. Teams from ICRISAT and NARS have identified varieties suited to specific production systems.

Disease resistance

ICRISAT has developed several grain mold-resistant male-sterile sorghum lines with good potential for developing grain mold-resistant hybrids using trait-based breeding approach[5]. Downy mildew (DM), ergot, smut and rust are some of the diseases of pearl millet that have received research attention. Due to the development of large-scale and cost-effective screening techniques, availability of sources with high levels of resistance, and relatively simpler inheritance, several OPVs and hybrids of pearl millet with high levels of resistance have been developed and adopted for cultivation. Recent development in molecular marker-assisted breeding (MAB) has enabled more effective host plant-based DM management. For instance, an extra early-maturing hybrid (HHB 67) developed by Haryana Agricultural University and currently grown on more than 0.4 m ha, has been showing signs of increasing susceptibility to DM.

A number of foliar disease-resistant groundnut varieties have been developed, among which ICGV 86590, ICG (FDRS) 10 (ICGV 87160), ICG (FDRS) 4 (ICGV 87157) and ICGV 86699 are highly popular among farmers. *Fusarium* wilt (FW), Ascochyta blight (AB) and botrytis gray mold (BGM) are important diseases of chickpea, particularly in the SAT. Availability of simple and effective field screening techniques and many highly resistant sources[14] have led to excellent progress in breeding FW-resistant cultivars such as ICCV 10. Germplasm accessions with moderate resistance to AB have also been identified. The resistance is controlled by many quantitative trait loci. Thus, efforts have been made to enhance the level of resistance by accumulating resistance genes from different sources. Recent breeding efforts have led to the development of lines with good agronomic characters and moderate levels of BGM resistance. Since sterility mosaic and FW are the major pigeonpea diseases, breeding varieties with dual resistance was given priority, of which Asha (ICPL 87119)[15], Laxmi (ICPL 85063) and Maruti (ICP 8863) are good examples.

Insect pest resistance

Sorghum varieties and hybrid parents resistant to shoot fly, stem borer and midge have been developed. Gains in productivity in midge-endemic areas in Australia through adoption and use of midge-resistant white grain cultivars such as ICSV 197 (ref. 16), ICSV 745 (ref. 17) and PM 13654 introduced from ICRISAT, Patancheru are estimated at 2.5% annually for the last five years, which translates into a cost reduction of US$ 4.0 per ton, or a cost saving of US$ 4.7 million at current average production levels. These benefits are well in excess of Australia's financial contribution to ICRISAT[18]. Several shoot fly-tolerant male-sterile lines and stem borer-resistant male-sterile lines have been developed with good potential to develop shoot fly- and stem borer-resistant hybrids[5]. Jassid-resistant and multiple resistance and/or tolerance to *Spodoptera*, leaf miner, jassid and thrips groundnut breeding lines have been developed at ICRISAT. In the case of pod borer in chickpea, several germplasm accessions/breeding lines/cultivars with moderate resistance and accessions of annual and perennial wild *Cicer* species with higher levels of resistance have been identified. In pigeonpea, we have developed varieties tolerant to *Maruca* and *Helicoverpa*. Attempts are being made to transfer insect resistance from wild relatives of pigeonpea.

Cultivars for better nutrition

Micronutrient malnutrition, primarily the result of diets poor in bio-available vitamins and minerals, causes blindness and anaemia (even death) in more than half of the world's population, especially among women and pre-school children. Research is being carried out at ICRISAT as part of the CGIAR's Challenge Programme on HarvestPlus project to explore the prospects of breeding for micronutrients and β-carotene-dense sorghum[19] and pearl millet under a high-yielding background.

Salinity-stress resistance

Considerable progress has been made in salinity-tolerance research at ICRISAT in terms of assessing genetic variability, identifying tolerant germplasm lines, varieties, hybrid parents and breeding lines, and identifying possible mechanisms of salinity tolerance that could enhance breeding efficiency.

Cultivars for alternative uses

The Government of India's recent policy on blending petrol and diesel with ethanol means an additional 4000 million litres of ethanol is needed, apart from 1000 million litres per annum for other purposes. Molasses, the traditional source of raw material for ethanol production with a contribution of 2000 million litres per annum[20], is unlikely to meet actual demand in the long run. Distilleries and sugarcane-based industries are showing increasing interest in using sweet sorghum as an alternative to make up for the possible deficit.

ICRISAT renewed its sweet sorghum research initiated in 1980 to help meet this demand for ethanol. Four promising lines were evaluated in the All India Coordinated Sorghum Improvement Program during the 2004 rainy season and two have been promoted for advanced testing during the 2005 rainy season. A Special/Sweet Sorghum Hybrid (NSSH-104) developed from an ICRISAT-bred male-sterile (seed) parent and SSV 84 has been recommended for release for commercial cultivation by the National Research Center for Sorghum, Hyderabad[21].

With growing health awareness, people in urban and peri-urban areas prefer low-fat/oil foods. Scientists at ICRISAT have developed large-seeded, relatively low-oil groundnut varieties such as Asha, which is popular among Gujarat and Maharashtra farmers since it can be used for both oil extraction and confectionery purposes.

Up-stream research

ICRISAT has a high throughput applied genomics laboratory and uses marker-assisted selection (MAS) as a potential method to hasten and improve precision and effectiveness of crop improvement. Molecular markers have been identified for stay green trait and resistance to shoot fly and *Striga* in sorghum, DM resistance and terminal drought tolerance in pearl millet. Research is in progress to identify markers for root mass and resistance to AB, BGM, and *Helicoverpa* pod borer in chickpea; and FW resistance and fertility restorer genes in pigeonpea.

Two new pearl millet hybrids with parental lines bred by MAS for DM resistance, have been developed jointly by ICRISAT and Indian NARS scientists. In January 2005, one of them, HHB 67-2, was released for commercial cultivation by the Haryana State Varietal Release Committee. This is the first public sector-bred, marker-assisted pearl millet breeding product to be released and is the crowning achievement of 15 years of investment in pearl millet MAS by ICRISAT, the Indian national programme, UK-based partners and the UK's DFID Plant Sciences Research Programme.

ICRISAT has pioneered in the development of transformation technologies for all ICRISAT mandate crops except pearl millet[22]. The first transgenic from ICRISAT is the transgenic groundnut for resistance to the Indian peanut clump virus that employed the coat protein and replicase genes from the virus itself. Transgenics have been developed in pigeonpea and chickpea with resistance to *Helicoverpa armigera* using the *Bt cry1Ab* and *cry1Ac* genes derived from the bacterium *Bacillus thuringiensis*. This material is currently undergoing contained field testing. During the coming years, ICRISAT and its Indian NARS partners will jointly test them before deployment. Besides groundnut rosette virus, peanut bud necrosis virus and peanut stem necrosis diseases are being addressed through transgenic approaches. Work is also in progress to develop transgenics in groundnut and chickpea for tolerance to abiotic stresses such as drought and low temperatures where transgenics carrying transcription factors like DREB and proline-overproduction genes are currently being tested in greenhouse studies. In cereals, transgenics have been developed for resistance to stem borer in sorghum and are currently under greenhouse testing.

Capacity building

Knowledge sharing

ICRISAT is instrumental in enhancing research and development capabilities of NARS in Asia, Africa and Latin America in various aspects of sorghum, pearl millet, groundnut, chickpea and pigeonpea improvement through training NARS scientists over the years from 1974. A total of 43 visiting scientists are working on various crops from 2001 to 2005 – sorghum (7), pearl millet (7), groundnut (7), chickpea (5), pigeonpea (3), and all five crops (14). A total of 1294 scientists were trained in sorghum – 20 postdoctoral fellows (PDFs), 107 research scholars (RSs), 219 research fellows (RFs), 783 in-service long-term (six months) and 119 in-service short-term trainees and 46 apprentices. A total of 456 NARS scientists have been trained in chickpea improvement. These include 27 in-service candidates for six-month training, 216 apprentices and short-term trainees, 14 PDFs, 199 RSs/RFs. A total of 1105 NARS scientists in Asia and Africa were trained in various aspects of groundnut improvement – 91 apprentices, 374 in-service trainees (six-months), 238 in-service trainees (short-term), 287 RFs, 91 RSs and 24 PDFs. A total of 773 scientists were trained in pearl millet – 463 in-service candidates for six-months, 127 apprentices and short-term trainees, 20 PDFs, 66 RSs and 97 RFs. A total of 745 scientists were trained in pigeonpea – 126 in-service candidates for six-months, 256 apprentices and short-term trainees, 31 PDFs, 74 RSs and 258 RFs.

ICRISAT conducts well-designated, short-term training courses regularly in specific areas to impart expertise to scientists of NARS – both private and public sectors – apart from the long-term capacity-building exercises in various disciplines. This has helped NARS to improve the efficiency of its crop improvement programmes and increase the pace of developing improved finished products.

e-learning

Apart from formal training, ICRISAT has taken a leading role in reaching research technologies to large farmers and other clienteles through e-learning. ICRISAT has recently established the Virtual Academy of Semi-Arid Tropics (VASAT). This is a strategic information, communication and non-formal distance education coalition for rural communities and intermediaries led by ICRISAT. Being a seamless virtual organization, VASAT will be made up of a coalition of international, national and state-level research, development and educational institutions, national open universities working with local ICT service providers, the private sector, civil society organizations and self-help groups. Operating initially in India, VASAT will later on expand in South Asia (Bangladesh, Bhutan, Maldives, Nepal and Sri Lanka) and sub-Saharan Africa. VASAT aims to mobilize communities and intermediaries of the dry tropics by sharing information, knowledge and skills related to climate literacy, drought preparedness and best practices in dry-land agriculture and other relevant issues. VASAT does this through the innovative interface of ICTs and distance learning.

Looking ahead

Future research on genetic enhancement needs to focus on developing technologies that stabilize current yield levels, such as host-plant resistance to biotic and abiotic yield constraints, crop-product diversification and value-addition and developing cultivars suitable for non-traditional uses apart from food and forage. Forging partnerships between public sector research organizations and private sector industries in developing research products suitable to these alternate uses should receive major attention.

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