Crop Improvement, Management and Utilization for Food Security and Health

Archival Report 2005

International Crops Research Institute for the Semi-Arid Tropics

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Global Theme on Crop Improvement, Management and Utilization for Food Security and Health

Archival Report 2005

International Crops Research Institute for the Semi-Arid Tropics
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Global Theme on Crop Improvement and Management

Archival Report 2005

Introduction and Highlights

Global Theme on Crop Improvement, Management and Utilization for Food Security and Health

CLL Gowda
Global Theme Leader

Introduction

The Global Theme on Crop Improvement, Management and Utilization for Food Security and Health aims to contribute to sustainable growth in crop production, farm income, food security and environmental protection through the development of improved and diversified cultivars, eco-friendly and cost-effective pest management practices, and commercialization of diversified and alternative uses of crop produce.

The purposes of the Theme are:

- To undertake research for genetic diversification and enhancement of ICRISAT mandate crops for high and stable grain and fodder yield with acceptable quality,
- To develop cost-effective and eco-friendly integrated pest management (IPM) technologies,
- To address alternative crop produce utilization strategies, including food and feed safety issues, and prospects for commercialization,
- To increase adoption of improved varieties by farmers through enhanced formal and informal seed-supply systems,
- To develop institutional mechanisms between public and private sector stakeholders to ensure sustainable demand for public sector-bred improved varieties, and
- To accelerate technology exchange and information sharing, using both conventional methods and information and communication technologies (ICT) for capacity building of NARS to achieve on-farm impact and to improve human and livestock health.

The expected outputs (with indicators in Italics) are:

1. Genetically diverse trait-specific populations and breeding lines developed for use in NARS programs *[Increased availability of diverse germplasm sources and breeding materials]*
2. Regionally adapted parental lines, varieties and hybrids developed for SAT regions *[Enhanced and newer options of locally-adapted cultivars]*
3. Effective disease and insect pest management technologies developed *[Increased adoption of cost-effective and eco-friendly IPM packages]*
4. Technologies for improved food, feed and fodder quality and safety disseminated *[Better options for food and feed safety to improve health of humans and livestock]*
5. Crops for diversification and stability of systems enhanced [*Better options for crop diversification and sustaining crop-livestock productivity]*
6. Dual-purpose and forage cultivars of mandate crops evaluated and promoted [*Increased options for raising livestock and crop productivity]*

7. Potential and opportunities for commercialization of diversified alternate crop uses assessed *[Better and novel products, safer food and feed, increased market demand]*
8. NARS capacity and impact accelerated through participatory approaches and technology exchange *[Efficient research methods and technology exchange practices]*

With the considerable genetic resources available at the ICRISAT genebank, and our mandate to provide enhanced breeding material and improved varieties to farmers, crop improvement is a priority activity. Emphasis will be on development of parental lines for cereals and varieties for legumes in Asia, and on varietal development and strengthening participatory breeding and varietal selection approaches in Sub-Saharan Africa. Improved varieties need good crop management to produce high yields, including eco-friendly IPM for crop protection. Resistances to biotic constraints (e.g., pod borers in chickpea and pigeonpea, aflatoxin in groundnut, grain mold and *Striga* in sorghum and downy mildew in pearl millet) will be integrated with other pest management strategies, including bio-pesticides (NPV and bacterial sprays). Opportunities to increase market demand through alternative uses for crop produce, commercialization, and linking income generating industrial utilization strategies with technology development activities will be further strengthened.

The following three Regional Projects focus on research activities in the Global Theme on Crop Improvement, Management and Utilization for Food Security and Health:

1. Improving crop productivity through genetic enhancement and eco-friendly pest management, and enhancing alternative uses of products in Asia (*Coordinator: KN Rai*)
2. Enhancing crop productivity and diversification of income sources of SAT farmers in Eastern and Southern Africa (*Coordinator: Mary A Mgonja*)
3. Increasing productivity and utilization of SAT crops in Western and Central Africa (*Coordinator: Eva Weltzien R*)

Research Highlights

Genetic resources

- We assembled 686 cultivated and 17 wild *Cicer* accessions originating from 46 countries from ICARDA, Syria and 1395 cultivated chickpea accessions originating from 37 countries from USDA, Griffin, USA, and four chickpea accessions from Australia.
- We evaluated 330 wild *Arachis* accessions of 42 species for drought related traits SPAD Chlorophyll Meter Reading (SCMR) and Specific Leaf Area (SLA). Most promising five accessions were ICGs 14938, 13260, 14874, 8144, and 8193 having high SCMR.
- Chickpea mini core collection (211 accessions) along with five control cultivars were evaluated for root length density and root depth, traits related to drought. ICCs 8261, and 10885 had greater root length density than the drought resistant control ICC 4958 (0.295 cm/cm^3). Similarly, ICCs 3512, 15697, 13523, 4872, and 8261 were greater in root depth than the control ICC 4958.
- Leaf samples for DNA extraction were collected from 2714 chickpea accessions. Finger printing using 35 SSR markers at ICRISAT and 15 at ICARDA is in progress.

Preliminary study reveals a large allelic diversity and a total of 873 alleles, with an average of 25 alleles per locus. The dinucleotide motifs detected a lower number of alleles (average 11) than the trinucleotide motifs (average 27). Similarly, gene diversity with dinucleotide motif was lower (average 0.723) than with trinucleotide motif (0.898). The mean diversity of all the SSR was 0.873.

- Groundnut composite collection consisting of 850 accessions from ICRISAT and 150 from EMBRAPA representing entire collection ecologically, taxonomically, and phenotypically was developed.
- Finger millet composite collection consisting of 1000 accessions representing entire collection ecologically, taxonomically, and phenotypically was developed.
- We evaluated selections from mini-core collection and purple pod lines of pigeonpea germplasm along with resistant and susceptible checks for resistance to *H. armigera*. Fifteen lines showed a DR of <4.0 compared to a DR of 2.8 in ICPL 332, 5.0 in ICPL 87119, and 8.7 in ICPL 87.
- We evaluated 8 newly developed varieties of pigeonpea along with ICPL 332 and ICPL 84060 for resistance to *H. armigera*. Data were recorded on pod damage by pod borer, pod fly, and pod wasp, and grain yield. Percentage pod damage was <15% in ICPL 20058, and ICPL 20042 compared to 20 % in ICPL 332 and 18.3% in 84060. The number of healthy pods were >80 in ICPL 97250, ICPL 20036, ICPL 97249, ICPL 20058, and ICPL 20042 compared to 76.9% in ICPL 332.
- Twenty-five chickpea lines were evaluated for resistance to pod borer, *H. armigera* across location in India. Principal component analysis placed the test genotypes into six groups, suggesting that there was a considerable diversity in chickpea genotypes to damage by *H. armigera*. Based on grain yield and insect damage the lines RIL 85, ICCL 86111, ICCL 87314, ICCL 87315, and ICC 506 may be used in chickpea improvement for resistance to *H. armigera*.
- A total of 5895 germplasm accessions (sorghum 1070, chickpea 569, pigeonpea 1281 and groundnut 2975) regenerated from medium term storage of the Gene Bank were evaluated for their seed health status using the standard blotter method. Of these only 197 accessions (sorghum 26, chickpea 49, groundnut 87, and pigeonpea 35) were free from seedborne pathogens. Major seedborne fungi across crops were species of *Cladosporium, Alternaria, Fusarium, Phoma, Curvularia, Bipolaris, Aspergillus, Penicillium* and *Rhizactonia*. Some of these seedborne fungi affected seed viability up to 5%.
- A total of 4503 seed samples of ICRISAT mandate crops comprising breeding lines and germplasm were exported to 42 countries.

Sorghum

- A preliminary identification of the 17 isolates (from ICRISAT-Patancheru) based on morphology, and crosses with tester isolates and AFLP markers revealed the presence of five *Fusarium* species in the sorghum grain mold complex. These were: *F. verticillioides, F. proliferatum, F. thapsinum, F. sacchari* and *F. andiyazi*. Among these, the frequency of *F. proliferatum* was highest, followed by *F. verticillioides, F. thapsinum*, and *F. andiyazi*. There is a need to evaluate large number of isolates to better understand the spectrum of *Fusarium* species involved in sorghum grain mold complex.

- One hundred germplasm lines were evaluated in the 2004-05 postrainy season for high stalk sugar content and biomass production ability. The sugar yield based on Brix reading and juice yield was estimated. One of the land race, IS 23526 (5.8 t ha^{-1}) significantly out-performed the check SSV 84 for sugar yield (3.5 t ha^{-1}). This line besides being early by seven days, had Brix reading (19.5%) comparable to the check SSV 84 (19.35%).
- Forty lines with high and low differentials were selected and evaluated for their performance stability for agronomic traits and grain Fe, Zn and β-carotene contents under three soil fertility levels (120 kg N, 80 Kg N and 40 Kg N) during the 2004-05 postrainy season. The results showed that variability among genotypes (G) was significant for Zn and Fe but the variability due to G×Fertility levels was not significant indicating the selections made at one fertility level perform similarly at other fertility levels.
- Two sets of 36 iso-nuclear allo-plasmic (18 in A_1 and 18 in A_2 CMS background) hybrids obtained by crossing iso-nuclear, allo-plasmic (A_1 and A_2) A-lines in 12 nuclear genetic backgrounds with three dual R-lines along with their parents (B-lines and dual R-lines) were screened for responses to shoot fly infestation during the 2005 rainy season. Significant differences were observed among the hybrids as well as parents for their responses to shoot fly as measured by deadhearts suffered by them. However, cytoplasm appeared to have limited role in differentiating the hybrids in their responses to shoot fly infestation. Thus, considering that A_1 and A_2-based hybrids are comparable for grain yield potential and grain traits, and maturity, and for responses to shoot fly infestation, A_2 offers immediate option for diversification of CMS base of hybrid parents.
- A coalition between sorghum grain producers, poultry feed manufacturers, poultry federation and research institutions and market linkages between sorghum grain producers and poultry feed manufacturers was established for enhanced use of sorghum in poultry feed. To up-scale the work on the use of sorghum and pearl millet grains in poultry feed, a project was successfully negotiated with CFC/FAO. The target areas for intervention are; Andhra Pradesh and Maharashtra states in India; Beizhen, Heishan and Yi provinces in China; and Suphan Buri, Kanchana Buri and Nakon Sawan provinces in Thailand. The project implementation was initiated in May 2005.
- Most of the private sector seed companies develop and market three-way cross hybrids for forage purpose using grain sorghum male-sterile lines as seed parents and Sudan grass lines as male parents. In order to evaluate the potential of ICRISAT-developed grain sorghum male-sterile lines and forage restorer lines/ varieties in hybrid combinations, 87 three-way cross hybrids [made by crossing forage/ sweet-stalk varieties onto male-sterile single cross F_1s (obtained by crossing grain sorghum A-lines with non-isogenic B-lines)] were evaluated in a replicated trial for forage yield potential and stalk sugar content at grain maturity stage during the 2005 rainy season. Several hybrids (28.8 t ha^{-1} to 46.6 t ha^{-1}) out yielded popular check variety SSG 59-3 (21.7 t ha^{-1}) for green fodder yield.
- Farmers' selections were more tolerant to lodging and senescence and were late maturing than breeders' selections. From these results, it is clear that farmers prefer large-sized grains and also fodder value traits such as stay-green and non-lodging. Breeder selections were based on grain yield, early maturity and tan plant color. However, the differences between farmers' and breeder's selections for these traits were marginal to be of any significance. Based on the performance of these genotypes

for grain yield, luster and seed size and fodder yield, 4 lines in the farmers group and 5 lines in the breeders group were selected for further evaluation.

- A total of 4877 seed samples of hybrid parents/ breeding lines were shared with scientists (public and private sector) and NGOs/ farmers based on specific requests. Of the 4877 seed samples, 2515 were shared with public sector scientists, 913 with private sector scientists and 764 with NGOs/ farmers in India. The rest of the seed samples (685) were shared with NARS (public and private sector scientists) outside India.
- Forty sorghum lines with high and low grain Fe and Zn were evaluated at NRCS, Hyderabad (India) during the 2004-05 postrainy season. The results revealed significant genetic variability for grain Fe and Zn contents. Some of the land races such as IS 7780 (38.5 ppm), IS 1192 (32.8 ppm), IS 24868 (32.8 ppm) and high-yielding B-line such as ICSB 561 (32.6 ppm) and ICSB 484 (29 ppm) had significantly higher Zn content compared to the trial mean value (25.4ppm). Similarly, lines such as ICSR 40 (56.7 ppm), PVK 801 (50.2 ppm), ICSB 561 (49.6 ppm), IS 152 (47.6ppm), ICSB 675 (46.2 ppm), ICSB 52 (45.6 ppm) and ICSB 38 (44.4 ppm) had significantly higher Fe content compared to the trial mean value (37.6 ppm).
- We confirmed the contrast for salinity tolerance using a set of sensitive and tolerant sorghum genotypes. Results agreed well with previous trials. In this trial, carried out in the glasshouse, during a time of the year where VPD is low, we found that the ratio of biomass achieved under salinity to that of control was about 40-50%, in contrast to about 10% in a previous trial carried out in outdoors conditions with these same genotypes, in a season with much higher evaporative demand (April-June). These results show the necessity to take careful consideration of the VPD while doing salinity response experiments.
- A large number of varieties have been released and some have multiple country releases in Eastern and Southern Africa. Many varieties released by national authorities have not reached the farmers. Availability of all classes of clean quality seed to stakeholder groups in the seed industry is key to enhancing the impact from crop breeding and also in enhancing agricultural productivity. We are ensuring that the initial seed materials that flow from ICRISAT breeding programs is pure and of the best quality to be used by other stakeholders in the seed chain. Breeder and nucleus seed of 8 sorghum, 12 pearl millet and 8 finger millet varieties were multiplied for supply to NARS.
- The long season photoperiod sensitive sorghums have over the years contributed significantly to the food security of the long season areas of central and northern Mozambique. However, the preliminary observations in Mozambique suggested that the genetic diversity of the long season sorghums has declined. Hence, the possibility of identifying long season sorghums with higher yield potential from Tanzania for re-introduction. A total of 33 long season photoperiod sensitive sorghums from Tanzania, Mozambique and Zambia and two improved long season varieties (Pato, Town and Sima) were evaluated in Nampula (Mozambique) and Naliendele (Tanzania) were characterized and will be used in developing experimental hybrids for testing in the target areas.
- A number of improved sorghum varieties suitable for the drought prone areas of eastern and northeastern Kenya as well as those suitable to the humid Lake Victoria zone have been identified. On farm demonstrations were established in five districts and mother and baby trial design was used to evaluate performance of improved varieties.

- A total of 134 introgressed progenies were tested in replicated trials at ICRISAT-Samanko, Mali. Development of improved longer-cycle populations is being done with recombination of the superior progenies identified in the yield trials. Generation advance and selection within these progenies was conducted in nurseries at ICRISAT-Samanko, on-farm at Wobougou and Sirimana in Mali.
- Four sorghum populations were developed through introgression of varieties from Nigeria (IS 7879), Malawi (IS 14417), Cameroon (IS 15401), and Mali (Torokanidje) into the Tall Guinea-race Population. These new longer-cycle Guinea-race populations were evaluated for adaptation at six locations in Nigeria (Minjibir, Bagauda in Sudan Savanah; Samaru, Maigana in N. Guinea Zone; Samarun Kataf, Lere in the S. Guinea Zone).
- A series of Sorghum Hybrid Yield trials were conducted, most in collaboration with NARS in the WCA region. Hybrids were assigned to specific trials based on maturity. These trials permit both assessment of combining ability of a limited number of A lines (FambeA, IS3534A, IPS001A, and CSM219A) with a larger number of restorer lines.
- The first ever large-scale Sorghum Hybrid Seed Production fields were established in Mali with two 0.5 ha isolation fields with Seguetana and CSM 388 as male parents, and FambeA and IPS001A as female parents in each field.
- Initiated activity targeting to develop a regional map of the dates of the end of the rainy season which will serve as the support to a regional recommendation of the varieties based on climatology. Photoperiod-sensitive varieties must be grouped by flowering dates, thus such a map will automatically integrate this concept. The expected final product is a flyer for each variety for every villages of the WCA region.
- Fifteen shoot fly-resistant and -susceptible sorghum genotypes were evaluated for resistance to *Atherigona soccata* under no-choice, dual-choice and multi-choice conditions in the field and greenhouse. Genotypes showing less susceptibility to shoot fly were trichomed and had a leaf glossiness score of <3.0. Genotypes IS 18551, IS 4664, IS 2312, SFCR 151, and ICSV 700 showed some adverse effects on the survival and development of *A. soccata*. Biochemical analysis of the plant samples for essential minerals, nutritional quality, and secondary metabolites is in progress.

Pearl millet

- Results of this year confirmed yield advantage of promising pearl millet forage hybrid ICMA 00999 x IP 17315 having 15.8 t ha^{-1}dry forage yield (36% more than sudan grass hybrid SSG 59-3) at 80-day harvest. Of the nine germplasm-derived improved open-pollinated populations evaluated during the rainy season, five had 12.8-17.1 t ha^{-1} dry forage yield (15.8 t for ICMA 00999 x IP 17315) at 80-day harvest. These populations have potential of being directly released as open-pollinated forage varieties, and also as promising germplasm for use as topcross pollinator of hybrids.
- Selection in the introgressed pearl millet populations for large seed size, white grain colour, and large panicle size sourced from late maturing or photosensitive germplasm continued. From amongst 370 large-seeded F_4 progenies, 177 progenies were selected based on the visual assessment of grain size and agronomic potential, of which 16% flowered 51-60 days (52 days for ICMB 96555).
- Of the 20 germplasm accessions evaluated for two seasons, 3 accessions (IP 6764, IP 8964 and IP 12240) had the highest Fe (50-55 ppm) and 4 accessions (IP 3122, IP

3859, IP 9453 and IP 8964) had the highest Zn (48-49 ppm) levels, although both the Fe and zn levels in these accessions were significantly lower than those in the elite breeding lines.

- Salinity tolerance of HHVBC tall has been confirmed at both ICBA (Dubai) and ICRISAT (Patancheru) and it has also been found very productive in saline field conditions at Gangavathi (India), hence four HHVDBC derived sub-populations earlier selected for four different heights in d_2 background (dwarf, medium height, tall and thick panicle) along with C_1 cycle bulk of HHVBC Tall were evaluated in pot culture at ICRISAT-Patancheru and in field condition at Gangavathi to assess the differences, if any, among these sub-populations for salinity tolerance measured in terms of both grain and fodder yield.
- In a set of 100 improved materials (hybrid parents, population progenies, OPVs and composites), several entries (including commercial OPVs and seed parents) were found having both high Fe (> 60 ppm) and high Zn (> 50 ppm). The correlation between the Fe and Zn levels was positive and highly significant (r= 0. 86). Since almost all the high Fe and Zn lines were largely from iniari-germplasm, seven improved iniari populations (AIMP 92901, EEBC and GB 8735l, ICTP 8203, CGP, GGP Bulk, PVGGP 6) were undertaken for investigating intra-population variability for Fe and Zn contents.
- A survey to assess incidence of downy mildew (DM) in pearl millet was conducted in Gujarat State, India. About 30% fields showed DM with incidence ranging from trace to 71%. Public sector hybrids, (GHB 558 and –577) had mean DM incidence of 3 and 12%, respectively, whereas private sector hybrids (Gowri, Nandi 3, -5, PG and several unknowns) had mean DM incidence of 2 to 14% with a range of 0 to 71%. Some other hybrids, such as Pioneer 7688, Proagro 9330 and -4444 were DM-free.
- Fourteen DM isolates from 4 districts (Jodhpur, Barmer, Bikaner and Cheru) of western Rajasthan (India) were evaluated for their virulence on host differential lines under greenhouse condition. The isolates from Barmer were more virulent than others, and these could be used in resistance breeding program.
- Nine 2005-series A-lines (3 A_1 cytoplasms and 6 A_4 cytoplasms) with 39-51 days to flowering and 12-35 cm panicle length were developed for dissemination. Under high disease pressure in the green house, eight of these were highly resistant (0-10% DM incidence) to at least three of the five diverse pathotypes (Jodhpur, Jalna, Jamnagar, Durgapura and Patancheru). Of these, one was resistant to all the five pathotypes, two to four pathotypes, five to three pathotypes, and one to one pathotype.
- Six A/B pairs earlier bred for both DM and smut resistance were field evaluated for smut incidence under high disease pressure in the smut nursery at Patancheru (90-100% smut in checks 81A/B and 841A/B). Three of these were highly resistant to smut (<5% severity) and one of these (ICMA 92777) was also highly resistant to Durgapura pathotype (<1% DM incidence) under high disease pressure in the green house. Others had 40-60% smut.
- Four three-way hybrids made on F_1 male-sterile (ICMA 95111x ICMB 97444) using 4 restorers, their 8 single-cross hybrids made on the two parental male-sterile lines, and 4 single-cross hybrids made on 843A (control) were evaluated to assess the combining ability of F_1 male-sterile in comparison with the parental male sterile lines. Preliminary indications were that three-way hybrids appeared as productive as the single-cross hybrids.
- The 11 arid zone restorer populations produced in the ICAR-ICRISAT partnership project between 1998 and 2003 at Nagaur, Rajasthan (India) for both per se performance and combining ability (on 4 A-lines). These populations are based on adapted landrace

sources and are meant to broaden the genetic base of restorer materials for arid zone breeding programs

- A large set of B x B crosses of adapted arid zone seed parents were evaluated for general combining ability for biomass at Nagaur, Rajasthan (India). This is based on earlier findings that a positive GCA for this trait is necessary to achieve simultaneous heterosis for both stover and grain yields, which are equally important in the arid zone. The objective is to identify adapted B x B crosses, from which new seed parents with a positive GCA for biomass can be selected.
- More than 200 pearl millet accessions from West Africa successfully multiplied (sibbed) and initially characterized for morphological and phenological traits. Extra early and fodder types identified.
- Various improved open-pollinated cultivars were tested on-farm at Sadore, Lelehi, Doutchi, Mangainze, Famale, Tahoua villages in Niger.
- Trials were set-up in Nigeria in three agro-ecological zones, on research stations, and on-farm to evaluate a range of new varieties, and the adaptive potential of some population bulks. In some areas population bulks have been identified for farmers' selection of single plants to derive progenies for further testing.
- Published a handbook on participatory plant breeding together with colleagues of University of Hohenheim. A training workshop was conducted for partners in Mali (25 participants) on participatory breeding, and in Nigeria (50 participants) on participatory variety testing.

Groundnut

- Significant efforts were invested in farmer participatory varietal selection and seed systems. As a result of these efforts, the search for a replacement of TMV 2 in Anantapur district (Andhra Pradesh, India) is nearing completion. ICGV 91114 is winning over farmers in the district and gaining increasing popularity among them each day. Another interesting development is the revival of groundnut in North India- a new cropping season for the crop is emerging after harvest of potato or mustard in Feb/Mar (spring season) in the region. This has been made possible by varieties such as Avtar (ICGV 93468) and SG 99 (ICGV 89280).
- Establishment of village level seed production and distribution system was encouraged in Shivapuram and West Narsapuram villages of Anantapur district (Andhra Pradesh, India). Many farmers, particularly those with irrigation facilities, agreed to take up seed production program in the postrainy season to provide seed for the rainy season crop.
- Among 84 foliar diseases resistant advanced breeding lines including controls evaluated in the 2004/05 postrainy season in 4 yield trials, 19 significantly outyielded the best control in their respective trials.
- Among 141 medium-duration advanced breeding lines including controls evaluated in the 2004/05 postrainy season in 5 yield trials under high input conditions, 17 lines produced significantly higher pod yield than the highest yielding control in the respective trials.
- No genotype was found to possess complete resistance to aflatoxin production and the relationships between physiological traits and aflatoxin production were inconsistent showing a large influence of G x E on these parameters. The traits associated with plant water status could only partly explain the variation in aflatoxin production among the genotypes. Genotypes with low aflatoxin risk were identified.

- Haulm samples from on-station yield trials were evaluated for their feed quality. Significant differences were observed among the genotypes for nitrogen content, in vitro digestibility and metabolizable energy content. No negative relationships were observed between the haulm quality traits and pod and haulm yields. The broad sense heritabilities for haulm quality traits were high enough to permit selection for these traits. In a controlled feeding trial, the live weight gain in sheep was cultivar dependent. Therefore, the choice of a groundnut cultivar is likely to have considerable influence on live stock productivity.
- Forty-one sets of international trials (4 foliar diseases resistant, 8 drought tolerant, 7 short-duration, 7 Medium-duration, 3 aflatoxin resistant and 12 confectionery) were supplied to collaborators in Afghanistan, Bangladesh, China, India, Indonesia, Philippines, South Africa and Sudan.
- Four sets of a new international trial formulated with red-seeded groundnut varieties and advanced breeding lines were dispatched for evaluation in Uzbekistan, Tajikistan, Armenia and Georgia.
- A short-duration groundnut variety ICGV 92195 was released by the Central Varietal Release Committee as 'Pratap Mungphali –2' for zone II (Rajasthan and Gujarat) in India.
- Two high-yielding varieties ICGV 86300 and ICGV 90173 as Rajarshi and Baidehi, respectively, in Nepal.
- ICGV 93468, a short-duration variety, is proposed for release as 'Avtar' in Uttar Pradesh, India for spring season cultivation. The variety is already popular with the farmers and was cultivated in 59,000 ha during the 2005 spring season.
- A confectionery variety, AK 303, selected from an F_4 population ((ICGV 88384 x JL 24) x (ICGV 88438 x ICG 5240) F_1) is proposed for release in Maharashtra, India.
- The best varieties in terms of yield and early leaf spot score were ICGV-SM 95714, 95695 and 95740 (813-947 kg/ha) compared to the best resistant control Valencia R2 (600kg/ha) and the susceptible check JL24 (428kg/ha).
- Breeder seed of popular groundnut varieties was produced to sustaining commercial production to meet market demand (ICGV-SM 90704, ICG 12991, JL 24, and CG 7) in Eastern and Southern Africa (ESA).
- A two-tier strategy was used for groundnut rosette disease (GRD) resistance selection from the segregating populations. First selection was done in the field where purported superior plants were tagged and harvested. The final selection was done in the laboratory using yield as another criteria. Out of 17 rosette disease resistant lines 6 were chosen for further advance.
- A new rosette resistant line ICGV-SM 99568 was released in Malawi.
- Characterized 36 advanced groundnut-breeding lines with multiple attributes (dual purpose, tolerant to aflatoxin contamination and resistant groundnut rosette disease) for resistance early leaf spot. Among 14 early maturing rosette resistant lines, one was highly tolerant to early leaf spot (score of 5 on 1-9 scale) at Samanko in Mali. The six aflatoxin resistant lines were also tolerant to early leaf spot.
- Mechanisms for sustainable breeder seed production such as revolving fund have been initiated in Niger and Nigeria. This is being encouraged in other countries.
- A report on market prospects for groundnut in West Africa was published as technical paper and has been widely distributed.
- Linkages have been developed between producers and processors and there is now a much greater interest in, and requirement for, market and price information in West

Africa. Attempts are being made to improve the distribution of such information through various pathways including rural radio and television networks.

- Seed of 5 popular groundnut varieties was given to farmers in Kolokani region of Mali. Individual farmers and associations were assisted in seed production at the community level.

Chickpea

- Completed and published a report "Adoption studies on improved chickpea varieties in Ethiopia".
- A Chickpea Scientists' Meet was organized at ICRISAT during January 2005. The meeting was attended by 45 scientists that included 28 Indian NARS scientists from 12 states in India and 17 ICRISAT's scientists. The NARS scientists visited experiments and interacted with ICRISAT's scientists. They selected breeding lines and germplasm of their interests, which were later supplied to them.
- Produced 28 t breeder seed of ICRISAT-related chickpea varieties (ICCV 2, ICCV 10, ICCC 37, KAK 2, and JG 11). The seed was distributed to various agencies as per allotment from Government of India.
- Two International Chickpea Screening Nurseries (ICSN-*Desi* and ICSN-*Kabuli*) were evaluated by NARS scientists during 2004/05. The data received from 18 locations for ICSN-*Desi* and 17 locations from ICSN-*Kabuli* was compiled in a report and distributed to Indian NARS during chickpea workshop.
- 30 sets of ICSN-*Desi* and 29 sets of ICSN-Kabuli were distributed to NARS scientists of 9 countries for evaluation during 2005/06.
- Mechanism of resistance to *Helicoverpa* was studied in eight desi (ICC-12475, -12476, -12477, -12478, -12479, -4918, -12426 and ICC-3137) and one kabuli (ICCV 2) under green house and field conditions. ICC 12478 suffered significantly less leaf damage, followed by ICC 12475 (ICC 506), ICC 12479 and ICC 12477. ICC 3137 was highly susceptible.
- In the diallel study, most crosses with ICC 12475, ICC 12478, and ICC 12479 had less pod borer damage, while crosses with ICC 3137 suffered high damage. ICC 12475, -12476, -12477, -12478 and ICC 12479 were least preferred for oviposition by *H. armigera* moths. Lowest larval and pupal weight and prolonged larval and pupal periods were recorded on artificial diets impregnated with lypholyzed leaf powder of ICC 12475; while higher growth were recorded on diets with ICC 12426 and ICC 4918.
- HPLC profile of leaf exudates showed that the malic acid was negatively correlated with damage rating at flowering (-0.28*), maturity (-0.32**) and pod damage (-0.22*). Oxalic acid showed negative and significant correlation with leaf damage rating in detached leaf assay (-0.22*). Acetic acid showed negative correlation with larval weight (-0.45*), damage rating at flowering (-0.33*), and at maturity (-0.26*). Citric acid showed negative and significant correlation with damage rating at flowering (-0.23*).
- A diallel study suggested that additive gene action was predominant for days to flowering, days to maturity, pod borer damage, pods per plant, seeds per pod, and 100 seed weight; while non-additive gene action was important for grain yield. The additive: dominance ratio was greater than unity for all traits (over dominance), except for grain yield (partial dominance). There was no material inheritance for maturity traits, pod borer damage and grain yield.

- We confirmed moderate resistance to *Ascochyta* blight (AB) (disease score 3.1-5 on a 1-9 scale) in three accessions (ICC 1915, ICC 3603 and ICC 11284), and moderate resistance to Botrytis grey mold (BGM) infection and colonization (disease score 3.1 to 5.0) in 59 accessions. Two accessions (ICC4841 and ICC 7668) scored 3.3 and 4.0 respectively.
- Although earlier reports indicated limited genotypic variation in chickpea for salinity tolerance, we found over a 6-fold range of variation in the seed yield per pot. In particular, we found that some genotypes had a 20% higher seed yield under salinity than the best released variety for salinity tolerance, CSG8962.
- We found that *desi* type were usually more tolerant than *kabuli* types to salinity. We found that seed yield per pot was well correlated to the number of pods per plants under salinity but poorly correlated to the seed size, showing that salinity effect played a role probably more during the pod setting and/or grain formation that during seed development and filling. We also found that maturity was significantly related to salinity tolerance, in a form of an inverse parabola. Extra early genotypes had fairly low seed yield under salinity.
- Application of a 100-125 mM NaCl solution to saturate the field capacity of Alfisol was a suitable treatment to find good phenotypic contrast in groundnut. We found that tolerant groundnut keep the ability to expand leaves. By contrast, there seemed to be no relation between the biomass produced under salinity and the accumulation of Na. As in sorghum, it seems that groundnuts are able to accumulate large amounts of Na in the stem. Whether this could be used as a screen for salinity tolerance has not been tested.
- *Helicoverpa armigera* is used routinely as a tool for research on insect host plant interactions, biological, physiological, behavioral, and toxicity studies. Hence, manipulation of its life cycle can be used as a tool to have adequate numbers of insects at the appropriate stage of development for experimental purposes. Therefore, studies were undertaken to determine the effect of storage temperature on the duration and viability of eggs. Percentage egg hatch and incubation period were significantly influenced by egg age, storage temperature, and storage duration. Average egg hatch ranged from 0.0 to 96.8% across temperatures (-20 to 35^0C) and storage durations. None of the eggs hatched at -20 and 0ºC. Day degrees required for egg hatching decrease with an increase in temperature from 10 to 27ºC, and egg age from 0 to 3 days. The day degree requirements were highest for 0 day-old eggs at 10ºC, and lowest at 27ºC. It is safer to store *H. armigera* eggs at 10ºC for 10 days, with a hatchability of >75.0%, and an incubation period of <2 days.

Pigeonpea

- In the A_4 cytoplasm group, the fertility restoration (Fr) of hybrids, identified in 2004, was confirmed and we found no variation over the two seasons. In the hybrids developed with CMS lines of A_1 and A_2 cytoplasm, on average, the stability of Fr was not very high and varied between 75-100%. Among the new crosses (only A_4 cytoplasm), out of 53 short-duration hybrids evaluated 34 were found as fully fertile and the remaining were male sterile. Among the new restorers ICPL 88034, ICPL 88039, ICPL 161 and ICPL 149 were promising.
- In the short-duration (SD) groups ICPH 2470 produced a record 3205 kg ha^{-1} yield with 77% superiority over control, at ICRISAT-Patancheru. Among the medium-duration group ICPH 2899 (3038 kg ha^{-1}, 27% superiority), ICPH 2658 (3636 kg ha^{-1},

40% superiority), ICPH 2715 (3071 kg ha^{-1}, 28% superiority) were found to be promising. In the mid-long-duration (A_1 cytoplasm) group. ICPH 2319 (3017 kg ha^{-1}) was the best with 61% superiority over the check. The other promising hybrids were ICPH 2307 (2855 kg ha^{-1}, 53% superiority), and ICPH 2306 (2600 kg ha^{-1}, 39% superiority).

- In addition, we got a big boost in strengthening our relationship with five public institutions through a Government of India project.
- Purified and multiplied seeds of 14 pigeonpea and 12 chickpea varieties for supply to NARS in ESA.
- Identified and selected populations in short duration (SD) pigeonpea with large seed and high yields and with phenology not delayed by cool temperature in ESA. The SD varieties developed from the populations will be targeted to East African Highlands where currently SD varieties cannot be grown due to delay in flowering and maturity.
- Identified and selected from populations in long duration (LD) pigeonpea with large seed and high yields and with phenology not accelerated by cool temperature. The LD varieties developed from the populations will be targeted to East African Highlands where currently LD varieties grown give low yield due to competition between maize and pigeonpea.
- Identified and selected populations with large seed and high yields in medium duration (MD) background whose phenology is insensitive temperature and photoperiod. The MD varieties developed from the populations will be targeted to Southern Africa where currently MD varieties grown give low yield due to delayed flowering and maturity and thus suffer from terminal drought stress. Constituted nurseries of the MD populations in October 2003-2004 and sent to Malawi and Tanzania for further evaluation. The lines all flowered early and matured in May and farmers, NGOs and private sector are keen to have them released.
- To overcome the variation in insect density and staggered flowering of the pigeonpea genotypes, we standardized the detached leaf assay to screen for resistance to *H. armigera* in pigeonpea under uniform insect pressure under laboratory conditions. Detached leaf assay can be used as a rapid screening technique to evaluate germplasm, segregating breeding materials, and mapping populations for resistance to *H. armigera*. However, this technique was not found to be as effective in pigeonpea as in case of chickpea, groundnut, and cotton. Leaf feeding damage ratings of the genotypes tested did not show the same trend as the pod damage ratings under natural infestation.
- Fifteen morphologically diverse lines of pigeonpea were studied for their interaction with *H. armigera* in the field. The genotypes ICP 12476, ICP 8102, and ICP 9879 suffered <40.5% pod damage by *H. armigera* compared to 40.8% in ICPL 332, 75.6% in ICPL 87, and 73.9% in ICPL 87119. These genotypes also had 49.6 to 58.4% healthy pods per plant compared to 66.7% in ICPL 332, 11.5% in ICPL 87, and 48.9% in ICPL 87119. The resistance of these pigeonpea genotypes with *H. armigera* will be studied in greater detail, and linked to physico-chemical traits of the host plant.
- We evaluated the effect of different protection regimes on *H. armigera*-resistant (ICPL 332) and susceptible (ICPL 87119) genotypes of pigeonpea to quantify the contribution of host plant resistance in *Helicoverpa* management. The results clearly suggest the usefulness of combining insect resistant varieties with insecticides for management of *H. armigera*.

Integrated pest management (IPM)

- We have further refined and standardized the protocol for greenhouse evaluation of dry root rot disease of chickpea, and confirmed high levels of resistance in 5 accessions. ICC 11764 scored < 4 (on a 1-9 rating scale) to *Rhizoctonia bataticola* infection.
- Evaluation of various insecticides for the management of *Maruca* through field studies conducted at ICRISAT-Patancheru during rainy season 2005 revealed maximum level reduction (82%) with Spinosad (Tracer) followed by indoxacarb (72%), Monocrotophos (40%) and Metarhizium (20%) reduction 48 hours after application. The observations five days after the application of treatments indicated 90% population reduction with Spinosad compared to 85% with Indoxacarb followed by 22% with Monocrotophos. The larval population in treatment of Metarizhium was on par with control (6 larvae plant^{-1}).
- A model to predict the incidence of chickpea pod borer (*Helicoverpa armigera*) validated the relation between pheromone trap catches followed by oviposition and larval load in the next one week and 15 days respectively. Pheromone trap catches during 2003-2004 postrainy season were at peak (52 moths/trap/day) during first week of December, which resulted in peak larval activity (4.5 larvae/plant) in the third week of December. This gave a clear indication of 15 days interval between moth catch and the pod borer damage. However, the adult activity during 2004-05 season indicated a decline in their population (< 10 moths per day per tarp), which reflected in lower larval population during the third week of December when crop was at reproductive phase.
- *Maruca* adults started invading pigeonpea crop during the second fortnight of August when extra-short duration pigeonpeas initiated flowering, which resulted in peak larval population by 17 September with 6.5 larvae plant^{-1}, and the population later declined to zero level by 15 October. Periodic observations on larval parasites during August-September did not reveal any parasitization.
- A total of 504 isolates involving bacteria, fungi and actinomycetes were added to the microbial collection. The new additions represent four beneficial traits: ability to grow in a culture medium without added nitrogen, ability to solubilize insoluble sources of phosphorous, plant-growth promotion (assessed by siderophore production), and antagonistic to disease-causing fungi.
- Hot water extract of 21 botanicals were studied for ability to kill neonate larvae of *Helicoverpa*. Neem oil (market sample) was used as reference. Like in the previous studies, hot-water extracts generally had higher activity than the relevant compost wash although there were prominent exceptions (Nerium, Parthenium, Pongamia and Prosopis). Six (*Anona, Calotropis, Chrysanthemum, Dhatura, Nerium* and *Prosopis*) of the 21 botanicals had activity close to or better than the reference (Neem oil).
- The long-term experiment initiated in 1999 was continued. Cowpea/cotton intercrop was grown in this year (2005/06). Cowpea grew well in all the four treatments and was harvested as a green manure. A biomass yield of 3.88 t ha^{-1} (in the treatment plot with conventional input) to 4.78 t ha^{-1} (in the treatment receiving conventional inputs ad plant biomass) meaning 77.6 to 95.6 kg N ha^{-1} was added to the relevant treatments. This is seventh year of the experiment. Protection of cotton (from *Helicoverpa*) with bio-pesticides alone seems promising this year also. The scouting team of FES has reported lower population of *Helicoverpa* in the biopesticide plots than the chemical protected plots on at least three different occasions.

- Feasibility of delivering the bacterium *Bacillus subtilis* (strain BCB 19) as a strip (1cm x 5cm) of filter paper was evaluated. Each strip (with cell protectants) was found to have 1.88×10^9 bacteria after 13 months storage at room temperature. Thirty such strips could be packed in a vial of about 30 ml capacity. Regular observations on counts will continue for some more time.

Variety Releases

Fourteen varieties were released in six countries (Australia, Ethiopia, Ghana, India, Malawi, Nepal and Uzbekistan). The varietal releases were in sorghum (1), pearl millet (2), chickpea (3) and groundnut (8).

Resource Mobilization

During 2005, the scientists in Crop Improvement and Management (along with scientists from other Global Themes) were successful in getting 41 special projects to augment the core funds of the Institute. The total amount of funds garnered in 2005 was US$ 7.45 million. We also submitted 20 project proposals/concept notes to various donors (details in Appendix 1).

Publications

Books/Book Chapters: 34; Journal Articles: 92; E-Journal Articles: 9; Conference/Workshop Papers: 108; Information Bulletins/Newsletter Articles/SATrends: 30; Methods Manual: 1; Oral Presentations: 6; Posters/Flyers/Success Stories: 28; Public Awareness Articles: 3; Release Proposal: 1; Reports: 10; Student Theses: 7; and Technical Reports: 3 (see Appendix 2 for detailed listing).

Global Theme on Crop Improvement and Management

Archival Report 2005

Regional Project 1

Improving crop productivity through genetic enhancement and eco-friendly pest management, and enhancing alternative uses of products in Asia

Regional Theme Coordinator: KN Rai

Regional Project Members:

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Regional Project 1: Improving crop productivity through genetic enhancement and eco-friendly pest management, and enhancing alternative uses of products in Asia

Output 1.1: Germplasm conserved, evaluated, documented and exchanged

Summary

Genetic resources are important and essential components of crop improvement. The benefits of these resources largely depend on the diversity of the collection, their adequate characterization and documentation, and user access to the collection. Some of the significant genebank activities to accomplish these objectives are as follows.

During 2005, we assembled 2633 new accessions (chickpea: 2014 and sorghum: 619) in the genebank. With these additions, the total accessions increased to 117,503 from 130 countries. A set of 483 sorghum germplasm samples, collected by a group of researchers from INRAN, UMA, ICRISAT and CIRAD in Niger in 2003, was received at Patancheru after obtaining the Germplasm Acquisition Agreement (GAA) from the Government of Niger. Efforts are underway for obtaining 424 pearl millet samples collected from this mission. A set of 622 groundnut accessions were acquired from National Agrobiological Sciences (NIAS), Ibaraki, Japan that were unique in comparison with those in the ICRISAT Genebank. Similarly, 840 chickpea accessions were acquired from USDA, Pullman, USA. Both the sets were planted for quarantine observations for possible release during 2006.

A total of 2984 accessions were processed for medium-term storage (MTS) and 8486 accessions for long-term storage (LTS). We also prepared 8225 seed samples of different crops for off-site duplication as safety back-up. Safety back-up collection was established at Niamey regional genebank for 11,791 accessions. Seed viability of 1741 accessions from MTS (three to eight years old) and 3238 accessions from LTS for (over 10 years old) was monitored. This resulted in identifying 179 accessions in MTS (<75% viability) and 69 accessions in LTS (<85% viability) for regeneration during 2006. Regenerated 3037 accessions with critical seed stock and viability for MTS; 5723 accessions for LTS and 4417 accessions for safety back-up. Additionally, 303 critical accessions were regenerated under controlled conditions of greenhouse facility. The seed health of 7582 accessions identified for LTS was tested using standard protocols and the results were documented.

We characterized 3916 accessions during 2004 rainy and 3413 during 2004–05 postrainy seasons (full characterization or collecting data on missing traits). Additionally, 3904 accessions of different crops were evaluated for special traits useful in crop improvement. Germplasm composite sets of 1000 accessions each of pigeonpea and finger millet and 850 accessions of groundnut were grown for evaluation. To enhance utilization of germplasm, mini-core sets of chickpea and groundnut were evaluated at several locations in six countries. Core set of finger millet was evaluated at three locations in India and one in Kenya and mini-core set of finger millet at one location in India. Pigeonpea core set (1290 accessions) was evaluated at ICRISAT-Patancheru.

The Genebank Information Management System was updated to meet the users' requirement. Germplasm databases of chickpea at ICARDA (Syria) and groundnut at NIAS (Japan) were compared for identifying unique accessions for the ICRISAT Genebank. Characterization and evaluation data on large number of cultivated and wild species accessions were computerized.

During the year, 30,985 germplasm samples were supplied to users on request. This included 4325 samples to scientists outside ICRISAT (22 countries and 87 requests) and 26,660 samples for use by ICRISAT scientists.

Activity 1.1.1: Assemble, conserve, and regenerate the global germplasm collection for safe storage and supply

Milestone: New germplasm collected from priority areas, and assembled germplasm safely conserved as active and base collection for utilization (2007)

During 2005, a total of 2633 new accessions were assembled in the genebank. This included 2014 accessions of chickpea (68 wild and 682 cultivated from ICARDA and 21 wild and 1243 cultivated from USDA-Pullman, USA) and 619 sorghum accessions. The sorghum accessions were those that were missing from the earlier Rockefeller Foundation Collections. These were subsequently acquired from National Seed Storage Laboratory, Fort Collins, USA. With these additions, the total number of accessions in the genebank increased to 117,503 from 130 countries. A set of 483 sorghum germplasm samples collected in Niger in 2003 by a group of researchers from INRAN, UMA, ICRISAT and CIRAD was received at Patancheru after obtaining the Germplasm Acquisition Agreement (GAA) from the Government of Niger. Efforts are underway for obtaining 424 pearl millet samples collected during this mission. A total of 622 groundnut accessions from National Agrobiological Sciences (NIAS), Tsukuba, Japan and 840 chickpea collections from USDA, Pullman, USA were identified as unique for assembly at ICRISAT Genebank. We are in the process of securing 231 pigeonpea samples that were collected in Mozambique (79), Tanzania (123) and Uganda (29) from ICRISAT Regional Program, Nairobi, Kenya.

We processed germplasm seed samples of 2984 accessions (sorghum: 279, pearl millet: 76, chickpea: 271, pigeonpea: 39, groundnut: 2036 and small millets: 283) for MTS and 8486 accessions (sorghum: 850, pearl millet: 1250, chickpea: 575, pigeonpea: 1281 and groundnut: 4530) for LTS. These were the harvests of 2004 rainy and 2004–05 postrainy season grow outs. With these additions, the total collection in LTS increased to 92,968 accessions that represent 79.1% of the entire collection.

During this year, the seed viability of 11,691 accessions for MTS and LTS was tested. This included: 1220 (sorghum), 1811 (pearl millet), 2649 (chickpea), 1281 (pigeonpea) and 4730 (groundnut) accessions. The seed viability of 1741 accessions (sorghum – 370, pearl millet – 561, pigeonpea – 570 and groundnut – 240) in MTS for 3 to 10 years; and 3238 accessions (pearl millet – 1836 and groundnut – 1402) in LTS for over 10 years was monitored. This led to identification of 179 accessions in MTS (<75% viability) and 69 accessions in LTS (<85% viability) for regeneration during 2006. A total of 7582 germplasm accessions (sorghum – 1070, chickpea – 569, pigeonpea – 1281, groundnut – 3998, and pearl millet – 664) regenerated from medium-term storage of ICRISAT Genebank were evaluated for seed health using the standard blotter method and the results were documented.

To achieve the germplasm safety back-up at other locations, we prepared seed samples of 8225 accessions (sorghum – 1932, chickpea – 2763, pigeonpea – 1208 and groundnut – 2322) from 2004 rainy season and postrainy season plantings. At regional genebank – Niamey, Niger, safety back-up collection was established for 11,791 accessions (pearl millet – 5205, groundnut – 2006 and small millets – 4580). A set of 1877 accessions of chickpea is awaiting back-up storage at ICARDA, Aleppo, Syria.

HD Upadhyaya and CLL Gowda

Milestone: Germplasm accessions with limited seed stock/viability regenerated for medium- and long-term conservation, and tested for seed health (2007)

We regenerated 3037 accessions (sorghum – 25, pearl millet – 771, chickpea – 220, pigeonpea – 1080, groundnut – 537, finger millet – 238, foxtail millet – 148, barnyard millet – 3, little millet – 3, proso millet – 2, and kodo millet – 10) for MTS and 5723 accessions representing sorghum (2000), pearl millet (769), chickpea (452), pigeonpea (427) and groundnut (2075) for LTS during the 2005. Special regenerations were carried for 4417 accessions (chickpea: 2667 and groundnut: 1750) for safety back-up. In the special facility for wild *Arachis*, 182 accessions representing 28 species were grown for seed increase. Additionally, 121 critical accessions of different crops (chickpea – 108, pigeonpea – 10, sorghum – 1 and finger millet – 2) were regenerated in the glasshouse facilities.

HD Upadhyaya and CLL Gowda

Seed health testing of germplasm accessions for medium- and long-term storage in the genebank: A total of 7582 germplasm accessions (sorghum – 1070, chickpea – 569, pigeonpea – 1281, groundnut – 3998, and pearl millet – 664) regenerated from medium-term storage of ICRISAT Genebank were evaluated for seed health using the standard blotter method. Only 233 of 7582 accessions were free from any seed-borne pathogens (sorghum – 26, pearl millet – 29, chickpea – 49, pigeonpea – 35, and groundnut – 94). Forty seed-associated fungal species in sorghum, 22 in pearl millet, 24 in chickpea, and 32 each in groundnut and pigeonpea were detected. The major fungi genera associated with seed of all five crops were species of *Cladosporium, Alternaria, Fusarium, Phoma, Curvularia, Bipolaris, Aspergillus, Penicillium, Rhizoctonia bataticola* and *Periconia*. Some of these fungi, such as species of *Alternaria, Fusarium, Curvularia, Phoma* and *Rhizoctonia* were seed-borne and thus affected seed germination up to 4.5% in sorghum, 2.7% in pearl millet, 4.2% in chickpea, 4.8% in pigeonpea and 0.75% in groundnut. Bacterial growth, in traces, was detected in all crops without any significant effects on seed viability.

RP Thakur and *HD Upadhyaya*

Milestone: Requested germplasm distributed to bona fide users for utilization (2007)

A total of 30,985 samples of in-trust germplasm accessions were distributed to scientists globally for utilization. This includes 4325 samples (329 sorghum; 369 pearl millet, 1511 chickpea; 98 pigeonpea; 339 groundnut; and 1679 small millets) to 22 countries (Table 1.1) under 87 consignments; and 26,660 samples to users within ICRISAT. The total included: sorghum – 8140, pearl millet – 2714, chickpea – 3627, pigeonpea – 3042, groundnut – 7573 and small millets – 1564. Additionally, leaf samples of germplasm composite sets (sorghum –

2300, chickpea – 2774, and pigeonpea – 1000) were provided for DNA extraction within the institute.

HD Upadhyaya, CLL Gowda and RP Thakur

Table 1.1. Germplasm samples distributed from ICRISAT-Patancheru Genebank to scientists globally during the year 2005.

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Small millets	Total
Bangladesh					1		1
Canada			213				213
China					188		188
Denmark	7						7
Fiji	10						10
France		49					49
Germany	37						37
Haiti	11				11		22
India	149	88	1065	46	119	1156	2623
Iran	58	7		19			84
Japan	1	8	208	3			220
Jordan		20					20
Kenya						506	506
Mexico	14						14
Niger		120					120
Pakistan		22					22
Papua New Guinea			24	16	19		59
Somalia	42						42
Spain			1				1
Thailand					1		1
USA		55		14			69
Uruguay						17	17
Total	**329**	**369**	**1511**	**98**	**339**	**1679**	**4325**

Activity 1.1.2: Undertake characterization, evaluation and documentation of germplasm to enhance its utility in crop improvement

Milestone: New germplasm characterized for morpho-agronomic characters and evaluated for special traits (2006)

During the 2005 rainy season, a total of 3916 accessions of pearl millet (512), pigeonpea (900) and groundnut (2504), and in the postrainy season, 3413 accessions of sorghum (156), pearl millet (512), chickpea (1745) and groundnut (1000) were characterized for morpho-agronomic traits (full characterization or collecting missing data).

In addition, 3904 accessions of different crops (sorghum – 129, pearl millet – 504, finger millet – 1020, foxtail millet – 175 chickpea – 202, pigeonpea – 1000 and groundnut – 874) were grown for recording agronomic and special traits useful in crop improvement. The traits/sets in different crops include: 32 zerazera type, 62 yellow endosperm and composite collection of 35 accessions in sorghum; a core set of 504 accessions of pearl millet and composite set of 1000 accessions; 20 elite accessions in finger millet; core set of 155 and 20 elite accessions in foxtail millet; 34 large-seeded *kabuli*, 16 early-maturing, 54 salinity tolerant, 58 extra-early *kabuli*, 20 each of drought tolerant lines (large root length density and deep roots) in chickpea; composite set of 1000 accessions of pigeonpea and composite set of 850 and 24 extra-early maturing accessions in groundnut.

The finger millet core collection was evaluated at three locations in India (ICRISAT-Patancheru, Bangalore and Vizianagaram), and at one location in Kenya. Pigeonpea core set (1290 accessions) was evaluated at ICRISAT-Patancheru location.

Finger millet composite collection of 1000 accessions (ICRISAT finger millet core collection – 622, agronomically elite – 222, core collection of Indian NARS – 50, resistance to stresses – 85, grain nutrition traits – 12, and genetic diversity – 9) was characterized for important morpho-agronomic characters. A pigeonpea composite collection of 1000 accessions was grown under pollination control cages for characterization and regeneration.

Several promising sources of germplasm were identified from evaluations during 2004-05. From chickpea germplasm composite set (3000 accessions) - ICCs 8318, 17256, 8324, and 12197 (*desi*), IG 70779 (*kabuli*) and ICC 812 (pea-shaped seed) for yield (2.74–3.35 t ha^{-1}), ICCs 12034, 13821, 16641, and ICCV 96329 (*kabuli*) and ICCs 17258, 5810, and ICCV 96030 (*desi*) for early flowering and yield (33–36 days to 50% flowering and 1.18–2.02 t ha^{-1}); ICCs 12034, 7346, and 14205 for large seed size and yield (45.0–45.7 g 100^{-1} seed weight and 1.18–2.02 t ha^{-1} grain yield) among *kabuli* types and ICCs 14648, 4871, and 7672 (29.2–35.4 g 100^{-1} seed weight and 1.25–2.26 t ha^{-1}) among the *desi* types.

From new chickpea introductions (USA), lines EC no's 543533, 543598, 543584, 543593, and 543599 (all *kabuli* type) were identified for large seed size and yield (45.5–54.9 g 100^{-1} seed weight; 1.70–1.91 t ha^{-1} seed yield).

Based on the evaluation of 16 large-seeded *kabuli* chickpea accessions at six environments, lines ICCs 17109, 16670, 7344, 14194, and 8155 (35–37 days to 50% flowering; 50–57 g 100^{-1} seed weight) were identified as good sources of earliness combined with large seed size in comparison to control ICCV 2 (40 days and 27 g 100^{-1} seed). Similarly, based on the evaluation data of 28 early-maturing chickpea accessions from six environments - ICCs 16641 and 16644 (31–32 days to 50% flowering) were identified as additional sources for extra-earliness. ICCs 2859, 10232, 10629, 11160, 11180, and 14648 (1.36–1.66 t ha^{-1}) produced significantly greater seed yield than the early-maturing controls Harigantars (1.10 t ha^{-1}) and ICCV 2 (1.27 t ha^{-1}) in the pooled analyses.

From amongst 58 extra-early *kabuli* elite accessions tested, 12 accessions were early flowering (23–26 days to 50% flowering), large-seeded (27.4–35.5 g 100^{-1} seed weight) and high-yielding (2.38–2.82 t ha^{-1}) in comparison with ICCV 2 (27 days, 26.1 g, and 2.36 t ha^{-1}).

Based on eight seasons data of 21 early-maturing groundnut accessions at ICRISAT-Patancheru, the test entries produced an average pod yield of 1.08 t ha^{-1}, 8.2% more than the average of all the controls at 1240 ^{o}Cd [equivalent to 75 days after sowing (DAS) in rainy season]; and 1.46 t ha^{-1}, 12.6% more than the average of controls at 1470 ^{o}Cd (equivalent to 90 DAS) in the postrainy season. Two new sources earliness (ICG 3540 and ICG 14855) produced 22.6% and 16.8% higher pod yield at 1240 ^{o}Cd and 10.6% and 23.7% higher at 1470 ^{o}Cd than the earliest-maturing control Chico. These accessions also produced 27.9% and 21.9% higher pod yield at 1240 ^{o}Cd and 4.0% and 16.2% higher at 1470 ^{o}Cd than the control JL 24, respectively.

HD Upadhyaya and CLL Gowda

Milestone: New germplasm sources identified for water use efficiency traits in groundnut, and drought avoidance and salinity tolerance in chickpea (2005)

Groundnut composite collection consisting of 850 accessions was evaluated in an augmented design with four repeated control cultivars for pod yield potential and drought related traits. SPAD Chlorophyll Meter Reading (SCMR) and Specific Leaf Area (SLA) were recorded on these accessions of groundnut composite collection at 60 and 80 days after sowing (DAS). ICGs 2741, 5725, 5728, 6323, and 7878 were identified with high SCMR (53.9–61.0) (known to represent high water use efficiency).

Based on eight seasons data of 18 cultivated groundnut accessions for drought-related traits, ICGs 5745, 6766, 7243, 14523, and ICG 14475 (129–150 and 132–153 SLA at 60 and 80 DAS and 42–44 SCMR at both sampling dates) were identified as additional sources for drought tolerance traits in comparison to control CMSG 84-1 (144 and 150 SLA and 43 and 42 SCMR at 60 and 80 DAS, respectively).

Chickpea mini-core was evaluated for root length and root depth (which are responsible for drought tolerance). ICCs 8261, 10885, 16796, 13816, 13599, 1915, 15264, 6306, and 5337 were identified with large root length and density; and ICCs 3512, 15697, 13523, 1356, 4872, 7272, 8261, 95, 440, and 1431 for deep root system.

ICCs 15510, 4953, 7255, 14199, and 12908 (2.52–3.36 t ha^{-1}) were the best five accessions in comparison to control Jumbo 2 (1.10 t ha^{-1}) among the 54 salinity-tolerant chickpea accessions evaluated for morpho-agronomic traits during 2004-05 postrainy season. Groundnut mini-core was evaluated for salinity tolerance. ICGs 4890 and 4911 were found tolerant to salinity.

HD Upadhyaya, J Kashiwagi, Vincent Vadez, PM Gaur and CLL Gowda

Milestone: Mini-core collections of chickpea and groundnut evaluated for agronomic traits at different locations in Asia, and Southern Africa (2007)

During this year, chickpea mini-core set was evaluated at three locations in India (Patancheru, Kanpur and Ludhiana) and one location each in Canada and Japan. At the Indian Institute of Pulses Research (IIPR), Kanpur, India, 13 accessions of chickpea were selected for large seed size (>45 g 100^{-1} seed weight) for utilization in breeding programs. These are – ICCs 7344, 12033, 12034, 14194, 14195, 14196, 14197, 14199, 14204, 14203, 14204, 14205 and EC 381882.

From the groundnut mini-core set evaluated at Shandong Peanut Research Institute (SDPRI) China, several accessions were identified promising. These included – ICGs 5662, 6057, 6766, 11219 and 11855 for large seed size (78.4–105.2 g 100^{-1} seed weight); ICGs 36, 76, 118, 397, 434, 1415, 1448, 1455, 1668, 5745, 6057, 6201, 7633 and 14710 for bacterial wilt resistance (score 'zero'); ICGs, 118, 1101, 6022, 8567, 10890, 12672 and 14482 for high oil content (54.0–55.4%); ICGs 3053, 5745, 8285 and 8490 for high oleic acid (60.9–64.7%) and low linoleic acid (18.0–21.2%); and ICGs 3053, 5745 and 8490 for high oleic acid/linoleic acid ratio (3.0–3.6%). These accessions merit further tests for confirming the results.

Groundnut mini-core evaluation by Field Crops Research Center, Khon Kaen, Thailand resulted in identifying ICGs 297, 1668, 1973, 3027 and 13099 for high pod yield (3583–4168 kg ha^{-1}); ICGs 2106, 3240, 7969, 12879 and 12988 for higher shelling percentage (79.8–82.1%); and ICGs 4538, 5662, 6993, 8760 and 9777 for large seed size (77.5–100.5 g 100^{-1} seed weight). Groundnut mini-core collection was also evaluated for morpho-agronomic traits at two locations in Vietnam.

HD Upadhyaya, CLL Gowda, Vincent Vadez and Scientists from NARS

Milestone: Passport, characterization and evaluation data of germplasm documented (2006)

The existing Genebank Information Management System (GIMS) has been working well for safe and efficient handling and reporting of the data. The germplasm characterization databases of different crops updated for 16,224 accessions and documented data on different traits involving germplasm sets. These characterization data include – sorghum (931 accessions for 2004 rainy season and 417 accessions for 2004–05 postrainy season); (foxtail millet (769), barnyard millet (384), proso millet (118); chickpea (978 accessions for two traits); pigeonpea (38 traits on 6668 accessions); and groundnut (41 traits on 5959 accessions). Core collection of 622 finger millet germplasm was characterized and data was tabulated.

HD Upadhyaya

Milestone: Mini-core collection of chickpea germplasm characterized for resistance to *Ascochyta* blight (AB), *Botrytis* gray mold (BGM), wilt, dry root rot and collar rot (2006)

From the chickpea mini-core evaluations at ICRISAT-Patancheru, several promising sources of multiple resistance to biotic and abiotic stresses were identified. These include - ICC 1915 [drought + salinity + *Ascochyta* blight (AB)]; ICC 6306 (drought + AB); ICC 13816 [drought + wilt + *Botrytis* gray mold (BGM)]; ICC 15264 (drought + BGM); ICC 3512 (drought + wilt); ICC 2277 [dry root rot (DRR) + salinity)]; ICC 12328 (DRR + salinity + drought); ICCs 7272, 8261 and 13523 (drought + salinity); ICCs 8261, 10885 and 15697 (drought + salinity + BGM) and ICCs 2969, 6874, 14402 and 15567 (wilt and *Helicoverpa* pod borer).

S Pande, HD Upadhyaya and PM Gaur

Evaluation of chickpea mini-core entries for resistance to fungal diseases: Based on epidemiological principles, we have re-standardized the resistance screening methods for AB, BGM, FW and DRR. These refined techniques were used for resistance evaluation of chickpea mini-core. A total of 211 accessions of chickpea mini-core were evaluated in controlled environment for resistance to *Ascochyta* blight (AB), *Botrytis* gray mold (BGM), *Fusarium* wilt (FW) and dry root rot (DRR) diseases. Three accessions (ICC 1915, ICC 6306 and ICC 11284) were found moderately resistant (disease score 3.1 to 5 on a 1–9 rating scale, where 1 = no symptom; 9 = >75% kill) to AB under controlled environment. Fifty-five accessions were identified as moderately resistant (3.1 to 5.0 rating on 1–9 rating scale) to BGM. High levels of resistance to FW were found in several mini-core accessions under field screening. Twenty-one accessions were asymptomatic and 25 accessions had <10% mortality. Of the 211 mini-core accessions, 6 were moderately resistant (3.1 to 5 rating on a 1–9 rating scale) to dry root rot infection in blotter paper technique under laboratory conditions. Eleven accessions (ICCs 2990, 4533, 6279, 7554, 7819, 9848, 12028, 12155, 13219, 13559 and13816) were resistant to BGM and wilt; and ICC 13441 was resistant to DRR and wilt; ICC 11284 was resistant to AB and BGM; and ICC 11764 and 12328 were resistant to BGM and DRR.

S Pande, GK Kishore, HD Upadhyaya and PM Gaur

Activity 1.1.3: Assure risk-free export and import of germplasm and breeding materials

Milestone: Requested Germplasm exported for utilization and new Germplasm imported for conservation after seed health evaluation and clearance through PQ/NBPGR (Annual)

Seed health testing of breeding material and germplasm accessions for export/import: A total of 4871 seed samples of ICRISAT mandate crops comprising of breeding lines and germplasm accessions were exported to 45 countries (109 consignments). Of these, 153 samples (3%) were rejected mainly due to poor germination and association of seed-borne fungi of quarantine significance. A bulk consignment of 300 kg groundnut (cv. Asha -ICGV 86564) was exported to the Philippines. This consignment was cleared by the National Plant Protection and Training Institute, Hyderabad. A number of seed samples, including 30 of finger millet for export to Kenya that were found infected by species of Bipolaris, Curvularia and Phoma, were salvaged by treatments with Benomyl, thiram, or their combinations.

A total of 2937 seed samples (sorghum – 500, pearl millet – 450, chickpea – 1253 and groundnut – 732) were imported from 8 countries (Australia, Brazil, Israel, Japan, Malawi, Niger, USA and Vietnam). Also a special permission was obtained from Directorate of Plant Protection, Quarantine and Storage, Faridabad, India to import 2648 dried and grounded samples of rice straw (1500 samples) and pigeonpea (1148) from Philippines, Nicaragua and China for the Patancheru-based ILRI program. The National Bureau of Plant Genetic Resources (NBPGR), Hyderabad released 328 germplasm samples of sorghum (210), chickpea (103), and groundnut (15). Of the above, nine accessions of chickpea that were infected with bacteria were grown in the greenhouse. The remaining 94 accessions of chickpea were released to the consignee. Ten of the 15 accessions of groundnut did not germinate hence only five were grown in the greenhouse.

Grow-out test for imports: Chickpea germplasm (129 accessions) from Australia that were found moderately resistant to *Ascochyta* blight and *Botrytis* grey mold under growth chamber conditions in 2004, were grown during the rainy season 2005 for multiplication in the post-entry quarantine isolation area (PEQIA). Some of these accessions showed symptoms of *Fusarium* wilt, *cucumber mosaic virus* and *alfalfa mosaic virus*. These infected samples were destroyed by incineration. Only 121 disease-free accessions were harvested and released to the scientist concerned. Twenty groundnut accessions (14 cultivated and 6 wild *Arachis*) were grown in the greenhouse till harvest to observe bacterial wilt infection (*Ralstonia solanacearum*). No apparent symptoms were observed on the plants. The harvested seed was further tested for the presence of the bacterium by plating the seed on tetrazolium chloride agar medium. All samples were found free from the bacterium and thus the samples were released to the concerned scientist.

Seventy-five chickpea accessions (24 from Syria and 51 from USA) were grown in the greenhouse for observation of bacterial infection (of unknown etiology). Seeds harvested from these accessions were tested for bacterial infection in nutrient agar medium. There were no bacterial symptoms observed either in the greenhouse or in the plated seed, and thus the samples were released.

RP Thakur

Output 1.2: Diverse range of populations, breeding lines and potential hybrid parents developed, evaluated and disseminated

Summary

The research carried out under this generic output includes a wide range of activities in the two cereals and three legumes, which constitute a major part of research in this regional project. Significant progress was made in both strategic and applied research areas dealing with focused germplasm evaluation and utilization, development of genetically diverse and productive breeding lines and populations with resistance to biotic stress factors and tolerance to drought, and cytoplasmic-genic male sterility (CMS) systems with both medium- and long-term perspectives to enhance sustained productivity of these crops.

In sorghum, a landrace (IS 23526) was identified that had Brix reading similar to the sweet-sorghum check variety SSV 84, but it had 65% more sugar yield and flowered a week earlier. Several other landraces with sugar yield comparable to SSV 84 were also identified. Germplasm lines identified for high levels of shoot fly and grain mold resistance were crossed with elite breeding lines possessing moderate resistance to these traits to further build the resistance levels in the breeding materials. Germplasm and breeding lines with high levels of both iron (Fe) and zinc (Zn) and salinity tolerance were identified, and it was shown that though nitrogen application had a significant effect on increasing the Fe levels, the genotype × nitrogen interaction was not significant. Several advanced B-lines and R-lines with grain yield and grain size higher than or comparable to the widely used commercial checks (B-line 296B and R-line RS 29) were developed. Grain mold research confirmed the earlier results that the probability of producing mold-resistant hybrids is higher from resistant × susceptible crosses, followed by resistant × resistant crosses, and that mold-resistant hybrids or parental lines had higher levels of flavan-4-ols and lower levels of ergosterol than the susceptible ones. A comparison of hybrids based on the A_1 and A_2 cytoplasm showed that there was no significant difference between these two cytoplasms for resistance to either grain mold or shoot fly, or for grain yield. Also, A-lines with these two

cytoplasms had similar grain yield in a diverse range of genetic backgrounds, while those with other CMS systems [A_3, A_1 (M), A_4 (VZM) and A_4 (G)] had lower grain yield.

In pearl millet, a topcross hybrid based on a germplasm accession as a pollen parent, that had earlier been found outyielding a commercial sorghum-sudan grass hybrid, again showed its yield superiority with 36% higher dry forage yield. Interestingly, open-pollinated varieties (OPVs) developed from germplasm-derived progenies were identified that were comparable to or had higher dry forage yield than this high-yielding pearl millet hybrid. Utilization of large-seeded and long panicle germplasm led to the development of early generation progenies that had >15 g of 1000-seed mass and 60–80 cm of panicle length. Two high-yielding (both grain and dry fodder) germplasm accessions with high levels of salinity tolerance were also identified. Improved populations, largely based on the iniari germplasm, with high levels of both Fe and Zn were identified, with some of these populations showing more than 2-fold within-population variability. A simple staining method using Perls Prussian Blue was standardized for rapid and cost-effective preliminary selection of germplasm with high Fe content. Early-generation progenies derived from composites targeted for arid Rajasthan were developed that were of early to mid-early maturity and had high levels of downy mildew (DM) resistance to the most virulent Jodhpur pathotype of the DM pathogen population. Trait-based breeding of potential seed parents led to the identification of a large number of advanced generation progenies with high yield potential and DM resistance to 1–2 DM pathotypes. High-yielding and DM resistant advanced generation progenies, mostly of medium maturity group, from improved populations (composites and OPVs) were also developed. Efforts were increased to develop seed parents with A_4 and A_5 cytoplasm and their respective restorers. Nine male-sterile lines (3 A_1 cytoplasm and 6 A_4 cytoplasm) of diverse morphological characteristics and with DM resistance to at least two diverse pathotypes of DM were designated and disseminated. Fourteen A_1-system elite restorers were converted into their A_4 restorer versions, and 39 A_1-system elite restorers were converted into their A_5-restorer versions. Based on the mean performance of isonuclear hybrids evaluated across two locations for two years, it was shown that there was no difference between the A_1 and A_5 cytoplasm for grain yield and other agronomic traits. A comprehensive genetical study of five diverse CMS systems involving 45 F_2 populations and their corresponding backcrosses was completed. The results showed generally trigenic control of male sterility in each CMS system with varying interactions.

In pigeonpea, sources of high levels of salinity tolerance were identified in improved seed parents, cultivated germplasm of pigeonpea and a wild species, C. scarabaeoides. Several advanced breeding lines with resistance to both Fusarium wilt and sterility mosaic were identified. Testcross evaluation of pigeonpea hybrids showed high frequency of restorers (96%), which enhances hybrid breeding efficiency with this CMS system. Pigeonpea hybrids of three maturity groups (extra-short, short and medium duration) evaluated at Patancheru showed hybrid seed yield advantage ranging from 50 to 200% over the check varieties of comparable maturity. Hybrid yield advantages of similar order in these three maturity groups were found in multilocation trials conducted at 4–6 locations.

In chickpea, new germplasm sources of resistance to Fusarium wilt (FW), Botrytis gray mold (BGM), Ascochyta blight (AB), dry root rot, and collar root rot were identified. Also, breeding lines with higher seed yield and larger seed size than controls and combining high levels of resistance to Fusarium wilt were identified both in desi and kabuli groups. Some of the advanced breeding lines with high levels of resistance to either Ascochyta blight or Botrytis gray mold were identified in desi chickpea. A genetical research found two loci *governing the number of flowers per axis. Seed-borne nature of the fungus causing* Fusarium *wilt was confirmed. A detached leaf method developed for rapid laboratory screening for* Helicoverpa *resistance was found effective in case of chickpea but not in case of pigeonpea. HPLC profile of leaf exudates showed significant negative correlation between malic acid and pod damage, oxalic acid and leaf damage, acetic acid and larval weight as well as leaf and pod damage, and citric acid and pod damage.*

In groundnut, seven germplasm accessions of two wild species (5 of A. duranensis *and 2 of* A. stenosperma*) were identified that had systemic infection to Tobacco streak virus, and two of these were also highly resistant to both late leaf spot and rust. The foliar disease resistance breeding produced several advanced breeding lines with high pod yield combined with moderate levels of resistance to late leaf spot, and high levels of resistance to rust in both Spanish Bunch and Virginia Bunch groups. Several advanced breeding lines with high pod yield and high levels of resistance to aflatoxin were developed. Some of the resistant lines had as low as 2.9–4.2* $\mu g\ kg^{-1}$ *of aflatoxin content. Drought-tolerance breeding program led to the development of several advanced breeding lines with high pod yield under rainfed condition, some of which outyielded the control even under irrigated condition. High-yielding advanced breeding lines with high oil content were also identified.*

Activity 1.2.1: Evaluate and introgress new germplasm sources of variability for yield components, resistance to biotic and abiotic stresses and quality traits

Milestone: Germplasm lines of sorghum and pearl millet with large seed, and high fodder yield and quality traits identified and introgressed (2005)

Race- and trait-based B-lines

In order to diversify the hybrid parental lines for grain yield and other traits, high-yielding B-lines were crossed with germplasm lines belonging to different races and having specific traits. The resulting crosses were advanced with selection for different race-specific traits while maintaining desired maturity and grain yield. The promising F_4 progenies with maintainer reaction were utilized for conversion into A-lines with A_1 and A_2 cytoplasmic-nuclear male sterility (CMS) systems. These are in the various stages of conversion.

Diversification of sweet sorghum hybrid parents

Considering that hybrids have high biomass yielding ability, sweet-stalk hybrid parents' research is being given strategic importance at ICRISAT-Patancheru. New germplasm lines were evaluated in replicated trials for sweet-stalk biomass yield, to identify promising sweet sorghum germplasm lines for use in introgression into the available grain sorghum hybrid parents in order to diversify them for sweet-stalk traits.

A total of 98 landraces and varieties, along with the controls SSV 74 and SSV 84, were evaluated in the 2004–05 postrainy season for stalk sugar content and biomass yield. Based on the performance for these traits, 45 lines were selected and evaluated along with controls NSSH 104, SSV 74 and SSV 84 during the 2005 rainy season. Brix reading was taken 18 days after 50% flowering. The sugar yield, based on Brix reading and juice yield, was estimated. One of the landraces, IS 23526 (5.8 t ha^{-1}) significantly out-performed the control SSV 84 for sugar yield (3.5 t ha^{-1}). This line, besides being early by 7 days, had high Brix reading (19.5%), which was comparable to the control SSV 84 (19.4%). The sugar yield potential of several other test lines, RSSV 106 (4.8 t ha^{-1}), NSS 254 (4.3 t ha^{-1}), IS 18521 (4.1 t ha^{-1}) and IS 4617 (3.9 t ha^{-1}), was comparable to that of SSV 84 (3.5 t ha^{-1}). The promising landraces will be introgressed into available hybrid parents.

BVS Reddy and S Ramesh

Shoot fly resistance breeding

Shoot fly is one of the major biotic constraints in both rainy and postrainy seasons. Considering that the available seed parents bred for shoot fly resistance (SFR) possess moderate resistance levels and grain yield potential, efforts are being made to diversify seed parents for SFR.

In order to diversify hybrid parents for SFR, 13 germplasm lines (IS 18551, IS 923, IS 1057, IS 1071, IS 1082, IS 1096, IS 2394, IS 4663, IS 5072, IS 4664, IS 5470, IS 5636 and IS 18369) with high levels of SFR were crossed onto shoot fly resistant breeding lines (8), advanced backcross progenies in conversion program (8) and new B-lines (3) (on A_1 cytoplasm) and the resulting F_1s (29, 26 and 10, respectively) were evaluated during the 2005 rainy season. From these, 25, 13 and 7 F_2s, respectively were selected.

From 14 F_1s generated from the crosses between shoot fly resistant B-lines and postrainy varieties, 4 F_2s were selected. Further, 31 F_2s derived from the crosses between shoot fly resistant breeding lines and elite B-lines, and 11 F_2s derived from the crosses between shoot fly resistant breeding lines and high-yielding varieties were evaluated during the 2005 rainy season and produced 17 F_3 and 9 F_3 progenies, respectively. Four F_4s were produced from 24 F_3 progenies of shoot fly resistant B-lines × shoot fly resistant B-lines crosses during the 2005 rainy season. All these progenies are being advanced with selection during the 2005–06 postrainy season.

BVS Reddy, S Ramesh and HC Sharma

Grain mold resistance breeding

Grain mold is one of the major biotic constraints in rainy season in India. Efforts are being made to diversify the hybrid seed parents for grain mold resistance (GMR), as the available hybrid seed parents possess moderate resistance levels and grain yield potential.

Several crosses were made involving grain mold-resistant B-lines, varieties and landraces and their selections. A total of 94 F_3s derived from these crosses were evaluated during the 2005 rainy season for grain yield and grain size, plant height and maturity, and 27 F_4s were produced. These 27 F_4s will be evaluated for grain mold resistance (GMR) during 2006 rainy season and those found resistant will be testcrossed onto A_1 and A_2 CMS systems for conversion into A-lines.

BVS Reddy, S Ramesh and RP Thakur

Germplasm evaluation and introgression in pearl millet

High biomass yield: Increased attention to develop hybrid parents or varieties for forage purposes has prompted genetic diversification of forage breeding material by exploiting germplasm accessions of diverse origin for high biomass yield. About 77 progenies of a wide flowering range (52–85 days) were used to constitute six OPVs (ICMV 05111-ICMV 05666). Each OPV was developed from intercrossing of 4–26 progenies selected for forage purpose during the previous year. Important traits considered while making these varietal groups were plant height, stem thickness, tillering and leafiness. Another variety (ICMV 05777) was developed from a germplasm accession (IP 6073) from the Central African Republic. Random mating of 38 S_3 progenies of an OPV (CO 8) resulted in ICMV 05888. Similarly, ICMV 05999 was developed from random mating of 91 S_1 progenies of another OPV (RMFB). All these nine OPVs were evaluated along with seven controls [comprising 2 forage hybrids, 3 dual-purpose hybrids, 1 open-pollinated variety (WC-C 75) and a sorghum-sudan grass hybrid (GK 908)]. High dry forage yielding ability of an earlier identified promising hybrid, ICMA 00999 × IP 17315 was again confirmed as it produced 36% more dry forage (on oven dried basis) than the sorghum-sudan grass hybrid GK 908 (11.7 t ha^{-1}) at 80-day harvest. Of the nine varieties, five had 12.8–17.1 t ha^{-1} dry forage yield (15.8 t ha^{-1} for ICMA 00999 × IP 17315) at 80-day harvest. Four of the five high-yielding varieties flowered in 61–73 days (GK 908 flowering in 72 days and ICMA 00999 × IP 17315 in 69 days). These OPVs, if found promising in multilocational trials, have potential of being directly released as open-pollinated forage varieties, and also as promising germplasm for use as pollinators of topcross hybrids. In addition to the varietal trial, a set of 21 new germplasm accessions was visually evaluated for forage yield, and 10 were selected for further evaluation and utilization. To introgress earliness in high biomass yield backgrounds, six germplasm-derived photosensitive improved populations were crossed with an extra-early-maturing composite (EEBC) and an early-maturing B-line (834B) that has high early seedling vigor. These 12 hybrids were evaluated and four were selected based on the visual assessment of earliness and high biomass yield for further evaluation and utilization.

Large seed size: Although seed parents having up to 14.5 g 1000^{-1} seed mass have already been developed, the quest for developing hybrid parents with still larger seed size (16–20 g 1000^{-1} seed mass) in diverse genetic backgrounds is in progress. About 370 F_4 progenies derived from the crosses involving lines derived from three large-seeded germplasm accessions in their parentage were evaluated and 174 progenies were selected based on the visual assessment of grain size and agronomic potential to generate 430 F_5 progenies. Of the selected 174 progenies, 16% flowered in 51–60 days (ICMB 96555 flowering in 52 days), of which 12 had >15 g 1000^{-1} seed mass. Additionally, 90 F_3s were selected (mostly d_2 dwarf) out of 229 planted based on visual assessment of large seed size and agronomic potential and 40% of the selected progenies flowered in 51–60 days (ICMB 96555 flowering in 52 days). Of these, 17 progenies had >15 g 1000^{-1} seed mass. About 40% of the large-seeded F_5 progenies and 47% three-way F_3 progenies with >15 g 1000^{-1} seed mass (4 had even up to 20 g 1000^{-1} seed mass) were of mid-late to late maturing type, indicating the necessity of crossing elite early and mid-early lines to mobilize the large seeded trait in the commercially exploitable background.

Panicle length: Panicle length is a highly heritable and important grain yield component. Cultivated pearl millet hybrids possess panicle length not exceeding 30 cm. Great potential exists in developing long panicle hybrid parents by using germplasm accessions with >100 cm panicle length. Our attempts till now reveal that although such accessions were very good source of panicle length, the genetic drag in terms of poor exertion, tall plant height, poor tillering, obvious late maturity, and more importantly, poor spikelet density was very high. Amongst the total 700 progenies (F_4–F_6 and beyond) produced during the 2005 summer season, based on the panicle length and other desirable features, only 166 long-panicled progenies having high agronomic scores were evaluated, of which 78 progenies were selected based on the visual assessment to generate 195 progenies for further evaluation. Progenies with panicle length up to a maximum of 82 cm, flowering in 56–70 days, were monoculm (not tillering), and had poor to medium spikelet density. Interestingly, some degree of earliness was evident in the progenies, ie, 39% of 78 progenies flowered in 46–55 days (NCd_2 flowered in 48 days), which had panicle length up to 60 cm. About 350 out of 700 advanced generation progenies were also screened against Durgapura pathotype under high disease pressure in the greenhouse condition (>95% incidence in susceptible controls ICMP 451 and 843B) and 41% were highly resistant (0–10% DM incidence). In order to improve spikelet density and tillering, 124 hybrids produced from crossing a set of 4 compact panicle lines, 3 good exsertion lines and 6 high-tillering lines with 9 long panicle progenies were evaluated, and 73 were selected and classified into five groups based on the panicle and plant traits, such as thick and long panicle (31 F_1s), medium-long to thin panicles (18 F_1s), dwarf-tillering (13 F_1s), short-height tillering (14 F_1s) and compact panicles (8 F_1s). Some of them were included in more than one group. In addition, we evaluated 116 germplasm accessions (compactness score 7–9 on a 1-9 scale, with 1 = loose and 9 = very compact, head length >25 cm and panicle girth >25 mm as per the genetic resources characterization data) as new sources of long and compact panicle traits and 18 were selected producing 25 S_1 progenies for further evaluation and utilization. The selected progenies flowered in 53–67 days (NCd_2 flowering in 51 days).

White seed color: White grains are expected to diversify uses of pearl millet in food industry. However, the main bottleneck is the non-availability of germplasm with white grain color in photoperiod-insensitive genetic background. About 75 white-grain F_3 progenies derived from 15 F_2s developed through crosses involving four germplasm-derived lines from three photosensitive germplasm accessions were evaluated and 38 were selected based on the visual assessment for white grain color and agronomic potential to generate 95 F_4 progenies. About 28% of the selected F_3 progenies flowered in 56–65 days (54 days for ICMB 94222). All the F_4 progenies will be further evaluated to produce early to mid-late maturing progenies with white grain so as to transfer the same into agronomically superior genetic backgrounds.

KN Rai, VN Kulkarni, HD Upadhyaya and M Blümmel

Milestone: Germplasm lines of sorghum and pearl millet with higher levels of Fe, Zn and ß-carotene contents; and salinity tolerance identified and introgressed (2006)

Micronutrient density

Hybrid parents of high-yielding commercial hybrids (10 B-lines and 14 R-lines) and 6 high-yielding released varieties were crossed with germplasm lines having high levels of β-carotene (3 germplasm lines), Zinc (2 germplasm lines) and Iron (1 germplasm line and 5 breeding lines) that were identified based on the evaluation of 86 diverse hybrid parents, varieties and germplasm lines. A total of 176 F_1s were obtained: 32 F_1s from the crosses between high-yielding breeding lines and the germplasm lines rich in β-carotene, 27 F_1s between high-yielding breeding lines and the germplasm lines rich in Zn and 117 F_1s between high-yielding breeding lines and the germplasm lines rich in Fe contents. These are being advanced during the 2005–06 postrainy season.

BVS Reddy and S Ramesh

Grain Fe and Zn density in germplasm accessions of pearl millet: The sibbed seeds of 20 diverse germplasm accessions (part of a trial of 120 entries) from both summer and rainy seasons (2004) were analyzed at the National Institute of Nutrition, Hyderabad, India, for grain Fe and Zn density. The mean Fe density ranged from 34 to 54 ppm and Zn from 35 to 49 ppm. Three accessions (IP 6764, IP 8964 and IP 12240) had the highest Fe of 50–55 ppm and 4 accessions (IP 3122, IP 3859, IP 9453 and IP 8964) had the highest Zn of 48–49 ppm across two seasons. The germplasm accession, IP 8964 had both higher Fe and Zn density. The levels of Fe and Zn in these accessions were significantly lower than those in the elite breeding lines with higher grain Fe and Zn. There was highly significant correlation between Fe and Zn density ($r = 0.79$; $P < 0.01$).

Grain and fodder yield of salinity tolerant germplasm of pearl millet in saline soils: A set of 15 germplasm accessions, identified as salinity tolerant based on three years (2002–04) evaluation at ICBA was evaluated at 10 dS m^{-1} salinity level at Gangavathi, Karnataka, India, during 2005 rainy season (second season) for grain and fodder yield. Early stages of crop growth was affected due to continuous rainfall that delayed the weeding operation resulting in 33% lower grain yield and 50% lower fodder yield compared to 2004 rainy season. Two germplasm accessions, IP 22269 and IP 6098, were identified for high grain (1210 and 1168 kg ha^{-1}) and fodder yield (3000 and 3500 kg ha^{-1}) compared to control Raj 171 (1008 kg ha^{-1} grain yield and 2583 kg ha^{-1} fodder yield); and three promising accessions, IP 3616, IP 6105 and IP 6101 (3083–3167 kg ha^{-1}) for high fodder yield compared to Raj 171 during 2005-rainy season. Based on the two seasons data the same two germplasm accessions (IP 22269 and IP 6098) were identified for grain (1411 and 1389 kg ha^{-1}) and fodder yield (5667 and 4806 kg ha^{-1}) compared to control Raj 171 and 2 of the 3 identified during 2005 (IP 3616 and IP 6105) for only fodder yield (5445 and 4196 kg ha^{-1}) as these had similar grain yield and higher fodder yield compared to control Raj 171 (1493 kg ha^{-1} grain and 3514 kg ha^{-1} fodder yield).

KN Rai, VN Kulkarni, V Vadez, HD Upadhyaya, P Pathak and TJ Rego

Milestone: New germplasm sources with different resistance mechanisms to *Helicoverpa*; resistance to *Ascochyta* blight (AB), *Botrytis* gray mold (BGM), wilt and root rot, and drought-avoidance root traits identified and introgressed in chickpea (2006)

Mechanism and inheritance of resistance to *Helicoverpa* in chickpea

Genetics of resistance to pod borer (*Helicoverpa armigera)* in chickpea was focussed on studying the nature of gene action and maternal effects, plant resistance mechanisms and interaction of different components of resistance and grain yield. Eight *desi* [ICC 12475 (ICC 506), ICC 12476, ICC 12477, ICC 12478, ICC 12479, ICC 4918, ICC 12426 or ICCC 37 and ICC 3137] and one kabuli [ICCV 2 (ICC 12968)] parents were selected based on earlier screening trials to study the genetics of resistance, using full diallel. ICCV 2 was the earliest to flower and mature followed by ICC 4918, ICCC 37, ICC 12478 and ICC 12477, while ICC 12479, ICC 12476 and ICC 3137 were late to flower and mature. ICC 12478 suffered significantly lower damage, followed by ICC 506, ICC 12479 and ICC 12477. ICC 3137 was highly susceptible and recorded lowest seed yield. Most of the crosses with ICC 506, ICC 12478 and ICC 12479 suffered low damage, while those with ICC 3137 suffered higher damage. ICCC 37 recorded higher yield, followed by ICC 12479 and ICC 12476.

Inheritance of resistance: Gene action and maternal effects were estimated from the full diallel trial. Additive gene action was predominant for days to initial flowering, days to 50% flowering, days to maturity, pod borer damage (%), pods plant^{-1}, seeds plant^{-1}, seeds pod^{-1} and 100-seed weight. While non-additive gene action was important for yield plant^{-1}, total plot yield and yield (kg ha^{-1}). The additive: dominance (A:D) ratio was greater than unity for days to 50% flowering, days to maturity, pod borer damage (%), pods plant^{-1}, seeds plant^{-1}, seeds pod^{-1} and 100-seed weight, indicating over dominance, while for yield plant^{-1} and yield (kg ha^{-1}), the ratio was less than unity, indicating partial dominance. There was no maternal inheritance for maturity-related traits, pod borer damage, and grain yield. The hybrid, ICC 12476 × ICCC 37 showed positive and significant specific combining ability (SCA) effects for seeds pod^{-1}, but the reciprocal hybrid ICCC 37 × ICC 12476 showed negatively significant SCA effects for number of seeds pod^{-1}. So the hybrid ICCC 37 × ICC 12476 may be showing cytoplasmic effect for the number of seeds pod^{-1}.

Mechanisms of resistance: The three mechanisms of resistance *viz.*, non-preference for oviposition, antibiosis and tolerance to *H. armigera* in chickpea genotypes were studied under laboratory, greenhouse and field conditions. Oviposition studies under no-choice, dual choice and multi-choice laboratory and multi-choice field conditions revealed that the resistant control genotype, ICC 506 recorded lowest number of eggs, followed by ICC 12476, ICC 12477 and ICC 12478. The highest oviposition was observed on the susceptible genotypes, ICC 12426 and ICC 4918. The genotypes ICC 12475, ICC 12476, ICC 12477, ICC 12478 and ICC 12479 were least preferred by *H. armigera* females for oviposition compared to ICC 4918, ICC 3137 and ICCV 2. In detached leaf assay studies, the survival rate and larval weights were lowest on the resistant control, ICC 12475 (ICC 506), followed by ICC 12476, ICC 12477, ICC 12478 and ICC 12479, suggesting that water-soluble compounds in the leaf exudates (malic and oxalic acid) were primarily responsible for resistance to *H. armigera*.

Tolerance: The genotypes ICC 12476, ICC 12477, ICC 12478 and ICC 12479 were found to be resistant and their levels of resistance were comparable to the resistant control, ICC 12475 under no-choice cage conditions. Under un-infested conditions, the per plant yield was greater in ICC 12426 followed by ICC 12478 and Annigeri. The resistant cultivars ICC 12478 and ICC 12475 recorded higher yield than the rest of the cultivars. At the podding stage of the crop, when plants were infested with the third instar larvae, the recovery resistance was very poor, as most of the plants were damaged.

Larvae fed on leaf material and on artificial diet with lyophilized leaf and pod powder recorded lowest larval and pupal weights and prolonged larval and pupal periods on the resistant genotype, ICC 506. Highest growth index, adult index, oviposition index and pupal index were recorded on ICC 12426 and ICC 4918, while the lowest on the resistant control, ICC 12475.

High Performance Liquid Chromatography (HPLC) profile of leaf exudates showed that the malic acid was negatively correlated with damage rating at flowering (–0.28*), at maturity (–0.32**) and pod damage (–0.22*). Oxalic acid showed negative significant correlation with damage rating in detached leaf assay (–0.22*). Acetic acid showed a negative correlation with larval weight (-0.45*), damage rating at flowering (–0.33**) and maturity (–0.26*). Citric acid showed negative and significant correlation with damage rating at flowering (–0.23*).

The genotypes, ICC 12476, ICC 12477, ICC 12478, ICC 12479 and ICCV 2 were on par with the resistant control, ICC 12475 for pod borer damage under protected conditions. ICC 12475, ICC 12426, ICC 12478 and ICC 12479 recorded higher grain yield under unprotected conditions. The genotypes ICC 12475 (3.77%) and ICC 12478 (6.59%) recorded the lowest reduction in grain yield under unprotected conditions, indicating the presence of tolerance mechanism in chickpea to *H. armigera.* The tolerant lines can be used in further breeding programs and the mechanisms responsible for the resistance can be exploited to develop resistant varieties.

Correlation of different components of resistance with grain yield showed significant positive correlation under protected conditions between number of larvae and eggs (0.89**), leaf damage and egg number (0.82*), yield plant^{-1} and egg number (0.77*), yield plant^{-1} and larva number (0.76*) and pod damage (%) and larval number (0.91**). Significant negative correlation was recorded between yield plant^{-1} and borer damage (%) (–0.79*), under unprotected conditions. These correlations and interaction of different components of resistance and grain yield will help in gene pyramiding.

CLL Gowda and HC Sharma

Resistance to *Helicoverpa* introgressed into diverse chickpea breeding lines

One thousand five hundred and eighty six progenies (363 F_7 progenies and 721 F_8 progenies from single-crosses, and 502 F_7 progenies from four-way crosses) were sown under natural infestation of *Helicoverpa* larvae to select progenies for resistance. Selections were visually made for plants with early maturity, lesser pod damage and higher yields. We selected 1161 progenies (236 F_7 and 490 F_8 progenies from single-crosses and 435 F_7 progenies from four-way crosses) for progeny testing next year.

CLL Gowda

International Chickpea Screening Nursery – *Helicoverpa* Resistance (ICSN-HR)

Using reliable field screening techniques developed at ICRISAT for screening against *Helicoverpa,* several resistant sources have been identified. The resistant (less susceptible) sources identified in field screening were used in crosses to transfer resistance in high-yielding varieties. Pedigree selection for low borer damage under pesticide-free conditions was found effective in identifying pod borer resistant lines. This trial is intended to share material showing resistance to *Helicoverpa* with the collaborating scientists of the national programs. Most lines are of short to medium duration, adapted to environments similar to southern and central India (16 to 22°N latitudes). The objective is to evaluate promising *Helicoverpa* resistant selections in varying environments and to provide an opportunity to NARS partners for selections for use as parents or as end products suitable for various conditions. The trial with 15 chickpea genotypes, including two controls, was sent to two collaborators.

CLL Gowda

Development of diverse range of breeding populations in chickpea

A total of 100 crosses were made during 2004. These included 71 crosses for AB resistance, 18 for BGM resistance, 3 each for *Helicoverpa* resistance, extra-large seeded kabuli lines and genetic studies. The resistance donor parents included ICCV 04516, ICCV 04538, ICC 3996, ICC 12004, ICC 12965, ICC 14917, PBG 5 and GL 90135 for resistance to AB; ICCV 98502 and ICCV 98503 for resistance to BGM; and IG 72933, IG 72953 and ICC 506 EB for resistance to *Helicoverpa* pod borer. Forty-one of these crosses were made in greenhouse during off-season and thus F_1s from these could be grown during the crop season 2004/05 along with 222 crosses made during the crop season 2003/04. Thus, a total of 263 F_1s were grown during crop season 2004/05. These included 227 (119 *desi* × *desi*, 103 *kabuli* × *kabuli* and 5 *desi* × *kabuli*) for improvement of yield, seed traits and resistance to *Fusarium* wilt; 32 for enhancing resistance to AB; and 4 for enhancing resistance to *Helicoverpa* pod borer. Fifty-four new crosses were made in greenhouse during the off-season. These included 18 crosses involving newly identified AB resistant line ICCV 04502, 8 crosses involving salinity-tolerant lines (ICC 2580 and L 550), 8 crosses involving lines with deeper and vigorous root systems (ICC 4958 and ICC 8261), 3 crosses involving dry root rot resistant parents (MPJG 98-9023, MPJG 98-11151), 8 crosses involving super-early line ICCV 96029, 7 crosses involving extra-large-seeded *kabuli* lines, and 2 crosses involving multipinnate line ICC 5714. Seventy crosses were advanced by one generation (60 F_1s and 10 F_2s) and 38 crosses by two generations (F_1 and F_2 from 20 crosses, and F_2 and F_3 from 10 crosses) during the off-season in greenhouse. The cross made between cultivated chickpea line ICC 506 EB and of *C. reticulatum* (IG 72953) for combining different mechanisms of resistance to *Helicoverpa* was advanced by two generations (F_2 and F_3) in the off-season.

PM Gaur

Evaluation of germplasm lines for AB resistance under controlled environment conditions

Ascochyta blight (AB) caused by *Ascochyta rabiei* is an important foliar disease of chickpea that can cause complete loss of grain yield. Epidemics of AB are frequently associated with prevailing cool and humid weather and incidence of this disease in chickpea growing areas is spatially separated. Few resistant sources for AB are available, but most of them are susceptible to *Fusarium* wilt. Hence, continued attempts are being made at ICRISAT-Patancheru under controlled environment conditions for identification of additional sources of resistance.

Resistance screening technique: Resistance screening in controlled environment enables a rapid identification for resistance to AB. For identification of resistance, 10-day-old seedlings raised in plastic trays (30 × 20 × 5 cm) filled with sterile sand and vermiculite (4:1) were spray-inoculated with a conidial suspension (5×10^4 conidia ml^{-1}) of *A. rabiei* multiplied on autoclaved *kabuli* chickpea seed. One line of susceptible cultivar Pb 7 was planted in each tray as control. Inoculated seedlings were incubated at 20 ± 2°C and 100% RH for 96 h. Thereafter, 100% RH was provided for 8–16 h a day. Disease severity was scored at 10 days after inoculation on 1–9 rating scale where 1 = no disease and 9 = >75% of the plants killed.

AB resistance in germplasm lines: Using the above standard procedure, we evaluated 344 germplasm accessions twice for resistance to AB. ILC 3864 and FLIP 83-23C were resistant to AB with a mean disease severity of ≤3.0 rating on 1–9 rating scale and 80 lines were moderately resistant (disease rating 3.1–5.0) in comparison to susceptible control (9.0 rating). Promising lines were included in *Ascochyta* Blight Nursery and will be tested in different locations in India.

***Ascochyta* Blight Nursery (ABN):** Thirty-six germplasm entries, identified as promising for AB resistance in the controlled environment evaluation, were included in ABN during 2004/05 season. The nursery was evaluated under field conditions at Dhaulakuan (CSKHPKV), Gurdaspur (PAU), Ludhiana (PAU), Hisar (CCSHAU) and ICRISAT-Patancheru (under controlled environment conditions) in India. Each entry was planted in two replications with one row 2–4 m long in each replication (2 m long in Gurdaspur, Ludhiana, Hisar; and 4 m long in Dhaulakuan). Artificial inoculations with conidial suspension were done at flowering and pod initiation stage of the crop in all locations. Susceptible cultivar Pb 7 was found susceptible at all the locations tested. All the entries were found highly susceptible to AB at Hisar. Fifteen were found moderately resistant (3.1 to 5.0 on 1–9 rating scale) at ICRISAT-Patancheru, Dhaulakuan, Gurdaspur and Ludhiana. Cultivars ICC 652, 15976, 15980 were found highly susceptible at Gurdaspur, while they were moderately resistant (<5 rating) at other locations.

Evaluation of germplasm lines for BGM resistance under controlled environment conditions

Botrytis gray mold (BGM) caused by *Botrytis cinerea* is another destructive foliar disease that can cause complete loss of grain yield in chickpea. Frequent epidemics of BGM are associated with cool and humid weather followed by frequent winter rains. Growing resistant sources is the most economical way to manage this disease. But adequate levels of resistance to BGM are not available in cultivated chickpea. Hence, continued attempts are being made at ICRISAT for identification of sources of resistance to BGM.

Resistance screening technique: A reliable and reproducible screening technique for BGM resistance in controlled environment has been established. Eight to ten-day-old seedlings of test lines, along with JG 62 as a susceptible control were inoculated with conidia of *B. cinerea* (3×10^5 conidia ml^{-1}) multiplied on autoclaved merigold flowers. Inoculated plants were maintained at 15 ± 2°C and 100% RH with a 12 h photoperiod. BGM severity was recorded on a 1–9 rating scale at 20 days after inoculation.

BGM resistance in germplasm lines: One hundred and sixty one promising lines identified for BGM during 1985 to 2000 were evaluated for BGM resistance in controlled environment. A set of 60 germplasm lines, selected based on the diversity in their genotyping profiles were also tested for BGM resistance. Of the 161 germplasm lines tested, 35 were found promising (<5 rating on 1–9 scale). Of the 60 diverse germplasm, 4 lines were found moderately resistant (<5 rating on 1–9 scale).

***Botrytis* Gray Mold Nursery (BGMN):** The nursery consisted of 29 BGM promising entries identified in the controlled environment evaluation at ICRISAT-Patancheru during 2004/05 season. One local susceptible cultivar was also included for comparison. The entries of this nursery were evaluated at ICRISAT-Patancheru, Pantnagar (GBPUA&T), Gurdaspur (PAU) and Ludhiana (PAU) in India; Tarahara in Nepal; and Ishrudi and Jessore in Bangladesh. The entries were evaluated under controlled environment conditions at ICRISAT-Patancheru. Each entry was planted in two replications with one row (2–4 m long) in each replication.

Artificial inoculations with conidial suspension were done at flowering and pod initiation stage of the crop in all the locations except in Tarahara, Nepal. Data from all the locations were received, except from Bangladesh. Susceptible cultivar H 208 showed susceptible reaction in all the locations in India and Nepal. BGMN at Gurdaspur location was planted in AB nursery and hence the reaction of these entries was not considered. Two entries (ICC 1069 and ICCL 87322) at Pantnagar; 10 entries (ICC 8509, 12339, ICCVs 89302, 98505, ICCL 86215, ICCX 860030-BP-BP, ICCX 880030-BP-BP-6PN-BPN-BP, ICCX 860023-BP-BP-BP-3P-BH-1H-BH, ICCX 860029-BH-1PN-BPN-B and ICCX-880355-BH-BP-5H-BH) at ICRISAT-Patancheru, India and three entries (ICCs 8509, 12512 and 12952) at Tarahara, Nepal had <5 rating on 1–9 rating scale. None was resistant at Ludhiana, India.

Evaluation of germplasm lines for wilt resistance under field conditions

Wilt caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC) is a very serious soil-borne disease in most of the chickpea growing areas in the world. Growing resistant lines is the best way to manage this disease. Though wilt resistant lines are available, their resistance frequently breaks down at other locations due to existence of physiological races in the pathogen. Hence we continued to identify lines with broad-based resistance.

Resistance screening for wilt: Large-scale evaluation of breeding and germplasm lines for resistance to wilt was conducted in a wilt sick plot at ICRISAT-Patancheru. Wilted chickpea plants were chopped and incorporated in the field every year to maintain threshold levels of the fungus. A multiple disease sick plot (MDSP) consisting of pathogens of wilt (*Fusarium oxysporum* f.sp. *ciceri*) followed by dry root rot (*Rhizoctonia bataticola*), collar rot (*Sclerotium rolfsii*), black root rot (*Fusarium solani*) and wet root rot (*Rhizoctonia solani*) is also available at ICRISAT-Patancheru for evaluating wilt promising material for wilt and root rots. Each test entry was planted in two rows 4 m long with two replications. Early-wilting susceptible cultivar ICC 4951 was sown after every four test rows, and late-wilting cultivar ICC 5003 and resistant cultivar ICC 11322 were sown alternately after every 12 test rows (ie, after every 15 rows), along with test material for proper comparison. Periodical observations on number of wilt and root rot infected plants were recorded. Lines showing <10% incidence were considered resistant and their resistance was confirmed in the greenhouse and laboratory using individual screening techniques.

Wilt and root rot resistance in germplasm lines: One hundred and forty-one advanced wilt and root rot promising selections were further evaluated for resistance to wilt and root rots in multiple disease sick plot (MDSP). Of the 141 lines evaluated, 70 had combined resistance to wilt, DRR and collar rot under field conditions.

Chickpea wilt observation nursery (CWON): Twenty-eight wilt promising entries identified at ICRISAT-Patancheru and two susceptible controls were included in this nursery that was evaluated at 12 locations in India: Akola, Dharwad, Gurdaspur, ICRISAT-Patancheru, Hisar, Hazribagh, Jabalpur, Junagadh, Ludhiana, Raipur, New Delhi, and Sehore during 2004/05 season. Each entry was planted in two replications in one row of 4 m in each replication. Data on wilt was recorded twice at flowering and at maturity stages of the crop. Data from 10 locations were received (Gurdaspur, ICRISAT, Hisar, Hazribagh, Jabalpur, Junagadh, Ludhiana, Raipur, New Delhi and Sehore) and compiled. Wilt sick nursery at Ludhiana consisted of mixture of three soil-borne diseases, foot rot (*Operculella padwickii*), black root rot (*F. solani*) and wilt (*F. oxysporum* f.sp. *ciceri*). Since foot rot and black root rot were dominant, most of the lines were found free from wilt. Hence, the reaction of the entries in this location was ignored. The susceptible cultivar ICC 4951 was susceptible at all the locations except Gurdaspur where its incidence was 27.6%. ICCX-950106-F4-43P-BP was resistant in seven locations; and ICCs 12467, 14409, 14433, and 11322 were resistant in six locations.

S Pande, PM Gaur, J Narayana Rao and GK Kishore

Quantification of fungal pathogens of chickpea in wilt and multiple disease sick plots

In the second year of conducting this experiment (initiated in the year 2003/04) to quantify fungal pathogens of wilt complex of chickpea in wilt (BIL 3C) and multiple disease sick plots (BIL 1) at ICRISAT-Patancheru, soil samples were collected and processed exactly like previous year before planting and after harvesting of chickpea crop in these two fields. As in the previous year, number of fungal colonies g^{-1} soil was counted at 48 to 96 h after incubation. Number of sclerotia of *S. rolfsii* was quantified by using rapid floatation technique. As in the previous year, fungal colonies of the wilt and root rot were high in the samples collected after harvest of the crop in both fields. Number of *Fusarium oxysporum* f.sp. *ciceri* (FOC) colonies was around 1300 g^{-1} soil before planting and increased enormously during the crop growth and reached to around 3000 g^{-1} soil after harvest of the crop in both fields. Colonies of FOC were recovered up to 75 cm depth before planting and up to 100 cm depth immediately after harvest of the crop in both fields. In BIL 1, colonies of *Fusarium solani* and *Rhizoctonia bataticola* were, respectively, around 310 and 190 g^{-1} of surface soil, collected before planting. These two pathogens too multiplied during the cropping period and doubled after harvest of the crop. Both these pathogens were recovered up to 50 cm depth before planting and up to 65 cm after the harvest of the crop in BIL 1. About three sclerotia of *S. rolfsii* 10 g^{-1} soil were recovered from the surface soil collected before planting while its number increased to 6.5 at the end of the crop season in this field. As in the previous year, negligible number of these root rot pathogens was observed in wilt sick plot. Number of colonies of wilt and root rot fungi decreased as the depth increased. It was observed that the number of colonies of wilt complex fungi increased from two to three folds after harvest of the crop during February than October (before planting). The wilt and multiple disease sick plots are kept fallow every year from February to October. It was evident that during this period, the number of colonies of these fungi is reduced drastically and the reduction may be due to the absence of the chickpea crop. However, the reduction is not below threshold levels of the pathogens as the susceptible control planted during October, killed with in the stipulated time (<30 days after sowing).

Succession of fungal pathogens of chickpea in wilt and multiple disease sick plots: This is the second year of conducting this experiment (initiated in the year 2003/04) to find out the sequence of occurrence of wilt complex diseases in chickpea in wilt and multiple disease sick plots. Methodology, including cultivars (JG 62, L 550 and WR 315), sampling and isolations on nutrient-rich (potato dextrose agar) and semi-synthetic media (czapek dox agar) were similar as in the previous year in both fields (Archival Report 2004). As in the previous year, isolations were made from root tip, root hair, epidermis and cortex, vascular bundles, and collar region in each cultivar at 10-day interval from both fields.

Multiple-disease sick plot: Wilt fungus was found dominant from seedling to harvesting stage of the crop. Isolation on both the media indicated that FOC was recorded from all the root parts from 20 days after sowing in highly susceptible (early wilter) and moderately susceptible (late wilter) cultivars and continued to be present till the death of the plants. All the plants of the cultivar L 550 (late wilter) wilted at 90 days after sowing (DAS). Highly susceptible cultivar JG 62 completely wilted in 30 days after sowing in this field. FOC was found in root tip and root hairs in resistant cultivar WR 315 at 50 days after sowing and continued till maturity. This late infection and restriction of the fungus at root tip in this cultivar may be due to its resistance to the wilt pathogen. Moreover, the plants of this cultivar remained healthy till maturity in this field indicating its resistance to this pathogen. Black root rot fungus (*Fusarium solaris*), attacks the crop between 20 and 30 days after sowing (ie, in seedling stage) when the soil moisture is high. Soil moisture stress and warm temperatures encourage the dry root rot (*Rhizoctonia bataticola*) fungus causing rotting of the roots. During this season, dry root rot appeared from 40 DAS till maturity in both late wilting L 550 and resistant WR 315.

Wilt sick plot: Similar to multiple disease sick plot, FOC was recorded from 20 days after sowing in all the root parts in early (JG 62) and late wilting (L550) cultivars. Susceptible cultivar JG 62 died completely within 30 days after sowing. FOC was observed from all the root parts up to 90 days in L 550 and later all the plants wilted. Resistant cultivar WR 315 yielded FOC only from root tip and root hair from 40 days after sowing as in multiple disease sick plot. Though basically it is a wilt sick plot, low intensities of black root rot fungus was recorded up to 30 days after sowing (ie, in seedling stage) was recorded. Similarly, dry root rot fungus was observed from 50 days after sowing till maturity in both late wilting L 550 and resistant WR 315.

S Pande and J Naranayana Rao

Detection of seed-borne nature of *Fusarium oxysporum* f.sp. *ciceri*: It is reported that the wilt fungus is transmitted through seed. To confirm the seed-borne nature of the wilt fungus, an experiment was conducted using chickpea seeds collected from different plants that wilted prior to maturity (late wilting) from wilt sick plot and from healthy plants of wilt susceptible cultivar JG 62 from wilt-free field during 2004 crop season. These seeds were air dried at room temperature, bulked separately and stored at 5°C in the refrigerator in the laboratory. An experiment to detect the seed born nature of FOC was conducted at ICRISAT-Patancheru. Four hundred seeds (100 seeds in each replication) were taken from wilted and healthy lots, surface sterilized with 2.5% clorox for 5 min and plated onto the modified czepek dox agar medium in 10 cm glass petri plates @ 10 seeds per plate. All the plates were incubated at 25°C with 12 h light and 12 h dark periods for seven days. About 22% of the seeds collected from wilted plants yielded FOC and no fungus was observed from seeds collected from healthy plants. This indicated that FOC was seed-borne and present in wilted seeds collected from late wilting plants.

S Pande

Seed treatment with fungicides to control seed-borne inoculum of *Fusarium oxysporum* f. sp. *Ciceri*: Chickpea seeds collected from wilted plants were treated with six fungicides and their combinations (1:1 commercial formulations) @ 2.5 μg kg^{-1} seed to control seed-borne inoculum of *Fusarium oxysporum* f. sp. *ciceri* (FOC). The treatments (fungicides and their combinations) included in this study were Bavistin, Benlate, Captan, Indofil M 45, Kavach, Thiram, Benlate + Thiram, Bavistin + Thiram, Bavistin + Indofil M 45, Captan + Thiram, Indofil M 45 + Thiram and Kavach + Thiram. Three hundred fungicide-treated seeds (3 replications with 100 seeds in one replication) from each treatment were plated on czepek dox agar medium @ 10 seeds per plate. Equal number of untreated seeds was also plated for proper control. All the plates were incubated in Percival incubator at 25°C with 12 h light and 12 h dark for seven days. FOC was present in 26.5% of untreated seeds (control treatment). FOC colonies were low in the seeds treated with fungicide combinations than individual fungicides and control. Lowest number of FOC colonies were recorded in the seeds treated with Benlate + Thiram (3.3%) followed by Bavistin + Thiram (5.3%), and Bavistin + Indofil M 45 (5.7%). Since thiram is unavailable to most of the farmers in several villages, it is more convenient to the farmers to use Bavistin + Indofil M 45.

S Pande

Establishment of *Fusarium oxysporum* f. sp. *ciceri* in the soil through seed transmission

It was evident that the wilt fungus is transmitted through seed harvested from wilt-affected plants (mostly late wilting). Wilt incidence has been increasing considerably in farmers' fields over the years. To find out the establishment of *Fusarium oxysporum* f. sp. *ciceri* in soil through infested seeds, we conducted an experiment consisting of three serial sowings representing three crop seasons in the same pot (undisturbed soil) under greenhouse conditions.

First sowing representing first crop season: One hundred seeds collected from wilted plants during 2004 crop season were sown in small (5 cm dia) ice-cream cups (pot) filled with sterilized soil + sand mixture (1:1). One seed was sown in each pot to avoid contamination. Seeds collected from healthy plants of the cultivar JG 62 were used as control for proper comparison. Seedlings were observed for 45 days for wilt symptoms. Data on number of plants wilted and days to wilt were recorded. Isolations were made from all the dead plants on *fusarium* selective medium (Czepak dox agar) for confirmation of wilt. At the end of the experiment, small quantity of soil from each pot was taken, dried and assessed for *fusarium* propagules on selective medium. Of the 100 plants, 19 plants exhibited wilt symptoms in 35 to 45 days after sowing. FOC was recovered from all the wilted plants on selective medium. About 100 to 250 propagules of FOC per gram of soil were recorded from the pots where wilt was observed.

Second sowing representing second crop season: Above-ground parts of all the plants from all the pots were removed by cutting at collar region so that the root system of each plant remained in soil. Soil in the pots was stirred with sterilized iron rod and pots were undisturbed for a week. Seeds collected from healthy plants of the cultivar JG 62 were planted @ one seed in one pot and observed for 45 days for wilt symptoms. Data on all the parameters were exactly recorded as in the first sowing. Plants in all the 19 pots, where wilt was observed in the first sowing plus five more new pots (total 24 pots), had wilt symptoms at the end of the experiment. It took about 25–30 days for all the 19 pots (old) and around 35 days for the five new pots to exhibit wilt symptoms in the second sowing. Isolation of wilted plants on selective medium yielded FOC. Number of propagules of FOC multiplied very fast in the pots during the crop season and reached to 900 to 1600 propagules g^{-1} of soil.

Third sowing representing third crop season: Roots of each plant were chopped and incorporated in soil in the pot and stirred with sterilized iron rod. Seven days later, chickpea seeds collected from healthy plants of the cultivar JG 62 were sown @ one seed in one pot and observed for 45 days for wilt symptoms. Data on all the parameters was recorded as in the first sowing. Wilt symptoms appeared in all the 24 pots which had wilt in the second sowing. Wilt was observed between 14 and 18 days after sowing, which was much earlier, compared to first and second sowings. All the wilted plants yielded FOC on selective medium. Soil collected from the pots from where wilt was observed, had 1900 to 3150 FOC propagules g^{-1} of soil and no propagules of FOC were observed in other pots.

S Pande

Milestone: New germplasm sources of resistance to biotic and abiotic stresses, and confectionery traits identified and introgressed in groundnut (2004)

Screening groundnut breeding lines for foliar disease resistance [late leaf spot (LLS) (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*)]

Resistance of advanced breeding lines to LLS and rust: Six replicated yield trials (Elite foliar diseases resistant groundnut variety erect bunch (Spanish (var. vulgaris) and Valencia (var. fastigiata)) (EFDRGVT-SB), Elite foliar diseases resistant groundnut variety spreading bunch (Virginia bunch (var. hypogaea)) (EFDRGVT-VB), Advanced foliar diseases resistant groundnut variety Spanish bunch (AFDRGVT-SB), Advanced foliar diseases resistant groundnut variety Virginia bunch (AFDRGVT-VB), Preliminary foliar diseases resistant groundnut variety Spanish bunch (PFDRGVT-SB) and Preliminary foliar diseases resistant groundnut variety Virginia bunch (PFDRGVT-VB), consisting of 109 advanced breeding lines were screened for resistance to rust and LLS in an artificial sick plot containing trial inoculum and infector-rows. Experiment was laid out in a broad-bed-and-furrow (BBF) system with two replications. Chemical sprays were used to control insect pests. At 50 days after sowing, plots were inoculated by spraying the infected and test rows with 20 L of mixed conidial suspension of *P. personata* and *P. arachis dis* urediniospores. After inoculation, perfo-irrigation was provided daily for 15 min in the evening hours for 30 days to increase humidity required for disease development. Diseases (LLS and rust) were scored based on a 1–9 rating scale at 75, 90 and 105 days after sowing (1 = no disease, 9 = 81-100% foliage damage).

Development of LLS and rust was uniform throughout the infector rows and 100% infection was observed in the susceptible controls. Of the 109 breeding lines, ICGV 05122 showed good resistance to LLS with an overall disease severity score of 4.0. Another two lines (ICGV 05089 and ICGV 05096) had a score of 4.5; 25 lines scored 5.0; and 7 lines scored 5.5. Remaining lines were found to be susceptible (disease score 6–8) at 103 days after sowing. Seventy-three lines showed good resistance to rust (disease score of 1 to 2); 26 lines scored 2.5 to 3; and the remaining advanced breeding lines scored >4 (on a 1–9 scale) at 103 days after sowing.

Resistance of F_2–F_6 population to LLS and rust: During the 2005 rainy season, 239 lines from 5 breeding populations (F_2–F_6) were evaluated for resistance to LLS and rust under field conditions. Test plants were evaluated based on their disease severities at the time of harvest measured on 1–9 disease rating scale. A few single plants from F_6 population showed high levels of resistance to LLS (disease score 1 to 3). Remaining lines scored >4 on 1–9 rating scale.

Inheritance of late leaf spot resistance: Progenies of three crosses (ICGV 11337 × JL 24, ICGV 13919 × JL 24 and ICGV 11337 × ICGV 13919) planted in replicated trial with their reciprocals along with 10 generations in 60 cm inter-row space and 10 cm space between plants with two germplasm parents and one susceptible cultivar (total 2440 single plants) were screened for resistance to LLS under field and controlled environment conditions during 2005 season.

Plants in field trials were spray-inoculated with conidial suspension of *Phaeoisariopsis personat* at 50 days after sowing. After inoculation, perfo-irrigation was provided daily for 15 min in the evening hours for 30 days. Subsequently, percent leaf area damage and percentage defoliation was measured in each plant. Plant reaction to LLS was recorded based on a 1–9 rating scale at 75, 90 and 105 days after sowing (DAS). In all three crosses, 89 progenies showed high levels of resistance to LLS with a score of 2.0; 225 had a score of 3.0; 205 observed score of 4.0; and 140 recorded score of 5.0 at 105 days after sowing. Remaining lines scored >6.0 score. Mean disease severity of all the plants in each generation showed that generation 2 (ICGV 11337 in Cross 1 and ICGV 13919 in Cross 2 and 3) was most resistant to LLS. Also, cross 3 (ICGV 11337 × ICGV 13919) recorded lower disease score in all the generations than other two crosses.

The fully expanded quadrifoliate leaves of 45-day-old plants (third or fourth from top) of each line were excised and planted in sand cultures (roughly 1.5 cm thick) prepared in plastic trays (39.5 cm × 29 cm × 7 cm) for evaluation under controlled environmental conditions. In each tray, 20 leaflets were planted and trays were covered with plastic bags and incubated in the growth chamber at 24°C temperature and 85% relative humidity. LLS inoculum (30,000 spores/ml) was sprayed on both the surfaces of each leaflet inserted in the sand plates. Leaves were sprayed with water daily up to 5 days after inoculation. Observations were taken as shown below:

- Incubation period: Every alternative day from 5 days after inoculation
- Latent period: Every alternative day from 5–37 days after inoculation
- Lesion number: Every alternative day from 5–21 and 30 days after inoculation
- Percent leaf area damage: Every alternative day from 5–21 and 30 days after inoculation
- Lesion diameter: 25 days after inoculation

Some plants showed latent period (LP) of 30–36 days after inoculation and 2–5 lesions with minimum lesion diameter (<0.5 mm). The screening results for LLS indicated that the resistance levels were higher in cross ICGV 11337 × ICGV 13919 then in cross ICGV 11337 × JL 24 and ICGV 13919 × JL 24. These lines during field evaluation scored 2–4 (on 1–9 rating scale), indicating that they contain good resistance to LLS.

Farid Waliyar and SN Nigam

Screening of wild *Arachis* species for resistance to *Tobacco streak virus* (TSV) in the glasshouse

Twenty-three accessions of wild *Arachis* species were screened twice in the glasshouse. Promising accessions were further evaluated. Seven accessions, viz., ICG 8139, 8200, 11550, 8195, 8203 and 8205 belonging to *A. duranensis* and ICG 13210 belonging to *A. stenosperma* showed consistent resistance to TSV. These accessions did not show any systemic infection. Two accessions (ICG 8139 and 11550) also possessed high levels of resistance to rust and late leaf spot and thus can be used in interspecific crosses to develop multiple disease-resistant groundnut varieties.

Farid Waliyar, P Lava Kumar and SN Nigam

Effect of virus titer and date of inoculation on infectivity of *Peanut bud necrosis virus* (PBNV) *Tobacco streak virus* (TSV) and *Indian peanut clump virus* (IPCV)

Experiments were conducted in the greenhouse with groundnut variety JL 24 to determine the effect of plant growth stage on infection with PBNV, TSV, and IPCV. Plants were inoculated at 10, 20 and 30 days after germination with three dilutions 1:10, 1:50 and 1:100 (leaf wt./buffer) of inoculum. Results indicated that IPCV, PBNV and TSV infection in groundnut can occur at 10 and 20 days after germination and result 100% infection. In case of plants inoculated at 30 days after germination, infection reduced by about 50% and symptoms development was delayed for all the three viruses. However, 90% of the test plants inoculated with IPCV were infected and showed mild symptoms. These results have implications on field protection of susceptible host plants and also in assessing host resistance against these viruses.

P Lava Kumar and Farid Waliyar

Survey for seed-borne groundnut virus diseases in genetic resources seed multiplication fields

In 2004 rainy season, germplasm lines were scored for seed-borne virus diseases in RP7 field at ICRISAT-Patancheru. Nineteen suspected plants were tagged and tested by ELISA. None contained any infected plants. All plants were uprooted and burned. During the post-rainy 2004/2005 survey, 20 suspected plants were tagged and tested by ELISA for PMV and PStV. Two plants (one in ICG 8323 and another one in ICG 10171) were positive to PMV. All plants were uprooted and burned.

In 2004 rainy season, one more field (RP5) was inspected and 14 suspected plants were found. They were tagged and tested by ELISA for the presence of PMV and PStV but none contained any virus. All the suspected plants were destroyed. In postrainy 2004/2005, 47 suspected plants were tagged and tested by ELISA for PMV, PStV but none contained virus. These suspected plants were destroyed.

P Lava Kumar and Farid Waliyar

Activity 1.2.2: Develop diverse range of populations and breeding lines with improved yield potential, resistance to biotic and abiotic stresses and better quality

Milestone: High-yielding sorghum lines with large grains and resistance to grain mold and shoot fly developed (2006)

Breeding for high grain yield and large grain size

A total of 74 F_2s derived from high-yielding B-lines (HYB) × HYB, Lustrous B-lines × HYB, new B-lines × advanced progenies and sweet-stalk B-lines × sweet-stalk B-lines crosses and 924 F_3s derived from HYB × HYB crosses were evaluated during the 2005 rainy season.

Based on grain size, plant height and overall agronomic visual score, 78 F_3s and 173 F_4s, respectively were produced, which are being evaluated during the 2005–06 postrainy season.

Several early-maturing advanced progenies derived from the crosses between postrainy season adapted varieties, high-yielding B-lines and landraces were evaluated during the 2004–05 postrainy season. A total of 44 F_6 progenies from 50 F_5 progenies, 530 F_5 progenies from 651 F_4 progenies and 140 F_4 progenies from 956 F_3 progenies, 63 F_7 progenies from 9 selections from participatory plant breeding program were selected and are being advanced through selection. These will be testcrossed on A_1 system A-lines to assess their male-sterility maintainer or fertility restorer reaction during the 2005–06 postrainy season.

BVS Reddy and S Ramesh

Grain mold-resistance (GMR) breeding

Testcrossing of agronomically superior grain mold-resistant advanced breeding lines: A total of 100 breeding lines previously screened for GMR that included B-lines, R-lines and varieties were evaluated during 2005 rainy season and 62 lines were selected based on the plant agronomic appearance. The varieties are being testcrossed onto A_1 and A_2-based A-lines during the 2005–06 postrainy season to assess their male-sterility maintainer or male-fertility restoration reaction.

A set of 72 F_5 progenies (derived from 102 F_4s of the crosses between grain mold resistant landraces, high-yielding B-lines (HYB) lines and grain mold resistant breeding lines) and another set of 17 F_5 progenies derived from crosses between GMR B-lines and HYB-lines were selected for GMR during the 2005 rainy season. Among the selected progenies, days to 50% flowering ranged from 61 to 75 days and plant height from 1.3 to 2.3 m. These will be further selected and testcrossed on A_1 and A_2 CMS systems to assess their male-sterility maintainer or male-fertility restoration reaction.

BVS Reddy, S Ramesh and RP Thakur

Evaluation of advanced breeding lines for grain mold resistance: Enhancing the level of grain mold resistance in breeding lines continues to be a priority. Ninety-six F_5 lines, selected from crosses involving 9 elite B-lines and 8 mold tolerant lines were evaluated for grain mold resistance in the field nursery. Each entry was grown unreplicated in 2 row-plots of 4 m long and overhead sprinklers were provided on rain-free days for grain mold infection and development from flowering to physiological maturity. In each entry 10 uniformly flowering plants were tagged. Panicle grain mold rating (PGMR) was recorded at physiological maturity on threshed grain mold rating (TGMR) on bulk threshed grain of 10 tagged panicle per plot using a 1–9 scale (1 = no mold, 2 = 1–5%, 3 = 6–10%, 4 = 11–20%, 5 = 21–30%, 6 = 31–40%, 7 = 41–50%, 8 = 51–75% and 9 = >75% grains molded). Considering the mean grain mold severity rating of 1–4 (up to 20% infection) as resistant and 4–9 as susceptible classes, 9 lines were found resistant and the remaining were susceptible, while the susceptible controls Bulk Y and 296B had scores of 8.4 and 9.0, respectively.

RP Thakur and BVS Reddy

Evaluation of single plant selections for grain mold resistance: One hundred single plant selections from the 2004 rainy season were evaluated in a RCB design with two replications, one row per replication in the grain mold nursery as described above. Both PGMR and TGMR scores revealed that 56 lines were resistant (≤4.0 score) compared to ≤1.4 in resistant control, IS 8545 and 9.0 in susceptible control, SPV 104. This shows a significant improvement in grain mold resistance level within one generation of pedigree selection. We have selected 124 single plants for further evaluation and selection.

RP Thakur

Evaluation of hybrids and their parents for grain mold resistance stability: Under the Indian Council of Agriculture Research (ICAR) (All India Coordinated Sorghum Improvement Project)-ICRISAT partnership project, we evaluated the resistance stability of 29 hybrids and their 18 parental lines through a collaborative Sorghum Grain Mold Resistance Stability Nursery (SGMRSN). In addition to the 47 test entries, the nursery consisted of two resistant (IS 25017 and IS 14384) and one susceptible (CSH 16) controls. The 50-entry nursery was conducted at five Indian locations (Coimbatore, Dharwad, Parbhani, Palem and Patancheru) in a RCB design with two replications. Each entry was planted in 2-row plots of 4 m. Sprinkler irrigation was provided from flowering to physiological maturity of the crop for infection and mold development. Five plants with uniform flowering were tagged in each row (10 plants $plot^{-1}$), and the panicle grain mold rating (PGMR) was recorded at physiological maturity and threshed grain mold rating (TGMR) on bulked threshed grain of 10 tagged panicles per plot with the help of a magnifying glass using a 1–5 scale (1 = no mold, 2 = 1–10%, 3 = 11–25%, 4 = 26–50% and 5 = >50% grains molded) on the tagged panicles. Data on agronomic traits, such as plant height, days to 50% flowering, glumes cover, and grain hardness were also recorded. The data from Coimbatore were not considered since insects damaged the nursery at the time of grain development.

The analysis of variance indicated highly significant (P <0.001) effects of location, genotype, and their interaction on mold severity scores. The mean PGMR of the 47 test entries across four locations varied from 2.0 to 3.7 compared to 1.4 to 2.2 in resistant controls and 3.4 in the susceptible control. The mean PGMR score across entries was highest at Patancheru (3.6) followed by Palem (3.0), Dharwad (2.9) and the lowest was at Parbhani (1.6). The mean TGMR of test entries across the four locations varied from 2.4 to 4.5 compared to 1.7 to 2.8 in the resistant controls and 4.2 in the susceptible control. The mean TGMR score across entries was highest again at Patancheru (3.9) and lowest at Parbhani (2.9). Considering the mean grain mold severity rating of 1–2.5 (up to 20% infection) as resistant and 2.5–5 as susceptible classes (on the 1–5 scale) both for PGMR and TGMR, 9 of the 28 hybrids and 4 of the 19 parental lines were resistant across locations and thus these seemed to have resistance stability against grain mold pathogens. Further evaluation of these hybrids and parental lines would be required to confirm the results.

RP Thakur and BVS Reddy

Shoot fly resistance (SFR) breeding

A total of 81 advanced (F_6) progenies derived from the crosses between HYB and shoot fly resistant breeding lines were screened for SFR using interlard fish meal screening technique during the 2005 rainy season. Eight lines which supported lower deadhearts (DH) at 17 days after emergence (DAE) (31% DH compared to 57% DH in the susceptible control, 296B) were selected. These will be testcrossed onto A_1 and A_2 cytoplasms during 2005-06 postrainy season.

From the advanced progenies evaluated during the 2004-05 postrainy season, 80 F_4s, 174 F_5s, and 17 F_6s were selected and are being advanced with selection. These will be testcrossed onto A_1 and A_2 CMS systems during the 2005–06 postrainy season. The 15 stabilized lines earlier confirmed as maintainers of A_1 and with SFR (39–57% DH compared to 42% DH in 296B at 21 DAE) for postrainy season adaptation were advanced for conversion into male-sterile lines during the 2005-06 postrainy season.

BVS Reddy, HC Sharma and S Ramesh

Milestone: Sorghum and pearl millet breeding lines (from existing collections) having high levels of Fe, Zn and β-carotene content; and salinity tolerance identified, and characterized for their yield potential and agronomic traits (2006)

Micronutrient density

A total of 40 lines with high and low differentials were selected and evaluated for their stability for agronomic traits and grain Fe, Zn and β-carotene contents under three applied nitrogen levels (120 kg, 80 kg and 40 kg N ha^{-1}) during the 2004–05 postrainy season. The results indicated significant genetic variability for grain Fe and Zn contents. The genotype × N interaction was not significant, indicating the selections made at one fertility level perform similarly at other fertility levels. The mean grain Fe content of the lines appeared to be highest when grown under recommended dose of nitrogen fertilization, while it was significantly lower when the lines were grown under low levels of N fertilization. The grain Zn content did not vary with the levels of N fertilization. These results indicate that the lines bred for high grain Fe and Zn contents need to be grown in recommended dose of managed fertility level to derive maximum benefit.

Based on the mean grain Fe, Zn and phytates contents of the entries across two locations [ICRISAT-Patancheru and National Research Centre for Sorghum (NRCS), Hyderabad], 12 entries (which include the lines with high and low Fe and Zn contents) have been selected to assess their stability across different soil Fe and Zn fertilization and soil types (alfisols and vertisols) at ICRISAT-Patancheru during 2005–06 postrainy season.

BVS Reddy and S Ramesh

Salinity tolerance

Promising hybrid parents and varieties were selected for soil salinity tolerance based on the pot culture experiments under induced salinity at ICRISAT-Patancheru. These selected lines were evaluated in two trials: (i) 21 varieties + 1 B-line + 2 R-lines + 1 hybrid + 5 susceptible controls and (ii) 33 hybrids + 22 parents (5 B-lines + 13 varieties + 4 restorers) were sown at Agriculture Research Station (ARS), Gangavathi, Karnataka, India under soil salinity – stress condition (10 dS m^{-1}) and at ICRISAT-Patancheru in pot culture. The trials at Gangavathi were vitiated due to poor plant stand resulting from heavy rains and shoot fly infestation. However, both trials were replanted. The results from both ARS, Gangavathi (field) and ICRISAT (pot culture) experiments are awaited. Twelve hybrid parents/varieties (ICSV112, GD65008, S35, JJ1041, ICSV 93046, ICSV 93034, CSV 15, NTJ 2, ICSR 170, ICSV 745, SPV 1022 and ICSB 406) were sent for testing in saline coastal areas by Central Rice Research Institute (CRRI), Cuttack, Orissa, India. These lines were found tolerant to salinity in pot-screening carried out at ICRISAT-Patancheru.

Seed of 15 salinity-tolerant entries (ICSV 93046, ICSV 745, SP 47513, SP 39262, SP 47529, S 35, ICSV 93048, ICSV 112, SP 47519, SP 39105, ICSR 93034, SP 39053, SP 40567, SP 47503 and SP 39007) was supplied to International Center for Biosaline Agriculture (ICBA), Dubai, for further screening under salinity stress in field conditions.

BVS Reddy, S Ramesh and V Vadez

Grain and fodder yield of salinity-tolerant improved populations of pearl millet in saline soils: Fourteen improved populations selected as salinity tolerant by ICBA were re-evaluated at 10 dS m^{-1} salinity level at Gangavathi, Karnataka, India, during 2005-rainy season (second season) for grain and dry fodder yield along with two OPVs (ICTP 8203 and Raj 171) and a pollinator (ICMP 451) as controls. HHVBC-tall had 1922 kg ha^{-1} of grain yield, which was significantly higher than two popular controls (90% more than Raj 171 and 122% more than ICTP 8203) with almost similar maturity (56 days to flower) compared to controls (54 days to flower in ICTP 8203 and 59 in Raj 171) during 2005. It also produced 48% more dry fodder yield than the high fodder yielding control Raj 171 (2583 kg ha^{-1}). Two more populations (Sudan Population III and Dauro genepool) were identified for higher grain yield (1508 and 1347 kg ha^{-1}) and fodder yield (2833 and 4000 kg ha^{-1}). Leonis genepool produced significantly higher fodder yield (132% more) than Raj 171. Based on the two seasons data, the promising dual-purpose populations adapted to saline conditions were HHVBC-tall, Sudan Population III, Dauro genepool, and the control Raj 171 (with 1452 to 1996 kg ha^{-1} of grain yield and 4009 to 4941 kg ha^{-1} of fodder yield). Another population, Leonis genepool (6117 kg ha^{-1}) was identified only for fodder purpose.

Evaluation of pearl millet hybrid parents for grain and fodder yield in saline soils: Nine salinity-tolerant and seven sensitive hybrid parents selected based on ICRISAT-Patancheru results and first year evaluation at Gangavathi were again evaluated at 10 dS m^{-1} salinity level at Gangavathi, Karnataka, India for grain and fodder yield during 2005 rainy season. Among the seed parents, the tolerant parent ICMB 95222 produced 130% more grain and 286% more fodder yield than the sensitive control ICMB 94111 (536 kg ha^{-1} grain and 2750 kg ha^{-1} of fodder yield) during 2005 rainy season. Other promising seed parents for grain yield were ICMB 01222 and 841B (74-79% more than ICMB 94111) and for fodder yield were 863B and ICMB 96333 (59-79% more than ICMB 94111). Among the restorer parents, the tolerant parents ICMP 451 and CZP 9621 had high grain (938 and 882 kg ha^{-1}) and fodder (6667 and 5000 kg ha^{-1}) yield compared to sensitive control H 77/833-2 (363 kg grain and 3667 kg fodder ha^{-1}). Based on the two seasons data, the seed parent ICMB 95222 was identified for high grain (1164 kg ha^{-1}) and fodder (6794 kg ha^{-1}) yield, ICMB 01222 only for high grain yield (1265 kg ha^{-1}), and ICMB 96333 and 863B only for fodder yield (about 3980 kg ha^{-1}). Among the restorer parents, ICMP 451 was identified for high grain (1311 kg ha^{-1}) and fodder (6721 kg ha^{-1}) yield and HTP 94/54 only for fodder yield (5478 kg ha^{-1}). These hybrid parents could be used in the production of high-yielding hybrids tolerant to salinity.

Inheritance pattern of salinity tolerance in pearl millet: Four hybrids produced from two salt-tolerant lines (ICMB 95333 and ICMP 451) and two sensitive lines (81B and ICMB 94111) along with the four parents and another high yielding hybrid identified previous years field trials were evaluated at ICRISAT-Patancheru in pot culture under saline and control conditions to determine the pattern of inheritance of salinity tolerance and to know whether salinity tolerance of one parent is enough to produce tolerant hybrids. Under saline conditions, flowering was delayed by 10 days compared to non-saline control condition (50 day to flower). Hybrids had significantly higher panicle weight than parents in both saline and control conditions and higher biomass weight only in saline condition. The two hybrids involving both tolerant parents had 10–27% higher panicle weight (26.9 and 30.9 g plant^{-1}), and the two hybrids with one tolerant parent had 7–9% higher panicle weight (25.9 and 26.4 g plant^{-1}) compared to the hybrid with two sensitive parents (24.3 g plant^{-1}) under saline conditions. The same conclusion did not hold good with respect to biomass yield. But for the parents 81B (sensitive parent) and ICMP 452 (tolerant parent), which were affected by downy mildew, the salinity susceptible index (calculated on the basis of panicle weight) was generally lower in the hybrids with at least one tolerant parent (0.91–0.98), and in tolerant parent (0.99) compared to the hybrid with two sensitive parents (1.01) and sensitive parent (1.21). This limited set of data indicated the dominance of salinity tolerance over sensitivity and the need of at least one tolerant parent for production of salinity-tolerant high-yielding hybrid.

Comparison of HHVBC sub-selections of pearl millet for salinity tolerance: Salinity tolerance of HHVBC-tall has been confirmed at both ICBA-Dubai and ICRISAT-Patancheru. Based on one-year field trial, it has also been found very productive in saline field conditions at Gangavathi, Karnataka, India. HHVDBC is d2 dwarf version of HHVBC-tall. Four HHVDBC-derived sub-populations earlier selected for different heights and panicle thickness (dwarf, medium height, tall and thick panicle) along with C_0 cycle bulk of HHVBC-tall were evaluated in pot culture at ICRISAT and in field condition at Gangavathi to assess the differences, if any, among these sub-populations for salinity tolerance, measured in terms of both grain and fodder yield. Significant differences were observed among HHVDBC-derived sub-populations for grain and fodder yield at Gangavathi, and for biomass yield and panicle weight in saline and control conditions of pot experiments at ICRISAT. HHVBC-tall C_1 produced 33% higher grain (2308 kg ha^{-1}) and 114% higher dry fodder yield (6250 kg ha^{-1}) than the HHVBC-tall C_0 (1734 kg ha^{-1} grain and 2917 kg ha^{-1} fodder). Other promising sub-population identified for both grain and dry fodder yield was HHVDBC-thick (31% more grain and 85% more fodder than HHVBC-tall C_0), and for only fodder yield was HHVDBC-medium height (6250 kg ha^{-1}). In pot culture experiments under saline conditions, all the sub-populations produced significantly higher panicle weight compared to sensitive control (13.1g plant^{-1}). Amongst the sub-populations, HHVBC-tall C_0 and HHVBC-tall C_1 produced higher biomass both in saline (37.2 and 32.5 g plant^{-1}) and control (73.9 and 76.5 g plant^{-1}) conditions, and higher panicle weight under saline conditions (28.4 and 26.7 g plant^{-1}) compared to other populations, which had 51.0–67.9 and 25.9–31.3 g plant^{-1} of biomass in control and saline conditions respectively and 21.4–23.8 g plant^{-1} panicle weight in saline conditions. Based on these results, HHVBC-tall C_1 was identified for higher grain and fodder yield under saline conditions.

Grain Fe and Zn density in improved populations of pearl millet: The trial consisting of 69 improved populations from diverse origin [ICRISAT-Asia (33), ICRISAT-WCA (32) and ICRISAT-ESA (4)] conducted during 2004 rainy season was repeated during 2005 summer season. As indicated by the trial means, the grain Fe was 12% higher during the rainy season (58 ppm). On the contrary, grain Zn was 11% lower during summer season (40 ppm). Significant genetic variability with approximate two-fold variation for both grain Fe (42–80 ppm) and Zn (27–50 ppm) was observed. Significant season × genotype interaction was noticed. The correlation between Fe and Zn was highly significant ($r = 0.76$; $P < 0.01$). Based on the mean data of two seasons, 7 populations having high Fe (>70 ppm Fe) and 8 populations having high Zn (>45 ppm Zn) were identified, and 6 of these common populations ICTP 8203, GGP Bulk (C_0), CGP, IAC-ISC-TCP-4, PVGGT-5 and Ugandi were identified for both high grain Fe and Zn density.

Intra-population variability for grain Fe and Zn density in pearl millet: One released variety each from Africa (GB 8735) and India (AIMP 92901) were identified for high grain Fe and Zn based on the two seasons evaluation of 30 populations (in the 120 entries trial) during 2004, and 4 populations (CGP, GGP bulk, ICTP 8203 and PVGGP 6) were identified based on evaluation of 69 populations during 2004 rainy season, for studying intra-population variability and deriving progenies with still higher Fe and Zn than the parental populations. Significant variability for both Fe and Zn was evident among the 64 S_3 progenies of AIMP 92901 and 68 S_2 progenies of GB 8735 (previously derived). The range in Fe and Zn density in AIMP 92901 and GB 8735 progenies showed approximately two and half fold variation for Fe (35–104 ppm in AIMP 92901 and 40–105 ppm in GB 8735) and two-fold variation for Zn (29–68 ppm in AIMP 92901 and 29-60 ppm in GB 8735) (Figs. 1.1 and 1.2). Significant positive correlations ($P < 0.01$) between Fe and Zn were observed in AIMP 92901 ($r = 0.68$) and in GB 8735 ($r = 0.76$). Based on the data, top nine progenies of both AIMP 92901 and GB 8735 were selected separately for Fe and Zn for random mating during 2006 summer to initiate recurrent selection for high Fe and high Zn. The top three progenies for both micronutrients from both the populations will be crossed to four B-lines (counterpart of designated A-lines) with high Fe and Zn to produce hybrids with still higher Fe and Zn. Field testing of 50 S_1 progenies derived from the remaining four populations is undergoing to study the intra-population variability for grain Fe and Zn.

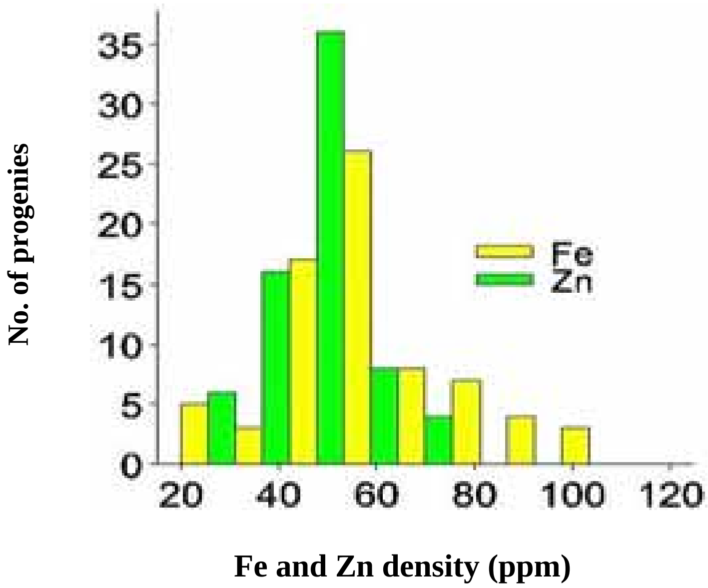

Figure 1.1. Frequency distribution of AIMP 92901 (S_3) progenies of pearl millet for grain Fe and Zn density, rainy season 2005.

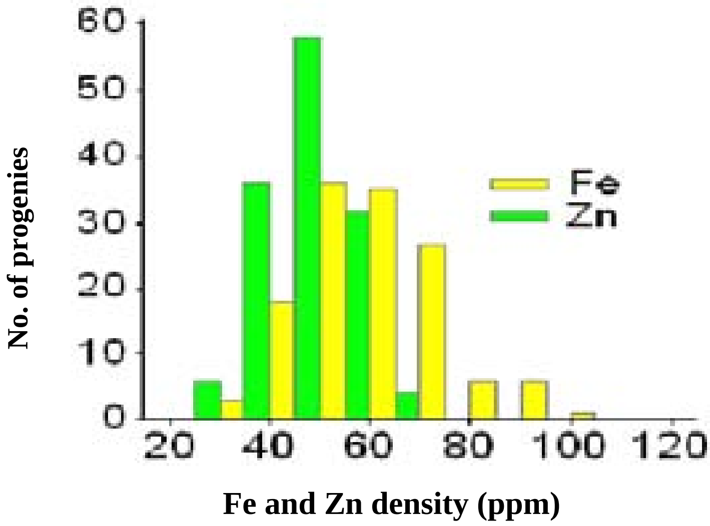

Figure 1.2. Frequency distribution of GB 8735 (S_2) progenies of pearl millet for grain Fe and Zn density, rainy season 2005.

Assessment of stability of Fe and Zn density in selected genotypes of pearl millet: Thirty lines that included 14 high (51–76 ppm Fe and 48–65 ppm Zn), 8 medium (41–45 ppm Fe and 41–46 ppm Zn), 6 low lines (30–38 ppm Fe and 24–34 ppm Zn) and 2 controls selected from the two seasons screening trial during 2004 were evaluated during 2005 summer and the same trial was repeated in rainy season 2005 for assessment of stability. The analysis of sibbed seeds of these 30 entries from summer season at National Institute of Nutrition, Hyderabad, indicated stability of the genotypes for grain Fe and Zn. The genotypes with high Fe and Zn remained high in the summer trials and majority of low remained low.

Inheritance of grain Fe and Zn density in pearl millet: From the two seasons screening of 120 entries during 2004, four lines each with high (Fe 60–75 ppm and Zn 56–65 ppm), medium (Fe 42–45 ppm and Zn 41–47 ppm) and low (Fe 30–36 ppm and Zn 24–34 ppm) density were identified and 12 × 12 full diallel crosses (including reciprocals) were generated during 2005 summer. First season evaluation of the diallel set of crosses was completed during 2005 rainy season. The sibbed seeds of three replicates of 132 F_1s and 12 parents were sent to NIN for laboratory analysis.

Compare the cost effectiveness of alternative Fe and Zn assessment protocols in pearl millet

A three-pronged approach has been followed to reduce the cost of grain Fe and Zn analysis; (i) the reduction of the cost involved in the grain sample production, (ii) the use of staining technique for quicker and cheaper analysis and (iii) the management of analytical cost of Fe and Zn through estimation of inter-laboratory correlations.

Comparison of selfed, sibbed and open-pollinated seed sources for Fe and Zn density: Since production of selfed seed for micronutrient analysis is much more cost-effective than producing sibbed seed, Fe and Zn density in these two seed sources were estimated to examine if there is any correlation between the two seed sources, and hence a possible guide for more cost-effective seed production in the future. Open- pollinated (OP), sibbed and selfed grain samples of 30 entries (15 inbred lines and 15 populations with a wide range of Fe and Zn levels) produced from the trial consisting of 120 entries, conducted during the 2004 summer season were analyzed for Fe and Zn density. Results showed highly significant correlation ($P < 0.01$) between selfed and sibbed seed both for Fe ($r = 0.68$) and Zn ($r = 0.78$). The correlation of OP seed with sibbed and selfed seed were 0.43 and 0.44 ($P < 0.05$) for Fe and 0.50 and 0.53 for Zn ($P < 0.01$). The initial results indicated that the grain samples obtained through selfing could be used in the grain Fe and Zn analysis. The three types of grain samples of the same 30 entries produced during the 2004 rainy season will be analyzed to confirm these results. Also, selfed, sibbed and open-pollinated grain samples of 30 populations produced during 2004 rainy season and 2005-summer season (from the trial consisting of 69 populations) will be analyzed to determine the relationship between three types of grain samples for Fe and Zn.

A rapid staining method of screening for grain Fe density: A simple, rapid and economic method of identification of high grain Fe genotypes was developed using Perls' Prussian stain. This protocol has great utility in screening large number of germplasm accessions or improved breeding lines within shortest possible time and with minimum cost (the chemical cost of analysis of each sample is $0.01), and helps in discarding the low-density lines.

Inter-laboratory correlations of grain Fe and Zn density: A randomly selected sample of 12 genotypes with a wide range of Fe and Zn levels as revealed from the lab analysis at NIN, Hyderabad were also analyzed at ICRISAT-Patancheru, India and at the Waite Analytical laboratory, Adelaide University, Australia. The correlations for Fe and Zn density among the laboratories were highly significant ($r = 0.77$ to 0.98; $P < 0.01$), indicating dependability of the results from any of these three laboratories. Since, ICRISAT-Patancheru laboratory charges for the analysis of Fe and Zn are very low (US$1.4) compared to NIN (US$20) and Waite (US$7), whenever there is large number of samples, initial screening will be done at ICRISAT-Patancheru and those with high Fe and Zn density will be analyzed in other laboratories for confirmation of the ICRISAT-laboratory results.

KN Rai, VN Kulkarni, V Vadez, P Pathak and TJ Rego

Milestone: High-yielding and DM resistant trait-specific (diverse maturity, large grains, large panicles, high tillering) advanced breeding lines of pearl millet developed (2007)

Development of hybrid parents adapted to arid Rajasthan, India

Development of high-yielding hybrids adapted to arid Rajasthan is a great challenge that could be achieved through the development of hybrid parents adapted to this region. Breeding early-maturing seed parents with resistance to downy mildew (DM) against the most virulent Jodhpur pathotype is a strategy that is expected to produce desired results. Two approaches have been followed to develop potential seed parents; (i) exploitation of ICRISAT-CAZRI B-composite (ICCZBC) and (ii) pedigree breeding in promising B× B crosses. Potential restorer progenies development is based on (i) the exploitation of Mandor Restorer Composite (MRC) and (ii) improved populations adapted to arid Rajasthan region.

Development of seed parent progenies adapted to western Rajasthan, India: Development of seed parent progenies was set in motion two years ago through the constitution of ICCZBC based on 91 crosses selected from the diallel set of 20 parents previously selected for Rajasthan adaptation. About 1100 S_1-S_2 progenies derived from ICCZBC were evaluated against Jodhpur pathotype under high disease pressure in greenhouse condition (>90% DM incidence in susceptible controls 843B and ICMP 451), of which 45% were highly resistant (0-10% DM incidence). Out of 200 DM resistant S_2 progenies (derived from previous evaluation at Patancheru) evaluated in the rainy season, 77 were selected, and 50 of these flowered in 41-50 days (843B flowering in 41 days and 81B in 55 days). Of the 174 progenies evaluated in the summer drought nursery, 78 were selected based the agronomic potential, of which 50 flowered in 41-50 days (843B flowered in 43 days and 842B in 50 days).

Seed parent progeny development targeted to arid Rajasthan (India) also got an early start through pedigree breeding in 18 promising B x B crosses (mostly from the diallel set used to constitute ICCZBC) and now we are in the process of identifying advanced generation DM resistant progenies. In this context, 1316 F_5 progenies derived from B × B crosses were evaluated for DM resistance against Jodhpur pathotype under high disease pressure in greenhouse condition (>90% DM incidence in susceptible controls 843A and ICMP 451), of which 85% were found to be resistant (0–20% DM incidence). Based on DM resistance and visually assessed agronomic potential, 708 progenies were selected and evaluated during the rainy season, of which 263 were selected. Of these, about 220 flowered in 41–50 days (843B flowered in 39 days, 842B in 45 days and 81B in 51 days). Additionally, 300 F_5 progenies selected at CAZRI, Jodhpur (India) were also screened against Jodhpur pathotype, of which 82% had 0–20% DM incidence. Of the 60 S_2 progenies evaluated in the summer drought nursery, 30 were selected based on the visually assessed agronomic potential, of which 17 flowered in 41-50 days (843B flowered in 43 days, ICMB 95111 in 49 days and 842B in 50 days).

Early-maturing potential B-line trial: Breeding early-maturing hybrids has been largely dependent on male-sterile line 843A, which is the earliest-maturing, and it has good-tillering, large grain size and good combining ability, but is susceptible to DM. In breeding early-maturing seed parents, 843B has been used extensively. Genetic diversification for earliness is underway through exploitation of Extra-Early-Dwarf B-Composite (EEDBC). Out of the 22 EEDBC-derived early-flowering B-lines (40-48 days) evaluated, 14 progenies flowered in 41–46 days (ICMB 95444 flowered in 44 days and 843B in 42 days). Five of them were selected based on visual assessment of agronomic potential, of which 3 were resistant to both Jalna and Durgapura pathotypes with less than 15% DM incidence under high disease pressure in the greenhouse condition (80–91% DM incidence in susceptible controls).

Development of restorers adapted to western Rajasthan, India: Deriving progenies from the populations adapted to western Rajasthan has been the strategy followed to develop restorers for this region. In this respect, high-yielding Rajasthan Composite Bajra-2 (RCB 2), early-maturing Mandor Restorer Composite (MRC) and ICMS 7704 have been exploited. More than 100 advanced generation progenies (S_6–S_8) from MRC/RCB 2/ICMS 7704, and an additional 28 progenies from MRC selected from the summer drought nursery were evaluated during rainy season, of which 60 were selected. MRC-derived progenies were affected by water-logging in early stages of crop growth, resulting in delayed flowering as indicated by the late flowering of the controls. Of the 53 progenies evaluated 20 were selected, of which 16 flowered in 46–55 days. Twenty-five early-maturing MRC progenies with maturity similar to that of H 77/833-2 (45 days to 50% flower) were selected to further evaluate under post-flowering drought condition. Of the 14 selected progenies from RCB 2/ICMS 7704, 8 flowered in 40–50 days (ICMR 356 flowered in 46 days and ICMP 451 in 49 days).

MRC progeny trial: Mandor Restorer Composite (MRC) has been exploited to derive restorers suitable for producing early-maturing and high-tillering hybrids similar to HHB 67. Twenty-eight advanced generation (S_7–S_8) progenies derived from early-maturing MRC were evaluated at Bawal, Jamnagar and Patancheru, India in replicated trials. At Bawal, 9 progenies were selected based on the visual assessment of the agronomic potential and 5 of these were also selected at Patancheru. Additionally, 7 more progenies were selected at Patancheru. Also, 5 progenies with superior agronomic potential than the controls were selected at Jamnagar. Eight of the selected progenies at Bawal flowered in 44–51 days (H 77/833-2 flowering in 45 days and RIB 3135-18 in 50 days) and 9 of them selected at Patancheru flowered in 44–49 days (45 days for both the controls). All of the selected progenies at Jamnagar flowered late (2–13 days late) compared to the control H 77/833-2 (47 days).

Development of trait-specific breeding lines

Grouping of advanced generation progenies based on visually distinguishable desirable phenotypic characters (target traits) [such as high-tillering, long panicle, thick panicle, large seed size, compact panicle, etc.] enhances the effectiveness of visual selection by making the within-group comparison of lines easier for specific traits. During such trait-specific grouping, variability for non-target trait is also maintained to develop lines with multiple desirable traits without compromising on DM resistance. In addition to the trait-specific grouping, advanced generation progenies are also grouped into those resembling specific plant types of commonly used A-/R-lines such as 81A type, ICMA 89111 type, 843A type, ICMR 356 type, etc., which are easily recognized by breeders and the seed producers.

Trait-specific seed parent progenies: About 2200 advanced generation (F_5/S_5 and beyond) seed parent progenies belonging to 9 different trait-specific groups [ranging from 27 (forage type progenies) to 792 (early-generation long panicle progenies)] were evaluated. About 960 progenies (ranging from 25 to 244 in various groups) were selected based on the visual assessment of agronomic potential and target trait of respective groups for further testing. Early-flowering type was the newly constituted group with 65 diverse progenies evaluated, and 43 selected based on the visual assessment of agronomic potential. Of these, 72% flowered in 45 days and earlier (843B flowering in 39 days and 841B in 46 days). A large proportion of the selected progenies (65–82%) from large seed, high-tillering, very dwarf, compact panicle, erect-type and forage-type groups flowered in 46–55 days (ICMB 89111 flowering in 46 days and 81B in 51–53 days). Proportions of such progenies were less in long panicle and thick-panicle groups, indicating the need for introducing earliness in these progenies. The selected long-panicle progenies had panicle length ranging from 30 to 60 cm. Similarly the selected thick-panicle progenies had panicle diameter of 40–50 mm.

About 290 progenies typical to plant type of some of the most widely used and diverse hybrid parents such as 81A, 843A, ICMA 88004, ICMA 89111 and ICMR 356 were evaluated, and 254 were selected based on the visual assessment of agronomic potential and plant type. Of these, 81% belonged to early to mid-late group, flowering in 41–50 days (81B flowering in 53 days, ICMB 89111 in 45 days, 843B in 39 days). In addition to these, nearly 1700 preliminary and elite potential progenies were evaluated to select 667 progenies of various maturity classes based on the visual assessment of grain yield potential. Of these, 4% were in early group, flowering in 45 days; 35% were in mid-early group, flowering in 46-50 days; and 42% were in mid-late group, flowering in 51–55 days (81B flowering in 51 days, ICMB 89111 in 45 days and 843B in 40 days).

Screening for DM resistance in greenhouse condition under high disease pressure (83–100% disease incidence in susceptible controls) against Durgapura pathotype showed 20–35% progenies having no DM incidence in very dwarf, compact panicle and erect groups, and 1–10% DM incidence in 10–20% of the other progenies. About 40% of the progenies averaged over 8 specific plant type groups were free from DM and about 20% progenies had less (1–10%) incidence, indicating large proportion of progenies being DM resistant. Amongst the early-generation long panicle progenies and advanced generation B × B progenies, which are yet to be classified into different trait-specific/plant type groups, about 40% were DM resistant (0–10% incidence).

Thick panicle B-line trial: High Head Volume Dwarf B-Composite (HHVDBC) is a good source for deriving lines with thick panicles, which is an important yield component. Twenty-three advanced generation (S_5) progenies derived from HHVDBC were evaluated and nine thick panicle progenies having more than 40 mm panicle diameter with higher grain yield potential (based on the agronomic score) compared to the control ICMB 01222 (32 mm diameter) were selected. Of these, three progenies flowered in 51–53 days (ICMB 01222 flowered in 50 days). Four out of nine selected progenies had at least 30 cm panicle length.

Trait-specific restorer parent progenies: Similar to the trait-specific grouping of seed parent progenies, the grouping of restorer progenies based on different target traits and specific plant type is underway. About 690 advanced generation progenies (S_8 and beyond) from 9 different trait-specific groups (ranging from 16 in the large seeded group to 141 in the early-maturing group) were evaluated. Based on the visual assessment of yield potential and agronomic traits, 162 progenies from only 6 trait-specific groups were selected as the remaining groups were affected by water-logging during the early stage of the crop growth, making their evaluation ineffective. Flowering in these groups was delayed by 7–10 days as indicated by ICMR 356 flowering in 53 days (flowers in 45–46 days under normal conditions). About 60% of the progenies (46–55 days to flower) in these trait-specific groups were of similar maturity as ICMR 356. In the process of updating the trait-specific groups, about 90 progenies were added in dual-purpose group and 40 in the stay-green group. An extra-early group with 36 progenies was constituted. Additionally, 49 early-maturing and genetically diverse lines flowering in 38–53 days were selected to initiate intercrossing among them to constitute an Extra-early restorer composite.

IPC 804 is a good restorer line of short plant height, sturdy and erect plant type, and long panicles. Thus we constituted IPC 804 plant type group with 189 progenies. Additionally, we also constituted IPC 804–medium height group with 115 progenies. These two groups along with 42 ICMR 356 type progenies were evaluated and 96 were selected based on the visual assessment of agronomic potential and plant type. About 62% of the selected progenies flowered in 46–60 days (ICMR 356 flowering in 53 days and IPC 804 in 55 days). In the process of updating specific plant type groups, 29 progenies were added in ICMR 356 type. In addition to these, about 154 progenies with very high agronomic performance from diverse groups of material were selected for further evaluation.

Genetic diversification of restorer lines

Exploitation of OPVs for restorer line development: High-yielding improved populations adapted to different agro-ecological conditions serve as primary sources for deriving restorer progenies. These diverse populations recognized for different traits help in selection of progenies of various morpho-physiological characters such as earliness, height, tillering, panicle and seed traits and dual-purpose traits. We evaluated early and advanced generation progenies obtained from different populations for their agronomic potential.

About 800 population progenies (S_1–S_4) derived from 12 diverse populations were evaluated and 286 were selected based on the visually-assessed agronomic potential. Of these, 12% progenies from JBV 2 and JBV 3 flowered in 40–50 days (ICMR 451 flowering in 48 days and HTP 94/54 in 54 days) and 13% of the selected from other populations flowered in 46–60 days.

Restorer progenies derived from population intercrosses: A total of 216 (F_3–F_5) progenies with high agronomic score (selected out from 600 progenies selected during 2005-summer) derived from MRC × long panicle, Jakharana × ESRC crosses and from population intercrosses were evaluated and 93 were selected to generate 247 progenies. Forty-six of the selected progenies flowered in 46–50 days (ICMR 356 flowering in 47 days and ICMP 451 in 48 days). Jakharana × ESRC progenies (154) were evaluated against Durgapura pathotype under high disease pressure in greenhouse condition (90% in ICMP451 and 100% in H 77/833-2), of which 53% of the progenies had 0–10% DM incidence**.**

Pedigree breeding of restorers of A_5 CMS system: Restorer development for A_5 CMS system is unique as A_5 restorers are rare in the germplasm. Therefore, a different approach involving incorporation of A_5 restorer genes(s) in diverse genetic backgrounds was followed to breed restorers of this CMS system. During 2004 rainy season, we evaluated 190 hybrids derived from crossing 8 elite male-fertile inbreds in A_5 cytoplasmic background as female parents with 31 high-yielding population progenies as male parents. Based on grain yield potential, agronomic traits and fertility restoration, 14 hybrids (involving 7 female parents and 10 male parents) were selected and their F_2 populations were produced to initiate pedigree selection for A_5 restorer line during the previous year. From these 14 F_2 populations evaluated during the 2005 summer season, 8 populations were selected based on the visual assessment of the promising segregants with respect to yield potential, agronomic traits and male-fertility restoration. We selected 117 plants from these 8 populations, which were advanced to F_3 generation. Also, 20 progenies of diverse pedigree from restorer breeding program were crossed with the individual plants of all 14 F_2s to diversify the genetic base of A_5 restorers program. More than 90 crosses made on the selected 8 F_2 populations were harvested for further evaluation/selection.

Potential restorer progenies: This group consisted of 395 progenies (S_4-S_6 and beyond) that were selected during summer and rainy season 2004 from different groups of breeding materials. These were evaluated during 2005 rainy season, of which 103 were selected based on the visually assessed grain yield potential and other agronomic traits to generate about 170 progenies. Of the selected progenies, 38 flowered in 46–55 days (ICMR 356 flowering in 55 days and ICMP 451 in 54 days). All 395 progenies were evaluated against Durgapura and Jalna pathotypes under high disease pressure in greenhouse condition (>95% in incidence in controls). Of these, 24% progenies were resistant (0–10% DM incidence) to Durgapura pathotype and 33% to Jalna pathotype.

Elite restorer progenies: About 470 progenies that included 288 diverse progenies (S_4–S_6 beyond) with high agronomic score selected from different groups of materials during 2005 summer season and the remnant seed source of 170 progenies were further evaluated during the rainy season. Since a major part of this block was affected by water logging, only 56 progenies were selected, and 18 of these flowered in 46-55 days (ICMR 356 flowering in 56 days and ICMP 451 in 54 days). The 288 progenies selected in 2005 summer were evaluated against Durgapura and Jalna pathotypes under high disease pressure in greenhouse condition (90–100% in susceptible controls). Of these, 32% of the progenies were resistant (0–10% DM incidence) to Durgapura pathotype and 37% to Jalna pathoype.

RCB2/ICMS 7704 Progenies trial: Exploitation of RCB 2 and ICMS 7704 is expected to produce restorer lines of dual-purpose hybrids. Nine progenies derived each from RCB 2 and ICMS 7704 were evaluated at Jamnagar and Patancheru in replicated trials. At Jamnagar, all the 5 progenies identified for good agronomic potential based on the visual assessment were from RCB 2, of which 4 flowered in 44–50 days (ICMP 451 flowering in 50 days and ICMR 356 in 44 days). At Patancheru, amongst 7 progenies (3 derived from RCB 2 and 4 from ICMS 7704) selected based on the agronomic score, 4 flowered in 46–52 days (ICMP 451 flowering in 49 days and ICMR 356 in 46 days). A progeny with the highest agronomic score (ICMS 7704 S1-103-2-3-2-2-2-4-B) derived from ICMS 7704 that flowered in 56 days having good panicle length (29 cm) was the best dual-purpose progeny. It was also identified for conversion into A-line of forage hybrids.

Dual-purpose restorer progenies trial: To expand the genetic base of dual-purpose restorers exploitation of a wide range of populations through inbreeding and selection has been one of the strategies in restorer line development. Twenty-eight previously selected advanced generation progenies derived from 13 different populations were evaluated at Patancheru, Hisar and Jamnagar. At Hisar, 6 progenies (with 4 score, where 1 = poor; 5 = best) were selected based on their visually assessed grain yield potential and other agronomic traits compared to controls ICMP 451 and HTP 94/54 (both with 3 score). Of these, 4 were also selected at Jamnagar. Additionally, 12 progenies (with 3–5 score) having superior scores than controls (both 2) were also selected at Jamnagar. At Patancheru, 13 progenies that had agronomic scores similar to or better than the controls (both 4) were selected. Of these, 3 were best with 5 score. Flowering behavior of the progenies at Patancheru and Jamnagar were similar compared to Hisar (11–14 days later). Selected progenies at Hisar flowered in 57–71 days (63 days for ICMP 451 and 71 for HTP 94/54) and at Jamnagar these flowered in 43–57 days (49 days for ICMP 451 and 56 for HTP 94/54). Amongst the 3 best progenies identified at Patancheru, 2 flowered in 52 days (49 days for ICMP 451 and 52 for HTP 94/54) and third was late by a week. Of the remaining 10 progenies, eight flowered in 46–53 days. Almost all the selected progenies in all the locations had ≥150 cm plant height.

KN Rai, VN Kulkarni and RP Thakur

Downy mildew resistance in advanced generation progenies from selected B × B crosses targeted for western Rajasthan, India

Maintaining high levels of downy mildew resistance in breeding lines is the key to the development of stable A-, B- and R-lines and their hybrids. Keeping this in view we screened large number of advanced generation breeding lines targeted for Rajasthan, India against two major pathotypes, Durgapura (Sg 212) and Jodhpur (Sg 139) in the greenhouse.

- A total of 1228 advanced breeding lines including 131 F_5, 375 F_6 progenies from B × B crosses, and 722 trait-specific progenies were screened against Durgapura pathotype in an unreplicated trial (one pot with 35–40 seedlings per line). Of these, 18% lines were disease free and 19% showed high levels of resistance (≤10% incidence).

- Similarly, a total of 2734 advanced breeding lines including 1616 F_5 progenies from B × B diallel crosses, and 440 S_1 and 678 S_2 progenies from ICCZ BC C were screened against Jodhpur pathotype. Of these, 37% were disease free, and 23% showed high levels of resistance (≤10% incidence).

- A total of 352 progenies from high head volume dwarf composite (HHVBC) were screened against Jalna (Sg 150) and 359 against Durgapura (Sg 212) pathotypes. Of these, 11% were disease free and 6% showed high levels of resistance (≤10% incidence) to Jalna pathotype; 15% lines were disease free and 8% were resistant to Durgapura pathotype.

RP Thakur and KN Rai

Hybrid parents adapted to the arid zone

Combining ability of Mandor Restorer Composite (MRC) progenies under arid zone conditions: Forty-one lines from MRC (selected based on DM resistance and agronomic value at ICRISAT-Patancheru) were testcrossed to five seed parents and the resulting hybrids were evaluated for general combining ability (GCA) at the Rajasthan Agricultural University station at Nagaur, Rajasthan, India. The mean grain yield of the trial, under severe drought stress, was only 341 kg ha^{-1}, but the differences among MRC line for the mean hybrid yields was highly significant (range of 201 to 522 kg ha^{-1}). The best of the control restorers (arid zone landrace-derived topcross pollinators) had average hybrid yields of 401 and 427 kg ha^{-1}). MRC lines with a positive and significant (P <0.05) GCA were detected for all traits measured: percent productive panicles (2), biomass (5), harvest index (11), grain yield (7), stover yield (5) and panicle harvest index (8). GCA for biomass was associated with GCA for both grain yield (r = 0.64, P <0.001) and stover yield (r = 0.93, P <0.0001), and GCAs for grain and stover yields were positively correlated (r = 0.35, P <0.10). This suggests that we could identify lines from the MRC with positive GCA for both grain and stover yields, but that both are dependant upon a positive GCA for total biomass. The most useful finding is that despite the selection of the MRC lines under favorable conditions at Patancheru (rather than in the arid zone), it was possible to identify superior lines in a very drought stressed environment. This is likely due to the selection of restorers with adaptation to the arid zone as the parents of the original MRC. Combining ability of landrace-based restorer populations in arid zone conditions: We continued the evaluation of the GCA of the landrace-based restorer populations that we bred with the objective of making a sample of the best of arid zone landrace germplasm more readily available for the breeding of restorers for the arid zone. The eleven populations plus four controls were crossed to four arid zone adapted seed parents, and the resulting hybrids (plus four single-cross hybrid controls) were evaluated at the Rajasthan Agricultural University station at Nagaur, India. Trial mean grain yield, under severe drought stress, was 338 kg ha^{-1}; with a range in individual entry grain yields of 182 to 528 kg ha^{-1}. Two of the restorer populations tested had a significant (P <0.05) positive GCA for grain yield (the Jakharana restorer population and the control inbred restorer RIB 3135-18) and three populations had a significant positive GCA for stover yield (Barmer, Jakharana, Jakharana × ESRC restorer populations). These same three populations, plus RIB 3135 had a significant GCA for total biomass productivity, which we consider to be the best measure of adaptation to severe stress conditions, and hence to the arid zone. The single-cross hybrid controls as a group had grain yields well above the trial average (405 vs. 338 kg ha^{-1}), but stover yields well below the trial average (1190 vs. 1410 kg ha^{-1}), indicating that the current conventional hybrids, selected mainly for grain yield, do not fully meet the needs of arid zone farmers for both grain and stover. This trial will be continued in order to sample a wider range of environments before recommending individual restorer populations for actual use in breeding programs.

GCA for biomass of B × B crosses in arid zone conditions: Earlier research suggested that a positive GCA for biomass productivity under arid zone environments is the most desirable characteristic in new seed parents for this zone, as only such seed parents can produce hybrids with simultaneous improvement in both grain and stover yield. We made a complete diallel among twelve B-lines thought to be adapted to the arid zone to identify maintainer germplasm with this ability. We selected 23 B × B F_1s from the diallel and testcrossed these (and two inbred A-line controls) to four arid zone restorers, to evaluate the general combining ability of the selected F_1s for biomass productivity. The resulting 100 testcrosses were evaluated at the Rajasthan Agricultural University station at Nagaur, India. Yields were relatively low because of the severe stress (trial mean grain and stover yields were 473 and 1910 kg ha^{-1}), but there were significant differences among B × B F_1s for most traits. Only one of the crosses had a significant ($P < 0.05$) positive GCA for biomass under these conditions. However, this did result in significant positive GCAs for both grain and stover yields. Interestingly, this was a cross between two B-lines which themselves had a positive GCA for biomass – ICMB 91444 and ICMB 93333, both of whom contain West African parentage. We will continue with the B × B cross evaluations to sample a wider range of environments, but will also start inbreeding the ICMB 91444 × ICMB 93333 cross to produce progenies for selection for GCA for biomass in the arid zone.

Selection of restorers from the Early Rajasthan population: The Early Rajasthan Population (ERP) was bred from 30 selected S_1 progenies from four early-maturing landraces from western Rajasthan. The base population has performed very well under stress and is the source of a released variety CZP 9802, as well as an early maturing restorer population for the arid zone. Because of the obvious value of the ERP for the arid zone, we initiated the process of deriving inbred lines from the restorer version of the population, as potential R-lines. In order to assure that the most valuable characteristic of the ERP – its adaptation to the arid zone – was retained, we conducted a replicated yield test of 192 ERP S_1 progenies at the Rajasthan Agricultural University station at Nagaur, India to select desirable progenies. Due to the severe stress, the mean grain yield of the trial was very low (246 kg ha^{-1}), but differences among progenies in grain yield (15 to 700 kg ha^{-1}) were highly significant. Importantly, there were also highly significant differences among progenies for key indicators of adaptation to severe stress – percent panicles with seed (28 to 100%) and panicle harvest index (29 to 78%) – as well as in time to flowering (41 to 62 days). Selection of progenies was based mainly on drought escape/tolerance traits rather than grain yield: percentage panicles with seed ≥90%, panicle harvest index ≥55% and flowering ≤52 days.

FR Bidinger

Stover productivity and quality of arid zone adapted seed parents: Because of the importance of animal products to the income of arid zone farmers, new cultivars of pearl millet for the arid zone should not only produce grain and stover yields superior to those of the landraces now grown, but the ruminant nutritional quality of their stover should be at least equal to that of the current landraces. As not much is known about nutritional quality of either the traditional landraces or of potential alternative hybrid cultivars, we conducted an experiment to assess stover quality in a set of six typical landraces and their eighteen topcross hybrids made on three arid zone adapted seed parents. Over four environments in 2003 and 2004, the yields of the landrace-based topcross hybrids exceeded that of the landrace pollinators by an average of 17% in the case of grain yield and 7% in the case of stover yield. There was no difference in nitrogen content of the landrace and topcross hybrid stover, and small (1–2%) but significant differences in the *in vitro* organic matter digestibility and metabolizable energy, in favor of the topcross hybrids. Combining the differences in stover productivity and quality between the landraces and the topcross hybrids resulted in a 13–14% increase in stover digestible dry matter, metabolizable energy and nitrogen per ha. Under the typical dry season, restricted intake feeding system of the arid zone (restricted due to limited stover supplies) these differences should translate into economic increases in animal productivity. Therefore, there is no *a priori* reason to be concerned about negative effects of arid zone hybrids, made with adapted parental lines, on either stover productivity or quality.

FR Bidinger and M Blümmel

Milestone: Pigeonpea breeding lines with resistance to *Helicoverpa*, wilt and sterility mosaic developed (2006)

Screening for wilt and sterility mosaic (SM) resistance: A total of 46 advanced breeding lines, 391 F_1 hybrids, and 62 backcross populations were screened in the wilt and sterility mosaic sick plots. The disease incidence was very high. Among the inbred lines, 45 were found resistant to both wilt and sterility mosaic diseases. In each line, five plants were selfed to produce pure seed. In the backcross populations, hand pollinations were done on the resistant segregants to advance the generation. Among the hybrids, 105 were found resistant to both wilt and sterility mosaic diseases, while 47 were resistant to wilt and 95 were resistant to sterility mosaic disease.

KB Saxena

Screening for salinity tolerance: Besides various management options, the development of salinity-tolerant varieties is the best option for saline areas. A protocol has been standardized at ICRISAT-Patancheru to screen pigeonpea genotypes for salinity tolerance, and a concentration of 75 mM was found to be critical for screening. SCMR (SPAD chlorophyll meter reading) was positively associated with higher biomass under salinity and this trait could be used as an early indicator for salinity tolerance. The shoot biomass data were analyzed using the residual maximum likelihood method. Among the wild species two accessions (ICPW 87 and ICPW 94) from *C. scarabaeoides* were most tolerant. Of the cultivated pigeonpea (*C. cajan*) accessions, ICP 13991, 14974, 13997, and 11412 exhibited high level of tolerance and ICP 13625, 13996, 14175, 11414, and 11420 showed high susceptibility. Among the maintainers, ICPB 2051, 2030 and 2039 were found tolerant while ICPB 2032 was highly susceptible.

N Srivastava and Vincent Vadez

Screening pigeonpea accessions and breeding lines for broad-based resistance against sterility mosaic isolates: Thirty-eight pigeonpea breeding lines developed at ICRISAT using broad-based sterility mosaic disease (SMD) resistant variety, ICP 7035, as one of the parents, were evaluated on-station for resistance against SMD during 2003–05. All these lines are of short to medium duration maturity (100−160 days to mature) types. From the 38 breeding lines, 12 promising lines (ICP 14404, 16166, 11719, 16169, 14478, 16165, 14834, 11632, 95029, 14399, 16294 and 16293) were evaluated during 2005-06 in on-station trials at Bangalore, Bidar and Gulbarga, Karnataka, India, against SMV-P and SMV-B isolates, respectively, to assess the maturity and resistance to SMD. Test plants were grown in SMD sick plots to allow infection to take place at young stage (12–15 days old plants). Local cultivars ICP 8863 and TTB 7 were used as susceptible controls, and these showed >80% infection.

At Bidar and Gulbarga, all the 12 genotypes attained 80% maturity in 140 days and showed good resistance to PPSMV-P isolate endemic in this region. Seven of 12 accessions showed no infection. In the remaining genotypes, SMD incidence ranged between 7.5 and 33%. All the 12 genotypes were selected by the local scientists for further validation. The seven genotypes (ICP 16166, 11719, 16169, 16293, 14834, 11632 and 95029) that showed no infection will be evaluated in the coordinated trials and on-farm. Evaluation of these genotypes against PPSMV-B isolate at Bangalore revealed that all the 12 accessions were infected (30–90% incidence). Although all the genotypes were infected, most of the genotypes produced flowers. In particular, ICP 14834, 16165, 11719, 14478, 11632 and 14399 (incidence 30–40%) showed apparently normal flowering. Five accessions, ICP 11719, 14834, 11632, 14399, 14478 and 16165, performed well against both PPSMV-P and PPSMV-B isolates.

On-farm trials to promote SMD resistant varieties: About 300 on-farm trials were organized with three medium-duration pigeonpea varieties, ICP 7035 (broad-based SMD and wilt resistant), ICP 87051 and ICPL 96058 (resistant to PPSMV-P isolate and wilt for central India). ICP 7035 was released for farmer cultivation by ICRISAT and University of Agriculture Sciences, Bangalore, India during May 2005.

Ten on-farm trials were conducted in three talukas (Chincholi, Aland and Gulbarga) in Gulbarga district of Karnataka (1 acre for test genotype and 0.5 acre for local control). Test varieties were ICP 7035 (3 farmers) and ICPL 96058 (7 farmers) with local controls, ICP 8863 and Asha. Sowings were done in second week of July. Genotypes were found performing well. All these trials were conducted with inputs, for commercial scale production.

Two hundred on-farm trials of ICPL 96058 were conducted in 15 villages of Mahaboobnagar district in Andhra Pradesh, India. Sowings were done in third week of July. No local controls were included in these trials. These trials were managed as per the traditional farmers practice. All the farmers in these trials are smallholders. Seeds were treated to prevent wilt infection. IPM methods were followed for pest control.

Twenty-five on-farm trials of ICPL 96058, ICP 7035 and ICP 87051 were organized in eight districts (Medak, Ranga Reddy, Kammam, Adilabad, Nizamabad, Nellore, Nalgonda and Warangal of Andhra Pradesh, India). Three varieties were supplied to farmers. ICP 8863 and other local varieties were included as controls.

Thirty-two frontline demonstrations of ICP 7035 were organized in four districts of southern Karnataka. These demonstrations were conducted in association with the State Extension Education Unit for the promotion of variety in diverse regions. Forty-eight on-farm trials of ICP 7035 were conducted in the SMD epidemic areas in three districts of Karnataka.

All the farmer-managed trials were conducted as per the native farmer methods. Seed was provided to the farmers. During the course of the trials, visits were made to monitor the farms, for the evaluation of performance, to obtain farmers opinion and to monitor SMD incidence in the region. All trial locations received good rainfall and varieties performed well. No SMD incidence was noticed on disease resistant varieties.

Survey for SMD incidence: In August 2005, a roving survey for SMD incidence was conducted to monitor 4–6 weeks old pigeonpea crop (most susceptible stage) in Gulbarga and Bidar districts (SMD hotspots) of Karnataka, India. Twenty-nine villages in four talukas (Aland, Gulbarga, Jewargi, Chittapur) of Gulbarga district; and 30 villages in five talukas (Basavakalyan, Bhalki, Bidar, Aurad, Humnabad) of Bidar district were surveyed. Most fields were free from SMD incidence (based on visual symptoms) although farmer-grown cultivars in these regions are highly susceptible to SMD. In few fields, especially in Bidar, around 1% SMD incidence was observed. Mite population was non-existent on the infected plants. Therefore, those infected plants may not act as source for secondary spread. Farmers were asked to remove the affected plants. Generally, frequent rains suppress multiplication of eriophyid mite vector and this restricts disease spread.

Training to farmers and field days: Training courses were conducted for farmers on IPM to manage SMD, wilt and pod borer. These included preparation of plant-based extracts for pest control and training in good agriculture practices and means to enhance pigeonpea productivity. Emphasis on management of SMD and wilt was through cultivation of resistant genotypes; and for pod borer management, a combination of traditional methods and judicious application of chemical sprays. Training courses were organized as one-day events, at Agriculture Research Stations, NGO training centers, and on-farm during field visits. In these events, farmers were given lectures in local language. We also demonstrated the affects of SMD on pigeonpea and performance of resistant varieties. Farmers selected for seed village program were given training in pigeonpea crop management to ensure quality seed production. Farmer field days were organized to demonstrate on-farm performance of pigeonpea varieties to the farmers. All the farmers training programs and field days were organized in collaboration with NGOs and State Extension Education Units. Information bulletins were prepared in local language and supplied to the farmers in such events.

Seed village system: Seed villages were established at 12 locations for the multiplication of ICPL 96058 and ICP 7035. These were established in association with local NGOs and Extension Education Units in Andhra Pradesh and Karnataka states in India. In this, a network of designated farmers multiplies the pigeonpea genotypes for seed purpose. Standard crop management practices were followed, external inputs such as fertilizer, one time irrigation was given at flowering, and isolation distance was maintained. The seed produced was collected and sold on par with the market price to the local farmers. The money generated will be used (as revolving fund) to continue the seed production next year. This system ensures timely availability of quality pigeonpea seed to the farmers at right time. At present, each seed village has the capacity to produce 100 to 200 kg seed for each season. This target will be enhanced in due course. Assured supply of quality seed at right time is encouraging farmers to participate in this program.

P Lava Kumar, Farid Waliyar and KB Saxena

Sterility mosaic (SM) caused by pigeonpea sterility mosaic virus (PPSMV) and *fusarium* wilt (FW) caused by *Fusarium udum* are destructive diseases of pigeonpea with an estimated annual yield losses of >US $400 million. Deployment of host-plant resistance is the best way for economical management of these diseases.

Combined resistance screening for sterility mosaic and *fusarium* wilt: Wilt sick plot for evaluation of breeding and germplasm lines for resistance to wilt was developed at ICRISAT-Patancheru. Chopped wilted pigeonpea plants are incorporated in the field every year to maintain threshold level of *F. udum*. Test material planted in wilt sick plot are inoculated using leaf staple technique at two-leaf stage with SM-infested leaves for SM infection. These techniques provide a simultaneous identification of wilt and SM resistant lines. Susceptible cultivars ICP 2376 for wilt (resistant to SM) and ICP 8863 for SM (resistant to wilt) were planted as indicator rows after every 10 test rows. Incidence of wilt and SM were recorded thrice at seedling, flowering and pod filling, and at maturity stages of the crop. Pigeonpea lines with <10% incidence to individual disease were considered as resistant.

Wilt and SM resistance in germplasm lines: Seventeen lines for wilt and SM resistance, six advanced lines for wilt and 26 advanced lines for SM were evaluated for combined resistance to FW and SM at ICRISAT-Patancheru. Good sources of combined resistance against wilt and SM diseases were observed. Nine lines (BDN 2010, BSMR 736, BSMR 846, KPL 43, KPL 44, MAL 3, ICP 9174, ICP 11438 and ICP 12290) were found resistant to both FW and SM diseases. Of the six advanced wilt promising lines, ICH 732 and ICP 6997 had resistant reaction (<10%) to both the diseases. Among the 26 SM promising lines, six lines (PT 1037, 2032, 2033, 2035, ICP 8090, ICP 8103) had combined resistance to both FW and SM. Additionally, seven lines were found asymptomatic and 10 were resistant (<10%) to SM.

Wilt and SM resistance in advanced breeding and inbred lines: Thirty advanced breeding and inbred lines were evaluated for combined resistance to FW and SM following standard evaluation techniques. Among the test lines, three lines ICPL 20097, ICPL 20098, ICPL 20099 were asymptomatic to both FW and SM. Twenty-three lines were found resistant to both diseases (<10% SM and wilt diseases).

Wilt and SM resistance in pigeonpea international nursery: Ten entries included in pigeonpea international nursery (PIN) were screened for combined resistance to both FW and SM following standard screening techniques. Six lines (ICPLs 87119, 96053, 96058, 96061, 99044 and 99050) were resistant to both FW and SM diseases

S Pande and KB Saxena

Wilt and SM resistance in *Helicoverpa* tolerant lines: Seventeen pigeonpea lines that were tolerant to pod borer, *Helicoverpa armigera*, were tested for their resistance to FW and SM diseases. ICP 7035 was asymptomatic to SM and ICPL 20042 was resistant to FW (<10% disease incidence). However, none of the *Helicoverpa* tolerant lines were resistant to both FW and SM diseases.

S Pande and HC Sharma

Disease Screening for Collaborators in pigeonpea

ICAR-ICRISAT collaborative research on pigeonpea wilt: Under ICAR-ICRISAT collaboration, 49 entries [32 entries in Advanced Variety Trial (AVT) and 17 entries in Initial Varietal Trial (IVT)] from Indian Institute of Pulses Research (IIPR), Kanpur, were received for evaluating for SM and wilt resistance under standard field evaluation techniques. Of the 17 IVT promising selections from IIPR Kanpur, two lines (MAL 23 and Bahar) were found asymptomatic, and MAL 13 was found resistant to both the diseases. Additionally four lines

[ICP 7119 (HY 3C), BRG 3, MAL 18 and MAL 20] were resistant to SM alone. Among 32 AVT entries, only KPL 96053 was found resistant (<10%) to both FW and SM.

Acharya NG Ranga Agricultural University (ANGRAU)-ICRISAT collaboration for Wilt and SM resistance in advanced breeding lines: One hundred and four advanced breeding populations and progenies received from ANGRAU-Warangal, India were evaluated for SM and wilt resistance following standard field evaluation techniques. Of the 104 breeding lines, five lines WB 119, F29/7, F 5-98-1-21-2-3-1, F5-98-8-4-1-1-2 and F-98-2-6-2 were asymptomatic and 19 lines were resistant to SM. One line, F5-98-2-7-1-2-1 had combined resistance (<10%) to both SM and wilt.

S Pande

Confirmation of wilt resistance of advanced wilt promising germplasm lines using root dip and pot screening techniques under greenhouse environment

Root dip technique: Twenty-three pigeonpea lines, which were found resistant under field environment for three consecutive years, were tested for confirmation of their resistance to wilt under controlled environment (greenhouse). A susceptible control ICP 2376 was included for proper comparison. Seedlings of each entry were raised separately in polythene bags (8 × 20 cm) filled with sterilized sand in the greenhouse. Eight-day-old shake culture of the fungus, *Fusarium udum* (ICRISAT isolate) and eight-day-old seedlings were used for inoculation. Conidial concentration used for this study was 2×10^5 ml^{-1}. Roots of five seedlings of each entry were trimmed, dipped in the conidial inoculum for 30 seconds and transplanted in pre-irrigated 15 cm (diameter) plastic pots filled with sterilized sand and black soil mixture (4:1). Each pot represented one replication and three pots were kept for each entry. Uninoculated controls for each entry were maintained. The experiment was kept for 30 days for wilt symptoms. Wilt-susceptible cultivar ICP 2376 had 100% wilt within 12 days after inoculation (DAI). Of the 23 cultivars tested, five cultivars, ICP 12749, ICPL 94062, IPA 40, V 71A and V 102 were free from wilt.

Sick-pot technique: The above experiment was repeated using sick-pot technique in the greenhouse to correlate the efficiency of the technique for wilt screening under controlled environment. Pure culture of *Fusarium udum* (ICRISAT isolate) was multiplied on sand-pigeonpea meal medium (90 g pure sand, 10 g pigeonpea granules and about 20 ml distilled water in 250 ml conical flasks and autoclaved at 20 lb pressure for one hour) and incubated at 25°C for 15 days. Whole contents of the flask were taken out after 15 days of incubation and uniformly powdered. About 200 g of the inoculum was mixed in two kg soil (sterilized black soil + sand mixture in 1:1) filled in 15 cm plastic pots. All the pots were kept moist with light irrigation for two days to allow the fungus to settle. Thus, the soil in the pots was made wilt sick for evaluation of pigeonpea lines for wilt resistance. Seedlings were raised in polythene bags as in the root dip technique. Eight-day-old seedlings grown on ploythene bags were taken out and transplanted in the *F. udum* sick pots @ five seedlings per pot. These pots were kept for each entry and each pot represented one replication. Pots were watered as and when required and observed for 30 days for wilt symptoms.

Results were similar to root dip technique, confirming the correlation between the techniques. Since both techniques gave similar results, root dip technique, which is easy to handle, can be used for confirmation of wilt resistance in greenhouse.

S Pande

Resistance to *Helicoverpa* introgressed into diverse chickpea breeding lines (2006)

Breeding lines for resistance to *Helicoverpa*

One thousand five hundred and eighty six progenies (363 F_7 progenies and 721 F_8 progenies from single-crosses, and 502 F_7 progenies from four-way crosses) were sown under natural infestation of *Helicoverpa* larvae to select progenies for resistance. Selections were visually made for plants with early maturity, lesser pod damage and higher yields. We selected 1161 progenies (236 F_7 and 490 F_8 progenies from single-crosses and 435 F_7 progenies from four-way crosses) for progeny testing next year.

CLL Gowda

International Chickpea Screening Nursery – *Helicoverpa* Resistance (ICSN-HR)

Using reliable field screening techniques developed at ICRISAT for screening against *Helicoverpa*, several resistant sources have been identified. The resistant (less susceptible) sources identified in field screening were used in crosses to transfer resistance in high-yielding varieties. Pedigree selection for low borer damage under pesticide-free conditions was found effective in identifying pod borer resistant lines. This trial is intended to share material showing resistance to *Helicoverpa* with the collaborating scientists of the national programs. Most lines are of short to medium duration, adapted to environments similar to southern and central India (16 to 22°N latitudes). The objective is to evaluate promising *Helicoverpa* resistant selections in varying environments and to provide an opportunity to NARS partners for selections for use as parents or as end products suitable for various conditions. The trial with 15 chickpea genotypes, including two controls, was sent to two collaborators.

CLL Gowda

Milestone: Diversified breeding lines with resistance to *Ascochyta* blight (AB), *Botrytis* gray mold (BGM), wilt, root rot, and drought avoidance root traits developed (2006)

Development of high-yielding *Fusarium* wilt resistant breeding lines in chickpea

A total of 71 advanced breeding lines (F_6 onwards) of *desi* chickpea were evaluated in one preliminary yield trial (PYT) and two advanced yield trials (AYTs) along with two controls, JG 11 and ICCC 37. Three lines (ICCX-970047-BP-BP-P49-BP-BP, ICCX-970047-BP-BP-P64-BP-BP and ICCX-970047-BP-BP-P68-BP-BP) in PYT and one line (ICCX-970047-BP-BP-P46-BP-BP) in AYT gave 6 to 15% higher yield than the best control JG 11 and had high resistance to FW (0 to 10% mortality). These lines were as early as JG 11 in maturity (94 to 96 days) and had larger seed (24 to 25 g 100^{-1} seed as compared to 20 g 100^{-1} seed of JG 11).

In *kabuli* chickpea, 42 advanced breeding lines were evaluated in one PYT and one AYT along with the controls KAK 2 and Vihar. Though several breeding lines gave higher yield (up to 25%) than the best control KAK 2, only one line (ICCX970075-BP-BP-P27-BP-BP) had the best combination of maturity duration (94 days), seed size (32 g 100^{-1} seed), yield (1560 kg ha^{-1}) and resistance to FW (3.9% mortality) and was superior to KAK 2 (97 days to maturity, 32 g 100^{-1} seed weight, 1400 kg ha^{-1} yield, and 20% mortality from FW).

PM Gaur and S Pande

Development of high-yielding *Ascochyta* blight (AB) and *Botrytis* gray mold (BGM) resistant lines in chickpea

Fifty AB/BGM resistant advanced breeding lines of *desi* chickpea were evaluated along with 10 controls (8 promising cultivars/breeding lines from Western Australia - Sona, Moti, Sonali, Rupali, WACPE 2078, WACPE 2098, WACPE 2099, ICCV 96836; and 2 cultivars from India - JG 11, ICCV 10), in a RBD with 3 replications under a special project funded by the Council of Grain Grower Organization Ltd (COGGO), Western Australia. The entries were screened against *Fusarium* wilt (FW) in a wilt-sick nursery and for AB and BGM under controlled environment conditions. There was no line that showed excellence in all attributes. Eleven lines showed high resistance to AB (score between 2.0 to 3.0 on 1–9 scale, where 1 = highly resistant and 9 = highly susceptible) and 12 lines showed high resistance (score between 3.7 and 4.0) to BGM. One line (ICCV 04526) had high resistance to both the diseases (2.3 score for AB and 4.0 score for BGM). Nine lines gave 10 to 30% higher yield over the best control (WACPE 2099) from Western Australia, which yielded 2.0 t ha^{-1}. However, no line gave higher yield than JG 11, the higher-yielding control from India.

PM Gaur, S Pande and CLL Gowda

Multiplication of BGM and AB promising chickpea lines: One hundred and seventeen BGM and AB promising lines identified in the earlier controlled environment evaluation were multiplied in a vertisol field at ICRISAT-Patancheru. These lines, originally received from Australia (NSW Agriculture), differed in number of days for flowering and pod maturity. In each line, 20–200 g of seed was harvested and tested to reconfirm BGM and AB resistance in controlled environment.

Reconfirmation of BGM resistance: Twelve-day-old seedlings raised in sand-vermiculite mixture (4:1) were used for artificial inoculation. A susceptible control JG 62 was used as indicator in each tray along with nine test entries. The experiment was conducted with 24 plants in three replications, ie, eight plants per replication. Seedlings were transferred to the controlled environment at 15°C and 100% RH and allowed to acclimatize for 24 h before inoculation. Seedlings were then inoculated with conidial suspension of *B. cinerea* @ 3×10^5 conidia ml^{-1} using the standard weather conditions (15°C and 100% RH with 12 h light and 12 h dark). Disease severity was quantified on a 1–9 rating scale at 20 days after inoculation. Based on the mean disease score, individual chickpea lines was categorized as immune (disease score 1.0), resistant (disease score 1.1–3.0), moderately resistant (disease score 3.1–5.0), susceptible (disease score 5.1–7.0) and highly susceptible (disease score 7.1–9.0). Of the 117 lines evaluated, 108 were moderately resistant, and 36 of these had a minimum disease severity 4.0 on 1–9 rating scale.

Reconfirmation of AB resistance: The lines mentioned above were also screened for AB to confirm their resistance to AB under controlled environment at ICRISAT-Patancheru. Seedlings were raised in sand-vermiculate mixture (4:1) for 12 days in greenhouse and transferred to controlled environment at 20°C and 100% RH. Seedlings were allowed to acclimatize for 24 h and then inoculated with *A. rabiei* conidial suspension of 5×10^4 conidia ml^{-1} and incubated at 20°C and 100% RH. Disease severity was measured on a 1–9 rating scale at regular intervals up to 14 DAI. The experiment was conducted in three replications with eight plants in each replication. Among 117 lines evaluated for AB resistance, high levels of disease resistance were observed in several lines. Seventy-three lines were resistant (disease score of 1 to 3 on a 1–9 rating scale) and 38 lines were moderately resistant (disease score 3.1 to 5.0) to AB infection. Of the 73 resistant lines, 19 lines had a score of ≤2.0 on a 1–9 rating scale.

Suresh Pande and G Krishna Kishore

Australia-ICRISAT collaborative research on chickpea

***Botrytis* gray mold:** In collaboration with Department of Agriculture, Western Australia (DAWA), Center for Legumes in Mediterranean Agriculture (CLIMA) and Council of Grain Growers Organization (COGGO), Australia, 60 chickpea improved breeding lines were evaluated for *Botrytis* gray mold resistance to BGM in controlled environment at ICRISAT-Patancheru. Ten-day-old seedlings of test lines, along with JG 62 as a susceptible control were inoculated with conidial suspension of *B. cinerea* (3×10^5 conidia ml^{-1}) multiplied on autoclaved merigold flowers. Inoculated plants were maintained at 15 ± 2°C and 100% RH with a 12 h photoperiod. BGM severity was recorded on a 1–9 rating scale at 20 days after inoculation. Based on the repeated resistance evaluations, 12 lines had score 4.2–5.0 and were identified as moderately resistant to BGM disease.

***Ascochyta* blight:** The same 60 lines tested for BGM were also screened for AB resistance under controlled environment. Seedlings were raised in sand-vermiculate mixture (4:1) for 12 days in greenhouse and transferred to controlled environment at 20°C and 100% RH. Seedlings were allowed to acclimatize for 24 h and then inoculated with *A. rabiei* conidial suspension of 5×10^4 conidia ml^{-1}. Disease severity was measured on a 1–9 rating scale at regular intervals up to 14 DAI. The experiment was conducted in three replications with eight plants in each replication. Among 60 lines evaluated for AB resistance, 13 had score of <3.0 rating and were identified as resistant, while 19 liens were identified as moderately resistant (3.1–5.0 rating).

Wilt: The above 60 breeding lines were also evaluated in wilt sick plot for identification of wilt resistance. Each line was planted in one-row of 4 m with two replications. Susceptible cultivars ICC 4951 (early wilter) and ICC 5003 (late wilter) had 100% wilt in both the replications.

Of the 60 entries, four entries ICCVs 93505, 93705, 95702 and 96853 had <10% wilt and were identified as resistant cultivars. The remaining 56 entries were susceptible with wilt incidence ranging from 11 to 100 %.

Suresh Pande and PM Gaur

Evaluation of diverse breeding populations to *fusarium* wilt

In collaboration with breeders at ICRISAT-Patancheru, four F_2 populations, 13 F_3 populations, 112 trial entries and 114 crossing-block entries were evaluated for wilt resistance in wilt-sick plot. Test entries also included lines from preliminary yield trial (PYT)-*desi* (21 entries), PYT-*kabuli* (24 entries), advanced yield trial (AYT)-*desi* (49 entries) and AYT-*kabuli* (18 entries). Three released *desi* cultivars ICC 37, JG 1 and Annegiri were used as controls in PYT and AYT *desi* trials; and two *kabuli* cultivars Vihar and KAK 2 as controls in PYT and AYT *kabuli* trials. Wilt-susceptible cultivar ICC 4951 after every three test rows and wilt resistant cultivar ICC 11322 after every 12 rows (ie, after every 9 test rows) were planted along with test material for proper comparison. FOC propagules were monitored every year before and after planting of the crop, and threshold levels of the pathogen was maintained by incorporating chopped wilted plants every year. Data on number of wilted plants were recorded at seedling, pod filling and maturity stages of the crop. Lines showing <10% wilt were considered as resistant and advanced for further evaluation. Wilt incidence in susceptible control, ICC 4951 was 100% within 30 days after sowing while it was <5% in resistant ICC 11322 at harvest across the field. Individual healthy plants were selected from F_2 and F_3 populations to advance the single plant progenies. Two entries (ICCX 970047-BP-BP-P49-BP-BP and ICCX 970047-BP-BP-P68-BP-BP) in PYT-*desi* trial; and four entries (ICCX 980061- F4- P22-BP, ICCX 980068-F4-P10-BP, ICCX 980068-F4-P13-BP and ICCX 980074-F4-P23-BP) in PYT-*kabuli*, had <10% wilt incidence. AYT-*desi*, ICCX-970047-BP-BP-P46-BP-BP was asymptomatic to wilt, while ICCX 970047-BP-BP-P72-BP-BP had 10% wilt incidence. One entry in AYT-*kabuli*, ICCX-970075-BP-BP-P16-BP-BP was asymptomatic to wilt, while ICCX-970075-BP-BP-P27-BP-BP had <10% wilt incidence.

S Pande and PM Gaur

Screening of advanced wilt promising lines for wilt and root rots: Advanced wilt promising selections were further evaluated for resistance to wilt and root rots in multiple disease sick plot (MDSP). MDSP at ICRISAT-Patancheru consisted of wilt (*Fusarium oxysporum* f.sp. *ciceri*) (dominant) followed by dry root rot (*Rhizoctonia bataticola*), collar rot (*Sclerotium rolfsii*), black root rot (*Fusarium solani*) and wet root rot (*Rhizoctonia solani*) pathogens. During this current season, 23 promising germplasm and breeding lines for wilt, four lines wilt plus dry root rot (DRR), 61 advanced promising breeding selections for wilt, 24 *desi* and 11 *kabuli* advanced promising selections from Kanpur for wilt and 18 wilt resistant germplasm lines were evaluated for resistance to wilt, DRR and collar rot in BIL 1. Wilt-susceptible early wilter JG 62 after every 4 test rows, wilt susceptible late wilter K 850 and wilt resistant WR 315 alternately were planted after every 12 test rows along with test material for proper comparison and also inoculum buildup/multiplication in this field. Inoculum levels of these pathogens were monitored before and after the chickpea crop every year. Observations on number of plants killed were recorded at seedling, flowering-pod filling and near maturity stages of the crop. Of the 23 advanced wilt promising germplasm and released lines, 11 lines (ICCs 338, 11223, 12243, 14344, 14391, 14434, 15949, 16124, IPC 98-51, KAK-2 and ICCX-850621-BH-BH-1H-BH-BH were found resistant to wilt, DRR and collar rot under field conditions. All the four wilt plus DRR promising lines tested, ICCs 14432, 14449, ICCX 850636-BH-26H-BH and ICCX 830235-BH-BH-5H were found resistant to wilt, DRR and collar rot diseases. Of the 61 advanced wilt promising breeding lines, 29 had combined resistance to wilt, DRR and collar rot under field conditions. Of the 24 *desi* and 11 *kabuli* selections from IIPR, Kanpur, 15 lines from *desi* and one *kabuli* line MPJGK 99-115 showed resistance to all the three diseases under field conditions. Of the 18 wilt resistant lines, 10 lines had resistance to wilt.

S Pande

ICAR-ICRISAT collaborative research on chickpea wilt and *Ascochyta* blight: Under ICRISAT-IIPR collaboration, lines from 12 trials, IVT 1 (LS) with 8 entries, AVT 1 (LS) 8 entries, AVT 2 (LS) 8 entries, IVT (RF) 11 entries, AVT 1 (RF) 10 entries, IVT 1 (bold) 11 entries, high input trial 9 entries, AVT 2 (*kabuli*) 6 entries, IVT (*kabuli*) 11 entries, AVT 1 (*desi*) 3 entries, IVT 1 (*desi*) 12 entries, and National Nursery (43 entries) were evaluated against wilt, following standard field evaluation techniques in wilt sick plot. NNAB with 49 entries was screened for *Ascochyta* blight resistance in controlled environment. Cultivar IDG 11 from IVT *desi* was found asymptomatic to wilt. Among the other lines, ALG 7 from AVT 1 (LS), A2LG 7 from AVT 2(LS), IRFG 10 from IVT (RF), ARFG 5, ARFG 8 from AVT 1 (RF), IBG 10 from IVT 1 (bold) were found resistant (<10%). In the National Nursery, resistant entries (<10% incidence) lines were, NNW 4, NNW 5, NNW 6, NNW 7, NNW 8, NNW 9, NNW 10, NNW 11, NNW 12, NNW 16, NNW 19, NNW 29 and NNW 33.

S Pande

Milestone: Diversified oil-type groundnut breeding lines of different duration with improved yield potential and resistance to biotic and abiotic stresses developed (2006)

Foliar diseases resistant breeding lines and varieties: Late leaf spot (LLS) and rust are the two most important foliar fungal diseases of groundnut in Asia. Together they cause up to 70% loss in pod yield besides adversely affecting the seed and fodder quality. Sixty-seven crosses were made (49 in the 2004/05 postrainy season and 18 in the 2005 rainy season) to generate populations for foliar disease resistance and high pod yield with desirable agronomic traits. The advanced breeding lines and different populations (from earlier crosses) were screened in the foliar disease screening nursery. The populations/progenies were scored for rust and LLS incidence on a scale of 1–9 (where 1 = no disease and 9 = >80% damaged foliage) at the time of harvest. In 418 F_2–F_7 foliar disease resistant breeding population grown in the 2004/05 postrainy season in a foliar disease nursery, 10 single plant and 394 bulk selections were made based on foliar disease resistance, pod yield and other desirable agronomic traits. The promising selections came from ICGV 92069 × ICGV 93184 and ICGV 96177 × ICGV 94088 crosses. Among 239 progeny bulks grown in an infector-row foliar disease screening nursery in the 2005 rainy season, 75 single plants and 266 bulk selections were made based on disease reaction, pod yield and other desirable agronomic traits. The promising selections, among others, came from ICGV 92069 × ICGV 93184 and ICGV 96246 × 92R/75 crosses.

In the 2004/05 postrainy season, 84 foliar disease resistant advanced breeding lines were evaluated in 4 replicated yield trials for foliar diseases and for desirable pod and seed characters in a disease-screening nursery. The severity of foliar diseases in the screening nursery was low. In the Elite (Spanish Bunch, SB) trial, 3 lines were significantly superior to the control ICGV 86590 (3.6 t ha^{-1} ± 0.22 t ha^{-1}). ICGV 02410 (4.7 t ha^{-1}) produced the highest yield in the trial. In the Elite (Virginia Bunch, VB) trial, ICGV 02446 produced significantly higher yield (4.9 t ha^{-1}) than the best control ICGS 76 (3.8 ± 0.21 t ha^{-1}). In the Preliminary (SB) trial, 14 lines produced significantly higher pod yields (3.8–4.6 t ha^{-1}) than the best control cultivar ICGS 44 (2.8 ± 0.34 t ha^{-1}). In the Preliminary (VB) trial, three lines (ICGV # 04093, 04087 and 04094) produced significantly higher pod yield (4.4, 4.2 and 4.1 t ha^{-1}, respectively) than the highest-yielding control ICGS 76 (3.5 ± 0.17 t ha^{-1}). In 2005 rainy season, 133 advanced breeding lines (in 6 different replicated yield trials) and 108 advanced breeding lines (in 2 augmented trials) were evaluated. The elite and advanced yield trials were evaluated under both irrigated and rainfed conditions. The preliminary trials were evaluated only under irrigated conditions. The infector-row system (for disease screening) was adopted only under irrigated conditions. The irrigated trials were artificially inoculated twice to create uniform disease (LLS and rust) pressure and were scored for disease reaction on a 1–9 scale on 72, 88 and 103 DAS. The rainfed trials had only natural disease infection and were not scored for disease reaction.

Under irrigated conditions, in Elite Trial (SB), three lines significantly outyielded (3.4–3.1 ± 0.26 t ha^{-1}) the highest-yielding control ICGS 44 (2.3 t ha^{-1}). In this trial, ICGV 02410 gave the highest pod yield of 3.4 t ha^{-1} with a disease score of 6.0 for LLS and 2 for rust compared with an 8.0 score for LLS and 7.5 score for rust in ICGS 44 at 103 DAS. Under rainfed conditions, four lines significantly outyielded (3.7–3.3 ± 0.14 t ha^{-1}) the highest-yielding control ICGV 86590 (2.8 t pods ha^{-1}). Of these, ICGV # 02410 and 02415 significantly outyielded the controls in both irrigated and rainfed trials. In Elite Trial (VB), evaluated under irrigated conditions, ICGV 02446 (3.6 ± 0.10 t ha^{-1}) gave significantly higher pod yield than the highest-yielding control ICGV 86699 (3.0 t ha^{-1}). ICGV 02446 scored 7 for LLS and 2 for rust compared with a 5.5 for LLS and 1.5 for rust of ICGV 86699 at 103 DAS. Six lines significantly outyielded (3.6–3.1 ± 0.15 t ha^{-1}) the highest-yielding control ICGV 86699 (2.4 t pods ha^{-1}) when the trial was grown under rainfed conditions. ICGV 02446 gave the highest pod yield under both rainfed and irrigated conditions. In Advanced Trial (SB), 14 lines produced significantly higher pod yield (3.7–2.9 ± 0.21 t ha^{-1}) than the highest-yielding control ICGV 86590 (2.0 t ha^{-1}). In this trial, the best yielding line ICGV 04093 had a score of 6.5 for LLS and 2 for rust compared with score 8.0 for LLS and 2 for rust in ICGV 86590. In the same trial under rainfed conditions, 14 lines significantly outyielded (4.0–3.4 ± 0.10 t ha^{-1}) the highest-yielding control ICGV 86590 (3.0 t pods ha^{-1}). In this trial, ICGV 04060 gave the highest pod yield (4.0 t ha^{-1}). Ten lines performed well under both irrigated and rainfed conditions.

In Preliminary Trial (SB), six lines significantly outyielded (3.3–2.8 ± 0.22 t ha^{-1}) the highest-yielding control ICGV 86590 (2.0 t ha^{-1}). The highest yielding test line ICGV 05097 scored a 5 for LLS and 2 for rust compared with 7.5 for LLS and 1.5 for rust in ICGV 86590.

In Augmented Trial-1, 4 lines out of the 72 (adjusted pod yield = 3.52–3.25 t ha^{-1}, rust score = 2.0, LLS score = 8.0–5.0) outyielded the highest-yielding control JL 24 (2.66 t ha^{-1}, 8.0, 8.5; LSI = 0.51) and the resistant control ICGV 86699 (1.80 t ha^{-1}, 2.0, 5.0; LSI = 0.51). The best entry in this trial was ICGX 000134 (3.5 t ha^{-1}; 2.0, 5.0). In Augmented Trial-2, no entry among the 28 test entries evaluated could outyield the best and the resistant controls. Nine foliar disease resistant lines were selected in the 2004/05 postrainy seasons for inclusion in international trials. The seed of these lines was multiplied in 2005 rainy season.

Two late leaf spot-resistant germplasm lines (ICG 11337 and ICG 13919) and a susceptible variety JL 24 were used as parents for studying the inheritance of components of late leaf spot resistance. Parents, F_1, F_2 and backcross generations were screened in the field and growth chambers for different components of resistance. Detailed observations, on incubation period, latent period, lesion number, % leaf area damage and lesion diameter were recorded by the pathology group on the detached leaves in the growth chambers. The field observations included % defoliation at 75, 90 and 105 days after planting and associated disease scores on a 1–9 scale. Data compilation is in progress.

***A. flavus*/aflatoxin resistant breeding lines and varieties:** Aflatoxin contamination of groundnut seeds caused by *Aspergillus flavus* poses serious health hazards to humans and livestock, and hampers international trade. Nine new crosses were made in the 2005 rainy season to develop aflatoxin-tolerant breeding lines. In the 2005/2006 postrainy season, 393 F_3–F_8 bulk and 196 single plant selections were planted for further selection.

Thirty–five advanced breeding lines were evaluated in 3 trials during the 2004/05 postrainy season in *A. flavus* sick plot to screen for tolerance to aflatoxin production. ICGV 02226 and

ICGV 02234 showed low aflatoxin content (2.89 and 4.21 $\mu g\ kg^{-1}$, respectively) compared to the zonal control Somnath (445.42 $\mu g\ kg^{-1}$). In the 2005 rainy season, 106 advanced breeding lines were evaluated in 5 replicated trials and 380 advanced breeding lines in 3 augmented trials. The elite and advanced trials were grown under both irrigated and rainfed conditions. The preliminary and augmented trials were conducted only under irrigation. All the replicated trials were also grown in an *A. flavus* sick plot to record observations on pre-harvest seed infection and aflatoxin production. The results on pre-harvest seed infection and aflatoxin contamination are awaited.

In Elite Trial, four lines (ICGV # 01099, 01073, 02194 and 01060) outyielded (3.3–2.8 ± 0.17 t ha^{-1}) the highest yielding control ICGS 11 (2.2 t ha^{-1}) and the resistant control J 11 (1.5 t ha^{-1}) under irrigated conditions. Under rainfed conditions, 9 lines gave significantly higher pod yield (2.4–1.7 ± 0.01 t ha^{-1}) than the highest-yielding control ICGS 11 (1.4 t ha^{-1}) and the resistant control J 11 (1.0 t ha^{-1}). ICGV 01060 performed the best under rainfed conditions. All the four lines performing well under irrigation also did well under rainfed conditions. In Advanced Trial (SB) under irrigated conditions, ICGV # 03311 and 03315 (3.0 ± 0.11 t ha^{-1}) outyielded the highest-yielding control ICGS 11 (2.2 t ha^{-1}) and resistant control J 11 (1.4 t ha^{-1}). The same two lines also outyielded (2.3 ± 0.06 t ha^{-1}) the highest-yielding control ICGS 11 (1.6 t ha^{-1}) and resistant control J 11 (1.1 t ha^{-1}) under rainfed conditions. In Advanced Trial (Dark Green Leaves) evaluated under irrigated conditions, ICGV 03398 c(2.9 ± 0.23 t ha^{-1}) outyielded the highest-yielding control ICGS 11 (1.8 t ha^{-1}) and the resistant control J 11 (1.2 t ha^{-1}). The same line also outyielded (2.0 ± 0.12 t ha^{-1}) the controls ICGS 11 (1.4 t ha^{-1}) and J 11 (1.0 t ha^{-1}) when evaluated under rainfed conditions. In Preliminary Trial-1, seven lines produced significantly higher pod yield (3.7–2.2 ± 0.13 t ha^{-1}) than the highest-yielding control ICGS 11 (1.8 t ha^{-1}) and the resistant control J 11 (1.5 t ha^{-1}) under irrigated conditions.

In Augmented Trial-1, 14 lines (adjusted pod yield = 3.96–2.83 t ha^{-1}) out of 65 test lines outyielded the highest-yielding control ICGS 76 (2.13 t ha^{-1}; LSI = 0.50). ICGX 000109 - treatment 60 (3.9 t ha^{-1}) was the best entry in the trial. In Augmented Trial-2, out of 120 test entries, 19 lines (adjusted pod yield = 2.63–1.76 t ha^{-1}) produced significantly higher yield than the highest-yielding control ICGS 76 (1.30 t ha^{-1}; LSI = 0.44). Three top entries in this trial were ICGX 000021 (2.63 t ha^{-1}), ICGX 000103 (2.5 t ha^{-1}) and ICGX 000021 (2.3 t ha^{-1}). In Augmented Trial-3, only ICGX 000109 (3.30 t ha^{-1}) outyielded the best control ICGS 76 (1.80 t ha^{-1}; LSI = 0.89).

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Drought resistant breeding lines and varieties: Drought reduces not only the pod and haulm yields but also affects the quality of the produce. It predisposes the crop to aflatoxin contamination by *A. flavus* infection. It can occur at any stage of the crop growth. Sixty crosses were made (49 in the 2004/05 postrainy season and 11 in the 2005 rainy season) between the breeding lines with high water use efficiency traits and new germplasm sources (ICG # 1834, 1891, 5100, 5341, 5465, 8230) to generate populations for selection under moisture stress.

In 710 F_2–F_7 drought tolerant breeding populations grown under imposed mid-season moisture stress (65–100 DAE), 1 single plant and 607 bulks were selected based on pod yield and other desirable agronomic traits. The promising selections came from (ICGV 96294 × ICGV 92004), (ICGV 87846 × ICGV 99240) and (ICGV 87846 × (ICGV 87290 × ICGV

87846) crosses. In 2005 rainy season, 223 single plants and 327 bulks based on pod yield and other desirable agronomic traits were selected from 467 F_2–F_7 drought-tolerant breeding populations. Crosses (ICGV 92069 × ICGV 93184) × (ICGS 44 × ICGV 76) and (ICGV 92069 × ICGV 93184) × ICGV 98300, among others, gave the most promising selections.

Among the 71 drought-tolerant advanced breeding lines evaluated in 5 replicated yield trials in the 2004/05 postrainy season under imposed mid-season moisture stress conditions and under full irrigated conditions, only one line ICGV 03115 in the advanced drought trial (VB) with pod yield of 2.9 t ha^{-1}, 76% shelling outturn and 39 g 100-seed weight outyielded ICGS 76 (2.2 ± 0.16 t ha^{-1}; 57 %; 40 g) under imposed stress. ICGV # 99029, 92267 and 99054 (3.1–3.3 t ha^{-1}) outperformed JL 24 (2.5 ± 0.27 t ha^{-1}) under fully irrigated conditions in the Elite on-farm trial.

In 2005 rainy season, 53-advanced breeding lines along with controls were evaluated in 4 replicated trials. The elite and advanced trials were grown under both irrigated and rainfed conditions whereas preliminary trials were grown only under rainfed conditions. Another 52 advanced breeding lines were evaluated in an augmented design under irrigated conditions only. In Elite Trial (SB) under irrigated conditions, eight lines produced significantly higher pod yield (5.1–4.2 ± 0.18 t ha^{-1}) than the highest-yielding control ICGV 00350 (3.2 t ha^{-1}). In this trial, the highest-yielding line ICGV 03063 gave 70% shelling outturn with 44 g of 100-seed weight compared with 68% shelling outturn and 35 g 100-seed weight of ICGV 00350. The same lines significantly outyielded (4.9–4.0 ± 0.10 t ha^{-1}) the highest yielding control ICGV 00350 (2.7 t ha^{-1}) when evaluated under rainfed conditions. In this trial, the highest-yielding line ICGV 03064 gave 60% shelling outturn with 38 g of 100-seed weight compared with 67% shelling outturn and 34 g 100-seed weight of ICGV 00350. ICGV # 03064, 03061, 03063 and 03056 were among the top five under both the growing conditions. In Preliminary Trial (SB), 10 lines significantly outyielded (5.1–4.2 ± 0.25 t ha^{-1}) the control ICGV 00350 (3.4 t ha^{-1}). In this trial, the highest yielding line ICGV 05153 gave 64% shelling outturn with 37 g 100-seed weight compared with 65% shelling outturn and 36 g 100-seed weight of ICGV 00350. In Augmented Trial-1, conducted with 48 test entries under irrigated conditions, 37 lines (adjusted pod yield = 5.83–3.63 t ha^{-1}) outyielded the control ICGV 00350 (3.40 t ha^{-1}; LSI = 0.13). The best entry in this trial was ICGX 000052 (5.8 t ha^{-1}). Twelve drought-tolerant lines were selected in the 2004/05 postrainy seasons for inclusion in international trials.

Three hundred twenty F_9 RILs and their parents (ICGV 86031 and TAG 24) were phenotyped twice in the pot culture for water-use-efficiency traits. Parental polymorphism is also being assessed with SSR markers in collaboration with GT-Biotechnology scientists. A diverse set of genotypes (189) has been selected to initiate association mapping. The set would be genotyped with SSR markers and phenotyped for different morphological traits of interest.

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High oil content breeding lines and varieties: Varieties adapted to local agroecological conditions are required for enhancing productivity. Lines with high oil content are required in countries where groundnut is mostly crushed for edible oil. In Elite Trial (High Oil Content), 12 lines gave significantly higher pod yield (4.9-4.1 ± 0.16 t ha^{-1}) than the highest-yielding control ICGV 86590 (3.7 t ha^{-1}) when evaluated under irrigated conditions. In this trial, ICGV 99033 gave the highest pod yield (4.9 t ha^{-1}) with 66% shelling outturn and 50 g of 100-seed weight compared with 69% shelling outturn and 40 g of 100-seed weight of control

ICGV 86590. The oil content in this trial ranged from 54.7 to 44.7% and the protein content from 26.9 to 18.4% in the 2004/2005 postrainy season. Eighteen lines had oil content ≥50%. The oil content in ICGV 86590 was 49.1%. Although ICGV 00017 had the highest oil content in the 2004/2005 postrainy season (54.7%), its yield was low in the 2005 rainy season (2.4 t ha^{-1}). Seven of the 12 significantly higher yielding lines had oil content between 52.5% and 50.1%. In evaluation under rainfed conditions, only 7 lines significantly outyielded (pod yield:-4.2–3.8 ± 0.15 t ha^{-1}) but 33 entries (49.3–55.5%) had higher oil content than the highest-yielding control ICGV 86590 (3.3 t ha^{-1}; 46.8%). ICGV 00434 gave the highest pod yield (4.2 t ha^{-1}) and ICGV 00351 had the maximum oil content (55.5%) in this trial. ICGV # 99017, 01273, and 01270 were among the top five under both growing conditions.

Medium-duration breeding lines and varieties: Varieties which take 110–120 days to mature at ICRISAT-Patancheru, fall in the medium-duration group. Seventeen crosses were made in the 2005 rainy season to generate new medium-duration populations for selection for high yield and desirable agronomical characteristics. In the 574 F_2–F_7 medium-duration breeding populations grown under high input conditions, 78 single plants and 642 bulks were selected based on high yield and other pod and seed characters. Among others, the most promising selections came from (ICGV 93023 × ICGV 92088) and (ICGV 93023 × ICGV 99160) crosses. These selections (572) were sown in the 2005 rainy season for further selection. Among these, 463 bulks and 293 single plants were selected based on high yield and other desirable agronomic traits. The most promising selections, among others, came from (TAG 24 × ICGV 98300), (JL 24 × ICGV 98300), (TAG 24 × ICGV 99032) and (TMV 2 × ICGV 98300) crosses. These selections (756) were sown in the 2005/2006 postrainy season for further evaluation and selection.

In the 2004/05 postrainy season, 128 medium-duration advanced breeding lines were evaluated in 5 replicated yield trials. In the Elite (SB) trial, three lines ICGV # 02323, 02322 and 03015 outyielded (5.6, 5.4 and 5.0 t ha^{-1}, respectively) the best control ICGV 86590 (3.8 ± 0.31 t ha^{-1}). In the Advanced (VB) trial, four lines ICGV # 03043, 03042, 03015 and 03037 produced significantly higher pod yield (5.5, 5.4, 5.2 and 5.1 t ha^{-1}, respectively) compared with ICGS 76 (3.7 ± 0.28 t ha^{-1}). In the Preliminary (SB) trial, two lines ICGV # 04112 and 04115 produced significantly higher pod yield (5.8 and 5.7 ± 0.42 t ha^{-1}) than the highest-yielding control ICGV 86590 (4.26 t ha^{-1}). In the Preliminary (VB) trial, seven lines produced significantly higher pod yield (3.9–4.9 ± 0.26 t ha^{-1}) than the highest-yielding control ICGV 86325 (3.1 t ha^{-1}). In the 2005 rainy season, 193 advanced breeding lines in 6 replicated trials and 76 lines in 2 augmented trials were evaluated for pod yield and other agronomic traits. Elite and advanced trials were grown under both irrigated and rainfed conditions, while all other trials were grown under irrigated conditions only.

In Elite Trial (SB), all the 16 lines produced significantly higher pod yield (4.8–3.2 ± 0.20 t ha^{-1}) than the highest-yielding control ICGS 44 (2.4 t ha^{-1}) under irrigated conditions. In this trial, ICGV 03043 gave the highest pod yield (4.8 t ha^{-1}) with 65% shelling outturn and 36 g of 100-seed weight compared with 69% shelling outturn and 36 g of 100- seed weight of control ICGS 44. In the same trial conducted under rainfed conditions, 15 lines significantly outyielded (3.8–2.5 ± 0.18 t ha^{-1}) the highest-yielding control ICGS 44 (1.9 t ha^{-1}). In this trial, ICGV 03016 produced the highest pod yield (3.8 t ha^{-1}). ICGV # 03043, 03014, 03042 and 03016 were common in the top five under both the growing conditions. In Advanced Trial (SB), evaluated under irrigated conditions, 14 lines significantly outyielded (5.2–3.4 ± 0.18 t ha^{-1}) the highest-yielding control ICGS 44 (2.6 t ha^{-1}). In this trial, ICGV 04122 gave the highest pod yield (5.2 t ha^{-1}) with 64% shelling outturn and 47 g of 100-seed weight compared with 69% shelling outturn and 34 g of 100-seed weight of ICGS 44. In the same trial under rainfed conditions, 15 lines significantly outyielded (4.5–2.2 ± 0.18 t ha^{-1}) the highest-yielding control ICGS 11 (1.6 t pods ha^{-1}). ICGV 04122 gave the highest pod yield (4.5 t ha^{-1}) in rainfed trial also. ICGV # 04122, 04148, 04112 and 04126 were common in the top five under both the growing conditions.

In Advanced Trial (VB), evaluated under irrigated conditions, 12 lines produced significantly higher pod yield (4.9–3.6 ± 0.19 t ha^{-1}) than the highest-yielding control ICGV 86325 (2.6 t ha^{-1}). In this trial ICGV 04149 gave the highest pod yield (4.9 t ha^{-1}) with 75% shelling outturn and 49 g of 100-seed weight compared with 75% shelling outturn and 45 g of 100-seed weight of ICGV 86325. When this trial was evaluated under rainfed conditions, the same 12 lines significantly outyielded (4.6–3.1 ± 0.13 t ha^{-1}) the highest-yielding control ICGV 86325 (2.5 t ha^{-1}). ICGV 04141 gave the highest pod yield (4.6 t ha^{-1}) in rainfed trial. ICGV # 04141, 04149, 04142 and 03035 were common in the top five under both the growing conditions.

In Preliminary Trial (SB), evaluated under irrigated conditions, 32 lines produced significantly higher pod yield (4.9–2.9 ± 0.20 t ha^{-1}) than the highest yielding control ICGV 95070 (2.8 t ha^{-1}). In this trial, ICGV 05034 gave the highest pod yield (4.9 t ha^{-1}) with 66% shelling outturn and 44 g of 100-seed weight compared with 67% shelling outturn and 37 g of 100-seed weight of ICGV 95070. In Preliminary Trial (VB), 11 lines significantly outyielded (4.7–3.3 ± 0.19 t ha^{-1}) the best control ICGS 76 (2.8 t ha^{-1}). In this trial, ICGV 05063 gave the highest pod yield (4.8 t ha^{-1}) with 72% shelling outturn and 64 g of 100-seed weight compared with 68% shelling outturn and 35 g of 100-seed weight of ICGS 76.

In Augmented Trial-1, 15 of the 44 lines significantly outyielded (adjusted pod yield = 5.05–3.58 t ha^{-1}) the best control ICGS 44 (2.94 t ha^{-1}; LSI = 0.59). In this trial, ICGX 000127 (5.1 t ha^{-1}) and ICGX 010029 (4.8 t ha^{-1}) were the best performers. In Augmented Trial-2, among the 24 test entries, 7 lines significantly outyielded (adjusted pod yield = 3.55–2.25 t ha^{-1}) the best control ICGV 86325 (1.76 t ha^{-1}; LSI = 0.43). Among the test lines, ICGX 000032 (3.6 t ha^{-1}) and ICGX 000124 (2.9 t ha^{-1}) were top ranking two lines. Eight medium duration lines were selected in the 2004/05 postrainy seasons for inclusion in international trials. The seed of these lines has been multiplied in the 2005 rainy season.

Confectionery type breeding lines and varieties: The food use of groundnut has been increasing over the years. Seed size, shape, uniformity and color assume importance when groundnut is used for direct consumption. Fifty eight new crosses (33 in the 2004/05 postrainy season and 25 in the 2005 rainy season) were made to generate populations for selection for confectionery traits, high yield and other desirable characters. ICGV # 95179, 00451, 00440, 94215 and ICG # 6767, 6670 and 1651 were the new parents used to develop new breeding populations.

Of the 665 F_2–F_7 confectionery breeding populations grown under high input conditions, 25 single plants and 279 bulks were selected for confectionery traits and high pod yield. The promising selections came from (ICGV 98408 × ICGV 88386) and (ICGV 96236 × ICGV 88386) crosses. These 304 selections (269 segregating populations and 35 in yield trials) were sown in the 2005 rainy season under high input conditions. In the 269 F_2–F_7 confectionery breeding populations grown under high input conditions in the 2005 rainy season, we made 261 bulk selections based on superior agronomic and confectionery traits.

The promising selections, among others, came from ICGV 96016 × Sunoleic and ICGV 99085 × ICGV 86564 crosses.

Thirty-five advanced breeding lines were evaluated in the 2004/05 postrainy season in 3 replicated trials. Five lines (ICGV # 02242, 02234, 02227, 02233 and 02226) in the Elite (SB) trial (3.3–3.9 ± 0.27 t ha^{-1}) and seven lines (3.0–4.7 ± 0.32 t ha^{-1}) in the preliminary yield (SB) trial significantly outyielded the control Somnath (2.2 t ha^{-1}). Fifty-one confectionery advanced breeding lines (including controls) were evaluated in three replicated yield trials under high input conditions during the 2005 rainy season. In Preliminary Trial (SB), ICGV 05174 (pod yield = 3.5 ± 0.20 t ha^{-1}; 100-seed weight = 58 g) gave significantly higher pod yield than the highest-yielding control ICGV 97045 (2.8 t ha^{-1}; 57 g). In Preliminary Trial (VB), ICGV 05200 (3.8 ± 0.15 t ha^{-1}; 69 g) produced significantly higher pod yield than the highest-yielding control ICGV 98432 (3.2 t ha^{-1}; 67 g). Fourteen confectionery elite breeding lines were selected in the 2004/05 postrainy season for inclusion in international trials. Their seed has been multiplied in the 2005 rainy season.

Short-duration breeding lines and varieties: Short-duration (<100 days) varieties are needed in areas where the growing season is short and the crop suffers from end-of-season drought. Such varieties are also suitable in multiple cropping systems, and rice-fallow conditions to utilize residual moisture. Five new crosses were made in the 2005 rainy season to generate breeding populations for selection for short-duration, high yield and other desirable agronomic characteristics. Selections (648 bulks and 520 single plants) made during the 2004/2005 postrainy season were sown during the 2005/2006 postrainy season for further selection.

We evaluated 114 lines (including controls) in 5 replicated trials and 360 lines in 3 augmented trials for yield and other agronomic traits under irrigated conditions in the 2005 rainy season. The elite and advanced yield trials were also evaluated under rainfed conditions. All the trials conducted under both irrigated and rainfed conditions were harvested when the crop accumulated 1470 °Cd equivalent to 90 days after sowing (DAS) at Patancheru. Under irrigation, in Elite Trial (SB), 12 lines significantly outyielded (pod yield = 2.3–1.8 ± 0.12 t ha^{-1}) the control JL 24 (pod yield = 1.4 t ha^{-1}; shelling outturn = 62%; 100-seed weight = 29 g). ICGV 02099 (2.3 t ha^{-1}; 66%; 37g) was the best entry among the 12 lines. In the same trial under rainfed conditions, 10 lines outyielded (1.8–1.4 ± 0.09 t ha^{-1}) the highest yielding control Chico (1.1 t ha^{-1}). The best entry in the trial was ICGV 02099 (1.8 t ha^{-1}). ICGV # 02099, 02022, 02144 and 02126 were among the top five under both the growing conditions. In irrigated Elite Trial (VB), 3 lines (ICGV # 98294, 98292 and 98293) gave significantly higher pod yield (2.9-2.6 ± 0.10 t ha^{-1}) than the best control ICGS 76 (2.1 t ha^{-1}; 66%; 42 g). When the same entries were evaluated under rainfed conditions, ICGV # 98292 (2.7 ± 0.09 t ha^{-1}), 98293 (2.5 ± 0.09 t ha^{-1}) and 98287 (1.9 ± 0.09 t ha^{-1}), outyielded the control ICGS 76 (1.5 t ha^{-1}). ICGV # 98292 and 98293 were common in the top three under both the growing conditions. In Elite Trial (large seeds) evaluated under irrigated conditions, none of the test entries significantly outyielded the best control ICGS 44 (2.0 t ha^{-1}; 64%; 40 g) for pod yield. However, ICGV # 01232 (45 g), 02131 (43 g), 01234 (43 g) and 99258 (42 g) recorded a higher 100-seed weight than ICGS 44. In the same trial under rainfed conditions, five lines outyielded (2.2–1.9 ± 0.16 t ha^{-1}) the highest-yielding control Somnath (1.4 t ha^{-1}). Only ICGV 01234 performed well under both the growing conditions.

In Advanced Trial (SB), 10 lines produced significantly higher pod yield (2.5–1.9 ± 0.09 t ha^{-1}) than the highest yielding control JL 24 (1.6 t ha^{-1}; 63% shelling outturn; 33 g 100 seed weight) and Chico (1.5 t ha^{-1}; 58 %; 31.0 g). The best entry was ICGV 03206 (2.5 t ha^{-1}; 71%; 37 g). When the entries were evaluated under rainfed conditions, 12 lines outyielded (1.9–1.5 ± 0.09 t ha^{-1}) the control Chico (1.2 t ha^{-1}). The best test line was ICGV 03207 (1.9 t ha^{-1}). ICGV # 03208 and 03210 were common in the top five under both the growing conditions. In Preliminary Trial, 10 lines significantly outyielded (2.0–1.6 ± 0.10 t ha^{-1}) the highest-yielding control Chico (1.3 t ha^{-1}; 69%; 23g) under irrigated conditions. The best entry in the trial was ICGV 04022 (2.0 t ha^{-1}; 64%; 36 g).

A special trial was formulated to compare the performance of top-yielding short-duration varieties developed over the years at ICRISAT Center. The trial consisted of 44 test entries and was grown under irrigated conditions only. It was harvested 90 DAS. Thirty-four entries gave significantly higher pod yield than the Indian national control JL 24 (0.86 ± 0.15 t ha^{-1}). Among the test lines only ICGV 99195 (2.4 t ha^{-1}; 64%; 34 g) gave significantly higher yield than ICGV 91114 (1.8 t ha^{-1}; 67%; 33 g), which is becoming popular among the farmers in India.

In Augmented Trial-1, 83 test lines (adjusted pod yield = 2.88–1.60 t ha^{-1}) out of 110 significantly outyielded the control Robut 33-1 (1.26 t ha^{-1}, LSI = 0.33). The top three entries in this trial were ICGX 000096 (2.9 t ha^{-1}), ICGX 000096 (2.8 t ha^{-1}) and ICGX 000014 (2.6 t ha^{-1}). In Augmented Trial-2, 59 out of 95 test lines (adjusted pod yield = 2.70–1.43 t ha^{-1}) significantly outyielded the control Robut 33-1 (1.02 t ha^{-1}, LSI= 0.39). The best entry in this trial was ICGX 000101 (2.7 t ha^{-1}). In Augmented Trial-3, we evaluated 140 test lines. Of these, 18 produced significantly higher yield (adjusted pod yield = 2.79–2.09 t ha^{-1}) than the highest-yielding control Robut 33-1 (1.57 t ha^{-1}, LSI = 0.51). ICGX 000003 (2.8 t ha^{-1}) and ICGX 000014 (2.7 t ha^{-1}) were the top two entries in this trial.

Adaptation to Anantapur (India) conditions: Breeding lines, specifically bred for Anantapur (Andhra Pradesh, India) conditions were evaluated in two different trials. In Trial-1, 43 test entries selected from previous trials and 6 controls were evaluated in a 7 × 7 lattice design, both under irrigated and rainfed conditions at ICRISAT-Patancheru. In this trial, six entries (3.1–2.9 ± 0.0.16 t ha^{-1}) outyielded the best control TAG 24 (2.4 t ha^{-1}) under irrigated conditions. Under rainfed conditions also, six lines produced significantly higher pod yield (2.6–2.3 ± 0.13 t ha^{-1}) than the highest-yielding control TAG 24 (2.0 t ha^{-1}). Three lines, ICGX 020006-treatment 4, ICGX 020006 and ICGX 020021, were common in the top five under both the growing conditions. In Trial-2, 36 test lines along with 9 controls were evaluated in an augmented design under irrigated conditions. In this trial, nine lines (adjusted pod yield = 4.19–2.89 t ha^{-1}) outyielded the best control TAG 24 (2.36 t ha^{-1}, LSI= 0.41). The top entry in this trial was ICGV 87846 followed by ICGV 99029 (4.06 t ha^{-1}).

SN Nigam and R Aruna

Aflatoxin resistance in germplasm and drought-tolerant breeding lines

Aflatoxins are toxic, immuno-suppressive, mutagenic carcinogens and can cause various health effects including liver and other cancers in humans and animals. This problem can be resolved by using cultivars that resist the toxin-producing fungus (*Aspergillus flavus*) infection and aflatoxin production.

One hundred-thirteen advanced breeding lines were evaluated during 2004–05 postrainy season for *A. flavus* seed infection and aflatoxin contamination. These lines comprised of six trials based on category of the materials and tested in three replications. The materials were screened in the sick plot. *A. flavus* inoculum was applied four times during the crop growth period, and end-of-season drought was imposed to facilitate the seed infection. At harvest, seed samples from each plot were collected separately; and analyzed for *A. flavus* seed infection using blotter plate method, and aflatoxin contamination by indirect competitive ELISA method. *A. flavus* infection ranged from 2.7% to 69.3% and aflatoxin contamination in these lines was 1.6 to 4849 μg kg^{-1}. Six of the 24 resistant lines (ICGV 01002, 01094, 01096, 01156, 02191 and 02194) showed <5 μg kg^{-1} aflatoxin. All the eight advanced dark green leaf lines were susceptible (>100 μg kg^{-1}) to aflatoxin contamination. Among 21 advanced Spanish bunch varieties, only two lines (ICGV 03319 and 03341), and one (ICGV 03389) out of 10 advanced Virginia bunch varieties showed <5 μg kg^{-1} aflatoxin.

One hundred-thirty advanced breeding lines (in six trials with four replications) were screened in the sick plot for resistance to *Aspergillus flavus* infection and aflatoxin contamination under artificially inoculated conditions during the 2005 rainy season. After harvest, the produce was dried under natural sunlight with the pods stripped manually. The samples are being processed for *A. flavus* infection and aflatoxin contamination.

Farid Waliyar and SN Nigam

Milestone: Diversified groundnut breeding lines with improved confectionery traits developed

Advanced confectionery groundnut lines assessed for mycotoxins: Aflatoxin resistance in confectionery groundnut is essential because the groundnuts are consumed directly as food. Also, aflatoxin resistance in confectionery groundnut is crucial from international trade point of view.

Twenty-six confectionery groundnut lines (Spanish and Virginia type) comprising two trials in three replications were screened during 2004–05 postrainy season in sick plot under artificially inoculated conditions. The inoculum multiplied on sorghum/maize/pearl millet seed was applied four times during the crop growth period. The predisposing end-of-season (30 days before harvest) drought was imposed to facilitate the fungal infection. Harvesting was done by lifting the plants and the produce was dried in sunlight before the kernels were shelled. *A. flavus* infection was determined using blotter plate method, and aflatoxin content was estimated by ELISA method. In Spanish bunch confectionery types, *A. flavus* infection ranged from 4 to 69% and aflatoxin content ranged from 2–1172 μg kg^{-1}. Three (ICGV 02226, 02229 and 02234) of the 13 elite Spanish bunch confectionery groundnut lines were resistant (<5 μg kg^{-1}). In Virginia bunch type, *A. flavus* infection and aflatoxin contamination ranged from 11 to 37% and 88 to 2103 μg kg^{-1}, respectively.

Farid Waliyar and SN Nigam

Activity 1.2.3: Develop regionally adapted parental lines of potential hybrids in sorghum, pearl millet and pigeonpea

Milestone: High-yielding male-sterile lines of sorghum with temperature insensitivity and resistance to grain mold and shoot fly developed (2007)

Race-specific and trait-based B-lines: In a program to develop high-yielding race-specific and grain mold and shoot fly resistant A/B-lines, several F_4 progenies with maintainer reaction were used for conversion into A-lines. These are in various stages of conversion.

New B–lines trial: The lines in advanced stages of conversion on A_1 and A_2 CMS systems (25 B on A_1 CMS + 2 controls; 22 B on A_2 CMS + 2 controls) were evaluated in a preliminary B-lines trial during the 2005 rainy season. The results revealed superiority of some of the A_1-based B-lines such as SP 2315 (3.9 t ha^{-1}) SP 2317 (3.8 t ha^{-1}) SP 2313 (3.7 t ha^{-1}) SP 2359 (3.7 t ha^{-1}) and SP 2305 (3.6 t ha^{-1}) over the control ICSB 52 (2.4 t ha^{-1}) with comparable maturity. These were numerically superior to another control 296B (2.8 t ha^{-1}) for grain yield. Similarly, several A_2-based B-lines such as SP 2785 (3.6 t ha^{-1}) SP 2895 (3.5 t ha^{-1}) SP 2859 (3.5 t ha^{-1}) SP 2853 (3.5 t ha^{-1}) SP 2779 (3.4t ha^{-1}) SP 2873 (3.3 t ha^{-1}) and SP 2783 (3.2 t ha^{-1}) were superior over the control ICSB 52 (2.0 tha^{-1}) with comparable maturity. These were also numerically superior to another control 296B (3.0 t ha^{-1}) for grain yield. Though none of the A_1-based B-lines were superior to the control ICSB 52 for grain size (3.1 g 100^{-1} grains), 15 B-lines with a grain size ranging from 2.4 to 2.7 g 100^{-1} grains were significantly superior to 296B (2.0 g 100^{-1} grains). Amongst the A_2-based B-lines, SP 2779 (3.0 g 100^{-1} grains) was significantly superior to the controls, ICSB 52 (2.7 g 100^{-1} grains) and 296B (2.1 g 100^{-1} grains) for grain size. Five B-lines (2.4 to 2.9 g 100^{-1} grains) were significantly superior to 296 B for grain size.

Elite A_1-system B-lines Trial (EBT): An EBT consisting of 14 high-yielding B-lines selected from the results of Advanced B-line Trial (conducted during the 2004 rainy season) was conducted during the 2005 rainy season. One of the test B-lines, ICSB 25005 (5.4 t ha^{-1}) was found to be exceptionally superior to the control 296B (2.1 t ha^{-1}) for grain yield with comparable maturity. ICSB 25003 (3.4 t ha^{-1}) and ICSB 25002 (3.1 t ha^{-1}) were other B-lines, which outyielded the control 296B (2.1 t ha^{-1}). Four B-lines ICSB 25001 (2.8 g 100^{-1} grains), ICSB 25005 (2.5 g 100^{-1} grains), ICSB 25002 (2.4 g 100^{-1} grains) and ICSB 25003 (2.3 g 100^{-1} grains) were significantly superior to 296B (2.0 g 100^{-1} grains) for grain size.

Stability of male-sterile lines: Hybrid seed production with CMS lines is usually undertaken in August-November sowings. As a result, the flowering in the seed production plots coincides with temperatures as low as 10°C during December–January and maximum temperatures as high as 45°C during March–April. It is known that female sterility (due to stigma non-receptivity or inadequate pollen tube germination and its growth) leads to poor seed set at low temperatures. On the other hand, male sterility of seed parents often breaks down at high temperatures. Under such circumstances, the quality of hybrid seed deteriorates with large number of selfed seeds leading to lower commercial yields of hybrids. Therefore, information on the stability of male-sterility at high temperatures in the male-sterile lines is useful.

All the designated A-, B- and R-lines, developed at ICRISAT-Patancheru, are being characterized as per Distinctiveness, Uniformity and Stability (DUS) test guidelines in phases. A total of 277 A-lines that were characterized in the first phase were evaluated for stability of male sterility during 2005 summer season along with the controls 296A and 27A. The maximum temperature during the flowering period ranged from 40 to 43°C. The stability of male-sterility was assessed using the criteria of seed set % under bagging. The results indicated that while most of the A-lines (204) showed no seed set, three A-lines (ICSB 40, ICSB 641 and ICSB 91001) showed 2 to 5% seed set and the remaining 70 lines showed above 5% seed set under bagging. The results indicate that male-sterility is a threshold trait requiring specific environment (ie, particular temperature regime) for complete expression. Also, expression of male-sterility depends on nuclear genetic background of A-lines. The lines which are sensitive to high temperature for the expression of male-sterility should be avoided for seed production during summer season in locations with high air temperature. All the designated A-lines that are being characterized in the second phase will also be evaluated for stability of male-sterility under high temperature during 2006 summer season.

BVS Reddy and S Ramesh

Milestone: High-yielding and DM resistant male-sterile lines of pearl millet developed and characterized (2007)

Seed parents development

Fully converted 5–9 A-lines in different cytoplasmic backgrounds and their counterpart B-lines selected for high yield potential, agronomic eliteness and high levels of DM resistance are designated every year for dissemination. Such a flow of A-/B-lines has been possible due to continuous addition of B-lines in the conversion program.

The 2005-series seed parents: Nine 2005-series A-lines having diverse nuclear and two cytoplasmic backgrounds (3 A_1 cytoplasms and 6 A_4 cytoplasms) were designated for distribution worldwide. All the lines were d_2 dwarf with a wide range of maturity (39–51 days to 50% flowering), panicle length (11–35 cm), panicle thickness (20–32 mm diameter), tillering ability (1–4 tiller plant^{-1}) and seed size (5.5–12 g 1000^{-1} seed mass). Important among these were ICMA 05555, a large-seeded (12 g 1000^{-1} seed mass compared to 10.9 g of 843B) A_1 CMS system male-sterile line, having thick-panicles (32 mm diameter compared to 23 mm of 843B), with maturity duration similar to that of 81B (50 days to 50% flower), and producing highest grain yield, 77% more than the control 81B (1355 kg ha^{-1}); ICMA 05111 and ICMA 05999 (both A_4 CMS) were high-yielding (16–51% more grain yield than 81B), high-tillering (about 4 tillers plant^{-1}, similar to 843B); ICMA 05888 (A_4) with long panicles (35 cm compared to 22 cm of 81B) producing 34% more yield than 81B; ICMA 05777 was early-maturing with 39 days to 50% flower (similar to 843B); ICMA 05222 and ICMA 05333 (both A_4) were high-yielding (about 25% more gain yield than 81B) and had thick panicles (30 mm diameter).

Eight of these male-sterile were highly resistant to DM with 0–10% incidence to at least three of the five diverse pathotypes (Jodhpur, Jalna, Jamnagar, Durgapura and Patancheru) under high disease pressure in the greenhouse condition (92–100% DM incidence in susceptible controls). Of these, ICMB 05333 was resistant to all five pathotypes, two to four pathotypes, five to three pathotypes, and one to two pathotypes.

A-/B-lines under backcrossing: Backcross conversion of 87 B-lines into 98 A-lines with different cytoplasmic backgrounds (29 A_1, 67 A_4 and 2 A_5) reached the advanced stage (BC_5 and beyond) with 32 candidate A/B pairs identified for 2006-series A-lines. We also evaluated 228 B-lines in early generation backcrossing and selected 168 (88 A_1, 106 A_4 and 61 A_5) for advancing to BC_2–BC_3. First backcross was made with 127 B-lines, of which 61 B-lines and their backcross progenies (34 A_1, 26 A_4 and 36 A_5) were selected for further backcrossing. Conversion of 34 elite maintainers of A_1 CMS system into A_4-system A-lines was completed and third backcross of these maintainers was completed to convert them into A_5-system A-lines. Above-mentioned crosses clearly indicate gradual shift from A_1 system A-lines to A_4 and A_5 system A-lines.

Marker-assisted backcross breeding to pyramid DM resistance genes in ICMA 89111: Attempts to transfer DM resistant QTL from 863B into ICMB 89111, a high-tillering male-sterile line with moderate DM resistance have been underway to further improve its DM resistance. In a continuing effort to pyramid DM resistance genes in ICMB 89111, 257 BC_5F_3 progenies (mostly d_2 dwarf) were evaluated, of which 97 progenies were selected based on visual assessment for phenotypic resemblance to ICMB 89111. About 22% of the 97 selected progenies flowered in 46–50 days, while 73% flowered in 51–55 days (ICMB 89111-P_2 flowered in 52 days and ICMB 89111 flowered in 45 days).

Screening seed parents for multiple disease resistance: Six A/B pairs, earlier bred (between 1988 and 1993) for both DM and smut resistance, were field evaluated for smut incidence under high disease pressure in the artificially inoculated smut nursery at Patancheru (90–100% smut in controls 81A/B and 841A/B). Three of these were highly resistant to smut (<5% severity) and one of these (ICMA 92777) was also highly resistant to DM with <5% incidence against Durgapura and Patancheru pathotypes under high disease pressure in the greenhouse condition (63–96% DM incidence in susceptible controls). Others had smut incidence in the range of 27–40%. It is interesting that a selection within ICMA 92777 made by a private seed company is the seed parent of one of the most popular hybrids in India.

Characterization of hybrid parents for performance *per se*

The evaluation of grain yield and yield contributing traits of counterpart B-lines of most of the designated A-lines developed up to 2001 had been completed. Recently designated B-lines, especially those developed during 2002–04 and other lines missing in the earlier evaluations, were grouped into d_2 dwarf and medium height groups and evaluation was done in replicated trials during the rainy season 2004 and summer season 2005.

D_2 dwarf B-lines: Average grain yield of the trial having 26 d_2 dwarf B-lines (counterparts of the designated A-lines) over two seasons ranged from 1441 to 2787 kg ha^{-1} with the yield level during summer being 63% more than the rainy season (1649 kg ha^{-1}). The correlation of grain yield between two seasons was positive and significant (r = 0.60**), indicating that rankings of the B-line followed broadly similar pattern in both the seasons. Three B-lines (43 days to 50% flower) were early-maturing, similar to that of 843B (41 days to 50% flower) and produced 18–47% of higher grain yield than 843B (1441 kg ha^{-1}). All the 18 B-lines yielding 15–58% more grain than the control 81B across two seasons were also significantly superior either in one or both the seasons, and 15 of them flowered earlier than 81B (56 days 50% flower). Of these high-yielding 18 B-lines, 13 had larger grain size >10.0 g 1000^{-1} seed mass compared to 81B (7.0 g 1000^{-1} seed mass) and 3 had even larger grain size (12.3–14.0 g 1000^{-1} seed mass) than 843B (11.7 g 1000^{-1} seed mass).

Medium height B-lines: Of the 18 medium-height B-lines (counterparts of the designated A-lines) evaluated for two seasons for field performance, 8 lines had 2721–3163 kg ha^{-1} of mean grain yield (2636 kg ha^{-1} for ICMB 88004 used as control) and flowered in 47–56 days (45 days for ICMB 88004). From amongst 8 high-yielding lines, 6 had larger grain size (11.6–14.3 g 1000^{-1} seed mass) than ICMB 88004 (11.4 g 1000^{-1} seed mass).

Characterization of hybrid parents for DUS traits: In order to document the designated hybrid parents to prevent IPR infringement, designated A-lines and some of the important and widely distributed R-lines were characterized for DUS traits. Characterization of 99 A/B pairs (designated until 2004 series) for 26 DUS traits (that included 17 essential traits) was completed for two seasons. Additional 9 A/B pairs of 2005-series were also characterized during the 2005 rainy season. Characterization of 43 selected entries from ICRISAT pollinator collection (IPC lines) for the same number of traits was completed for two seasons. Additional, 41 IPC lines were also characterized during the 2005 rainy season. Characterization data, along with details will be published in the International Sorghum and Millet Newsletter, and also placed on the ICRISAT webpage.

Agronomic performance of F_1 seed parents: An earlier study had shown that a male-sterile F_1 (ICMA 95111 × ICMB 97444) derived from two morphologically similar but genetically diverse seed parents (DM resistant versions of 843B) had 22% higher grain yield than its high-yielding parental line. To assess the combining ability of male-sterile F_1 in comparison with the parental male sterile lines, 4 three-way hybrids made on a male-sterile F_1 with 4 restorers, their 8 single-cross hybrids made on the two parental male-sterile lines, and 4 single-cross hybrids made on 843A (control) were evaluated. Three-way hybrids either had practically similar or slightly lower grain yield levels than the respective single-cross hybrids. Phenotypically, three-way hybrids were as good as single-crosses as indicated by the similar standard deviation values for days to flowering, plant height and panicle parameters. This is due to the morphologically similar parents of male-sterile F_1 and to some extent, masking effect of male parents. Thus, the male-sterile F_1s besides their higher seed yield in the hybrid seed production plots, provide a good avenue in the production of three-way hybrids that may have grain yield comparable to single-cross hybrids, and a mechanism for more effective resistance gene deployment.

KN Rai, VN Kulkarni and RP Thakur

Downy mildew resistance in B-lines: Twenty-four 2005 series B-lines were evaluated against five pathotypes – Jodhpur (Sg 139), Jalna (Sg 150), Jamnagar (Sg 200), Durgapura (Sg 212) and Patancheru (Sg 409) in a completely randomized design with two replications in greenhouse. Of the 24 lines, 16, 10, 14, 15 and 4 were resistant (≤10% incidence) to Jodhpur, Jalna, Jamnagar, Durgapura and Patancheru pathotypes, respectively relative to 96–100% incidence in the susceptible control 7042S. Four B-lines were resistant (≤10% incidence) to all five pathotypes, 2 lines to four pathotypes, 7 lines to three pathotypes and 3 lines to two pathotypes. The remaining 6 lines had differential disease incidence to all five pathotypes. The 4 B-lines that were resistant to all five pathotypes could be used in resistance breeding program as seed parents.

RP Thakur and KN Rai

2006-series restorers: Restorer line development envisages designating 5 to 9 restorers every year similar to the approach followed for the A-/B-lines. Sixty-three A_4 restorer progenies and 64 A_1 restorer progenies were identified that are being further evaluated for fertility restoration, agronomic eliteness and DM resistance to designate them during 2006.

Backcross breeding to develop restorers of A_4 and A_5 CMS systems: Several A_4-system male-sterile lines have been developed and disseminated, and many more can be rapidly developed. The development of A-lines with A_5 cytoplasm can be even faster. The utility of these A-lines in hybrid development, however, is considerably constrained by the lack of their restorers. We have been converting 49 elite inbreds (32 from ICRISAT, 15 from six national program institutions, and one each from two private seed companies) into A_4 and A_5 restorer versions. Fourteen A_1-system R-lines have now been converted into A_4-system R-lines, and 39 A_1-system R-lines into A_5-system R-lines.

Population breeding of restorers of A_4 CMS systems: Identification of A_4 restorer progenies from those derived from the populations possessing moderate levels of A_4 restorers has been pursued as one of the objectives, leading to identification of 68 progenies during previous year, based on visually assessed grain yield potential and agronomic traits. These potential A_4 restorers were testcrossed on different A_4-system A-lines (3–9) to test their fertility restoration in different genetic backgrounds. Testcross data on fertility/sterility reaction confirmed 19 of these being A_4 restorers (flowering in 51–61 days compared to 51 days for ICMP 451). More than 60 progenies were derived from these 19 selected progenies, which were crossed to 6 A_4 system A-lines to reconfirm their fertility reaction before designating them. These progenies were also evaluated for DM resistance against Durgapura and Jalna pathotypes under high disease pressure in greenhouse condition (90–100% in susceptible controls). Of these, 34% were resistant (0–10% DM incidence) to Durgapura pathotype and 16% were resistant to Jalna pathotype.

Hybrid performance of seed parents and restorer parents

Although ICRISAT focuses its majority of efforts on developing hybrid parents, some of the designated parental lines are also evaluated for their hybrid yield potential. This activity is expected to speed up the hybrid breeding process by zeroing down to few parents or to the progenies with the parents of successful hybrids in the pedigree. While these hybrid evaluation trials aid in replacing existing hybrid parents, these also serve as channel for cost-effective breeding of high-yielding hybrids.

Combining ability of seed parents and potential restorers: A set of 11 A-lines (6 A_1, 4 A_4 and 1 A_5) that included 4 established A-lines (81A, 843A, 863A and ICMA 88004) were crossed with 10 potential restorer progenies previously selected for their grain yield potential and agronomic traits in a line × tester design for estimation of combining ability for grain yield and yield-related traits. The crosses (110) and parents were planted in separate but adjoining blocks, replicated two times in 1-row plots of 5 m length. From amongst the A-lines, 6 had positive (though not significant) general combining ability (gca) effects for grain yield. Of these, four were new lines and two of these long panicle A-lines (ICMA 04111 and ICMA 04777) had significant positive gca effects for panicle length and days to 50% flowering. These lines have been developed as improvement over 81A. The other two high-tillering lines had significant positive gca effect for tillering significant negative gca effect for days to 50% flower. Two potential restorers had positive significant gca effect for grain yield, along with another four having positive gca effect (though not significant). Among these 6 A-lines, 2 had negative significant gca effects for days to flower and 2 had positive significant gca for 1000-seed mass.

Among the 110 hybrids, 14 hybrids had at least 5% more grain yield than the highest-yielding control 7688 (4980 kg ha^{-1}). Four hybrids involved potential R-line ICMS 77004-S1-52-3-1-2-1-2-1 and 4 hybrids involved 81A as female parent. Of these 14 hybrids, 12 flowered in 44-47 days (46 days for 7688 and 45 days for PB 106). All the high-yielding hybrids possessed large grain size (10.6-13.5 g 1000^{-1} seed mass) than the control 7688 (10.4 g 1000^{-1} seed mass). As the results are based on un-replicated one-row plots, these hybrids should be evaluated in different locations to confirm their grain yield potential.

Hybrids observation nursery: About 308 hybrids involving 23 A-lines of different plant types (81A, 863A, ICMA 88004 and ICMA 89111 types) and 20 potential restorers were planted in an observation nursery in un-replicated one-row plots. Hybrids were visually assessed for grain yield potential and other agronomic traits (scores 1 = poor and 5 = best). Both A-lines and potential restorers that were involved in production of more than one high-yielding hybrids were identified. Two high-tillering A-lines were involved in producing 4 or more high-yielding hybrids (ICMA 02111 involved in 5 hybrids and ICMA 04999 involved in 4 hybrids). Three 863A type male-sterile lines along with 863A itself, and ICMA 94111 (ICMA 88004 type) and ICMA 04777 (81A type) were involved in producing 2 high-yielding hybrids each. From amongst 7 potential restorers involved in production of at least 2 high-yielding hybrids, a thick and long panicle potential restorer produced 10 high-yielding hybrids, followed by a MRC-derived progeny and ICMS 7704-derived progeny, each involved in 4 hybrids each. These hybrid parents were identified on the basis of limited testing of hybrids that needs to be evaluated systematically in larger plot size in multilocation trials.

Performance of hybrids with probable adaptation to arid Rajasthan, India: Early maturity and high-tillering are the two traits considered important in breeding hybrids adapted to arid Rajasthan. Hence, breeding hybrid parents mostly revolves around basic phenotypes of the commercial hybrids grown in the region. Two early-maturing male-sterile lines with high-tillering (similar to 843A) and 843A itself were crossed to twenty-two H 77/833-2 type MRC-derived advanced generation progenies and these hybrids were evaluated at Patancheru in an observation nursery with HHB 67, HHB 67-2 and ICMR 356 as controls. Grain yield was recorded in un-replicated one-row plots. About 25 high-yielding hybrids were identified. Of these, five hybrid which had maturity similar to HHB 67 and HHB 67-2 (38–39 days to 50% flower), outyielded HHB 67 by 33–41% and HHB 67–2 by 24–32%. Additional 12 hybrids (41–43 days to 50% flower) that had maturity similar to that of ICMH 356 (41 day to 50% flower) outyielded the latter by 7–13%. Most of these hybrids were either uniformly fertile or segregated for fertile (F) and sterile (S) plants. Twelve hybrids were based on ICMA 96111 and 10 hybrids on ICMA 03666. Similarly, 4 hybrids each were based on the MRC progenies. These hybrids need to be evaluated in arid Rajasthan for confirmation of their yield potential and adaptation.

KN Rai, VN Kulkarni and RP Thakur

Milestone: High-yielding and disease resistant dual-restorers of sorghum and pearl millet developed (Annual)

Restorer progenies adapted to rainy season

A total of 457 F_2s derived from 1560 crosses included in several elite R-line × R-line half-diallel crosses were evaluated during the 2005 rainy season and 605 F_3s were selected based on grain yield potential and grain size on visual observation basis. Besides these, a total of 900 F_5 progenies derived from various crosses and their testcrosses were evaluated during the 2005 rainy season. Several F_6 selections with male-fertility restoration reaction were made for the following traits on A_1: brown midrib - 74, sweet-stalk - 11, high-yielding - 5, pop sorghum - 2, lustrous grain - 12, waxy leaf - 1; on A2: brown midrib - 48, sweet-stalk - 23, high grain yield - 2 and high forage yield - 18.

Restorer progenies adapted to postrainy season

From the 306 F_3s derived from R- × R-crosses that were evaluated during the 2004–05 postrainy season, 140 F_4s were selected. These will be advanced through selection and testcrossed on A_1 and A_2 during the 2005–06 postrainy season.

Restorer lines (R-lines)

The advanced breeding lines with male-fertility restoration reaction on A_1 CMS system were evaluated in replicated yield trials. Initially, the lines are evaluated in Preliminary R-lines Trial (PRT) and those found promising are evaluated in Advanced R-lines Trial (ART). The superior lines from ART are evaluated in Elite R-line Trial (ERT). The promising lines with good plant type (tall stature with tan plant color and longer panicles with white bold grains) derived from various programs are tested in Preliminary Varietal Trial (PVT) and Advanced Varietal Trial (AVT). The results of these trials are summarized below.

PRT: None of the 22 test R-lines in PRT was significantly superior to the controls RS 29 and ICSR 89058 for grain yield. However, some of the test R-lines such as SP 3821 (3.7 t ha^{-1}), SP 3750 (3.5 t ha^{-1}), SP 3822 (3.4t ha^{-1}), SP 3646 (3.4 t ha^{-1}) and SP 3647 (3.3 t ha^{-1}) were comparable to the controls, RS 29 (3.3 t ha^{-1}) and ICSR 89058 (3.1 t ha^{-1}) for grain yield. These R-lines (2.0 to 2.2 g 100^{-1} grains) were comparable to the controls RS 29 (2.1 g 100^{-1} grains) and ICSR 89058 (2.0 g 100^{-1} grains) for grain size. These will enhance in diversifying the R-line gene pool as these are derived from diverse parentage.

ART: The promising R-lines (70) derived from various trait-specific groups were evaluated in ART. Seventeen R-lines significantly out performed (grain yield ranging from 4.0 t ha^{-1} to 3.4 t ha^{-1}) the control RS 29 (2.3 t ha^{-1}) for grain yield with comparable maturity. Two of the test R-lines, SP 6637 (4.0 t ha^{-1}) and SP 6617 (3.9 t ha^{-1}) were significantly superior to the control ICSR 89058 (2.7 t ha^{-1}) and several others (grain yield ranging from 3.6 t ha^{-1} to 2.6 t ha^{-1}) were on par with control ICSR 89058 (2.7 t ha^{-1}). One test R-line SP 6660 (2.4 g 100^{-1} grains) had significantly larger grains than the controls RS 29 (2.1 g 100^{-1} grains) and ICSR 89058 (2.1 g 100^{-1} grains). These 17 lines were designated in 2005.

ERT: None of the test R-lines were significantly superior to the controls RS 29 (2.8 t ha^{-1}) and ICSR 89058 (3.7 t ha^{-1}) for grain yield. Nevertheless, three of the seven test R-lines, ICSR 24002 (3.2 t ha^{-1}), ICSR 24005 (3.2 t ha^{-1}) and ICSR 24009 (3.1 t ha^{-1}) were on par with the control RS 29 (2.8 t ha^{-1}) and were of comparable maturity. ICSR 24007 (2.9 g 100^{-1} grains) had significantly larger grains than the controls RS 29 (2.2 g 100^{-1} grains) and ICSR 89058 (2.3 g 100^{-1} grains). The grain size of some of the R-lines, ICSR 24002 (2.4 g 100^{-1} grains), ICSR 24005 (2.3 g 100^{-1} grains), ICSR 24009 (2.2 g 100^{-1} grains) and ICSR 24008

(2.5g 100^{-1} grains) were comparable to those of controls, RS 29 (2.2 g 100^{-1} grains) and ICSR 89058 (2.3 g 100^{-1} grains). These were designated in 2004 as they are expected to contribute to diversity.

PVT: None of the test varieties significantly outyielded the control varieties. Nevertheless, one test variety SP 5116 (3.1 t ha^{-1}) was comparable with the controls JJ 1041 (3.2 t ha^{-1}) and CSV 15 (3.5 t ha^{-1}) with similar maturity period. The varieties such as SP 5116 (2.4 g 100^{-1} grains), SP 5110 (2.9 g 100^{-1} grains) SP 5106 (2.7 g 100^{-1} grains) SP 5109 (3.0 g 100^{-1} grains) and SP 5127 (3.1 g 100^{-1} grains) had significantly larger grains than those of the controls JJ 1041 (2.1 g 100^{-1} grains) and CSV 15 (2.1 g 100^{-1} grains).

AVT: Though none of the test varieties out performed the control varieties JJ 1041 and CSV 15, some of the varieties such as ICSV 24022 (3.7 t ha^{-1}), ICSV 24001(3.6 t ha^{-1}), ICSV 24010 (3.5 t ha^{-1}), ICSV 24023 (3.5 t ha^{-1}) and ICSV 24012 (3.4 t ha^{-1}) were numerically superior to the control JJ 1041 (3.3 t ha^{-1}). All these, except ICSV 24001 had significantly larger grains (2.9 to 2.9 g 100^{-1} grains) than those of the controls JJ 1041 (2.1 g 100^{-1} grains) and CSV 15 (2.1 g 100^{-1} grains). These were designated in 2004. The selected lines will be evaluated for foliar disease resistance.

BVS Reddy and S Ramesh

Evaluation of new and diverse 2005-series pearl millet R-lines against multiple pathotypes of downy mildew: Downy mildew resistance in R-lines (as in A- and B-lines) is important to breed resistant hybrids. A total of 734 restorer progenies including 416 potential R-lines and 318 elite R-lines were screened in greenhouse against Durgapura (Sg 212) and Jalna (Sg 150) pathotypes in an unreplicated single pot with 35–40 seedlings/pot/line. Of these, 12% lines were disease free and 14% lines had 1–10% incidence to Durgapura pathotype; 17% lines were disease free and 16% lines had 1–10% incidence) to Jalna pathotype; and 7% to both Durgapura and Jalna pathotypes.

Of the 713 advanced progenies including 363 long panicle progenies (F_{5-8}), 162 S_{3-4} Jhakrana × ESRC, and 188 RCB2 (S_{2-8}) screened against Durgapura pathotype in the same manner as mentioned above, 19% progenies were disease free and 21% had 1–10% disease incidence. Similarly, 134 progenies from the GB 8735 screened against Jalna pathotype, 7% were disease free and 25% had 1–10% incidence.

A total of 374 R-lines, including 298 elite restorers and 76 A_4 restorers were screened in the downy mildew disease nursery in a single replication (1 row of 4 m long). Of these, 32% lines were disease free and 22% had 1–10% incidence at the soft dough stage.

RP Thakur and KN Rai

Milestone: Stable and diversified male-sterile lines and their restorers with resistance to wilt and sterility mosaic diseases developed in pigeonpea (2006)

Search for new fertility restorers and male-sterility maintainers: In any dynamic hybrid program, significant genetic diversity among R- and A-lines is essential and to achieve this, we evaluated 282 new hybrid combinations with A_4 cytoplasm. Among these, 271 hybrids were found to restore pollen fertility and only 11 maintained male-sterility. This confirms the previous year's observation of high frequency (96%) of fertility restoration in A_4 cytoplasm.

All the male-sterile F_1s combinations were backcrossed to their recurrent patents for generating BC_1F_1 progenies.

New hybrid combinations: To identify high-yielding hybrids and new male-sterility maintainers, an attempt was made to develop new hybrid combinations. With the experience gained in the past 2–3 years, we decided to give emphasis to only A_4 hybrids. A total of 397 F_1 hybrids were made with hand pollination. This included 232 short-duration, 164 medium-duration and one long-duration hybrids. Only 42 new combinations were tried with the A-lines of A_2 cytoplasm. A_1 cytoplasm was used only in 20 short-duration combinations.

KB Saxena

Evaluation of CMS lines and their restorers for SM and wilt resistance: By following standard field screening methods, 122 pigeonpea cytoplasmic male-sterile lines and their restorers were evaluated for SM and wilt resistance in wilt and SM nursery. One line CMS 99044 was asymptomatic (0%) and 9 lines had <10% incidence for both wilt and SM diseases. Additional two lines ICPA 2014 and ICPA 2037 were asymptomatic for wilt and 18 lines were asymptomatic for SM.

S Pande and KB Saxena

Milestone: Promising pigeonpea hybrids in different maturity groups with resistance to wilt and sterility mosaic identified and hybrid seed production technology developed (2006)

Evaluation of F_1 hybrids: During 2005 rainy season, a total of 287 experimental hybrids were evaluated in 30 trials. Of these, 282 hybrids were developed on A-lines with A_4 cytoplasm. Of the 31 short-duration hybrids evaluated, 11 were found promising with yield advantage over the best control UPAS 120 ranging between 31 to 207%. ICPH 3310 recorded the highest yield of 4580 kg ha^{-1}. Among the Maruti-maturity group (160 days) hybrids, ICPH 2733 (71% superiority), ICPH 3366 (62% superiority), and ICPH 2671 (59% superiority) were outstanding. In the Asha maturity group (180–200 days) the highest yield of 3364 kg ha^{-1} (102% superiority) was recorded by ICPH 2741. The other promising hybrids in this group were ICPH 3489, ICPH 3479, ICPH 3401, ICPH 2786, and ICPH 3464. Twenty-four hybrids were also resistant to both wilt and sterility mosaic. These hybrids will be re-evaluated for their yield performance and disease resistance.

KB Saxena

Evaluation of hybrids and their parents for resistance to wilt and SM: Four hundred and eleven hybrids and their parents were evaluated for SM and wilt resistance following standard field screening technique. Of these, 33 hybrids and advanced breeding lines (ICPH 2319, ICPH 2897, ICPH 2899, ICPH 2900, ICPH 2326, ICPH 2327, ICPH 2336, ICPH 2897, ICPH 2898, ICPH 2899, ICPH 2900, ICPH 2352, ICPH 2911, ICPH 2913, ICPH 2914, ICPH 2915, ICPH 2916, ICPH 2903, ICEA P00020, GUPH 1126-4, IPH 487-2, ICP 11174, ICP 11376, ICPL 99050, ICPL 96053, ICPL 96058, ICPL 96052, ICPL 87119, ICPL 20125, ICPL 20094, ICPL 20096, ICPL 20098 and ICPL 20099) were symptomatic to both SM and wilt, while 28 were resistant to both diseases (<10% SM and wilt diseases). Additionally, seven lines (ICP 15045, ICP 11376-5, ICP 8863, ICPL 87119, ICPL 20107, ICPL 99048 and

ICPL 20128) were asymptomatic, while 13 were resistant (<10% to wilt). Similarly, 69 entries were asymptomatic to SM, while 30 had <10% SM incidence.

S Pande and KB Saxena

Activity 1.2.4: Conduct strategic research to improve the efficiency of genetic enhancement

Milestone: Breeding methods of producing sorghum hybrids with sweet stalk and resistance to grain mold/shoot fly developed (2007)

Evaluation of sorghum hybrids for grain mold resistance: To develop grain mold resistant hybrids and to study the association of various agronomic and morphological traits (days to 50% flowering, plant height, panicle shape, glumes cover, glume color and grain color) to grain mold resistance, 168 F_1s were developed by crossing 8 A-lines (ICSA 369, -370, -371, -400, -384, -382, -52, -101) and 21 testers (IS 41720, -41397, -41675, -18758C-618-2, -18758C-618-3, -30469C-140-2, -30469-1508-2, -84, ICSV 96105, -96094, SPV 462, ICSR 89013, -91011, -89018, -89058, -92001, -91019, -91029, PVK 801, GD 65055, -65028) in the 2004-2005 postrainy season. These 168 hybrids along with their parents and controls (Bulk Y, IS 25017, IS 20, IS 14384, PVK 801, CSH 16) were screened for grain mold resistance in 2 replications (2 row-plots of 4 m long/ replication) in a RCB design at ICRISAT-Patancheru in the 2005 rainy season. Grain mold screening was done under field conditions using overhead sprinkler irrigation from flowering to physiological maturity. Grain mold severity (PGMR) was recorded on 10 uniformly flowered-tagged plants in each plot using a 1–9 scale at physiological maturity. Mold scoring was also done on threshed bulk grain (TGMR) from the tagged panicles using the same 1–9 scale.

Based on grain mold severity rating of 1–4 as resistant and 4.1 to 9 as susceptible the entries were classified into these two groups. Both PGMR and TGMR scores on susceptible controls (SPV 104, CSH 16, Bulk Y) were >7.0, while resistant controls (IS 25017, IS 20 and IS 14384) showed ratings of 1.0. The hybrids were classified into four categories according to resistance (R) and susceptibility (S) of parental lines as R × R, R × S, S × R and S × S. All the 24 hybrids of R × R cross were resistant (≤4.0 score) both for PGMR and TGMR; of 60 hybrids of R × S cross 42 were resistant; of 24 hybrids of S ×R cross 16 were resistant and of 60 hybrids of S × S cross 13 were resistant. These results confirm our earlier findings that there is high probability of producing grain mold resistant hybrids when both parents are resistant, and low probability when both parents are susceptible. Plant height, grain and glumes color do contribute to resistance due to barrier to infection by mold fungi.

Biochemical analyses for ergosterol and flavan-4-ols were carried out for 25 hybrids (15 resistant and 10 susceptible) and their parental lines. Susceptible hybrids showed higher level of ergosterol (20.6 µg g^{-1}) than the resistant hybrids (8.7 µg g^{-1}) both in white- and red-grain backgrounds. Similarly, susceptible parental lines showed higher amounts of ergosterol than the resistant lines. In contrast to ergosterol, higher levels of flavan-4-ols were found in resistant hybrids ($2.04A_{550}$ g^{-1}) than in susceptible hybrids ($1.31A_{550}$ g^{-1}), and red-grain hybrids had more flavan-4-ols than the white-grain. Similarly, resistant parents showed higher level of flavan-4-ols ($5.27A_{550}$ g^{-1}) than the susceptible ones ($0.66A_{550}$ g^{-1}).

RP Thakur and BVS Reddy

Milestone: Character association and breeding efficiency of alternate CMS systems in sorghum and pearl millet quantified (2006)

The need for cytoplasmic diversification of A-lines (and hybrids) to mitigate the potential risk of unforeseen disease and insect pest outbreaks associated with cytoplasmic uniformity of cytoplasmic-nuclear male sterility (CMS)-based hybrids is a common knowledge. Cytoplasmic diversification also enhances the opportunities for diversifying the nuclear genetic base of A-lines as some of the outstanding restorers of one cytoplasm are found to be maintainers of other cytoplasms. However, in pursuit of diversifying the CMS base of hybrid seed parents, and hence the hybrids, the performance of hybrid seed parents and the hybrids based on alternative CMS systems for grain yield and other agronomic traits of importance cannot be compromised. Therefore, a series of studies were made to assess the efficiency of A_2 CMS system in comparison to the widely used A_1 CMS system in terms of mean performance, combining ability and heterosis for grain yield and other agronomic traits and responses to shoot fly infestation and grain mold infection at ICRISAT-Patancheru.

Grain yield and other agronomic traits: The studies on the evaluation of A_1 and A_2-based two sets of 18 isonuclear hybrids each during 2001 and 2002 rainy seasons and 2002–03 and 2003–04 postrainy seasons at ICRISAT-Patancheru revealed that A_2 CMS system is as efficient as A_1 (with a slight edge of A_2 over A_1) for commercial exploitation in terms of the development of heterotic hybrids for both rainy and postrainy season adaptation.

BVS Reddy and S Ramesh

Responses to shoot fly infestation

Two sets each of six isonuclear, alloplasmic A-lines with A_1 and A_2 cytoplasms in six different nuclear genetic backgrounds (Set 1 consisted of lines ICSB17, ICSB 37, ICSB 38, ICSB 42, ICSB 88001 and ICSB 88005 and Set 2 consisted of lines ICSB 11, ICSB 26, ICSB 88004, ICSB 18757, PM 17467B and PM 7061B) were crossed with three dual-restorers (ICSR 93001, ICSR 92003 and ICSR 93031) to produce two sets of 36 hybrids each. The two sets of hybrids along with the parents were screened (for the second time) for their responses to shoot fly infestation using infestor-row technique during 2005 rainy season at ICRISAT-Patancheru in a split-split plot design in three replications. The percentage of hybrids and the parents showing deadheart (DH) symptoms at 21 days after sowing (DAS) as a response to shoot fly infestation was estimated. As mean squares due to interaction of A-lines and R-lines with year and cytoplasm were non-significant, the *gca* effects of A-lines and mean performance and *sca* effects of hybrids in A_1 and A_2 cytoplasm backgrounds for mean DH% were estimated based on the combined data over 2004 and 2005 rainy seasons and the results are discussed below.

CMS effects on *gca* effects of A-lines: Significant CMS effects on *gca* of A-lines for shoot fly deadheart % were observed in only one nuclear genetic background (ICSA 88005) in set I and in two nuclear genetic backgrounds (ICSA 26 and ICSA 18757) in set II, and there were no definite trends favoring any particular CMS system. While the A-line ICSA 88005 in A_1 CMS system was a better general combiner compared to that in A_2 CMS system; the A-lines, ICSA 26 and ICSA 18757 in A_2 CMS system were better general combiners compared to those in A_1 CMS system.

CMS effects on *per se* performance and *sca* effects of crosses: As is true for *gca* effects, significant CMS effects on mean deadheart % of crosses were observed only in two nuclear genetic backgrounds both in set I (ICSA 17 × ICSR 93001 and ICSA 88005 × ICSR 93001) and Set II (ICSA 26 × ICSR 93001 and ICSA 18757 × ICSR 93031) with no definite trend favoring any particular CMS system. As far as *sca* effects were concerned, significant CMS effects were noticed only in one nuclear genetic background (ICSA 88005 × ICSR 93001) in set I. The *sca* effects of A_1 and A_2 CMS-based crosses were comparable in all nuclear genetic backgrounds in set II. The results clearly indicated that, by and large, A_1 and A_2 CMS-based A-lines as well as crosses were comparable for responses to shoot fly deadhearts %. Where significant CMS effects on *gca* and *sca* effects for shoot fly deadhearts % were detected, the magnitude varied with the nuclear genetic background with no definite trend favoring any particular CMS system.

Thus, considering that A_1 and A_2-based hybrids are comparable for grain yield potential, grain traits, maturity, and for responses to shoot fly, A_2 offers immediate option for the required diversification of CMS base of hybrid parents and hence hybrids to prevent eventual risk associated with the use of single cytoplasm (A_1-based hybrids) to stabilize the yield potential of hybrids.

BVS Reddy, HC Sharma and S Ramesh

Responses to grain mold infection

The two sets of isonuclear, alloplasmic hybrids (which were tested for responses to shoot fly infestation) along with the parents were evaluated (for second time) for their response to grain mold infection under sprinkler irrigation during 2005 rainy season at ICRISAT-Patancheru in a split-split-plot design in three replications. The hybrids and the parents were scored for average panicle grain mold rating (PGMR) taken on 10 panicles using a 1 to 9 scale, where 1 = no mold, 2 = 1–5%, 3 = 6–10%, 4 = 11–20%, 5 = 21–30%, 6 = 31–40%, 7 = 41–50%, 8 = 51–75%, 9 = >75% panicle surface area colonized by grain mold fungi. The *gca* effects of A-lines and mean performance and *sca* effects of crosses in A_1 and A_2 cytoplasm backgrounds for mean PGMR scores were estimated based on the combined data of 2004 and 2005 rainy seasons and the results are discussed below.

CMS effects on combining ability and mean performance: Cytoplasms seldom had any influence either on *gca* effects of A-lines or *sca* effects of hybrid combinations for PGMR in any of the nuclear genetic backgrounds. However, significant differences between individual A_1 and A_2 cytoplasm-based hybrids for mean PGMR severity scores were observed in two nuclear genetic backgrounds (PM 17467A × ICSR 93001 and ICSA 11 × ICSR 92003) in set II for mean PGMR severity scores, though no definite pattern of association of PGMR severity scores with a particular cytoplasm was observed. For example, while A_1 cytoplasm-based hybrid (PM 17467A × ICSR 93001) showed significantly lower PGMR scores than those based on A_2 cytoplasm, A_2 cytoplasm-based hybrid (ICSA 11 × ICSR 92003) showed significantly lower PGMR scores than those based on A_1 cytoplasm. However, when mean PGMR scores over all the hybrids were considered, there were no differences between A_1 and A_2 cytoplasm-based hybrids.

Thus, considering that A_1 and A_2-based hybrids are comparable for grain yield potential and grain traits, and maturity, and for responses to grain mold, A_2 offers immediate option for the required diversification of CMS base of hybrid parents and hence hybrids to prevent any potential risk associated with the use of single cytoplasm (A_1)-based hybrids to stabilize the yield potential of hybrids.

BVS Reddy, RP Thakur and S Ramesh

Breeding efficiency of male-sterile cytoplasms (A_1 and A_2) *vs.* fertile (B-line) cytoplasm in hybrid combinations: Two sets each of 36 isonuclear (A × R) hybrids (36 in A_1 and 36 in A_2 CMS backgrounds) were made by crossing isonuclear, alloplasmic (A_1 and A_2) A-lines in 12 nuclear genetic backgrounds with three dual restorer (R)-lines. The male-fertile counterparts of the 12 male-sterile lines were emasculated and crossed with the same three dual R-lines and produced 36 B × R hybrids. The two sets of 36 A × R and one set of 36 B × R crosses were evaluated at ICRISAT-Patancheru during 2005 rainy season in split-split-plot design using three replications with R-lines in main plots, A-lines as sub-plots and cytoplasms in sub-sub-plots. The 12 A-lines and their B-lines were evaluated in a separate trial using randomized complete block design with three replications. Sufficient care was taken for adequate supply of pollen grains to A-lines for meaningful comparison of yield performance of A-lines vs B-lines.

The comparison of A × R and B × R crosses (in both A_1 and A_2 backgrounds) indicated that, while there were no differences between A × R and B × R crosses for days to 50% flowering, A × R (both A_1 and A_2) crosses were significantly taller (by 0.2m in A_1 and by 0.1m in A_2 backgrounds) and manifested higher grain yield (by 0.7 t ha^{-1} in A_1 and by 0.9 t ha^{-1} in A_2 backgrounds) compared to those of B × R crosses when average performance of A_1 and A_2-based A × R and B × R hybrids as separate groups was considered. However, when grain size was considered, A × R (in A_1 background) crosses were significantly bolder (by 0.08 g 100^{-1} seed) than B × R crosses, while in A_2 background there were no differences between A × R and B × R crosses.

Significant cytoplasm effects were observed for all the traits except grain size when individual nuclear genetic background of A × R (both A_1 and A_2) and B × R crosses were examined. Where significant cytoplasm effects were detected in some of the nuclear genetic backgrounds, not only the magnitudes of differences between A × R and B × R crosses varied with nuclear genetic backgrounds, but also were small to have any practical importance for days to 50% flowering, plant height and grain size. Also, there was no definite trend favoring either A × R or B × R crosses for any trait, ie, while A × R crosses, besides being early, were taller and possessed larger grains compared to those of B × R crosses in a few nuclear genetic backgrounds, the reverse was true in few other nuclear genetic backgrounds. However, in most of the nuclear genetic backgrounds, A × R (both A_1 and A_2) crosses were significantly superior to B × R crosses for grain yield. Thus, the use of CMS-based hybrids for commercial exploitation of heterosis is not only justified by the feasibility of large and economy-scale hybrid seed production, but also for superior grain yield.

BVS Reddy and S Ramesh

Breeding efficiency of male-sterile cytoplasms [A_1, A_2, A_3, A_4 (M), A_4 (VZM) and A_4 (G)] vs fertile (B-line) cytoplasm: The isonuclear alloplasmic A-lines in eight nuclear genetic backgrounds (ICSA/B 11, ICSA/B 17, ICSA/B 26, ICSA/B 37, ICSA/B 38, ICSA/B 42, ICSA/B 88001 and ICSA/B 88004) along with their B-lines were evaluated in a randomized complete block design with three replications at ICRISAT-Patancheru during 2005 rainy season. Precautions were taken for the sufficient supply of pollen grains to A-lines for meaningful assessment of A-lines vs their B-lines for grain yield.

The analysis of variance indicated significant variability among the A-lines for days to 50% flowering, plant height and grain yield. While there were significant differences among male-sterility-inducing cytoplasms and between male-sterility inducing cytoplasms and their B-lines for all the traits, the magnitudes of differences for days to 50% flowering and plant height were small to have any practical significance. Also, there was no definite trend in association of days to 50% flowering and plant height with either sterile or fertile cytoplasm. In general, the grain yield potential of A_1- and A_2-based A-lines in most of the nuclear genetic backgrounds was comparable (which is advantageous from hybrid seed production point of view) to that of B-lines. However, grain yield potential of other cytoplasms [A_3, A_4 (M), A_4 (VZM), and A_4 (G)]-based A-lines were significantly lower than that of A_1 and A_2-based A-lines as well as B-lines. For grain size, A-lines based on all the six cytoplasms comparable to B-lines.

BVS Reddy and S Ramesh

Effect of A_1 and A_2 cytoplasm on grain mold resistance: To understand the effects of different cytoplasm on mold resistance, a set of 72 hybrids were made by crossing A_1 and A_2 CMS lines in the genetic backgrounds of 12 B-lines (ICSB 17, -37, -38, -42, -88001, -88005, ICSB-11, -26, -88004, ISB 18757, PM 17467 and PM 7061B) with three R-lines (ICSR 93001, ICSR 92003 and ICSR 93031). Two experiments, each consisting of 36 hybrids, 9 parental lines and 4 controls were conducted in a RCB design with two replications. Each entry was planted in 2-row plots of 4 m long. Overhead sprinkler irrigation was provided on rain-free days for the mold infection and development. Panicle gain mold rating (PGMR) was recorded using a 1–9 scale (1 = no mold and 9 = >75% molded grains on a panicle) on the 10-tagged panicles per plot and threshed grain mold rating (TGMR) was recorded on the bulk grain from the tagged panicles per plot. These experiments were conducted in 2004 and repeated during the 2005 rainy season for further confirmation of the earlier results.

The results showed that all the 12 B-lines were susceptible (>4.0 score) with the mean PGMR and TGMR scores ranging from 5.0 (ICSB 11) to 9.0 (ICSB 42). Of the three R-lines, only ICSR 93001 was resistant and the other two had severity scores of 6.0 to 7.5 compared to score 8.3 of the susceptible control (Bulk Y) and score 1.0 of the resistant control line (IS 14384). In experiment 1, all the 36 hybrids were susceptible with grain mold ratings ranging from 5.0 to 9.0. In experiment 2, 29 of the 36 hybrids were resistant and the remaining 7 susceptible without indicating any pattern. Thus, in both experiments, there were no clear effects of A_1 and A_2 cytoplasm on grain mold severity ratings of their hybrids. These results are similar to those obtained in 2004.

RP Thakur and BVS Reddy

CMS effect on grain yield

Continued efforts in diversification of cytoplasmic-nuclear male-sterility in pearl millet have lead to the identification of more stable CMS systems such as A_4 (0.0–0.3% pollen shedders) and A_5 (no pollen shedders), compared to A_1 CMS systems (0.0–2.5% pollen shedder). These new CMS systems also have higher maintainer frequency in both African and ICRISAT-bred improved populations and hence, provide great opportunities for genetic diversification of A-lines Evaluation of isonuclear hybrids in six environments (2 year × 3 locations) had already shown that the hybrids with the A_4 cytoplasm produce only 5% less grain yield than A_1-hybrids. We evaluated 45 hybrids developed by crossing two isonuclear A-lines ($A_1$and A_5 cytoplasm) and their maintainers (fertile cytoplasm) in each of the three genetic backgrounds (81B, 5054B and ICMB 88004) as female parents with five dual-restorers as male parents. A replicated trial of these 45 hybrids was conducted at two locations (ICRISAT-Patancheru, Millet Research Station, Jamnagar, India) for two years. The results showed that there was no significant difference between the hybrids of A_1 and A_5 CMS systems, with the A_5-hybrids giving 97–102% mean grain yield of the A_1-system hybrids. Also, the hybrids of the two CMS systems were very similar with respect to plant height, time to flower, panicle length and tillering. This indicated that A_5 cytoplasm has no adverse effect on grain yield and other important agronomic traits.

Bi-directional recurrent selection for maintainer and restorer frequencies

A bi-directional recurrent selection for fertility and sterility reactions of the A_1 and A_4 CMS systems was conducted for five cycles in Early Smut Resistant Composite II (ESRC II) and for three cycles in the OPV Raj 171 to assess the selection response of maintainer and restorer frequencies in two populations. Male-sterile lines $81A_1$ and $81A_4$ were used as testers to evaluate fertility restoration and sterility maintenance properties of plants of these populations in their testcrosses during the selection process. Recurrent selection bulks of these populations (in the maintainer and restorer streams and with respect to A_1 as well as A_4 CMS system) along with the original C_0 bulks of both populations were crossed onto A_1- and A_4-system male-sterile lines in three genetic backgrounds ($81A_1$ and $81A_4$, $5054A_1$ and $5054A_4$, and $ICMA_1$ 88004 and $ICMA_4$ 88004). The resulting top cross hybrids were first evaluated for the frequency of male-sterile plants (a measure of maintainer frequency) and male-fertile plants (a measure of restorer frequency) during the rainy season 2004 and the same was repeated during the summer 2005.

Genetic changes in maintainer and restorer frequencies: The results of the 2004 evaluation were confirmed during the summer 2005. The results based on the two seasons evaluations revealed that two selection cycles in ESRC II were effective in rapidly increasing the mean frequency of maintainers from 29% (C_0 bulk) to 90% (C_2 bulk) with respect to the A_1 CMS system, and from 42% (C_0 bulk) to 99% (C_2 bulk) with respect to the A_4 CMS system in the topcross hybrids made on $81A_1$ and $81A_4$ CMS systems when selection was carried for improving maintainer frequency. Similarly, the mean frequency of restorers increased from 71% in C_0 bulk to 96% in the C_3 bulk with respect to the A_1 CMS system, and from 58 to 96% in the C_2 bulk with respect to the A_4 CMS system. In Raj 171, one cycle of selection increased the mean frequency of maintainers from 22% (C_0 bulk) to 98% (C_1 bulk) with respect to theA_1 CMS system, and from 49% (C_0 bulk) to 99% (C_1 bulk) with respect to the A_4 CMS system. Similarly, one cycle of selection for fertility restoration increased the mean frequency of restorers from 78% (C_0 bulk) to 98% (C_1 bulk) with respect to the A_1 CMS system, and from 46% (C_0 bulk) to 96% (C_1 bulk) with respect to the A_4 CMS system. Broadly speaking, the results showed that both CMS systems were equally effective in genetic improvement of both populations for fertility restoration as well as for sterility maintenance reaction. Results of topcross hybrids made on the A_1 and A_4 system A-lines in the genetic background of 5054B and ICMB 88004 were broadly supportive of these findings on the patterns of genetic changes for restorer and maintainer frequency.

Associated changes in grain yield and agronomic traits associated with recurrent selection

To examine the influence of bi-directional selection for male fertility restoration and sterility reaction in ESRC II and Raj 171 on grain yield and agronomic traits, different cycle bulks of both the populations were evaluated. The ESRC II trial consisted of 21 bulks (C_0 bulk, and five bulks each for the restorer and maintainer stream of each of the two CMS system). Similarly, Raj 171 trial consisted of 13 bulks. First replicated trials were conducted separately for ESRC II and Raj 171 selection bulks during the rainy season 2004 and the same was repeated during the summer season 2005 at Patancheru. The results of 2004 evaluations were confirmed during 2005. The results based on the two seasons evaluation revealed that the selection either for fertility restoration or for sterility maintenance in ESRC II had no adverse effect on the mean grain yield with respect to the A_1 CMS system or for sterility maintenance reaction with respect to the A_4 CMS system. There were indications of significant decline in the mean grain yield in the C_4 and C_5 restorer bulks of the A_4 CMS system. Changes in other traits such as time to flower, plant height, panicle length, tillering ability and seed weight were non- significant. Results from Raj 171 trial also showed that recurrent selection for fertility/sterility traits with respect to either of the two CMS systems had no adverse effect on the mean grain yield and agronomic traits.

Genetics of panicle and seed size

Genetic manipulation of yield-related traits is a common approach followed to improve grain yield in crop plants. Inheritance of such traits plays a key role in deciding the selection strategy. Hitherto, studies on inheritance pattern of panicle and seed traits have been conducted with genotypes having panicle length not more than 30 cm long, panicle diameter not more than 30 mm and 1000-grain mass not more than 12 g. But, pearl millet improvement program at ICRISAT-Patancheru has produced breeding lines having panicle length >60 cm, panicle diameter >45 mm and 1000-grain mass >16 g, which are expected to enter hybrid programs of SAT regions in the near future. Hence, the study of genetic analysis of these traits in the changed character state by means of generation means and triple test cross analysis was planned. During the 2005-rainy season, contrasting inbred lines with almost similar maturity and diverse genetic background for panicle length (long panicle ranging from 55 cm to 82 cm and short panicle ranging from 14.5 cm to 17.9 cm), panicle diameter (thick panicle ranging 42 cm to 61 cm and thin panicle ranging 15 mm to 19 mm) and seed size (large-seed ranging from 16.4 to 19.2 g and small-seed ranging from 4.1 to 7.5 g for 1000-seed mass) were selected based on morphological data. Six contrasting parents in each group were crossed to generate 9 F_1s (3 in each group) during the 2005 post rainy season.

KN Rai, VN Kulkarni and RP Thakur

Milestone: Genetics of fertility restoration on diverse CMS systems investigated in sorghum and pearl millet (2007)

Appropriate breeding materials for genetic studies: Isonuclear alloplasmic A-lines based on the widely used A_1 (*milo*) cytoplasm and alternative cytoplasms (non-*milo*) and their common R-lines (on one nuclear genetic background) have been developed. These are appropriate genetic material for conducting strategic research in areas such as assessing the effects of non-*milo* cytoplasms on mean performance and combining ability of A-lines and hybrids for agronomic traits as well as resistance to biotic and abiotic constraints in comparison to widely exploited *milo* cytoplasm, and inheritance of male fertility restoration of *milo* and non-*milo* cytoplasms without any confounding effects of nuclear genetic background of A-lines and R-lines. Such strategic information is essential for assessing feasibility of utilization of alternative cytoplasms for diversifying cytoplasm base of sorghum seed parents and hence hybrids and for improving the efficiency of breeding R-lines for different CMS systems.

Two common R-lines (ICSR 94453 and IS 33844-5) on A_1, A_2, A_3, A_4 CMS systems were crossed with A_1, A_2, A_3, A_4 (M), A_4 (VZM), A_4 (G)-based A-lines in six nuclear genetic backgrounds (ICSA 11, ICSA 37, ICSA 38, ICSA 42, ICSA 88001 and ICSA 88004) during 2005 rainy season. As the seed could not be obtained in all possible combinations due to continuous rain and pest attack, the same set was planted during the 2005–06 postrainy season for obtaining F_1s.

BVS Reddy and S Ramesh

Genetics of CMS systems

Genetics of fertility restoration of diverse cytoplasmic-nuclear male-sterility (CMS) systems in pearl millet was studied in F_2, BC_1 and BC_2 populations of the crosses involving isonuclear A-lines of the five diverse CMS systems (A_1, A_4, A_{egp}, A_5 and A_v) in three diverse nuclear genetic backgrounds (81B, 5054B and ICMB 88004), and six pollen parents restoring the male fertility of hybrids based on any one, two or three male-sterile cytoplasm. Linkage between the fertility restorer genes of the A_1 and A_4 CMS systems, allelism among the fertility restorer genes of these CMS systems and molecular markers linked to fertility restorer genes of the A_1 and A_4 CMS systems were also studied. In a majority of crosses across the CMS systems, fertility restoration was governed by a trigenic inheritance mechanism, represented either by dominant alleles of one basic gene and two duplicate-complimentary genes (F_2 ratio 45:19 and BC_1 ratio 1:1) or dominant alleles of any two of the three duplicate-complimentary genes (F_2 ratio 54:10 and BC_1 ratio 3:1). In few other crosses, different trigenic mechanisms with F_2 ratio of 57F:7S and 63F:1S and corresponding BC_1 ratio of 3F:1S and 7F:1S, respectively, were also observed. Although monogenic and digenic (F_2 ratio 15F:1S and 9F:7S and BC_1 ratio 3F:1S and 1F:3S) ratios were also observed in a few crosses, these resulted from the segregation of one or two genes out of the three involved in the trigenic inheritance. Segregation patterns of testcrosses from individual plants of F_2 and BC_1 populations derived from two B × R crosses were broadly supportive of the trigenic inheritance mechanism. Test of allelism studied from the fertility/sterility reaction of the three-way hybrids obtained by crossing A-lines with the F_1s of inter-crosses among three restorer lines (IPC 1518, IPC 511 and IPC 804) indicated the presence of same alleles of all the fertility restorer genes for the A_1 CMS system, whereas different alleles are indicated for the A_4 system. Joint segregation analysis revealed the presence of linkage between the fertility restorer genes of A_1 and A_4 CMS systems. A linkage map of 708.8 cM was constructed using 397 individuals and 36 molecular (SSR and RFLP) and morphological markers in the F_2 mapping population derived from the cross 81B × IPC 804. For the A_1 CMS system, two QTL (*Rf1a* and *Rf1b*) and for the A_4 system, three QTL (*Rf4a*, *Rf4b* and *Rf4c*) were identified with different unlinked genomic regions involved in the fertility restoration of these CMS systems. Based on the overall inheritance pattern observed, possible genotypes of the A-lines irrespective of CMS background were assigned as *rf*_a *rf*_a *rf*_b *rf*_b *Rf*_c *Rf*_c or *rf*_a *rf*_a *rf*_b *rf*_b *rf*_c *rf*_c and of the restorer lines as *Rf*_a *Rf*_a *Rf*_b *Rf*_b *rf*_c *rf*_c or *Rf*_a *Rf*_a *Rf*_b *Rf*_b *Rf*_c *Rf*_c (underscore to be replaced with the numbers '1', '4' or '5' or alphabet ‘e’ or ‘v’ denoting the CMS systems). The information emanating from the study has implications in the breeding of maintainer and restorer lines of diverse CMS systems.

KN Rai, VN Kulkarni and Dev Vart Yadav

Milestone: Changes in virulence patterns in pearl millet downy mildew pathogen populations and effectiveness of resistance genes deployment assessed (2006)

The pearl millet downy mildew pathogen, *Sclerospora graminicola*, is a highly dynamic organism, hence its virulence shift is monitored through on-farm survey and multilocation virulence nursery.

On-farm downy mildew survey in Gujarat, India: An Indian Council of Agriculture Research-ICRISAT collaborative downy mildew survey was conducted in 70 pearl millet fields in 18 talukas of 8 districts (Ahmadabad, Anand, Banaskanta, Gandhinagar, Kheda, Mehasana, Rajkot and Surendranagar) in Gujarat, India during September. About 30% of the fields had disease, with the incidence ranging from traces to 70%. However, no disease was observed in Rajkot and Surendranagar districts. Public sector hybrids, GHB 558 and –577 had mean incidence of 3% and 12%, respectively, whereas private sector hybrids (Gowri, Nandi 3, -5, PG and several unknowns) had mean incidence of 2 to 14% with a range of 0 to 71%. Some other hybrids, such as Pioneer 7688, Proagro 9330 and -4444 were disease-free.

RP Thakur

Evaluation of new isolates from Gujarat, India: Fourteen oosporic samples collected from six districts of Gujarat (Kheda – 3, Anand – 2, Jamnagar – 1, Mehsana – 1, Banaskantha – 5 and Gandhinagar – 2) from different susceptible hybrids were evaluated for their oospore content (oospores g^{-1} of leaf powder) and viability using TTC (Triphenyl tetrazolium chloride) method. Four samples did not contain oospores whereas the 10 samples had varied number of oospores from 1.2×10^6 g^{-1} leaf powder from Narsandha, Kheda district (designated Sg 433) to 68.8×10^6 g^{-1} leaf powder from Sunav, Anand district (designated Sg 435). There was significant difference in the viability of oospores, ranging from 29% in Sg 435 (Sunav, Anand) to 54% in Sg 437 (Jamnagar) and Sg 442 (Tarana, Gandhinagar). These nine isolates have been established on a susceptible genotype, 7042S for further studies on pathogenicity and virulence.

RP Thakur

Pearl Millet Downy Mildew Virulence Nursery (PMDMVN): The PMDMVN-2005 consisting of 23 test entries and one local resistant and one local susceptible controls was established at 12 locations (Durgapura, Mandor, Fatehpur Sekhawati, Hisar, Anand, Jamnagar, Aurangabad, Dhule, Gwalior, Patancheru, Mysore and Coimbatore) in India under the ICAR-ICRISAT partnership project. The nursery was conducted in a RCB design with three replications. Each entry was grown in 2-row plots of 4 m. Downy mildew incidence data were recorded at 30- and 60-days after seedling emergence. The data from Fatehpur Sekhawati and Aurangabad were not considered because of low disease pressure (<50% on the susceptible control). At 60-days, the mean disease incidence across 10 locations ranged from 77 to 99% on the susceptible control 7042S, indicating adequate disease pressure at all the 10 locations. The pathogen population at Anand was more virulent, infecting 12 of the 23 test entries by recording higher disease incidence than the trial mean, followed by Mysore, Patancheru, Jamnagar, Durgapura, Dhule and Coimbatore locations. The pathogen population at Mandor appeared to be least virulent with only one entry having more incidence than the trial mean. Only two entries (IP 18292 and IP 18293) showed high level of resistance stability with mean incidence of 4–6% across locations. Among the new B-lines, ICMB 93333 was the most resistant with a range of 0 to 7% incidence. Other four B-lines (ICMB 99013, ICMB 94555, ICMB 95444 and ICMB 97111) were also found resistant with mean incidence ≤8%.

RP Thakur

Milestone: Pathogenic nature of and variability in sorghum grain mold fungi determined, and greenhouse screening technique refined (2006)

Refine greenhouse-screening technique to identify resistance to the major individual grain mold pathogens: In order to develop an effective grain mold resistance breeding program, it is important to identify resistance to the individual pathogens. This could be done by artificially inoculating the sorghum panicle at the right stage and providing congenial condition for infection establishment and disease development. With this objective in view, a greenhouse grain mold-screening technique has been developed that involves: (i) spray inoculation of pot-gown sorghum plants at full anthesis with spore suspension (1×10^6 spores mL^{-1}) with the target pathogen; (ii) provide panicle wetness (95–100% RH) for 48 h by misting following inoculation at 25–28°C to facilitate infection establishment; (iii) again provide panicle wetness at physiological maturity (PM) for 72 h by misting to promote grain colonization by the pathogen; (iv) score for visual grain mold severity as percentage grain colonized on a panicle at physiological maturity; and (v) determine grain infection severity by plating grains using the blotter method.

Using this technique, a set of 20 sorghum lines including one resistant and one susceptible controls were screened for infection by *Fusarium verticilloides*, *Curvularia lunata* and *Alternaria alternata* in three different sets of experiment. Results indicated differential susceptibility levels of sorghum lines to individual fungi. Based on grain colonization scores, ICSB 370-2 was found to be resistant (<10% colonization) to *Fusarium verticilloides* and *A. alternata* whereas SGMR 40-1-2-3 was resistant to *C. lunata* and *A. alternata*.

RP Thakur

Analyze *Fusarium* isolates for their fumonisins production potential: A preliminary identification of the 17 isolates (from ICRISAT-Patancheru) based on morphology, crosses with tester isolates, and AFLP markers had revealed the presence of five *Fusarium* species in the sorghum grain mold complex (WFO Morasas, Medical Research Council, South Africa and JF Lesley, Kansas State University). These were: *F. verticillioides*, *F. proliferatum*, *F. thapsinum*, *F. sacchari* and *F. andiyazi*. Among these, the frequency of *F. proliferatum* was highest, followed by *F. verticillioides*, *F. thapsinum*, and *F. andiyazi*. In order to determine the frequency of these species in the grain mold complex, we attempted to evaluate large number of *Fusarium* isolates collected from different locations in India.

Of the 948 cultures of *Fusarium* spp. obtained from sorghum grain mold variability nursery conducted at five locations in India during 2002–04, a total of 682 were characterized during the past 2 years by comparing the growth patterns and pigmentation (images of abaxial and adaxial surfaces on PDA plates) with those of the reference cultures, and were grouped into six species. The across-location mean frequency of occurrence was highest for *F. proliferatum* (48%), followed by *F. thapsinum* (33%) and the lowest was for *F. sacchari* (2%). Among the locations, the frequency of occurrence of *F. proliferatum* was highest at Parbhani (66%) and lowest at Surat (28%); for *F. thapsinum* it was highest at Patancheru (50%), and lowest at Palem (23%); and for *F. verticillioides*, it was highest at Surat (16%), and lowest at Parbhani (5%). The results indicate variation in frequency distribution of *Fusarium* species in different sorghum growing areas and thus resistance identification to different *Fusarium* species should be planned accordingly.

Fumonisins estimation in *Fusarium* isolates: Fumonisins (FB_1 and FB_2) estimation of 12 isolates by HPLC at Iowa State University, USA revealed that *F. proliferatum* produced the highest levels of FB_1 (7.56 µg g^{-1} grain) and FB_2 (8.7480 µg g^{-1} grain), followed by other strains. Several other strains of each species produced FB_1 in various levels, but those of *F. sacchari*, *F. andiyazi*, and some strains of *F. proliferatum*, and *F. verticillioides* did not produce FB_2. Among the 682 *Fusarium* isolates assayed for their fumonisins production potential using competitive ELISA method at ICRISAT-Patancheru, the range of FB_1 production levels across the five locations varied from 0–811 µg kg^{-1} grain by *F. sacchari* to 0–4765 µg kg^{-1} grain by *F. proliferatum*, followed by *F. thapsinum*. Among five locations, isolates from Surat produced relatively low levels of FB_1 compared to those from other locations. Further investigations are needed to understand the role of environment on fungal growth and fumonisins production levels.

RP Thakur

Milestone: *Helicoverpa* resistance screening techniques refined, and mechanism and inheritance resistance studied in chickpea and pigeonpea (2006)

Mechanism and inheritance of resistance to *Helicoverpa* in chickpea

Genetics of resistance to pod borer (*Helicoverpa armigera)* in chickpea was focussed on studying the nature of gene action and maternal effects, plant resistance mechanisms and interaction of different components of resistance and grain yield. Eight *desi* [ICC 12475 (ICC 506), ICC 12476, ICC 12477, ICC 12478, ICC 12479, ICC 4918, ICC 12426 or ICCC 37 and ICC 3137] and one *kabuli* [ICCV 2 (ICC 12968)] parents were selected based on earlier screening trials to study the genetics of resistance, using a full diallel. ICCV 2 was the earliest to flower and mature followed by ICC 4918, ICCC 37, ICC 12478 and ICC 12477, while ICC 12479, ICC 12476 and ICC 3137 were late to flower and mature. ICC 12478 suffered significantly lower pod borer damage, followed by ICC 506, ICC 12479 and ICC 12477. ICC 3137 was highly susceptible and recorded lowest seed yield. Most of the crosses with ICC 506, ICC 12478 and ICC 12479 suffered low damage, while those with ICC 3137 suffered higher damage. ICCC 37 recorded higher yield, followed by ICC 12479 and ICC 12476.

Inheritance of resistance: Gene action and maternal effects were estimated from the full diallel trial. Additive gene action was predominant for days to initial flowering, days to 50% flowering, days to maturity, pod borer damage (%), pods $plant^{-1}$, seeds $plant^{-1}$, seeds pod^{-1} and 100-seed weight. While non-additive gene action was important for yield $plant^{-1}$, total plot yield and yield (kg ha^{-1}). The additive: dominance (A:D) ratio was greater than unity for days to 50% flowering, days to maturity, pod borer damage (%), pods $plant^{-1}$, seeds $plant^{-1}$, seeds pod^{-1} and 100-seed weight, indicating over dominance, while for yield $plant^{-1}$ and yield (kg ha^{-1}), the ratio was less than unity, indicating partial dominance. There was no maternal inheritance for maturity-related traits, pod borer damage, and grain yield. The hybrid, ICC 12476 × ICCC 37 showed positive and significant specific combining ability (SCA) effects for seeds pod^{-1}, but the reciprocal hybrid ICCC 37 × ICC 12476 showed negatively significant SCA effects for number of seeds pod^{-1}. So the hybrid ICCC 37 × ICC 12476 may be showing cytoplasmic effect for the number of seeds pod^{-1}.

Mechanisms of resistance: The three mechanisms of resistance *viz.*, non-preference for oviposition, antibiosis and tolerance to *H. armigera* in chickpea genotypes were studied under laboratory, greenhouse and field conditions. Oviposition studies under no-choice, dual choice and multi-choice laboratory and multi-choice field conditions revealed that the resistant control genotype, ICC 506 recorded lowest number of eggs, followed by ICC 12476, ICC 12477 and ICC 12478. The highest oviposition was observed on the susceptible genotypes, ICC 12426 and ICC 4918. The genotypes ICC 506, ICC 12476, ICC 12477, ICC 12478 and ICC 12479 were least preferred by *H. armigera* females for oviposition compared to ICC 4918, ICC 3137 and ICCV 2. In detached leaf assay studies, the survival rate and larval weights were lowest on the resistant control, ICC 12475 (ICC 506), followed by ICC 12476, ICC 12477, ICC 12478 and ICC 12479, suggesting that water-soluble compounds in the leaf exudates (malic and oxalic acid) were primarily responsible for resistance to *H. armigera*.

Tolerance: The genotypes ICC 12476, ICC 12477, ICC 12478 and ICC 12479 were found to be resistant and their levels of resistance were comparable to the resistant control, ICC 12475 (ICC 506) under no-choice cage conditions. Under un-infested conditions, the per plant yield was greater in ICC 12426 followed by ICC 12478 and Annigeri. The resistant cultivars ICC 12478 and ICC 12475 recorded higher yield than the rest of the cultivars. At the podding stage of the crop, when plants were infested with the third instar larvae, the recovery resistance was very poor, as most of the plants were damaged.

Larvae fed on leaf material and on artificial diet with lyophilized leaf and pod powder recorded lowest larval and pupal weights and prolonged larval and pupal periods on the resistant genotype, ICC 506. Highest growth index, adult index, oviposition index and pupal index were recorded on ICC 12426 and ICC 4918, while the lowest on the resistant control, ICC 12475 (ICC 506).

High Performance Liquid Chromatography (HPLC) profile of leaf exudates showed that the malic acid was negatively correlated with damage rating at flowering (–0.28, PL0.05), at maturity (–0.32, PL0.01) and pod damage (–0.22, PL0.05). Oxalic acid showed negative significant correlation with damage rating in detached leaf assay (–0.22, PL0.05). Acetic acid showed a negative correlation with larval weight (-0.45, PL0.05), damage rating at flowering (–0.33, PL0.01) and maturity (–0.26, PL0.05). Citric acid showed negative and significant correlation with damage rating at flowering (–0.23, PL0.05).

The genotypes, ICC 12476, ICC 12477, ICC 12478, ICC 12479 and ICCV 2 were on par with the resistant control, ICC 12475 for pod borer damage under protected conditions. ICC 12475, ICC 12426, ICC 12478 and ICC 12479 recorded higher grain yield under unprotected conditions. The genotypes ICC 12475 (3.77%) and ICC 12478 (6.59%) recorded the lowest reduction in grain yield under unprotected conditions, indicating the presence of tolerance mechanism in chickpea to *H. armigera*. The tolerant lines can be used in further breeding programs and the mechanisms responsible for the resistance can be exploited to develop resistant varieties.

Correlation of different components of resistance with grain yield showed significant positive correlation under protected conditions between number of larvae and eggs (0.89, PL0.01), leaf damage and egg number (0.82, PL0.05), yield plant^{-1} and egg number (0.77, PL0.05), yield plant^{-1} and larva number (0.76, PL0.05) and pod damage (%) and larval number (0.91, PL0.01). Significant negative correlation was recorded between yield plant^{-1} and borer damage (%) (–0.79, PL0.05), under unprotected conditions. These correlations and interaction of different components of resistance and grain yield will help in gene pyramiding.

CLL Gowda and HC Sharma

Milestone: Allelic relationship of genes for early flowering and other agronomically important traits in chickpea established (2005)

Allelic relationships, penetrance and expressivity of genes controlling number of flowers per axis in chickpea

A double-flowered (two flowers per pedicel) line ICC 4929, a triple-flowered line IPC 99-18 and a multi-flowered line JGM 7 were intercrossed in all possible combinations and flowering behavior of parents, F_1s and F_2s was studied to establish allelic relationships, penetrance and expressivity of genes controlling number of flowers per axis in chickpea. The F_1s from the double-flowered × triple-flowered cross were double-flowered, whereas F_1s from double-flowered × multi-flowered and triple-flowered × multi-flowered crosses were single-flowered. The F_2s from double-flowered × triple-flowered cross gave a good fit to a 3:1 ratio for double-flowered and triple-flowered plants. The F_2s from double-flowered x multi-flowered cross segregated in a ratio of 9:3:3:1 for single-flowered, double-flowered, multi-flowered and double- and multi-flowered plants. The F_2s from triple-flowered x multi-flowered cross segregated in a ratio 9:3:4 for single-flowered, triple-flowered and multi-flowered plants. The results clearly established that two loci control number of flowers per axis in chickpea. The double-flowered and triple-flowered traits are controlled by a single-locus (***Sfl***) and the allele for double-flowered trait (sfl_d) is dominant over the allele for triple-flowered trait (sfl_t)**.** The multi-flowered trait is controlled by a different gene (***cym***). Single-flowered plants have dominant alleles at the both the loci (***Sfl_ Cym_***). The double-flower, the triple-flower and the multi-flower traits showed complete penetrance, but variable expressivity. The expressivity was 96.3% for double-flower and 76.4% for double-pod in ICC 4929; 81.2% for triple-flower and 0.0% for triple-pod in IPC 99-18; and 51.3% for multi-flower and 24.7% for multi-pod in JGM 7. Average number of flowers per axis and average number of pods per axis were higher in multi-flowered line JGM 7 than double-flowered line ICC 4929 and triple-flowered line IPC 99-18.

PM Gaur

Allelic relationships of genes controlling stem fasciation in chickpea

Several spontaneous mutants (ICC 2042, ICC 5645, ICC 14871) and one induced mutant (JGM 2) for stem fasciation are known in chickpea. A study was conducted to establish allelic relationships of genes controlling stem fasciation. The four mutants were crossed in all possible combinations. The F_1s from the crosses ICC 2042 × ICC 5645, ICC 2042 × ICC 14871 and ICC 5645 × ICC 14871 had fascinated stem and bred true in F_2. This indicated the presence of a common gene for stem fasciation in the three spontaneous mutants. The F_1s of the crosses of the induced mutant JGM 2 with all spontaneous mutants had normal F_1 plants and segregated in a ratio of 9 normal: 7 fasciated plants in F_2. Thus, the gene for stem fasciation in the induced mutant JGM 7 is not allelic to the common gene for stem fasciation in spontaneous mutants (ICC 2042, ICC 5645 and ICC 14871). The two genes in dominant condition produce normal phenotype. Fasciated plants showed significantly higher mean values for pods per plant and yield per plant than normal plants in F_2 of JGM-2 × ICC 2042. However, in F_2 of JGM-2 × ICC 5645 and JGM-2 × ICC 14871 normal plants had higher mean values than the fascinated plants.

PM Gaur

Milestone: Pathotypes of *Ascochyta* blight (AB), *Botrytis* gray mold (BGM) and *Fusarium* wilts in chickpea and pigeonpea characterized and host plant differentials identified (2006)

Morphological and pathogenic characterization of *A. rabiei*: *Ascochyta rabiei*-infected chickpea plants were collected from 13 locations in northwest plain zones of India during different crop seasons. Following standard mycological procedures, 16 pathogen isolates were observed. Single-spore isolates of these cultures were obtained and stored on potato dextrose agar at 4°C. Morphological and pathogenic characters of these single-spore isolates were studied. Isolates differed in their morphology, pycnidial color (brown to slate grey), formation of pycnidiospores (5.5×10^4 to 3.1×10^5 cm^{-2}) and pycnidial size (156.0 × 116.0 µm to 263.5 × 231.5 µm).

Morphological and pathogenic characterization of *B. cinerea*: To determine the genetic diversity of *B. cinerea* isolates and improve the efficiency of breeding for resistance, the fungus was collected from infected chickpea plants from different locations in Nepal, Bangladesh and India. Thirty-two *B. cinerea* isolates infecting chickpea, lentil and marigold were collected using BGM-specific medium containing tannic acid. Preliminary analysis of eight Indian isolates using 20 RAPD primers (decamers) categorized them into two distinct groups. For further detailed molecular analysis using SSR markers, pure cultures of these isolates were sent to University of Melbourne, Australia.

S Pande and GK Kishore

Morphological and pathogenic characterization of races of *Fusarium oxysporum* f.sp. *ciceri*: Breakdown of host-plant resistance to *Fusarium* wilt is often reported due to the existence of different races of the pathogen. We initiated characterization of *F. oxysporum* f. sp. *ciceri* isolates from major chickpea growing areas of India. A total of 64 isolates of *Fusarium* (60 isolates collected from different locations from India during 1995–2004 and 4 race cultures reported during 1980) were used for characterization of the fungus. Microscopic observations of all these cultures indicated that some of them were black root rot pathogen *F. solani*. Therefore, pathogenicity test using susceptible cultivar JG 62 was conducted to segregate wilt, root rot and non-pathogenic groups. Standard root dip technique was employed for conducting pathogenicity test. Fifteen seedlings of the cultivar JG 62 were dipped in the inoculum of each isolate and transplanted in three pre-irrigated, 15 cm (diameter) plastic pots @ five plants per pot. Each pot represented one replication and all the pots in each replication were arranged in completely randomized block design. Outmost care was taken to avoid cross contamination while preparing the inoculum and during inoculation. The seedlings were observed for wilt symptoms for 30 days.

Three types of reactions were recorded from all these 64 isolates. Nineteen isolates [4 isolates from ICRISAT (AP), 4 from Hisar (Haryana), 1 from Gulbarga (Karnataka), 2 from Rahuri (Maharashtra), 1 from Ludhiana (Punjab), 2 from Pantnagar (Uttaranchal), 3 from Kanpur (Uttar Pradesh), Race 1 (Hyderabad) and Race 2 (Kanpur)] expressed initial wilt symptoms caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC) between 9 and 18 days after inoculation, while 27 isolates produced black root rot symptoms caused by *Fusarium solani*. The remaining 19 isolates were found non-pathogenic to chickpea. Single-spore isolates were obtained from all these pathogenic isolates of FOC following standard mycological techniques. All the single-spore isolates of FOC were tested for their virulence on a susceptible cultivar JG 62 and aggressive isolates were stored in paraffin oil at 4°C for further studies.

Since representation of FOC cultures was not properly covered across the country, collection of isolates was continued in 2004/05 season. Accordingly, 25 isolates were collected from 8 locations in 7 states of India [Dholi (Bihar), Junagadh (Gujarat), Dhaulakuan (Himachal Pradesh), Sehore (Madhya Pradesh), Badnapur (Maharashtra), Ludhiana, Gurdaspur (Punjab), Gaziabad (Uttar Pradesh)]. Pathogenicity tests and single spore isolations are in progress.

S Pande

Morphological and pathogenic characterization of races of *Fusarium udum*: *Fusarium* wilt-infected pigeonpea plants were collected from nine locations in India during 2004 season. *F. udum* was isolated in the laboratory from each sample, using specific medium. These isolates were tested for their virulence on a common susceptible cultivar ICP 2376. All these nine strains (Patancheru, Badnapur, Bangalore, Gulbarga, Akola, Khargoan, Muradnagar, Warangal and Varanasi) were purified by single-spore cutting. In preliminary investigations, morphological differences were observed among different isolates, and pathological differences are being studied in detail.

S Pande and GK Kishore

Milestone: Physiological mechanisms and traits involved in drought avoidance and salinity tolerance characterized in chickpea (2005)

Methodology development for water use efficiency (WUE). In some C_3 crops, an association between water use efficiency (WUE) and Δ(leaf discrimination against ^{13}C) has been used as an indirect selection criterion. However, there is no report so far on the applicability of this technique to chickpea. Therefore, Δ^{13}C method has been under test on 10 diverse chickpea genotypes grown in pots in controlled glasshouse facility. In collaboration with Japan International Research Center for Agricultural Science (JIRCAS), it was shown that WUE of chickpea could be estimated by using Δ^{13}C technique. In 2005, leaf samples of chickpea from the mini-core collection were collected that will be sent to JIRCAS for the analysis.

J Kashiwagi

Milestone: Photoperiod-temperature responses of CMS lines assessed (2006)

Stability of CMS lines: For production of high yielding hybrids, it is essential to identify stable CMS lines. Three CMS lines with diverse cytoplasm were selected for this study. These include ICPA 2067 (A_1 cytoplasm), ICPA 2052 (A_2 cytoplasm), and ICPA 2039 (A_4 cytoplasm). These lines were evaluated at Parbhani and Patancheru during 2004 and 2005 rainy season. Anthers were squashed in 2% aceto-carmine and three microscopic fields were examined for each floral bud. The number of sterile and fertile pollen grains was counted in each microscopic field at one-week interval. The observations showed that ICPA 2039 was the most stable CMS line at both locations. In case of ICPA 2052, five out of 49 plants showed fertile pollen grains (5–30%) and all other plants were sterile throughout the season at Patancheru. More or less similar results were observed at Parbhani. ICPA 2067 was found to be the most sensitive to environmental factors, as 24 out of 28 male-sterile plants, reverted to male-fertility at Patancheru. At Parbhani also, 24 out of 36 male-sterile plants reverted to male-fertility. The reasons for these changes are being examined.

Cytological study conducted at Parbhani showed that the breakdown of tapetum layer at the time of tetrad formation was the reason for male-sterility in the plants. In case of fertile genotypes the tapetum layer remained until the formation of pollen grains. In the environment-sensitive genotypes, the phenomenon of tapetum breakdown is affected by changes in the temperature and photoperiod and hence these lines converted to fertility.

VA Dalvi and KB Saxena

Output 1.3: Effective and eco-friendly IPM technologies designed and evaluated for legumes

Summary

Although the development of improved cultivars with high yield potential and resistance to major insect pests and diseases is a major part of research in this project, these efforts are backed by development and integration of other components of the integrated pest management (IPM), especially in the legumes. Earlier studies had clearly established the effectiveness of Helicoverpa *nuclear polyhedrosis virus (HNPV) for* Helicoverpa *management. A study addressing the problem of bad odour (malodor) and persistence of its virulence during storage showed that of the several preservatives, 10% acetone or 10% ethyl alcohol were most effective for more than six months of storage and substantial suppression of malodor. Also, adopting a simple, affordable farm-level technique, large-scale production of red hairy NPV (RHNPV) with 10000 larvae was successfully carried out at the farm level to demonstrate the usefulness of this technology for highly migratory red hairy caterpillar management. Botanical as well as microbial bio-pesticides (bacterial and fungal origin) have been found to prevent crop damage by insect pests. Research showed a high degree of differential compatibility between the botanicals and microorganisms, implying that identification of botanicals compatible with microorganisms is essential. Alternatively, selection for microbial strains compatible with desired botanicals would also have long-term beneficial effects for these biological options for managing insect pests. On-farm evaluation of an IDM technology that packages compost, Trichoderma and gypsum was found to be highly effective with 99% reduction in aflatoxin contamination, leading to 2 $\mu g\ kg^{-1}$ of aflatoxin in groundnut.*

Activity 1.3.1: Develop cost-effective and eco-friendly components of IPM technologies

Milestone: *Metarhizium* evaluated for the management of groundnut leafminer and *Maruca* (2005)

Evaluation of various insecticides for the management of *Maruca* through field studies conducted at ICRISAT-Patancheru during rainy season 2005 revealed maximum population reduction (82%) with Spinosad (Tracer) followed by indoxacarb (72%), monocrotophos (40%) and *metarhizium* (20%) 48 h after application. Five days after the application of treatments there was 90% population reduction with Spinosad compared to 85% with indoxacarb followed by 22% with monocrotophos. The larval population in *metarihzium* treatment was on par with control (6 larvae plant^{-1}).

GV Ranga Rao

The Year 4 work plan of IPM and IDM farmer participatory trials of IFAD TAG 532-ICRISAT project at various locations in four countries was successfully implemented. The IPM package consisting of botanicals, bio-agents, chemicals and pheromone traps for different legumes is now ready for up scaling in India, Nepal and Vietnam. The use of bio-agent in disease control is also gaining popularity among farmers.

SN Nigam and GV Ranga Rao

Milestone: Components of Aflatoxin (groundnut) and *Helicoverpa* (pulses) management technologies evaluated (2005)

Compatibility of entomopathogenic microorganisms and botanicals

Bacillus subtilis strain BCB 19 of a bacteria and a fungal entomopathogen *Metarrhizium anisopliae* strain GVR had earlier been developed for biological control of *Helicoverpa armigera*. Botanicals have often been used experimentally to prevent crop damage by this and other insects. Therefore, there was an interest to learn if these two microorganisms would survive in the presence of four widely uses botanicals - *Azadirachta indica*, *Gliricidia sepium*, *Calotropis procera*, and *Nerium odorum* in field studies. Hot-water extract and bio-extract (wash of compost prepared from foliage of a given botanical) each of the four botanicals were included in the study. To assess compatibility, both a botanical extract and water suspension of a given microorganism were mixed at a concentration/level recommended for spray and the different mixtures were kept at 26ºC in a glass bottle. Samples from the different mixtures were drawn for determining population of a given microorganism on day 1 and day 7. The study revealed that the strain BCB 19 survived in both types of extracts of all the four botanicals (5.49 to 7.03 $\log_{10}$ mL^{-1}) up to seven days (Table 1.2). In hot-water extracts of two botanicals (*Calotropis procera*, and *Nerium odorum*), population of BCB 19 increased by about 10-times when assessed after seven days. But the fungus *Metarrhizium anisopliae* strain GVR survived well (4.48 to 5.04 $\log_{10}$ mL^{-1}) for seven days, only in bio-extract but not in the hot-water extract of the four botanicals. Thus, identification of botanicals compatible with desired microorganisms is essential. Alternatively, selection for microbial strains compatible with desired botanicals would also be a good idea to have long-term beneficial effects of these biological options of managing insect pests.

Table 1.2. Population (log_{10} mL^{-1}) of *Bacillus subtilis* (strain BCB 19) and *Metarhizium anisopliae* in selected botanicals.

		BCB 19		Metarhizium	
Treatment	Name of botanical	Day 1	Day 7	Day 1	Day 7
Biowash	*Azadirachta indica*	5.70	5.62	5.00	4.48
	Gliricidia sepium	5.63	5.58	5.04	4.78
	Calotropis procera	5.53	5.49	4.78	4.90
	Nerium odorum	5.41	5.52	4.70	4.70
Hot water	*Azadirachta indica*	5.28	6.45	4.30	ND[1]
Extract	*Gliricidia sepium*	6.51	6.36	4.78	ND
	Calotropis procera	5.96	6.86	4.90	ND
	Nerium odorum	5.79	7.03	4.95	ND

1 = ND = Not detected at dilution 10^3.

Population of plant growth promoting rhizobacteria (PGPR) in compost samples and market products

Current trends in agriculture are focused on the diminution of the use of chemical pesticides and inorganic fertilizers. This is strongly indicated by the fact that crops on about 31 million ha (76,326 ha in India) are currently grown without such input (www.orgprints.org, 23 March 2006) on farms widely known to follow organic farming (OF) practices, with third party certification by accredited agencies. Without chemicals, growing good crops on such farms were difficult to believe. High microbial activity of plant growth promoting rhizobacteria (PGPR) in the major inputs (eg, compost) used by farmers was hypothesized as one plausible reason of the high yields. Most of those OF practitioners that we visited used products involving cow dung and, therefore, was included in this study. Compost samples were obtained from seven farmers' fields following OF practices. One sample (with three replications) was from the compost prepared at ICRISAT-Patancheru using the method widely used by organic farmers. Population of four different groups of bacteria (siderophore producers, nitrogen fixers (*Azotobacter* like), phosphate (P) solubilizers, and *Pseudomonas fluorescens* (indicator of bacteria with ability to suppress disease-causing fungi) was identified in these samples. All these bacteria are generally classified as PGPR. Some PGPR are known to function inside plant tissue after entering through roots and express beneficial traits. Several PGPR bacteria are also sold as biofertilizers. We obtained market products of such bacteria from five private sector companies in India and evaluated the population of the relevant bacteria in these products. Results suggested surprisingly high population of beneficial bacteria in composts and lower than expected (10^7 per g carrier or per mL in liquid formulations, as per regulatory system in India) in market samples. Most compost samples were rich in all the three groups of agriculturally beneficial bacteria that were determined - siderophore producers (6.07–8.11 log_{10} g^{-1}), P-solubilizers (<2.00-7.85 log_{10} g^{-1}), and *P. fluroscens* (<3.0–6.89 log_{10} g^{-1}). Also the cow dung and Amrit Paani (another product used widely by organic farmers and prepared using cow dung) were rich in all these bacteria. On the contrary, most products from biofertilizer companies had lower than the expected (10^7 per g carrier-based or per mL liquid-based products) population of desired bacteria. Market products were studied only for three groups of bacteria - nitrogen fixers (3.30–7.45 log_{10} g^{-1}), P-solubilizers (4.70–6.62 $\log_{10}$ g^{-1}), and *P. fluorescens* (2.0–6.81 $\log_{10}$ g^{-1}). The poor quality of the market products thus raises an important question on the justification for spending resources on doing research on PGPR for putting them on market place, when farmers' traditional knowledge products are already rich in such beneficial bacteria. Another important implication of these results is on the manner in which the inputs such as composts are presently used by farmers – by heaping it generally in hot summer when they have spare time before soil incorporation. What happens to the population of these beneficial bacteria will be an interesting piece of investigation.

OP Rupela

Management options for aflatoxin control

To develop low-cost options for the management of aflatoxin contamination in groundnut, a field trial was laid-out at ICRISAT center during 2005 rainy season. The trial comprised of four treatments (application of compost, gypsum and their combination and control) and planted in six replications using randomized complete block design. A susceptible cultivar (JL 24) was used in the trial. Highly toxigenic strain (AF 11−4) of *A. flavus* multiplied on maize/sorghum/pearl millet seed was broadcasted in the field before sowing, followed by row application of inoculum at fortnight intervals starting from 25 days after sowing. Terminal drought was imposed 30 days before harvest to facilitate the seed infection and aflatoxins contamination. Harvesting at 110 days after sowing was done by up-rooting the plant and the produce was dried under sunlight for 5−7 days before the pods were stripped. An increase of 2−11% in pod and haulm yields were observed in treatments over the control (with 857 and 2026 kg ha^{-1} pod and haulm yields, respectively). *A. flavus* infection (0–2%) and aflatoxin contamination (2−4 μg kg^{-1}) was very low in all the graded samples, except in damaged seed. It is very difficult to draw any conclusion of the treatment effect with this kind of data. Low level of *A. flavus* seed infection and aflatoxin contamination could be due to failure to impose the terminal moisture stress conditions in the field as there were continuous rains during the imposed drought stress period.

Farid Waliyar

The validation of chickpea pod borer forecast model revealed the relation between pheromone trap catches and oviposition and larval load in the following 1-3 week period. Pheromone trap catches during 2003–04 postrainy season were at peak (52 moths/trap/day) during first week of December which resulted in peak larval activity (4.5 larvae $plant^{-1}$) in the third week of December. This had given a clear indication of 15 days interval between moth catch and the damage. However, the adult activity during 2004–05 postrainy season was much less (<10 moths/tarp/day) and the consequent lower larval population (1.2 larvae $plant^{-1}$) during the third week of December, when crop was at reproductive phase.

GV Ranga Rao

Milestone: Technologies for mass production, storage and utilization of NPV, bacteria and fungi pathogenic to insect-pests developed (2006)

Helicoverpa nuclear polyhedrosis virus (HNPV) is one of the critical inputs of *Helicoverpa* IPM strategy. Several strains of HNPV are in use in the management of this pest. Of the HNPV strains from six locations (ICRISAT-Patancheru, Ludhiana, Junagadh, Akola, Dharwad and Coimbatore), ICRISAT-Patancheru strain was found to be more virulent based on the lowest LC50 values (0.54×10^8) on fifth day. The studies conducted on their DNA characterization indicated the presence of three to four major polypeptides viz., VP42.32 ± 0.92, VP34.74 ± 0.27, VP31.77 ± 0.44, VP30.66 ± 0.27 in all the strains except the strain from Junagadh, which had an extra polypeptide with 19 ± 1.41 kDa and several minor polypeptides. These studies provided clear-cut evidence on the degree of virulence of various strains. The virulence strains identified would be of immense value for increasing the biotic potential of HNPV under field conditions.

The production and storage of HNPV under various conditions often encountered the problems of bad smell (mal-odor) and persistence of virulence over long periods. In order to address this constraint, studies conducted in evaluating different preservatives for efficient long-term storage of HNPV indicated that virus with 10% acetone resulted in 73% mortality of larvae 10 months after storage, followed by 70%, 63%, 57%, 53%, 47% with 10% ethyl alcohol, 10% phenol, 10% dettol, 10% methanol and 10% ethyl acetate, respectively. Though most of these preservatives showed good response to HNPV storage up to six months, 10% acetone and 10% ethyl alcohol were found to be effective for more than six months while suppressing the malodor substantially. These preservatives are easily available and affordable with an extra input of Rs. 3–12 ha^{-1}. The results obtained can be effectively utilized by the industry and farming communities.

Adopting a simple, affordable farm-level technique, large-scale production of red hairy NPV (RHNPV) with 10000 larvae was successfully carried at the farm level during 2005. This technology would be an added asset in managing the outbreaks of sporadic and highly migratory red hairy caterpillar (RHC) using RHNPV bio-pesticide.

GV Ranga Rao

Activity 1.3.2: Integrated IPM components and validate for effective pest/disease management

Milestone: Low-cost agro-practices for management of groundnut aflatoxin contamination and HPR integrated and tested in farmers fields (2005)

Several research reports indicate that cultural practices such as application of farm yard manure, gypsum, crop residues, and application of several bio-control agents such as non-toxigenic strains of *A. flavus*, *Trichoderma*, *Bacillus* and *Pseudomonas* reduce the aflatoxin contamination. Hence the components, viz., compost, gypsum and *Trichoderma viride* alone and their combination were tested in participatory on-farm trials. The trial was conducted in 10 farmers' fields at Ontillu, M.C. Palem, and Mullaguruvaripalli villages in Pileru. The following components were tested at each farmer's field by adopting plot size of 10×10 m^2. Compost was incorporated in the soil after field preparation, *Trichoderma* was applied in the soil before sowing and gypsum was applied at flowering time. The plantings were carried out during the second fortnight of July using local variety TMV 2 which is very susceptible to aflatoxin contamination.

Components:

1. Application of compost @ 5 t ha^{-1}
2. Application of Trichoderma @ 100 kg ha^{-1}
3. Application of gypsum @ 500 kg ha^{-1}
4. Compost + Trichoderma + Gypsum application
5. Farmers practice (control): At Pileru: Farmers apply neither farm yard manure nor fertilizer whereas at Anantapur farmers applied Muriate of potash, urea and single super phosphate.

In Anantapur district, only *Trichoderma viride* was tested at Rekulakunta village in 10 farmers' fields. *Trichoderma* was applied adjacent to the rows one week after germination. Harvesting was done by uprooting the plants that were field dried. Later, the pods were stripped manually and pod and haulm yields were recorded. Pod samples from each plot were drawn for toxin estimation. After drawing the bulk sample, the damaged pods were sorted out then remaining pods were shelled and sorted into large and small kernels. Results for the bulk samples are presented and other category kernel's processing is in progress.

At Pileru, no significant difference was observed among the treatments with regard to pod and haulm yields. Very low yields were obtained in all the treatments, which may be due to uneven distribution of rainfall that resulted in poor pegging and pod development and pod loss at the time of harvest. Bulk seed samples from all the plots were used for aflatoxin estimation using ELISA. Results on aflatoxin contamination levels in different treatments are very encouraging. Highest aflatoxin contamination 369 µg kg^{-1} was observed in untreated control plot. All the four treatments responded to the treatments by reducing aflatoxin contamination. Highest reduction in aflatoxin contamination (99% showing only 2 µg kg^{-1} of aflatoxin) was observed in the plots with compost when *Trichoderma* and gypsum were applied together, followed by individual application of gypsum, compost and *Trichoderma* over the control plots. Application of compost, *Trichoderma* and gypsum are known to reduce *A. flavus* seed infection and aflatoxin contamination. In the present study, all the individual treatments responded well to reduce the aflatoxin contamination and combination of treatment showed the confounding effect for the reduction of aflatoxin contamination in groundnut.

In Anantapur area, the results indicated that there was 13% increase in pod yield in *Trichoderma*-treated plots over the control plot yield (590 kg ha^{-1}) and there was not much difference in haulm yield. However, there was no aflatoxin contamination in all the 10 treated and control plots.

Farid Waliyar

Phytosanitary aspects of maize for aflatoxin contamination: To assess the aflatoxin situation in maize, surveys were undertaken in the major maize producing districts (Karimnagar, Nizamabad and Medak) of Andhra Pradesh, India. Maize (cobs and kernels) samples were collected 1–7 days after harvest, from rainy season and postrainy season crops grown in 2004–05 and also from various storages for aflatoxin analysis. Maize kernels were analyzed for the total aflatoxin content by ELISA. Of 1151 samples of rainy season crop analyzed, 6% contained >20 µg kg^{-1} aflatoxin (above permissible limit) and about 40% of the samples tested positive to aflatoxins, but the toxin content in these were within the permissible limits of 1–20 µg kg^{-1}. Of 310 maize samples analyzed from postrainy season crop, 8.6% contained >20 μg kg^{-1} of aflatoxins and 46.7% contained aflatoxins within permissible limit, and 44.7% samples tested negative. Out of 100 maize samples analyzed from storages, 20% contained >20 μg kg^{-1} aflatoxin, 76% contained permissible levels and a 4% samples were free from aflatoxins. Sixty percent of the samples analyzed tested positive to aflatoxin, but the toxin content was higher than permissible limits in only 9% of the samples. Being predisposed to *A. flavus* infestation, aflatoxin concentration may increase in the contaminated samples during storage. This indeed was reflected in stored samples, wherein 96% of the samples tested positive to aflatoxin, with 20% having >20 μg kg^{-1} aflatoxin.

A roving survey was undertaken to monitor the status of maize cultivation and to obtain information on general sowing practices of farmers in Karimnagar and Nizamabad districts to implement 'good agriculture practices (GAPs)' for maize cultivation, and to use these data for comparative purposes. Farmers fields for experimental studies to implement GAPs were selected in Gundannapalli, Vattemla, and Shatrajpalli villages in Karimnagar. Two farmers from each of these villages were selected to implement GAPs and to study the affect on pre- and post-harvest aflatoxin contamination.

Farid Waliyar, SV Reddy and P Lava Kumar

Output 1.4: Alternative uses and food/feed quality of crop produce researched and promoted

Summary

Increasing the grain yield through genetic enhancement and IPM technologies contributes to farm income and thus to improved livelihoods. Commercialization of the crop produce through quality improvement and alternative food/feed options can further contribute to these efforts of livelihood improvement. Such commercialization requires inter-institutional alliances. Thus, a DFID-funded sorghum project on "Exploring market opportunities through research, industry and users coalition: sorghum poultry feed" was successfully completed. Based on the experience in this project, which operated on a limited scale in Andhra Pradesh (India) villages, another project, funded by CFC, was launched, which pursues this research on larger scale in more number of villages in Andhra Pradesh and Maharashtra states of India (both for sorghum and pearl millet); and also includes villages in China and Thailand (for sorghum). This project is intended to accelerate the utilization of sorghum and pearl millet grains (as supplement to maize) in poultry feed and bring better economic returns to farmers cultivating these crops. Similarly, considering the growing need for alternative fodder resources for the livestock, forage research was initiated to address this demand and bring in better economic returns to farmers. Single-cross hybrids of sorghum and topcross hybrids of pearl millet were identified that had significantly higher green forage yields than the commercial sorghum-sudan grass hybrids. Further, several three-way sorghum hybrids were identified that had significantly higher green forage yield than the commercial sorghum-sudan grass hybrids. Some of these sorghum hybrids also had higher stalk sugar content and more than four times grain yield than the sorghum-sudan grass hybrids. Considering the growing importance of sweet sorghum for ethanol production to address the energy requirements, breeding materials and hybrids of sorghum having sugar yield and millable cane yield higher than the control variety SSV 84 were identified.

Groundnut variety ICGV 91114 is increasingly becoming popular with farmers in the drought-prone Anantapur district of Andhra Pradesh. An on-farm IDM research involving fungicidal spray showed that pod and haulm yields of this variety can be increased by 30–40% over the non-IDM treatment; and rust severity came down to <5 from rating 7 in the non-IDM treatment on 1–9 scale, which consequently leads to improved fodder quality. Economic analysis indicated higher grosss returns from adoption of ICGV 91114 due to higher pod and haulm yields as well as higher milk yields from animals fed with this variety.

Activity 1.4.1: Documentation and synthesis of available knowledge on utilization patterns and food and feed safety

Milestone: Current knowledge on alternate uses of sorghum and pearl millet synthesized (2005)

Project completion summary report was prepared for the project DFID/NRIL – Exploring marketing opportunities through a research industry, and users coalition: sorghum poultry feed and submitted to DFID.

CLL Gowda, BVS Reddy, P Parthasarathy Rao and Farid Waliyar

Milestone: Poultry feed efficiency of sorghum and pearl millet-based rations assessed (2007)

A strong coalition between sorghum grain producers, poultry feed manufacturers, poultry federation and research institutions, and market linkages between sorghum grain producers and poultry feed manufacturers was established for enhanced use of sorghum in poultry feed. The results were compiled and published in the form of a poster "**Sorghum-based poultry feed rations: a potential alternative to maize**" and a research article titled "**Performance of layers on sorghum-based poultry feed rations".** Further, the interviews conducted by Crop Post-Harvest Program, UK with various stake holders (scientists, project participating farmers, poultry feed manufacturers) in DFID funded project have been published as a booklet titled "Behind the market".

BVS Reddy, P Parthasarathy Rao and RP Thakur

Milestones: Food and feed safety issues of low-aflatoxin groundnut lines addressed (2006)

On-farm participatory varietals selections have been carried out for three years in Andhra Pradesh, India including 2005 rainy season (DFID aflatoxin project). Four varieties (ICGV 91278, 91328, 94379, 94434) in Anantapur area and five varieties (ICGV 91114, 91341, 93305, 94379, 94434) in Pileru area (selected by farmers from 14 originally tested) were evaluated for their yield and aflatoxin contamination. The trials were planted in 18 farmer's fields in six villages each of the two districts. Performance of the four selected groundnut improved varieties was better in all the 18 farmer's fields in six villages in Anantapur district and produced higher pod and haulm yield than the control TMV 2. Highest pod yield (1029 kg ha^{-1}) was obtained with ICGV 94434 in Cherlopalli village. The variety ICGV 94434 produced 40–43% higher pod yield in three villages and in remaining three villages it produced 23–34% higher pod yield than the control TMV 2. ICGV 94379 produced 26% and

40% higher pod yield in two villages. Overall, the mean pod yield of ICGV 94434 was 34% higher and the remaining three varieties produced 15–17% higher pod yield than the control TMV 2, which yielded 590 kg ha^{-1}. Similarly, mean haulm yield increased by 12 to 23%. The aflatoxin contamination was almost nil in two villages (Danduvaripalli and Gummalagunta) and higher level of aflatoxin contamination was observed in West Narsapuram and Cherlopalli. At West Narsapuram post-harvest rains caused delay in drying of the produce and finally resulted in high level (13–241 μg kg^{-1}) of aflatoxin contamination. ICGV 94379 was tolerant (<4.0 μg kg^{-1}) in five of the six villages and it also produced 17% higher pod yield than the control TMV 2. Overall mean (six villages pooled) of aflatoxin contamination indicated that all the four improved varieties showed reduction in aflatoxin contamination ranging from 40 to 73% over the control. The highest reduction (73%) in toxin contamination was recorded in ICGV 94379. Considering the complex nature of the aflatoxin problem in groundnut, the overall mean of the six villages indicated that the improved varieties showed good tolerance to aflatoxin contamination. In addition, these lines produced 15–34% higher pod and haulm yields than the local control TMV 2.

In Piler area, pod and haulm yields ranged from 226 to 1255 and 816 to 2654 kg ha^{-1}, respectively across the six villages. All the improved varieties produced higher pod and haulm yields than control TMV 2 in all the villages. In M.C. Palem, four of the five improved varieties produced significantly higher pod yield. Highest mean pod yield (593 kg ha^{-1}) and haulm yield (1933 kg ha^{-1}) was obtained in ICGV 94379, followed by pod yield of 586 kg ha^{-1} and haulm yield of 1835 kg ha^{-1} in ICGV 91114. On average, 16–61% increase in mean pod yield and 30–54% increase in mean haulm yield was recorded. Aflatoxin contamination ranged from 0 to 869 μg kg^{-1} across the villages and improved varieties showed lower level (90 to 242 μg kg^{-1}) of aflatoxin contamination than the control TMV 2 (310 μg kg^{-1}). In general, the aflatoxin contamination in Piler area was higher than the normal situation because of the continuous rains during pre-harvest, harvest and post-harvest stages. The improved varieties were developed with aflatoxin resistance mainly for pre-harvest situations. Since the improved varieties were exposed to adverse post-harvest rains, delayed pod drying, these became vulnerable to aflatoxin contamination. However, even in this adverse post-harvest environmental situation, there was about 36–73% reduction in overall mean aflatoxin levels in improved varieties than the control TMV 2. The highest (73%) mean aflatoxin reduction was observed in ICGV 91341, followed by 67% in ICGV 91114. ICGV 91114 recorded 59% higher pod yield than TMV 2. Therefore, our approach to combine resistance with other management practices is of major importance. In this context, low-cost aflatoxin management technologies showed encouraging results. Using some of the management practices, aflatoxin contamination was reduced by 99%.

Collective ownership of threshers by poorer farmers in the villages was due to awareness of aflatoxins and to promote early pod separation. The involvement of local NGOs and Department of Agriculture in the process also substantially increased their awareness and interest in combating the aflatoxin problem. ICRISAT and NGOs effort in facilitating the process established method of collective use of farm machinery. This helped to empower and enhance the livelihood opportunities of the women and poor farmers by increasing their incomes, as well as helping to produce groundnuts and groundnut fodder with reduced levels of aflatoxin content. The project's objective of promoting early pod stripping will also be sustainable after the projects withdrawn.

From a policy perspective, the Aflatoxin Awareness Panel's activities were instrumental in positively motivating the Government of Andhra Pradesh, India to pay conscious attention to aflatoxin awareness and aflatoxin detection. It has complimented ICRISAT's efforts to influence the Government to set up an aflatoxin analysis laboratory in Anantapur, which was completely funded by the State Government. Now farmers in Anantapur will be able to check their farm products to target different markets and benefit from a better price.

Many awareness programs such as newspapers, flyers, TV programs, meetings and field demonstrations helped to increase awareness in the primary project area but also in many other regions in Asia and Africa. A British Broadcasting Corporation (BBC) program on ICRISAT activities was recorded for telecast around the world. As secondary impact of DFID investment in aflatoxin research, is the establishment of ELISA detection facilities and training of appropriate staff in Malawi and Mozambique is important. The access to this technology helped farmers' associations to successfully export aflatoxin-free groundnut. This technology will be further transferred to other countries in Asia and Africa.

Farid Waliyar

Activity 1.4.2: Develop technological options and institutional alliances to enhance market demand for crop produce

Milestone: Institutional alliances to promote the use of sorghum in poultry feed developed (2006)

In March 2005, a project supported by DFID on "Exploring marketing opportunities through research, industry and users coalition: sorghum poultry feed" was successfully concluded involving selected villages of Ranga Reddy and Mahabubnagar districts of Andhra Pradesh, India. Encouraged by the success, another project to up-scale the findings by expanding the coverage to more areas -Udityal in Andhra Pradesh, Parbhani and Beed districts in Maharashtra in India; Beizhen, Heishan and Yi provinces in China; and Suphan Buri, Kanchana Buri and Nakon Sawan provinces in Thailand–was successfully negotiated with CFC/FAO and received the approval for funding. The project implementation was launched in May 2005. The work, which involves coalition building among various stakeholders, is in progress and the highlights of progress achieved during year1 are described below.

Based on work plans of the project in year-1, in Andhra Pradesh, two clusters-Udityal cluster (6 villages) and Palavai cluster (5 villages) comprising of 668 farmers were selected in Mahabubnagar district; and in Maharashtra three clusters-Koak cluster (5 villages) in Parbhani district, Anjanpur cluster (6 villages) in Ambajogai Taluk and Patoda cluster (5 villages) in Patoda Taluk in Beed district comprising of 1050 farmers were selected in India. Two clusters one each in Beizhen, Heishan and Yi provinces in China, and Suphan Buri, Kanchana Buri and Nakon Sawan provinces in Thailand were identified.

ICRISAT, the Project Executing Agency (PEA) with the support of coalition partners' facilitated the formation of farmers associations in all the clusters. The capacity building needs of the partners and farmers were identified and strengthened by conducting various training programs. Initially, farmers were made aware of improved cultivars and production technologies for sorghum and pearl millet for enhancing the grain production. Several training programs, exposure visits, and on-farm meetings were conducted on the use of improved crop production technologies. Innovative input chain and marketing linkages were developed for marketing surplus grain. Farmers' capacity on grading, bulking and marketing of surplus grain produce were built. As a result of this, farmers from one of the clusters (Anjanpur) in Maharashtra (India) could market their sorghum grain at 10% higher than the prevailing price in the market.

A Alur, Ch Ravinder Reddy, BVS Reddy, P Parthasarathy Rao and CLL Gowda

Activity 1.4.3: Improve fodder yield and quality for enhanced ruminant nutrition

Milestone: Effective IPM technologies to enhance fodder quality of dual-purpose and pest resistant sorghum and groundnut varieties validated (2005)

On-station evaluation of early and medium-maturing groundnut cultivars for higher quality and quantity of haulms and pods

Groundnut provides valuable edible oil for human and nutritious fodder for cattle in Deccan Plateau, India. Pod and fodder yields are very low in groundnut due to several diseases. Among these diseases, late leaf spot [(LLS) *Phaeoisariopsis personata*] and rust (*Puccinia arachidis*) are most destructive and often cause severe losses in quantity and quality in farmers' fields. Cultivars having moderate resistance to foliar diseases, when combined with moderate levels of management (economical use of fungicide), produce higher quantities of healthy fodder as well as pods. Healthy fodder has high digestibility and increases milk yield in dairy cattle. Therefore, to identify high-yielding dual-purpose groundnut cultivars with economical level of foliar disease management, a replicated trial consisting of 10 early- and six medium-maturing genotypes with six disease management levels was conducted at ICRISAT-Patancheru during 2004 rainy season. Highly susceptible cultivar TMV 2 was included as one of the entries for comparison. Plot size was four rows of 9 m with 60 × 10 cm inter- and intra-row spacing. Disease management levels using fungicide chlorothalonil (Kavach @ 2 g L^{-1} water) were: (1) no spray, (2) one fungicide spray at 60 days after sowing (DAS), (3) two fungicide sprays at 60 and 75 DAS, (4) three fungicide sprays at 60, 75 and 90 DAS (for medium-maturing cultivars only), (5) weather-based advisory system using leaf wetness counter and (6) continuous fungicide spray from 30 DAS till maturity with 10-day interval. Design of the experiment was split-plot with spray schedules as main plots and genotypes as sub-plots. Severity of foliar diseases was recorded on 1–9 rating scale at regular intervals of crop growth. At harvest, dry weights of fodder and pods were recorded and yield per hectare was calculated.

One fungicide spray at 60 DAS for early maturing and two fungicide sprays at 60 and 75 DAS for medium-maturing genotypes gave higher yields and healthy fodder with low foliar disease severities. Lowest foliar disease severities (3.7 to 4.3 for LLS and 5.3 for rust) and highest healthy fodder (2.0 to 2.5 t ha^{-1}) and pod yields (1.46 to 1.6 t ha^{-1}) were recorded in ICGV 99201, ICGV 99206 among early-maturing cultivars. Among medium-maturing cultivars, lowest disease severity (up to 4.0 for both LLS and rust), highest fodder (up to 3.8 t ha^{-1}) and pod (1.59 to 1.74 t ha^{-1}) yields were obtained in ICGV 99032 and ICGV 99054.

S Pande

On-farm validation and promotion of integrated disease management (IDM) technology in groundnut

One hundred and twenty one farmers were selected from five villages, Jalalapuram (43), Lingareddypalli (46), Talupuru (22), Antaraganga (5) and Jonnalakothapalli (5) in Anantapur, India in the year 2004 rainy season to promote IDM technology that involved fungicidal spray schedule mentioned above. Nearly 80% of the trials during this season were sown with short-duration dual-purpose cultivar ICGV 91114, as this cultivar was preferred by several farmers. Other cultivars included in these trials were ICGV 89104 (early-maturing); and ICGV 92020 and ICGV 92093 (medium-maturing). All these trials were conducted in close collaboration with District Agricultural Advisory and Transfer of Technology Center (DAATTC), Acharya NG Ranga Agricultural University (ANGRAU), Anantapur and Accion Fraterna/RDT-Anantapur. Each trial was planted in 0.2–0.3 ha and was compared with local cultivar, (JL 24/TMV 2) for pod and fodder yields. In addition to these trials, farmers in several villages in the states of Andhra Pradesh, Karnataka and Tamil Nadu (India) adopted the technology during 2004 rainy season. Plantings were completed by 12 July 2004 due to arrival of timely monsoons in all the selected villages. Fortunately, unlike the previous years, there was a good distribution of rains and pod and fodder yields were high compared to previous years. Mean severity of foliar diseases across the villages in the most preferred cultivar, ICGV 91114 with IDM was <5 rating on 1–9 rating scale and fodder (haulm) and pod yields, respectively, were 2.46 and 2.08 t ha^{-1}, while severity of foliar diseases in non-IDM plots was around 7 rating and haulm and pod yields were 1.94 and 1.41 t ha^{-1}. Thus, the dual-purpose cultivar ICGV 91114 was found suitable under rainfed cultivation in Anantapur district of Deccan Plateau, Andhra Pradesh, India.

S Pande

Promotion of improved foliar disease resistant groundnut cultivars in the Deccan Plateau of India

Groundnut is grown extensively in the Deccan Plateau of India (75% of cropped area) by resource poor farmers; and groundnut haulms are the major source of home grown fodder for their animals. However, Anantapur district (Andhra Pradesh) in the heart of the Deccan Plateau faces fodder shortage of around 10 to 15% of the total requirement varying from 240,000 t in a drought year to 75,000 t in a normal year. Within the district, in about one-fourth of the 63 mandals (divisions), the fodder shortage is more acute. These mandals fall in the low to medium rainfall category and are located mainly in the western and central part of the district. The state government is trying to mitigate the fodder shortage through various programs that include community fodder cultivation on tank beds, supply of straw on subsidy, cattle camps, demonstrating the use of azolla (an alternate and less expensive livestock feed with unique combination of proteins, minerals, vitamins and essential amino acids), supply of fodder seed for cultivation on private lands, etc. However, these programs are not able to mitigate the shortage and a majority of farmers are buying crop residues, mainly paddy straw. The preference for paddy straw is twofold: as a cereal supplement to groundnut haulm, and as a cover to protect the staked groundnut haulm from rains. A majority of those purchased paddy straw were marginal and small farmers.

The main source of supply is from the command area of Tungabhadra river high-level canal irrigation (HLCI) that passes through the central and northwestern part of the district. Here paddy accounts for more than 10–15% of cropped area. Villages within a radius of 50–60 km of these command areas buy their supplies of paddy straw immediately after harvest. During drought years, villages at a distance of 150–200 km also get their supplies from the canal irrigation areas. Additionally, during summer months and acute drought years, the state government procures paddy straw from the coastal districts that are 400–500 km away.

Since farmers were keen to augment their own fodder resources, they identified new groundnut cultivar ICGV 91114, resistant to foliar diseases to meet their multiple requirements ie, higher pod yield and haulm yield to improve food security and increased incomes from sale of pods, haulms, and dairy products. Economic analysis indicated higher gross returns from adoption of ICGV 91114 due to higher pod yields, higher haulm yields, and higher milk yield from animals fed with these haulms.

Based on reconnaissance surveys in 2005, it was found that the improved groundnut cultivar ICGV 91114 is grown in more than 120 villages covering 4 districts in Andhra Pradesh state and 3 districts in Karnataka state. Two-thirds of the villages are located in Anantapur district. The location of these villages was recorded using GPS instrument. A majority of the villages are located in the low to medium rainfall mandals indicating the importance of this cultivar for resource poor farmers in marginal environments. Tracking these villages at some future point would give insights into factors leading to faster spread in some locations as compared to others. The spread of the improved cultivar as documented is, however, an underestimate since information on adoption was not recorded from several villages located in the hinterlands, ie, far away from state or national highways.

The potential impacts on marginal and small farmers would depend on the linkages between small farmers, the public sector actors (seed sector, extension, marketing, etc.) and other stakeholders in the groundnut and the milk economy (dairy cooperatives, etc.). The linkage between adoption of the improved technology, higher incomes, asset acquisition reinvestment in agriculture and improvement in overall quality of life will have to wait until the technology is adopted on a larger scale at the household level. At present, it is observed that a majority of the farmers are risk averse and hence are adopting the new technology only on 10–20% of their cropped area.

S Pande and P Parthasarathy Rao

Milestone: Village level seed multiplication system established and effect of plant diseases on yield and nutritive value of crop residues of groundnut and sorghum assessed (2005)

To study the effect of plant diseases on yield and nutritive value of groundnut haulms in relation to animal health, 72 haulm samples from six groundnut varieties (ICGS 44, ICGS 11, DRG 12, ICGV 86325, ICGV 92020 and ICGV 92093) were collected and processed by ELISA for aflatoxin contamination. The aflatoxin contamination in these samples ranged from 0 to 33 μg kg^{-1} and about 25% of the samples were found to be contaminated with the toxin. Among the six groundnut varieties, all the 15 haulm samples from ICGV 86325 were contaminated in the range of 12̃33 μg kg^{-1}. In remaining varieties, the aflatoxin contamination level was very low.

Milk samples from the feeding trials (conducted with farmers in Anantapur district, India) were collected and analyzed by ELISA for aflatoxin M1 contamination. Aflatoxin M1 concentration in these samples ranged from 0 to 15 μg kg^{-1}. Of the 328 samples tested, 42% contained >0.5 μg kg^{-1} (non-permissible level) of aflatoxin M1 contamination.

Farid Waliyar

Establishment of village-level seed system for groundnut in Anantapur district, India

Groundnut is grown extensively in the Deccan Plateau of India by resource-poor farmers. Seed is very important and expensive component of groundnut cultivation. There is no organized seed system for groundnut in this region. Few farmers store their rainy season produce as seed for the following season. Most of the poor farmers depend on large farmers or government agencies for the seed. Since seed to grain multiplication ratio is very low in groundnut, it is not possible for any single agency to supply the seed to all the groundnut growing farmers. Therefore, a village-level seed multiplication system was established in four villages in the district Anantapur in collaboration with District Agricultural Advisory and Transfer of Technology Center (DAATTC), ANGRAU-Anantapur, and Rural Development Trust (RDT) NGOs, during 2004 post rainy season. Six farmers in the village Jalalapuram, nine farmers in the village Lingareddypally, four farmers in the village Talupuru and three farmers in the village Vasanthapuram in the district Anantapur participated in the seed multiplication of the cultivar ICGV 91114 in 12 ha during the 2004 postrainy season. The produce was sold to many other farmers as seed in all these villages.

Establishment of village-level seed system for chickpea in Nepal: Chickpea is one of the important grain legume crops in Nepal and is being cultivated profitably in rice-fallow lands. Non-availability of seeds of improved chickpea varieties is one of the constraints for low yields in this country. Seed is an important component of Nepalese farming systems. Formal seed system is lacking in this country and farmers obtain seed for planting mostly from previous harvest and thus there is no difference between seed and grain. Resource poor farmers obtain seed from others or purchase from local market. Therefore, to ensure continuous supply of good quality seed, we initiated farmer seed system in collaboration with National Grain Legumes Research Program (NGLRP) and National Oilseeds Research Program (NORP) for producing the seed of improved variety Avarodhi during 2004/05 postrainy season. This system is run by a few farmer groups/self help groups (SHG). Nine farmers in the Rajahar village, Nawalparasi district, and six farmers in the village Bardibas, Mohattari district multiplied the cultivars Avarodhi and Tara during 2004 postrainy season. Grain yield in Avarodhi was 1620 kg ha^{-1} in the Bardibas village and 818 kg ha^{-1} in the Rajahar village, while that of Tara was 800 kg ha^{-1} in the village Rajahar and 500 kg ha^{-1} in the village Bardibas. All the seed was sold to other farmers in the village for sowing in the 2005 postrainy season. Thus, the village-level seed system was found successful in these two villages in Nepal.

On-station evaluation of the effect of plant diseases on yield and nutritive value of crop residues of dual-purpose groundnut cultivars: Late leaf spot [(LLS) *Phaeoisariopsis personata*] and rust (*Puccinia arachidis*) are destructive diseases and cause severe losses in yield and nutritive quality of crop residues. Management of these foliar diseases increases the yield as well as it enhances the quality of the crop residue. Therefore, a replicated trial consisting of 10 early- and six medium-maturing genotypes with five disease management levels to identify high-yielding dual-purpose groundnut cultivars was conducted at ICRISAT-Patancheru during 2004 rainy season. Highly susceptible cultivar TMV 2 was included as one of the entries for proper comparison. Plot size was four rows of 9 m with 60 × 10 cm inter-and intra-row spacing. Disease management levels using fungicide chlorothalonil (Kavach @ 2 g L^{-1} water) were (1) no spray, (2) one fungicide spray at 60 days after sowing (DAS), (3) two fungicide sprays at 60 and 75 DAS, (for medium-maturing cultivars only), (4) continuous fungicide spray from 30 DAS till maturity with 10-day interval. Design of the experiment was split-plot, with spray schedules as main plots and genotypes as sub-plots. Severity of foliar diseases was recorded on 1–9 rating scale at regular intervals of crop growth. The quality of crop residue, ie, haulms was found superior in fungicide-sprayed plots of early and medium maturing cultivars than unsprayed plots of TMV 2. Foliar disease severity rating was up to 5 on a 1–9 rating scale in the plots that received one fungicide spray at 60 DAS (early-maturing cultivars) and two fungicide sprays at 60 and 75 DAS (medium-maturing cultivars) compared to 9.0 rating in unsprayed plots of susceptible TMV 2. Among early-maturing cultivars with one fungicide spray at 60 DAS, haulm and pod yields were significantly higher in ICGV 99201 (2.40 and 1.65 t ha^{-1}) and ICGV 99206 (2.5 and 1.46 t ha^{-1}) than TMV 2 (1.79 and 0.81 t ha^{-1}). Among medium-maturing genotypes, with two sprays at 60 and 75 DAS, haulm and pod yields respectively were 3.8 and 1.74 t ha^{-1} in ICGV 99032 and 3.9 and 1.74 t ha^{-1} in ICGV 99054 compared to 1.79 and 0.81 t ha^{-1} in TMV 2.

Suresh Pande

Milestone: High-tillering sorghum population further improved for high biomass yield and quality traits (2006)

Population improvement with recurrent selection involving male-sterility-inducing gene (ms_3), besides offering greater opportunity for increasing the frequency of existing desirable genes/traits, would allow introgression of other genes/traits of importance. Such improved and/or introgressed trait-specific population would provide valuable base material for the development of broad-based trait-specific hybrid parents and high-yielding varieties. At ICRISAT-Patancheru, a high tillering population (ICSP-HT) is being improved for high tillering, sweet-stalk trait and resistance to foliar diseases.

The sweet-stalk varieties, SSV 74 and SSV 84 were crossed to male sterile plants of ICSP-HT population to introgress sweet-stalk trait. The ICSP-HT population (C_9) bulk and F_2 crosses bulk (derived from crossing SSV 84 and SSV 74 with male-steriles of ICSP-HT population) were evaluated in rainy season 2005. Selections were made separately for male-sterile and male-fertile plants in the population as well as in bulks. The bulk was advanced to F_3 and the population bulk was advanced to C_{10}. From population bulk, 181 male-sterile and 86 male-fertile plants were selected. From ICSP-HT population × SSV 84 cross bulk, 31 male-sterile and 35 male-fertile plants were selected; and from ICSP-HT population × SSV 74 cross bulk, 57 male-sterile and 61 male-fertile plants were selected. The C_{10} population bulk and F_3 crosses bulks was reconstituted by mixing the seed of male-sterile and male-fertile plants in 3:1 ratio (separately for each bulk).

BVS Reddy and S Ramesh

Milestone: Sorghum and pearl millet hybrid parents with high forage yield potential and forage quality developed (2006)

In recent years, there has been a growing demand for fodder resources due to spurt in dairy industry in India, especially in peri-urban areas. Because of its quick growth, ratoonability and tolerance to biotic and abiotic stresses, sorghum is an excellent candidate crop for meeting the increasing demand for both green and dry fodder (stover).

Germplasm lines and the breeding lines (290) were evaluated during the 2004-05 postrainy season for high stalk-sugar and biomass. Some of the trait-specific B-lines developed earlier in different programs were evaluated for biomass production ability and stalk-sugar content. Also, some hybrids made in the postrainy season were evaluated for the above two traits in the summer nursery. Besides these, tillering lines selected from different programs were evaluated for green fodder yield and stalk-sugar content. Based on these activities, the following trials (constituted from selected lines from the postrainy season) were conducted in the 2005 rainy season.

Sweet sorghum preliminary varieties/restorers trial (SSPVRT): The germplasm and the breeding lines (290) were evaluated in an un-replicated nursery; and 42 sweet-stalk varieties and restorers were evaluated in a replicated trial during the 2004-05 postrainy season for stalk-sugar content and biomass. Based on the performance for these traits, 99 lines were selected and evaluated in a replicated trial along with controls NSSH 104, SSV 74 and SSV 84 during 2005 rainy season. Brix reading was taken at 18 days after 50% flowering. The sugar yield was estimated based on Brix reading and juice yield. Some of the breeding progenies, SP 4481-1 (6.5 t ha^{-1}), SP 4484-2 (6.4 t ha^{-1}) SP 4504-3 (6.1 t ha^{-1}), SP 4484-3 (5.6 t ha^{-1}) and SP 4511-3 (5.4 t ha^{-1}) were significantly superior to the control SSV 84 (3.2 t ha^{-1}) for sugar yield based on Brix reading and juice yield. The millable cane yield of these progenies (64.9 to 102.8 t ha^{-1}) was also significantly superior to that of SSV 84 (49.8 t ha^{-1}). These progenies will be further advanced with selection.

Sweet sorghum advanced B-lines trial (SSABLT): A total of 67 high-yielding and trait-specific B-lines developed earlier in different programs were evaluated for biomass production ability and stalk-sugar content along with the controls SSV 74, SSV 84 and 296B in a sweet-stalk preliminary B-lines trial. Based on the Brix reading at maturity, 43 B-lines were selected and evaluated in SSABLT along with the same controls during 2005 rainy season. None of the B-lines performed better than the controls SSV 74 and SSV 84 for sugar yield based on Brix reading and juice yield. However, 13 B-lines (1.4 to 2.7 t ha^{-1}) significantly outperformed the control 296B (0.6 t ha^{-1}) for sugar yield.

Sweet sorghum preliminary hybrid (non-tillering) trial (SSPHT): A total of 158 hybrids involving 25 female parents and 14 male parents were evaluated during 2005 rainy season. Based on the sugar yield estimated at flowering stage, top performing 25% of the lines were selected and the sweet-stalk parameters were recorded at maturity. The hybrid ICSA 675 × SSV 74 (6.7 t ha^{-1}) was significantly superior to NSSH 104 (4.3 t ha^{-1}) for sugar yield, and comparable for total soluble sugars (12.1% as against 13.5% in NSSH 104) . Eleven hybrids (4.4 to 5.5 t ha^{-1}) were numerically superior to NSSH 104 for sugar yield.

Sweet sorghum advanced hybrids (non-tillering) trial (SSAHT): A total of 30 selected sorghum hybrids were evaluated along with the controls SSV 74, SSV 84 and NSSH 104 during 2005 rainy season. None of the hybrids were comparable to the control NSSH 104 (5.5 t ha^{-1}) for sugar yield. However, nine hybrids (25.2 to 35.1 t ha^{-1}) were comparable to NSSH 104 (32.7 t ha^{-1}) for juice yield, and three hybrids (15.8 to 17.2%) were comparable to NSSH 104 (18.0%) for Brix reading at maturity.

Sorghum forage and tillering lines trial (SFTT): High tillering lines (61) selected from different programs were evaluated along with the controls SSG 59-3, GK 908 and GK 911 for green fodder yield and stalk-sugar content at 50% flowering during 2005 rainy season. A total of 22 hybrids (89.2 to 160.3 t ha^{-1}) significantly outperformed the controls SSG 59-3 (51.7 t ha^{-1}), GK 908 (60.5 t ha^{-1}) and GK 911 (60.4 t ha^{-1}) for fresh fodder yield. The stalk-sugar content of 15 of these 22 lines (11.2 to 15.8 Brix) significantly outperformed the control GK 908 (Brix 8.1%). These lines are promising for further selection and multilocation testing.

Three-way cross trial: Most of the private sector seed companies develop and market three-way hybrids for forage purposes, using grain sorghum male-sterile lines as seed parents and sudan grass lines as male parents. In order to evaluate the potential of ICRISAT-developed grain sorghum male-sterile lines and forage restorer lines/varieties in hybrid combinations, 87 three-way hybrids were made by crossing forage/sweet-stalk varieties onto male-sterile single cross F_1s (obtained by crossing grain sorghum A-lines with non-isogenic B-lines). These were evaluated in a replicated trial for forage yield potential and stalk-sugar content at grain maturity during the 2005 rainy season. Forty-seven hybrids (28.8 to 46.6 t ha^{-1}) outyielded popular control variety SSG 59-3 (21.7 t ha^{-1}) for green fodder yield. The Brix reading of these selected hybrids ranged from 5.5 to 18.4% against 12.9% in SSG 59-3. Two test hybrids [(ICSA 351 × ICSB 394) × ICSV 25263] (Brix 18.4%) and [(ICSA 73 × ICSB 369) × ICSR 93025] (Brix 17.6%) had significantly higher stalk-sugar content than SSG 59-3 (Brix 12.9%). Further, stalk-sugar content of 30 hybrids (Brix ranging from 17.1 to 12.9% was either numerically higher or on par with of SSG 59-3 (Brix 12.9%). The grain yield potential of many of these hybrids (0.8 to 2.7 t ha^{-1}) was significantly superior to that of the control SSG 59-3 (0.2 t ha^{-1}).

BVS Reddy, M Blümmel and S Ramesh

Hybrid yield potential of forage-type male-sterile lines: Among the seed parents (A-lines) developed for grain/dual-purpose hybrid production, eight A-lines had potential as seed parents of forage hybrids. Three of these male-sterile lines (ICMA 89111, ICMA 00999 and ICMA 03222) were crossed with each of the nine forage populations to produce 27 experimental hybrids, which were evaluated along with seven controls comprising 2 pearl millet forage hybrids, 3 dual-purpose hybrids, 1 OPV (WC-C 75) and 1 sorghum-sudan grass hybrid (GK 908) for forage yield at 80-day harvest. From amongst the controls, earlier identified forage pearl millet hybrid ICMA 00999 × IP 17315 (14.3 t ha^{-1}) had 13% higher dry forage yield than GK 908 (12.7 t ha^{-1}). Of the test hybrids, seven hybrids (3 on ICMA 89111 and 4 on ICMA 00999) had 14.3-16.3 t ha^{-1} dry forage yield. All these experimental hybrids flowered in 64–78 days (74 days for the control hybrid). Forage varieties such as ICMV 05222 and ICMV 05111 (both tall, thick stem type) had significant positive gca effects for dry forage yield at 80-day harvest, plant height and days to 50% flower, indicating delayed flowering and plant height were associated with increased dry forage yield. The highest yielding hybrid was again on ICMA 00999 that involved ICMV 05222 as the population pollen parent.

KN Rai, VN Kulkarni and M Blümmel

Output 1.5: New technologies evaluated, disseminated and their impact documented

Summary

Crop production and protection technologies developed at research stations must be validated on-farm for their relevance in terms of yield gains, farmers' acceptance and cost effectiveness. This should be backed by technology transfer efforts to enhance the pace and scale of their adoption. Impact assessment must constitute an integral part of technology development and dissemination.

An Integrated Crop Management (ICM) technology for chickpea that consists of a BGM-tolerant cultivar ICC 14344 (Avarodhi), fungicidal treatment, wider row spacing, application of rhizobium, DAP fertilizer, and judicious use of pesticides to control BGM and pests was adopted by 20,000 farmers in rice-fallow lands in 14 districts of Terai region of Nepal (Fig. 1.3). In addition, 250 farmers planted these ICM trials in two villages in central Nepal. Six ICRISAT-bred chickpea varieties were evaluated in on-farm participatory variety selection in Uttar Pradesh, Haryana and Uttaranchal states of India, where chickpea was intercropped with sugarcane. BGM severity was lower and grain yields were higher in all the improved cultivars as compared to the locals. The large-seeded kabuli variety KAK 2 emerged as the most preferred variety. An impact assessment report on chickpea adoption in Ehiopia was published. Results of a survey conducted with 300 households in four chickpea growing districts in central Ethiopia showed 6 to 66% variation in adoption across the districts, which resulted largely from the lack of awareness of improved varieties among the farmers. Of the five varieties that had been adopted, Mariye had the largest coverage. Important characteristics influencing adoption were high yield, early maturity and drought tolerance.

Groundnut variety ICGV 91114 has been rapidly spreading in the Anantapur district of Andhra Pradesh, grown by 450 farmers in 45 villages in 371 ha just for seed increase. Farmers' preference for this variety over the traditional TMV 2 is due to its earliness, ability to tolerate mid-season and terminal drought, tolerance to pests and diseases, more number of uniform pods, and higher pod and haulm yields. This variety has now also spread to three districts of the neighboring Karnataka state.

Results of an initial evaluation of short-duration pigeonpea in the rice-fallow areas of northern Philippines appeared promising as are the prospects of vegetable pigeonpea for local consumption, and perennial pigeonpea for rehabilitation of degraded lands.

Two International Chickpea Screening Nurseries, (ICSN-Desi *and ICSN*-Kabuli*), were evaluated by NARS scientists during 2004/05. Thirty sets of ICSN*-Desi *and 29 sets of ICSN-*Kabuli *were distributed to NARS scientists of 9 countries for evaluation during 2005/06. Forty-one sets of International Groundnut Varieties Trials (4 foliar diseases resistant, 8 drought tolerant, 7 short-duration, 7 medium-duration, 3 aflatoxin resistant and 12 confectionery) were supplied to collaborators in Afghanistan, Bangladesh, China, India, Indonesia, Philippines, South Africa and Sudan. Four sets of a new international trial, formulated with red-seeded groundnut varieties and advanced breeding lines, were dispatched to the Project Facilitation Unit (PFU), Tashkent, Uzbekistan. These sets will be evaluated in Uzbekistan, Tajikistan, Armenia and Georgia.*

On specific seed requests (including selections made during the Scientists Field Days), we supplied 12,659 seed samples of sorghum (5648), pearl millet (4273), chickpea (1853), and pigeonpea (885). Also, we supplied 527 breeding lines and 237 segregating populations of groundnut. Eight varieties of chickpea (3) and groundnut (5), and one hybrid of sorghum were released by NARS during 2005.

Activity 1.5.1: Farmer participatory research and development

Milestone: Effectiveness of farmers' participatory selection of sorghum for postrainy season adaptation evaluated (2005)

In order to assess the effectiveness of farmers' participatory selection for postrainy season adaptation, a replicated trial consisting of 52 lines (26 farmer selection and 26 breeder selection) adapted to postrainy season that was selected from F_6 generations were evaluated at ICRISAT-Patancheru; Regional Agricultural Research Station, Bijapur; and Akola (India) during the 2004–05 postrainy season. Data received from Bijapur along with Patancheru were analyzed and the results are reported below. The data from Akola were not received.

Data were recorded for days to 50% flowering, plant height (m), stay-green score (taken on a scale 1 to 5 at harvest, where 1 = >75% green, 2 = up to 75%, 3 =2 6–50%, 4 = 10–25% green, and 5 = <10% green), lodging score (taken on a scale 1 to 5 where 1 = no lodging, 2 = up to 25% lodged, 3 = 26–50%, 4 = 51–75%, 5 = >75% of plants lodged), grain lustre and shape score (taken on a scale 1 to 5, where 1 = lustre and globular like M 35-1, 2 = lustre but not globular, 3 = less lustre but globular, 4 = less lustre and flat and 5 = less lustre and flat with beak), grain size (g 100^{-1}) and grain yield (t ha^{-1}). At both Bijapur and Patancheru, the mean grain yield of breeders' selections (Patancheru: 3.2 t ha^{-1}, Bijapur: 1.1 t ha^{-1}) was marginally superior to that of farmers' selections (Patancheru: 2.7 t ha^{-1}, Bijapur: 1.1 t ha^{-1}). However, grain size of farmers' selections (Patancheru: 3.2 g 100^{-1}, Bijapur: 3.3 g 100^{-1}) were marginally superior to that of breeders' selections (Patancheru: 3.1 g 100^{-1}, Bijapur: 3.0 g 100^{-1}). Farmers' selections were more tolerant to lodging and senescence and were late maturing than breeders' selections at both the locations. However, for grain lustre, contrasting results were obtained in two locations. While, farmers' selections were more lustrous at Bijapur, breeders' selections were more lustrous at ICRISAT-Patancheru. From these results, it is clear that farmers prefer bold grains and also fodder traits such as stay-green and non-lodging. Breeder selections were based on grain yield, early maturity and tan plant color. However, the differences between farmers' and breeder's selections for these traits were marginal to be of any significance. Based on the performance of these genotypes for grain yield, grain lustre and size and fodder yield, 4 lines in the farmers' selection group and 5 lines in the breeders' selection group were selected for further evaluation.

BVS Reddy and S Ramesh

Milestone: Farmer-participatory on-farm research on PVS and ICM in legumes implemented (2005)

The Year 4 work plan of farmer participatory varietal selection trials of IFAD TAG 532-ICRISAT project at various locations in four countries (China, Nepal, India and Vietnam) was successfully implemented. At ICRISAT-Patancheru, during 2004/05 postrainy season, 9.7 t of 8 varieties and during 2005 rainy season, 3.5 t breeder seed of three varieties was produced and supplied to different seed producing agencies.

The improved variety ICGV 91114 is winning over TMV 2 in Anantapur district, India. The variety is now being grown by 450 farmers in 45 villages spread over 371 ha in the district for seed increase. During the field visits in different villages and farmer-scientist interaction meetings, farmers rated this variety as superior to TMV 2 because of its earliness, ability to withstand mid- and end-of-season droughts, tolerance to diseases and pests, more numbers of uniform pods and higher pod and haulm yields. About 6.5 t seed of farmer-preferred groundnut varieties were made available to collaborators in Anantapur, Chhattisgarh, Gujarat and Orissa states of India.

A short-duration groundnut variety ICGV 92195, proposed by Maharana Pratap University of Agriculture and Technology (MPUA&T), Udaipur, Rajasthan, India was released by Central Varietal Release Committee as 'Pratap Mungphali-2' for zone II (Rajasthan and Gujarat) in India. National Agricultural Research Council released two high-yielding varieties, ICGV 86300 and ICGV 90173 as Rajarshi and Baidehi, respectively, in Nepal. ICGV 93468, a short-duration variety is proposed for release as 'Avtar' in Uttar Pradesh, India for spring season cultivation. This variety is already popular with the farmers and was cultivated on 59,000 ha during the 2005 spring season. A confectionery variety, AK 303, selected from a F_4 population [(ICGV 88384 × JL 24) × (ICGV 88438 × ICG 5240) F_1)], is proposed for release in Maharashtra. Of the material supplied to cooperators in India in the past, 47 lines were included in multi-location trials in different states. Of the 21 new varieties proposed for inclusion in All India Coordinated Varietal Trials, 10 varieties either have ICRISAT supplied germplasm or breeding lines in their parentage, or are direct introductions (ICGV 91114 by ARS, Anantapur; ICGV 98223 by MPUA&T, Udaipur; and four large-seeded varieties ICGV 96110, ICGV 97045, ICGV 98396 and ICGV 98412) by the Project Coordinator of All India Groundnut Improvement Project.

After one more year of on-farm trials, Ministry of Agriculture, Forestry and Fisheries (MAFF) intend to propose two groundnut varieties (ICGV 88438 and ICGV 95278) for release in East Timor. This year we have supplied 10 new varieties consisting of ICGV# 95070, 96172, 95069, 96165 and 97128 (high yielding) and 98379, 98381, 98378, 98375 and 99017 (foliar disease resistant) for evaluation in East-Timor.

SN Nigam and R Aruna

Training camps in IPM and HNPV production

During the 2005, in order to strengthen the NARS capacity, 240 farmers and 314 researchers were given training in IPM with special emphasis on HNPV production. Under Development Marketplace (DM) 2005 so far 104 (78 farmers and 26 NARS staff) members of the farming community were given in-depth training in HNPV production at ICRISAT Center, Patancheru.

GV Ranga Rao

Monitoring and evaluation of on-farm participatory chickpea ICM trials in Nepal

Chickpea is the most important grain legume in Nepal. Its production has drastically decreased since last two decades in this country due to wilt, root rots, botrytis gray mold (BGM), Helicoverpa pod borer, boron deficiency and poor nodulation. Technologies are available to manage these constraints. These single factor management measures were integrated as an integrated crop management (ICM) technology for the overall management of chickpea crop in Nepal. The ICM technology was evaluated and scaled up in Terai region of Nepal through participatory approaches by involving large number of farmers. In collaboration with scientists from Nepal Agricultural Research Council (NARC), 250 farmers participatory ICM trials were planted in two villages, Rajahar (50 trials) and Bardibas (200 trials) of Central Nepal during 2004/05 season. These trials were in addition to about 20,000 farmers growing chickpea in rice-fallow lands in 14 districts in Nepal (Fig. 1.3). The technology consisted of BGM-tolerant cultivar ICC 14344 (Avarodhi), fungicide seed treatment, wider row spacing, application of Rhizobium, fertilizer (DAP), and judicious use of pesticides to control BGM and pod borer. Plant stand was significantly higher in ICM plots than non-ICM plots across the locations. Severities of BGM and pod borer damage were significantly lower in ICM plots than non-ICM plots in all the trials in all locations. Mean grain yield was 1.35 t ha^{-1} (0.8 to 2.0 t ha^{-1}) in the cultivar Avarodhi and 1.47 t ha^{-1} in the cultivar Tara across the locations.

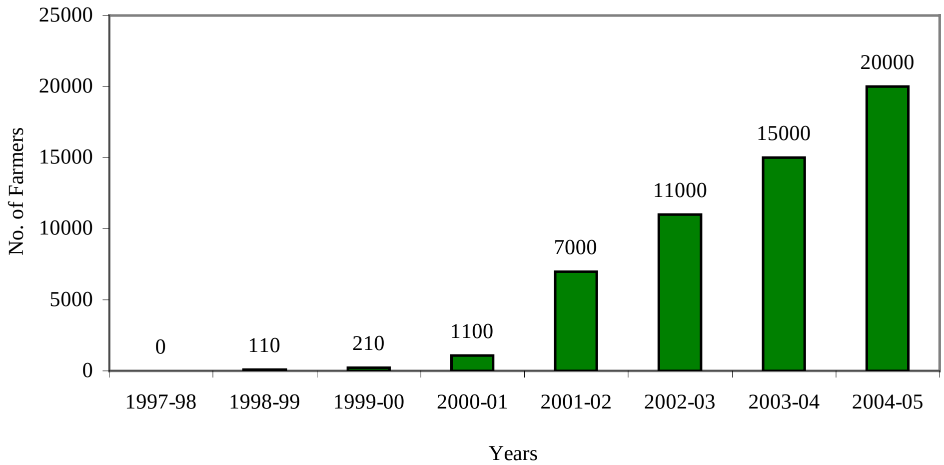

Figure 1.3. Adoption of ICM technology of chickpea in Nepal.

Monitoring and evaluation of chickpea on-farm ICM and PVS trials in north western plains of India

Under crop diversification and resource conservation technology of Rice-Wheat Consortium (RWC), two chickpea trials [ICM trial and participatory varietal selection (PVS) trial] were conducted in collaboration with the Project Directorate for Cropping Systems Research (PDCSR), Modipuram, India in several farmers fields in the villages Barkhanda, Mohammadpur, Kazampur (district Ghaziabad), Ielnna (Bulendshahar district), Uttar Pradesh; Taprana (district Karnal) Dungali, Sirsali, Adhoya, (district Kurukshetra, Haryana), village Kitcha [district Udham Singh Nagar, Uttaranchal (UA)] and also at the research farm of Project Directorate for Cropping Systems Research (PDCSR) and Agricultural and Processed Food Products Exports Development Authority (APEDA), Modipuram, Uttar Pradesh, India.

ICM trial: Growing chickpea with ICM technology as a highly remunerative crop after rice for diversifying rice wheat cropping system was advocated in several villages in Indo-Gangetic Plain (IGP) of India, Nepal and Bangladesh. ICM technology consisted of improved high-yielding cultivar, fungicide seed treatment, wider row spacing, and need-based application of pesticides to manage diseases and insects. In most of the locations, chickpea was planted either on beds or by zero tillage, as intercrop with sugarcane in the furrows. BGM was observed (<4 rating on 1–9 rating scale) in IPM plots, while it had 7 rating in non-IPM plots across the locations. The low disease in IPM plots was attributed to timely application of fungicide Bavistin. Mean grain yield was almost double in IPM plots than non-IPM plots across locations.

Participatory varietal selection trial: Six ICRISAT-bred improved chickpea varieties (ICCV 2, JG 11, ICCV 10, ICCC 37, KAK 2 and Vihar) were included in a participatory varietal selection (PVS) trial that was conducted in several villages in participatory mode in farmers' fields in the states of UP, Haryana, Uttaranchal and also at research farms of PDCSR and APEDA, Modipuram. In several locations, chickpea was planted in the furrows as intercrop with sugarcane. Severity of BGM was recorded low (up to 5 rating) in all the improved cultivars compared to local cultivar (up to 8 rating). Mean grain yields were high in all the improved cultivars than local cultivars in all the trials. Of the improved cultivars, KAK 2 was most liked by many farmers.

PDCSR, Modipuram: All the six entries of the PVS trial ICCV 10, JG 11, ICCC 37, KAK 2, ICCV 2 and Vihar were planted as paired rows on beds and on flat at the research farm of PDCSR, Modipuram. Of all the cultivars, KAK 2, ICCV 2 and ICCV 10 performed well with low disease severities and high grain yield on broad beds than on flat.

APEDA, Modipuram: Of the five cultivars, HC 1, ICCV 10, Pusa 1053, Pusa 1088 (K), Pusa 1103, cultivar ICCV 10 planted under zero tillage after rice. Vegetative growth of the cultivar PUSA 1088 planted on beds after land preparation was luxurious with abundant podding. PUSA 1088 and ICCV 10 had higher grain yield than other cultivars.

Monitoring and evaluation of on-farm participatory groundnut IDM trials in Andhra Pradesh

Groundnut is the major crop in Anantapur district (India) and is grown in >700,000 ha every year. Late leaf spot and rust are destructive diseases in groundnut and cause severe losses in quality and quantity of haulms and pods. Groundnut haulms are the major source of fodder for cattle in this district. To manage these two diseases, integrated disease management (IDM) technology, developed at ICRISAT-Patancheru was evaluated, promoted and scaled up in the state of Andhra Pradesh, India, by involving large number of farmers in a participatory approach. The technology consisted of combination of improved dual-purpose groundnut cultivar with moderate levels of host plant-resistance, fungicide seed treatment and judicious use of fungicide, chlorothalonil (Kavach). One fungicide spray at 60 days after sowing (DAS) for early-maturing cultivars ICGVs 91114, 89104; and two sprays at 60 and 75 DAS for medium-maturing cultivars, ICGVs 92020, 92093 were scheduled for all IDM trials. One hundred and twenty one farmers' participatory IDM trials in five villages (46 farmers in Lingareddypalli, 43 farmers in Jalalapuram, 22 in Talupuru, 5 in Anataraganga and 5 in Jonnalakothapalli) in the Anantapur district (India) were conducted in collaboration with District Agricultural Advisory and Transfer of Technology Center (DAATTC) during 2004 rainy season. In addition to these trials, several farmers in 20 villages in the states of Andhra Pradesh, Karnataka and Tamil Nadu adopted the technology during 2004 rainy season. During this year, the weather was congenial for groundnut production in Anantapur. Severity of foliar diseases was comparatively low in IDM plots in all the cultivars than non-IDM plots of local cultivar in all the villages. Mean LLS and rust severities had up to 5 rating in IDM plots compared to around 7 rating in non-IDM plots across the villages. Haulm yields were 2. 46 t ha^{-1} in IDM and 1.94 t ha^{-1} in non-IDM plots, while pod yields were 2.08 t ha^{-1} in IDM and 1.41 kg ha^{-1} in non-IDM plots across the villages.

Farmers training program on IDM of foliar diseases in groundnut, Anantapur, Andhra Pradesh, India

A training program on the management of foliar diseases of groundnut was conducted at Anantapur (India) from 28 to 29 June 2004 at the DAATT Center. About 94 farmers (50 farmers from Lingareddypalli, 30 from Talupuru, seven each from Antaraganga and Jonnalakothapalli) from four partner villages attended this program. In the fifth village Jalalapuram, as there was good rain and all the farmers were busy in groundnut sowings, and the program was conducted in the evening in the village itself. About 96 farmers both participating and non-participating attended the program in this village. The program was conducted in local language (Telugu). Its main theme was "healthy groundnut, more pods, and more milk" through integrated disease management (IDM). The program included discussions on foliar and soil-borne diseases, and aflatoxin contamination and their management. Additionally, improved package and practices of groundnut cultivation and principles of farmers' participatory research and its impact were also discussed. IDM promotional material on groundnut diseases and aflatoxin management in Telugu was distributed to the farmers.

Farmers training program on IPM/ICM in chickpea in the villages Rajahar (Nawalparasi), Bardibas (Mohattari) and Lalbandi (Sarlahi), Nepal

Rajahar (Nawalparasi): A training course on production technologies for chickpea was conducted in the village Rajahar, district Nawalparasi on 1 October 2004 in collaboration with NGLRP and FORWARD (NGO). Twenty-seven participating farmers and several non-participating farmers attended this program. Topics covered in this program were, agronomic management, major disease and insect pests and their management, seed production and post harvest technologies for chickpea. Additionally, a field day was conducted by NGLRP in the village Rajahar, district Nawalparasi on 24 March 2005. About 26 farmers from the village Rajahar and 10 scientists from NGLRP, FORWARD and Agriculture Service Center participated the field day. Field trials on integrated pest management (IPM), participatory varietal selection (PVS), and seed multiplication were visited by the group. There was good interaction between farmers, researchers and extension personnel.

Bardibas (Mohattari) and Lalbandi (Sarlahi): Hands-on training on improved packages for chickpea production with special emphasis on IPM was conducted by NORP, Nawalpur in the villages Bardibas (Mohattari) on 18 January 2005 and Lalbandi (Sarlahi) on 19 January 2005. About 25 farmers participated in each village. In addition to the general discussion on the production practices in chickpea, farmers were specially educated about the diseases, insect pests and their management, seed production and storage. Farmers showed keen interest in learning IDM practices and adopting them. Farmers' field days were conducted by NORP in Bardibas on 19 March 2005 and in Lalbandi on 20 March 2005. About 25 farmers in the village Bardibas and 29 farmers in the village Lalbandi attended the field day. All the farmers in both the villages were impressed with the performance of IPM technology and the cultivar Avarodhi.

S Pande

Activity 1.5.2: Monitor and document the impact of improved technologies

Milestone: Utilization of ICRISAT-bred parental lines of sorghum and pearl millet by NARS and private sector and adoption of their hybrids assessed in India (2006)

Seed Producers' Sorghum Hybrid Trial (SPSHT) Report: The public and private sector scientists utilize ICRISAT-bred seed parents for developing commercial hybrids. To assess the performance of sorghum hybrids produced by different private sector organizations, "Seed producers' sorghum hybrid trials" are being coordinated in postrainy and rainy seasons. Under this activity, SPSHT 2004-05 Postrainy trial (9 entries, 4 locations) and SPSHT 2005 Rainy trial (9 entries-Tulasi 207, Kaveri 901, Kaveri 2244, MLSH 57, BSH 10, BSH 15, CSH 18, CSH 20 and local), at 5 locations (Ankur Seeds, Bagpur; Ankur Seeds, Dharwad; Basant Agrotech, Akola; Emergent Genetics, Jalna and ICRISAT- Patancheru) were conducted.

The results of postrainy season SPSHT-2004-05 showed that the hybrid performance differed with locations and no single hybrid performed better in all the locations for any of the traits such as grain yield, grain size, and days to 50% flowering. Two hybrids SR 344 and MLSH 117 at Dharwad; all the hybrids except MLSH 117 at Patancheru; and two hybrids, Kuber and SR 351 at Bijapur were significantly superior to the controls used in the respective locations. Three hybrids, EGSH 64, 746611 and SR 344 were on par with local control at Jalna. The hybrid Kuber along with superior grain yield performance also had large grains than the rest of the hybrids at three of the four locations.

The results of rainy season SPSHT-2005 showed that no single hybrid excelled in all the locations for grain yield, but they were on par with the control CSH 20 at all the locations. However, the hybrids MLSH 57, BSH 10 and BSH 15 outperformed the control CSH 18 significantly in three of the five locations. However, all the hybrids were on par with the control CSH 20 at all the locations except Kaveri 901 in two locations (Nagpur and Akola) where it showed poor performance. MLSH 57 and BSH 15 were highest yielders at two locations each. The hybrids MLSH 57, Kaveri 901 and Kaveri 2244 had significantly larger grains than both the controls CSH 18 and CSH 20 at two or more locations. The summary reports on the results of postrainy season SPSHT-2004-05 and rainy season SPSHT-2005 were distributed to consortium partners.

BVS Reddy and S Ramesh

Impact assessment of breeding materials: A questionnaire was developed to assess the impact of ICRISAT-developed sorghum hybrid parents and breeding materials and strategic research information in a systematic manner. A Special Project Scientist was appointed at ICRISAT for the purpose.

BVS Reddy and S Ramesh

Impact assessment: In order to assess the utilization ICRISAT-bred parental lines of pearl millet by the private sector and adoption of their hybrids in India, impact assessment was initiated. Questionnaires were prepared in consultation with the Hybrid Seed Parents Research Consortium Advisory Committee and ICRISAT's socio-economists, and circulated to private sector members for their response during the consultation meeting. An Impact Assessment Economist was appointed to conduct this study.

CLL Gowda, KN Rai, BVS Reddy, KB Saxena, VN Kulkarni and S Ramesh

Milestone: Farmers' acceptance of ICM technologies including improved varieties in chickpea, pigeonpea and groundnut documented (2005)

Impact of ICM technologies including improved varieties in legumes documented

During the year, project locations in China, India, Nepal and Vietnam were visited to monitor on-farm farmer participatory trials. At each location, farmer-scientist interaction meetings were organized to assess farmers' response to improved technologies. Farmers showed tremendous response to the improved technology at all the locations visited.

SN Nigam and R Aruna

Milestone: Impact assessment of chickpea cultivars in Ethiopia completed (2005)

Adoption studies of improved chickpea varieties in Ethiopia

A report of the study conducted in Ethiopia to assess the adoption of improved chickpea varieties and the constraints to adoption of improved varieties was published in 2005. Chickpea is one of the most important pulse crops in Ethiopia, the largest chickpea growing country in Africa with a share of over 40% in the chickpea production. Bulk of the Ethiopian chickpea production is used for human consumption. Thus, chickpea is an important source of dietary protein, fiber and minerals for many Ethiopians, particularly the rural poor. Over 300 households were surveyed in four chickpea growing districts of central Ethiopia representing major chickpea production areas of the country. The adoption of improved varieties varied considerably (6 to 66%) from one district to another, mainly because of variations in the awareness of improved varieties among farmers. The variety *Mariye* had the highest adoption followed by *Shasho, Dubie, Arerti* and *Worku*. Important characteristics of improved varieties that were liked by farmers included drought tolerance, high yield and early maturity. The non-availability of the seed of improved varieties has also contributed to the low adoption rate of improved varieties. Extension activities have to be enhanced and made more effective to increase the farmers' awareness about the improved varieties, and an efficient seed production and distribution system needs to be established in the country. Of course, efforts are needed to develop improved varieties resistant to abiotic and biotic stresses, with high yield potential and seed traits preferred by the market.

PM Gaur, CLL Gowda, MCS Bantilan and HA Freeman

Activity 1.5.3: Exchange improved techniques and new knowledge with ARIs, NARS, NGOs, private sector, and farmer groups

ICAR-ICRISAT groundnut scientists' meet: ICAR-ICRISAT Groundnut Scientists meet was organized at ICRISAT during 2–3 October 2005. Forty-four scientists from different ICAR institutions and state agricultural universities participated in the meet. ICRISAT scientists working on different aspects of groundnut crop improvement presented the highlights in their area of work. Participants visited groundnut research fields and made selections in the breeding material for different traits of interest. The participants selected 527 advanced breeding lines and 237 segregating populations. Material has been dispatched to the respective NARS partners.

Forty-one sets of international trials (4 foliar diseases resistant, 8 drought-tolerant, 7 short-duration, 7 medium-duration, 3 aflatoxin tolerant and 12 confectionery) were supplied to cooperators in Afghanistan, Bangladesh, China, India, Indonesia, Philippines, South Africa and Sudan. We supplied 164 advanced breeding populations to cooperators in eight countries (Afghanistan, Fiji Islands, India, Iran, Philippines, South Africa, East Timor and Uzbekistan).

SN Nigam and R Aruna

Milestone: Seeds of parental lines, breeding populations, and advanced breeding lines and varieties multiplied and distributed to researchers, collaborators and farmers on request (Annual)

Sorghum scientists' field days: Field visits were arranged for public and private sector scientists. Sorghum Scientists' field day was organized at ICRISAT-Patancheru on 10 January 2005 for public sector scientists and on 24 February 2005 for public and private sector scientists for selection of the breeding materials.

Seed supplies: A total of 5648 seed samples of hybrid parents/breeding lines were shared with scientists (public and private sector), NGOs and farmers based on specific requests. Of the 5648 seed samples, 2663 were shared with public sector scientists, 1313 with private sector scientists and 721 with NGOs and farmers in India. The rest of the seed samples (951) were shared with NARS (public and private sector scientists) outside India. The seed of selected breeding material are being supplied as per new guidelines of hybrid parents' research consortium to scientists in private sector.

BVS Reddy

Seed production and supply: We produced 325 kg breeder seed of ICTP 8203, and 158 kg supplied from the reserve seed stock. We also supplied 126 kg breeder seed of three hybrid parental lines. In addition, 70 kg breeder seed of two seed parental lines (ICMA/B 94555 and 842A/B) were multiplied. We provided 471 seed samples (432 in India and 39 overseas) of breeding lines and hybrid parents. In response to 2004 Scientists' Field Day requests, we supplied 2174 pearl millet seed samples to 14 public-sector organizations and 1628 seed samples to 22 private sector organizations. Three new seed companies joined the Hybrid Parents Research Consortium in 2005, and we supplied 345 seed samples for lines selected during the 2005 summer season.

KN Rai and VN Kulkarni

Seed production and distribution: Breeder seed of three short-duration varieties ICPL 88039 (795 kg), ICPL 87 (25 kg) and ICPL 87091 (25 kg); and four medium-duration varieties ICPL 87119 (1055 kg), ICPL 85063 (675 kg), ICPL 8863 (460 kg), and ICP 7035 (250 kg) was multiplied in isolation. This seed will be used to meet the national and international seed requirements.

During the 2005, a total of 2870 kg seed was supplied to 40 NARS and private seed sector partners. A total of 885 pigeonpea seed samples were supplied to private seed companies and NARS in India and other countries. This includes 490 samples of hybrids, 212 CMS A/B-lines, and 183 fertility restorer lines.

Promotion of pigeonpea in the Philippines: Under a new initiative ICRISAT and the Philippines Government will collaborate in promoting pigeonpea in northern regions of the Philippines. The initial trials of short-duration lines ICPL 88039 and ICPL 88034 have shown promise in rice-fallow system. During the 2006, a number of demonstrations have been planned. Also, it is proposed to promote vegetable pigeonpea for local consumption and to try to rehabilitate degraded lands with perennial pigeonpeas. We have supplied about 100 kg seed of six varieties to the Philippines to undertake the testing program in different agro-ecological zones.

KB Saxena

Chickpea scientists' meet organized at ICRISAT-Patancheru

A one-day Chickpea Scientists' Meet was organized at ICRISAT on 6 January 2005 for the scientists of National Agricultural Research System (NARS) of India. The meeting was attended by 45 scientists that included 28 Indian NARS scientists from 12 states and 17 ICRISAT scientists. The participants visited various experiments on physiology, pathology, entomology, genetic resources, wide hybridization, genetics and breeding of chickpea and the visit facilitated interaction between ICRISAT and NARS scientists. The NARS scientists selected germplasm and breeding materials of their interests. ICRISAT supplied 1853 chickpea seed samples indented by NARS after the crop harvest.

PM Gaur and CLL Gowda

Multiplication and distribution of seeds of chickpea advanced breeding lines and cultivars

Two International Chickpea Screening Nurseries (ICSN-*Desi* and ICSN-*Kabuli*) were evaluated by NARS scientists during 2004/05. A total of 75 sets (37 of ICSN-*Desi* and 38 of ICSN-*Kabuli*) were supplied to 12 countries – Australia (2), Bangladesh (2), Canada (8), China (4), Ethiopia (6), India (41), Iran (2), Israel (1), Mexico (1), Myanmar (2), Nepal (4) and South Africa (2). The results were received from 20 locations for ICSN-*Desi* and from 19 locations for ICSN-*Kabuli*. The results received from Indian locations were compiled in a report and distributed to Indian NARS during annual group meet of All India Coordinated Research Project on Chickpea held at Kolkata during September 2005. A total of 59 sets of ICSN (30 of ICSN-*Desi* and 29 of ICSN-*Kabuli*) were distributed to NARS during 2005 for 2005/06 crop season.

About 29.0 t breeder seed of ICRISAT-related chickpea varieties ICCV 2 (7.58 t), ICCV 10 (5.76 t), ICCC 37 (18.5 t), KAK 2 (1.92 t), JG 11 (0.56 t), and JGK 1 (0.25 t) was produced. The seed was first distributed to various agencies as per the allotment from Government of India, and the remaining seed was distributed to farmers and NGOs.

PM Gaur

Milestone: ICRISAT partnerships with NARS, networks and regional fora strengthened (Annual)

Collaborative evaluation of nursery for aphid resistance: Aphid infestation was severe during the 2001 rainy season and postrainy seasons in India, especially several parts of Maharashtra. The infestation was severe in the 2001 rainy and postrainy seasons and resistant seed parents were identified by scoring the infestation damage on 1 to 5 scale, where 1 = free from aphids and 5 = >60% leaf area damaged. Based on the subsequent screenings in 2002, 2003 and 2004, an aphid nursery consisting of 62 aphid resistant lines along with two controls was constituted and was sent for evaluation in India.

Collaborative evaluation of selected lines for micronutrient density: A total of 40 sorghum lines with high and low grain Fe and Zn contents selected based on the 2004 postrainy season evaluation of 86 diverse sorghum lines were sent to National Research Centre for Sorghum (NRCS), Hyderabad, India during the 2004–05 postrainy season for yield performance and grain Fe and Zn contents at NRCS, Hyderabad. The results revealed significant genetic variability for grain Fe and Zn contents. Some of the landraces such as IS 7780 (38.5 ppm), IS 1192 (32.8 ppm), IS 24868 (32.8 ppm) and high-yielding B-line such as ICSB 561 (32.6 ppm) and ICSB 484 (29 ppm) had significantly higher Zn content compared to the trial mean value (25.4ppm). Similarly, lines such as ICSR 40 (56.7 ppm), PVK 801 (50.2 ppm), ICSB 561 (49.6 ppm), IS 152 (47.6ppm), ICSB 675 (46.2 ppm), ICSB 52 (45.6 ppm) and ICSB 38 (44.4 ppm) had significantly higher Fe content compared to the trial mean value (37.6 ppm).

BVS Reddy

Pearl millet trials and nurseries for NARS: Under the ICAR-ICRISAT partnership project, 5 trials related to hybrid parents research were sent to 10 locations and two nurseries were sent to 8 locations. Of these, 2 B-line trials and 3 R-line trials were conducted at Patancheru. Dialog was initiated with the All India Coordinated Pearl Millet Improvement Project Coordinator to strengthen the research partnership in areas such as forage hybrids, hybrids for arid Rajasthan, salinity tolerance, biofortification, seed production in Rajasthan, alternative use of pearl millet grain for alcohol production, and training and publications.

Pearl Millet Consortium Hybrid Trial: The trial consisting of 17 test hybrids from 11 private seed companies, along with three controls: ICMH 356 (ICRISAT), PB 106 (Proagro) and 7688 (Pioneer) was conducted at three diverse locations with varying productivity levels showed that overall none of the hybrids outperformed the best control hybrid 7688 either for grain yield or dry fodder yield. At Aurangabad, two hybrids had significantly higher grain yield, with BBH-111 having 20% more grain yield and Kaveri-456 having 13% more grain yield than highest-yielding control 7688 (4505 kg ha^{-1}). The same two high grain yielding hybrids also had significantly higher dry fodder yield, with BBH-111 having 32% more fodder yield and Kaveri-456 having 9% more fodder yield than 7688 (7484 kg ha^{-1}).

Although statistically not higher than 7688 at any of the locations, the average grain yield of GSMH-55 was identical to that of the highest-yielding hybrid Kaveri-456. It is recognized that the limited data set from just three locations is inadequate to make any definitive conclusions about the performance of these hybrids. It is suggested that the Consortium Hybrid Trial in the future be conducted at 8–10 locations.

KN Rai and VN Kulkarni

Milestone: Technical information and pubic awareness literature/documents developed and disseminated (Annual)

The 2005 issue of International *Arachis* Newsletter with 20 articles from 4 countries and news and views items from different parts of the world was published on time.

Researchers from different countries [China (2), Nepal (3), Iran (1), the Philippines (3), Uzbekistan (1), Vietnam (2), India (2)] were trained in different groundnut breeding and seed production technologies. Queries related to different aspects of groundnut from farmers and students were attended to on various occasions. Three posters and two success story flyers on various aspects of groundnut were prepared for different occasions and information sharing.

Farmer friendly literature on ICM in groundnut, pigeonpea and chickpea: A 2-page handout in Telugu and English entitled ‘ICGV 91114 – The Alternative to Groundnut in Anantapur is Better Groundnut’ was prepared and distributed to farmers in Anantapur, Andhra Pradesh. It also contained information on low-cost production technologies.

SN Nigam and R Aruna

Global Theme on Crop Improvement and Management

Archival Report 2005

Regional Project 2

Enhancing crop productivity and diversification of income sources of SAT farmers in Eastern and Southern Africa (ESA)

Regional Theme Coordinator: Mary A Mgonja

Regional Project Members:

SN Silim, ES Monyo, E Gwata, MA Mgonja, RB Jones, B Mitaru and C Dominquez

Regional Project 2: Enhancing crop productivity and diversification of income sources of SAT farmers in Eastern and Southern Africa (ESA)

Output 2.1: Genetically diverse and regionally adapted germplasm and breeding populations *[Increased availability of diverse germplasm sources and breeding materials]*

A large number of varieties have been released (some varieties in many countries) indicating that requests for pure seed will be high. Many varieties released by national authorities have never been multiplied and accessed by farmers. Availability of all classes of good quality seed to stakeholder groups in the seed industry is key to enhancing the impact from crop breeding and also in enhancing agricultural productivity.

In 2005 a total of 344 sorghum and 79 pearl millet lines were planted for purity assessment. Various quantities of seed were also multiplied for different classes of seed for sorghum, pearl millet and finger millet. Indexing of all groundnut varieties and germplasm at ICRISAT Lilongwe was completed. The groundnut breeder seed produced at Malawi is sufficient to produce 169 hectares of Foundation seed.

Nucleus seed of all improved cultivars of pigeonpea and chickpea was produced. Breeder seed of five long-duration and one medium-duration pigeonpea was developed at Kampi ya Mawe Research Station. Similarly, pure seed of three chickpea kabuli genotypes and one desi type was produced at Kabete Research Station. The seed is maintained under short-term storage conditions at ICRISAT-Nairobi.

Advanced lines of short-duration pigeonpea attaining 50% flowering within 65 days were observed at Kiboko Research Station (KRS) in eastern Kenya. In spite of a severe drought, the cultivars flowered and matured within 3 months at Kampi ya Mawe Research Station (KMRS) in eastern Kenya. These early maturity and ratoonability traits should enhance adoption of the new short-duration cultivars by farmers. Medium-duration cultivars that are insensitive to photoperiod were evaluated at Chitedze Research Station [CRS (13^o59' S and 33^o44' E] in Malawi and yielded about 2 t ha^{-1} indicating success in the development of the medium-duration pigeonpea types insensitive to photoperiod and warm temperatures. In Tanzania, ICEAP 00068 having large, cream seed and ratoonability was released (as cultivar 'Tumia'). Two long-duration pigeonpea cultivars (ICEAP 00040 and ICEAP 00020) showed superior (10%) dhal *recovery. ICEAP 00020 is still at the pre-release stage but ICEAP 00040 was released previously for commercial production in Malawi (as cultivar 'Kachangu').*

The groundnut program centred on development and evaluation of groundnut breeding populations and breeding lines with resistance to foliar diseases. The program maintains breeding populations for groundnut rosette and ELS disease, and gene pyramiding for multiple resistance.

Preliminary sorghum yield evaluation was done on materials that were already in the F_6 and F_7 generations and were planted at Alupe, Kenya. Ten lines were selected for inclusion in regional evaluation trials based on the yield data and other agronomic characteristics such *as flowering, agronomic score and midge reaction. Eleven restorer lines selected from crosses between KARI Mtama 1X SC691-14-NIG-FET were identified and advanced based on their short stature and large seed. A total of 15 experimental hybrids were developed and tested at Alupe. On-farm demonstrations were carried out with a number of improved sorghum and finger millet varieties suitable for the drought prone areas of eastern and north eastern Kenya as well as those suitable to the humid Lake Victoria zone. The best performing sorghum lines were IESV92036 and IS8193. Overall, the highest yielding and blast resistant finger millet lines were KNE688, ACC32 and KNE814.*

Activity 2.1.1: Maintenance breeding: verify and maintain purity of released varieties, elite lines and hybrid seed parents

Milestone: At least 5 sorghum and 3 pearl millet popular varieties purified by 2007

A large number of varieties have been released and some have multiple country releases indicating that requests for pure clean stocks of seed will be large. Many varieties released by national authorities have not been multiplied and accessed by farmers. Availability of all classes of quality seed to stakeholder groups in the seed industry is key to enhancing the impact from crop breeding and also in enhancing agricultural productivity. As a CGIAR institute we have a role in ensuring that the initial seed materials that flow from ICRISAT breeding programs is pure and of the best quality as this will be used by other stakeholders in the seed chain. In 2005 all breeding materials were catalogued and computerized in the Bulawayo genebank and various sources for each variety were identified. These sources were sampled and planted out–a variety in four rows and one row for hybrid parental lines (Table 2.1). Observations were made for each source to assess uniformity, trueness to type and other distinctive traits. The best three sources for each were identified and would be used for further multiplication of the variety/parental line. The highly contaminated sources were discarded from the store.

Sorghum

- Most varieties had a uniformity level of 80%
- 18% of varieties had 100% uniformity in all sources
- Seed of Macia that some seed companies and NGOs had was absolutely not true to type
- Chokwe (ICSV112) will need to be reintroduced
- Sorghum A lines shedding pollen were insignificant
- Off types in sorghum A lines were also very small
- Each of the sorghum released varieties had a source that was 95-100% pure

Table 2.1. Maintenance breeding for sorghum and millet in ESA.

Crop	Description	No of lines planted
Sorghum	Released varieties	30
Sorghum	Regional trial entries	78
Sorghum	A & B lines	163
Sorghum	Restorer lines	73
Pearl millet	Released varieties	20
Pearl millet	A & B lines	59

Pearl Millet A &B lines and varieties

- A number of pearl millet A lines were shedding pollen
- 18 pearl millet lines need to be reintroduced
- Eventually all inbred lines for pearl millet need to be reintroduced
- The released pearl millet varieties are reasonably uniform

Conclusion:

- The activity helped identify true sources of varieties and parental that were uniform and true to type materials
- Schedule for seed production need to ensure that we always have a reliable source of clean quality seed
- The clean stocks will be planted to provide nucleus seed for each variety

MA Mgonja and S Kudita

Milestone: At least 5 kg each nuclear seed of elite groundnut varieties of different maturity groups produced each year; at least 200kg of the most promising varieties under on-farm produced for large scale promotional testing with collaborators annually and at least one ton of each variety under commercial production in ESA produced each year in support of commercial production

The groundnut improvement program based at Lilongwe, Malawi has developed a number of varieties that are released by NARS for farmer use in their respective countries. We also have the mandate to maintain the breeder seed of released varieties. We completed indexing of all varieties and germplasm at ICRISAT Lilongwe. Two elite varieties ICGS 31 (released in Botswana) and ICGV-SM 99537 were completely missing. We requested and secured fresh seed of ICGS 31 from NARS Botswana and shared the same with the breeder from Patancheru for safe keeping at the ICRISAT genebank. Similarly we requested and obtained fresh seed of ICGV-SM 99537 from Zimbabwe. This seed is now being multiplied at ICRISAT-Bulawayo. A sample will be made available for ICRISAT-Malawi and the Genebank in India after harvest.

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Milestone: Nucleus seed of all improved cultivars of sorghum, pearl millet, groundnuts, chickpea and pigeonpea produced and made available to NARS and other partners on request

Nucleus and breeder seed production is an essential component of the breeding program. Seed production at the regional centers facilitates the conduct of regional collaborative trials as well as on-farm adaptive trials with NARS and NGOs. The breeder seed production activity is also an important activity necessary to get adequate quantities of seed for foundation and certified seed production by NGOs and the private sector. This targets needs of collaborating partners for implementation of promotion and scaling out of improved varieties

Sorghum: Nucleus seed of 27 cultivars were multiplied and 135 kg of seed obtained. Breeder seed of 8 varieties was also multiplied and about 200 kg of seed is available.

Foundation seed quantities available are: Macia (625 kg); 5DX160 (150 kg); Gadam El Hamam (200 kg); Kari Mtama 1 (400 kg); and ZSV3 (120 kg).

Pearl millet: Nucleus seed of 12 varieties (107 kg) and breeder seed for 6 varieties (160 kg) was produced. Foundation seed for three varieties, namely Okashana 1 (1550 kg); PMV 3 (437 kg); ICMV221 (120 kg) are available.

Finger millet: A total of 60 kg of nucleus seed of 8 finger millet varieties and breeder/ foundation seed for U15 (60 kg); P224 (50 kg) and ACC32 (49 kg) is available.

Fodder finger millet: A total of 40 kg of finger millet seed suitable for use as fodder was multiplied and availed to collaborators in University of Warwick in UK.

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Groundnuts: The following breeder seed of popular varieties was produced to sustain commercial production to meet market demand; ICGV-SM 90704 (6.2 t), ICG 12991 (5.1 t), JL 24 (1.6 t), CG 7 (0.68 t), plus various quantities of nucleus seed ranging from 1–39 kg for 45 varieties in Advanced, Elite and released status.

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Pigeonpeas and chickpeas: Limited quantities of pigeonpea breeder seed of 6 varieties (ICEAP 00040, 00053, 00850, 00576-1, 00911 and 00557) were multiplied at Kampi ya Mawe research station. The plants were raised in an environment isolated from insect pollinators in order to maintain genetic purity.

Using single plant selections, nuclear seed of 13 (eight *desi* + five *kabuli*) chickpea genotypes was constituted at Kabete field station. These genotypes included ICCV 95423, ICCV 95423, ICCV 96329, ICCV 96329, ICCV 92318, ICCV 97105 and ICCV 97105. Further multiplication of the seed will be conducted at ICRISAT-Nairobi. At least three of these genotypes are earmarked for release by the national programs in ESA.

SN Silim and E Gwata

Activity 2.1.2: Develop and evaluate trait specific populations and breeding lines for adaptation to specific environments, pest and diseases and for product market/food safety requirements

Milestone: At least 1 short-duration, 2 medium-duration and 2 long-duration pigeonpea varieties with end user quality traits identified or released

Short-duration: Advanced lines of short-duration pigeonpea attaining 50% flowering within 65 days were observed at Kiboko research station (KRS) in eastern Kenya. The genotype ICEAP 00994 obtained 1.4 t ha^{-1} while the commercial cultivar ICPL 87091 obtained 40% less grain yield. In spite of the severe drought during the season, the cultivars flowered and matured within 3 months at Kampi yaMawe research station (KMRS) in eastern Kenya. However, the yield was relatively low, but farmers in the area usually harvest a second (ratoon) crop. The yield from the ratoon crop can be as high as 80% of the first crop. These qualities (early maturity, ratoonability) should enhance adoption of the new short-duration cultivars by farmers.

Medium-duration cultivars: Medium-duration cultivars that are insensitive to photoperiod were evaluated at Chitedze Research Station [(CRS) 13^{o}59' S and 33^{o}44' E] in Malawi. The highest grain yield (1.95 t ha^{-1}) was obtained for the experimental cultivar ICEAP 01160/15 compared to 0.36 t ha^{-1} of the commercial cultivar ICEAP 00068. However, the grain size (11.55 g 100 seed^{-1}) of this genotype was relatively small. Large grains (16.43 g) were observed for the experimental cultivar ICEAP 01172/6 which also obtained three fold higher grain yield than ICEAP 00068. In spite of the severe terminal drought experience at CRS, these improved genotypes flowered and matured before the end of May. The results obtained from this field evaluation indicated that medium-duration pigeonpea types insensitive to photoperiod and warm temperatures were developed successfully. The experimental cultivars are likely to attain higher grain yield under optimum moisture conditions.

Long-duration cultivars for *Dhal* processing: The end-user qualities for pigeonpea that are important in our region include large, cream seed and high *dhal* recovery. Compared with the industry average, two cultivars (ICEAP 00040 and ICEAP 00020) showed superior (10%) *dhal* recovery. ICEP 00020 is still at the pre-release stage but ICEAP 00040 was released previously for commercial production in Malawi (as cultivar 'Kachangu'). This germplasm will be useful in the region in pigeonpea breeding programs aimed at improving both traits.

SN Silim and E Gwata

Activity 2.1.3: Develop new improved varieties, hybrids, seed parents with end-user preferred plant and grain traits for food security and markets

Milestone: Breeding populations with resistance to ELS, Rosette, LLS and Rust developed and stability of resistance assessed

Development and evaluation of breeding populations, with resistance to foliar diseases: **A**ctivities centred around development and evaluation of groundnut breeding populations and breeding lines with resistance to foliar diseases. The program maintains populations for rosette disease and the aphid vector, ELS disease and gene pyramiding for multiple resistances.

Breeding populations with resistance to the Groundnut Rosette Virus (GRV): Breeding material and populations developed for the purpose of studying the inheritance of resistance were screened for superior progeny rows using the infector row technique.

From the 65 progeny rows, 79 single plants were selected from 42 progenies based on field observations but only 26 combined GRV resistance with yield potential. From the inheritance study, all ten progenies in the study were field selected, but upon adding the yield criteria, only one progeny will be advanced.

Breeding populations with resistance to the Groundnut Rosette Disease (GRD): A nursery consisting of 17 GRD resistant F_6 progenies was evaluated using the infector row technique (Fig. 2.1). A two tier strategy was used for selection from the segregating populations. First selection was done in the field where observed superior plants were tagged and harvested. The final selection was done in the laboratory using yield as a second criterion. After combining field disease resistance with yield performance, only 6 plants from 4 progenies were finally selected for further advance.

Figure 2.1. A susceptible variety in an endemic year can spell a disaster for the farmer. (Note susceptible variety on the right side of the block)

Breeding populations with resistance to the Groundnut Aphid Vector: This study involved two nurseries in F_5 generation each with 46 progeny populations. Out of 111 plants carrying vector resistance, only 29 progeny populations combined yield potential with high levels of vector resistance. The fact that a higher proportion of resistant high yielding progenies were identified from this nursery speaks of the importance of incorporating your resistance source in an already known high yielding adaptable genotype.

Breeding populations with resistance to early leaf spot (ELS) disease: Breeding populations for ELS disease resistance ranged from F_2, F_3, and F_4 populations (Fig. 2.2). The greatest problem we have with ELS is that resistance in early maturity background is very rare. Secondly, resistance is associated with poor quality including poor kernel reticulation and loss of palatability.

Figure 2.2. Effective screening for ELS clearly separates resistance from susceptible lines.

The F_2 nursery consisted of 443 segregating lines from germplasm crosses. Of these, 131 were selected with good levels of field resistance, but when this was complimented with yield potential only 23 were retained. The second population consisted of 101 F_3 progenies, of lines combining ELS resistance with confectionary traits – particularly seed size. Only 21 progenies combining ELS resistance and confectionary traits were retained. The third nursery consisted of 650 F_4 progeny rows, of which 343 were identified for field resistance but only 61 retained at the final selection. The fourth nursery included 42 F_4 progeny rows of interspecific hybrids obtained through embryo rescue at ICRISAT-Patancheru. We could not find any evidence of superior performance, partly because of the very limited amount of seed per row (5-8). All 42 progenies were advanced to give opportunity for observing more plants for their reaction to ELS.

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Breeding populations for multiple resistance - gene pyramiding: These populations were developed for multiple stress resistance to improve yield stability of varieties. Deployment of multiple resistances is important to guard against genetic vulnerability and possible breakdown of resistances.

Key findings from the nurseries above include:

- Excellent lines combining resistance to aphid and ELS (179), aphid and rust (27) in F_7. These were promoted to progeny trials.

- Excellent breeding lines (Spanish) in with resistance to the aphid vector and GRV (49), ELS and Rosette (51), GRV and dormancy (45), and rosette and dormancy (25) identified in F_6 generation.
- Excellent Spanish single plant selections (8) resistant to aphid identified in the F_5 generation.
- Populations with a combination Aphid and ELS, Aphid and Rosette, and Aphid and GRV currently in F_3, F_4 and F_5 advanced to further generations.

High levels of ELS resistance from the populations above trace their origin to gene blocks from wild *Arachis spp.* most often associated with low yield potential. Continuous backcrossing and recovery of resistance in high yielding genetic background is therefore essential.

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Milestone: Wide range of varieties, hybrids and seed parents with market traits evaluated

Sorghum:

- Preliminary sorghum yield trial with 64 entries: These materials (F_6 and F_7 generations) were planted in Alupe, Kenya. Most of these materials flowered in about 68 days and had a mean yield of 3.471 t ha^{-1}. Ten lines were selected for inclusion in regional evaluation trials based on the yield data and other agronomic characteristics like flowering, agronomic score and midge reaction.

- Eleven restorer lines selected from crosses between KARI Mtama 1X SC691-14-NIG-FET selected for their short stature and large seed were identified and can be used to make high-yielding short-statured hybrids.

- A total of 15 experimental hybrids were developed at Alupe during the 2005 long rains season for evaluation along with other hybrids developed earlier.

- On-farm demonstrations: A number of improved varieties suitable for the drought prone areas of eastern and north eastern Kenya as well as those suitable to the humid Lake Victoria zone have been identified. Some of these varieties are still in the pre-release status; partly because there has been limited effort in the promotion of these improved elite sorghum varieties. In some cases there is need to submit on-farm performance data which is also a pre-requisite for their release. On-farm demonstrations were therefore established in five districts in Kenya in collaboration with partners from Kenya Agricultural Research Institute (KARI). The mother and baby trial design was used. The mother trial had 8 entries (6 improved, 1 commercial and a local variety) replicated four times. Fifteen baby trials were planted in the surrounding environments. The baby trials were not replicated. Each farmer with a baby trial had 2 improved varieties, 1 commercial and a local check. Field days were also conducted and attended by more than 500 farmers and policy makers. *Striga* was also recognized as a very serious biotic stress for sorghum that needed judicious and collaborative efforts through integrating genetic (conventional and molecular techniques) with crop and soil fertility management technologies.

Progress:

Sorghum:

Data analysis for the mother trials has been completed and the best performers are Seredo, IESV92036 and IS8193 across the four sites. At least 50% of the data from the baby trials has been received and analysis has been completed. The mean yield for the Alupe sites was 4.76 t ha^{-1}; Siaya 3.94 t ha^{-1} and Migori 0.914 t ha^{-1}. Data from Siaya are given in Table 2.2.

Table 2.2. Sorghum on-farm evaluation trials across 22 farmers in Siaya district of Kenya, 2005.

Ranked from highest to lowest yielder	Name	Grain yield (t ha^{-1})	Shoot fly damage: 1. None 2. Low 3. Average 4. High	Overall disease score: 1. None 2. Low 3. Average 4. High	Days to 75% maturity: 1. Early 2. Medium 3. Late
1	Seredo	4.540	1.6	1.9	1.0
2	Local check	4.400	1.9	2.0	2.5
3	IESV 92036	3.980	2.0	1.8	1.3
4	IS 8193	3.840	1.8	1.9	1.8
5	IESV 92022/1-SH	3.840	1.9	2.1	2.5
6	Wagita	3.800	2.0	1.9	2.5
7	IES 93042-SH	3.750	2.0	1.9	2.8
8	IESV 92055/S-SH	3.370	1.9	2.6	1.8
Grand mean		3.940	1.9	2.0	2.0
SE		0.989	0.20	0.46	0.52

Finger millet:

Promotion of blast resistant finger millet in Western and Nyanza provinces of Kenya: With the exception of Sudan, finger millet is the most important millet in the ESA region. Finger millet is increasing in importance due to the unique nutritional components and also its marketing potential. Finger millet blast is an important disease that can cause high yield losses (Fig. 2.3). Previous work characterized blast pathogen populations and also identified some finger millet resistant varieties. Promotion and demonstration of potential of improved and blast resistant varieties was carried out in Kenya and Uganda using four farmers' varieties (Acc14, 29, 32 and 44) and ICRISAT germplasm lines KNE620, 629, 688, 814 and 1149. Yields across the mother and baby trials in the two countries ranged from 1.06 t ha^{-1} to 1.85 t ha^{-1}. Overall, the highest yielding materials were KNE688; ACC32, KNE814. These were also the most blast resistant varieties.

Figure 2.3. Blast resistant and high-yielding finger millet variety.

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Output 2.2: Regionally adapted parental lines, varieties and hybrids with market traits developed for SAT regions

*ICRISAT and NARS scientists in ESA recognize the advantage in pursuing regionalized crop improvement strategies and using the **lead NARS** approach to improve efficiency in crop improvement. A number of sorghum and pearl millet Lead NARS project have been developed and are under implementation. The groundnut programs have defined priority research issues for non-confectionary groundnut for the short-duration production domain (which is by far the largest) and confectionary groundnuts for the medium- to long- duration domains.*

***A regional sorghum hybrid evaluation** indicated the highest yields to be from SDSH93025, SDSH98008, DC75; ZWSH 1 and SDSH90003 with yields from 2.14 to 2.69 t ha-1. **Sorghum cultivar evaluation** including some high-yielding, large grain sorghum varieties and restorers acquired from ICRISAT India and tested in Zimbabwe for three years were evaluated in Nampula province of Mozambique to identify new materials. The line SDSL98018 the highest yielding, followed by some of the new high-yielding large grain variety SP993527. In Alupe, Kenya, the IESV92036-SH had the highest yield (5.15 t ha^{-1}), followed by SDSH93025 (4.643) and Wagita 3.789 t ha^{-1}. There are some varieties which are very competitive and can yield as well as the hybrids. The NARS breeders in Kenya have been encouraged to release the most promising varieties for farmers' access.*

The ICRISAT ESA program has a range of ***groundnut*** *lines of varying maturity range and grading qualities. In the short duration category the focus is on incorporation of dormancy, large seeded, yield, quality and adaptation, and selecting for drought resistance with a focus on the confectionary market. At Chitedze Research Station, several short-duration high-yielding varieties–some with yields ≥ 200% over the standard check JL 24–were identified. The best five varieties were ICGV 94536, ICGV-SM 99598, ICGV-SM 98543, ICGV-SM 00528 and ICGV-SM 98544 with kernel yields ranging from 2.5 to 2.7 t* ha^{-1} *compared to the control JL 24 (1.6 t* ha^{-1}*). In the* ***elite short-duration drought tolerance and dormancy groundnut variety trial****, the best five entries in terms of yield performance to be ICGV-SM 95598, ICGV-SM 98519, ICGV-SM 86021, ICGV-SM 95599, and ICGV 94139 with yields ranging from 2.6 to 3.1 t* ha^{-1} *compared to 1.6 t* ha^{-1} *to 2.1 t* ha^{-1} *for the controls. Among the best five lines with resistance to Early Leaf Spots are ICGV-SM 93541, ICGV-SM 96678, ICGV-SM 95714, ICGV-SM 95695, ICGV-SM 95740. The top five* ***rosette resistant*** *entries were ICGV-SM 99543, ICGV-SM 99566, ICGV-SM 01513, ICGV-SM 01514 and ICGV-SM 01506.*

The Malawi national program has released a rosette resistant variety (ICGV-SM 99568) in August 2005.

There is a growing demand for chickpeas particularly kabuli *types on the international markets. In ESA, both* desi *and* kabuli *types are popular with smallholder farmers because of their ability to utilize residual soil moisture.* ***A range of chickpea genotypes fitting various agro-ecological and farming systems were evaluated****. The results indicated very good grain yield potential for chickpeas in ESA. However, on-farm yields are generally low due to the broadcasting habit instead of row planting and also due to lack of adequate inputs such as pesticides.*

Activity 2.2.1: Delineate agro-ecological zones; identify themes and recommendation domains for regionalized breeding approaches

Milestones: At least two lead NARS/ projects led by NARS on behalf of the region

NARS breeders in ECA have provided climatic information for sorghum, pearl millet and finger millet growing conditions to allow AEZ and GIS mapping to determine production and recommendation domains for these crops in the region (Fig. 2.4). NARS have also provided similar information for the test sites to facilitate mapping of sites that fall within the same AEZ for initial determination of test sites for regional testing of germplasm. The ESA region in collaboration with NARS scientists in the respective Sub Regional Organization recognize the added advantage in pursuing regionalized crop improvement strategies and using the **lead NARS** approach to improve efficiency in crop improvement. Through the ECASARM network/ASARECA and in collaboration with ICRISAT, a number of Lead NARS projects have been developed and are under implementation.

These include:

- Fighting *Striga*: Resistant genes deployed to boost sorghum productivity: Lead NARS-Eritrea
- Increasing sorghum utilization and marketability through variety identification and food products diversification: Lead NARS-Tanzania
- Integrated *Striga* management for improved sorghum production in ECA: Lead NARS-Tanzania
- Photoperiod sensitive sorghum improvement: Lead NARS-Zambia

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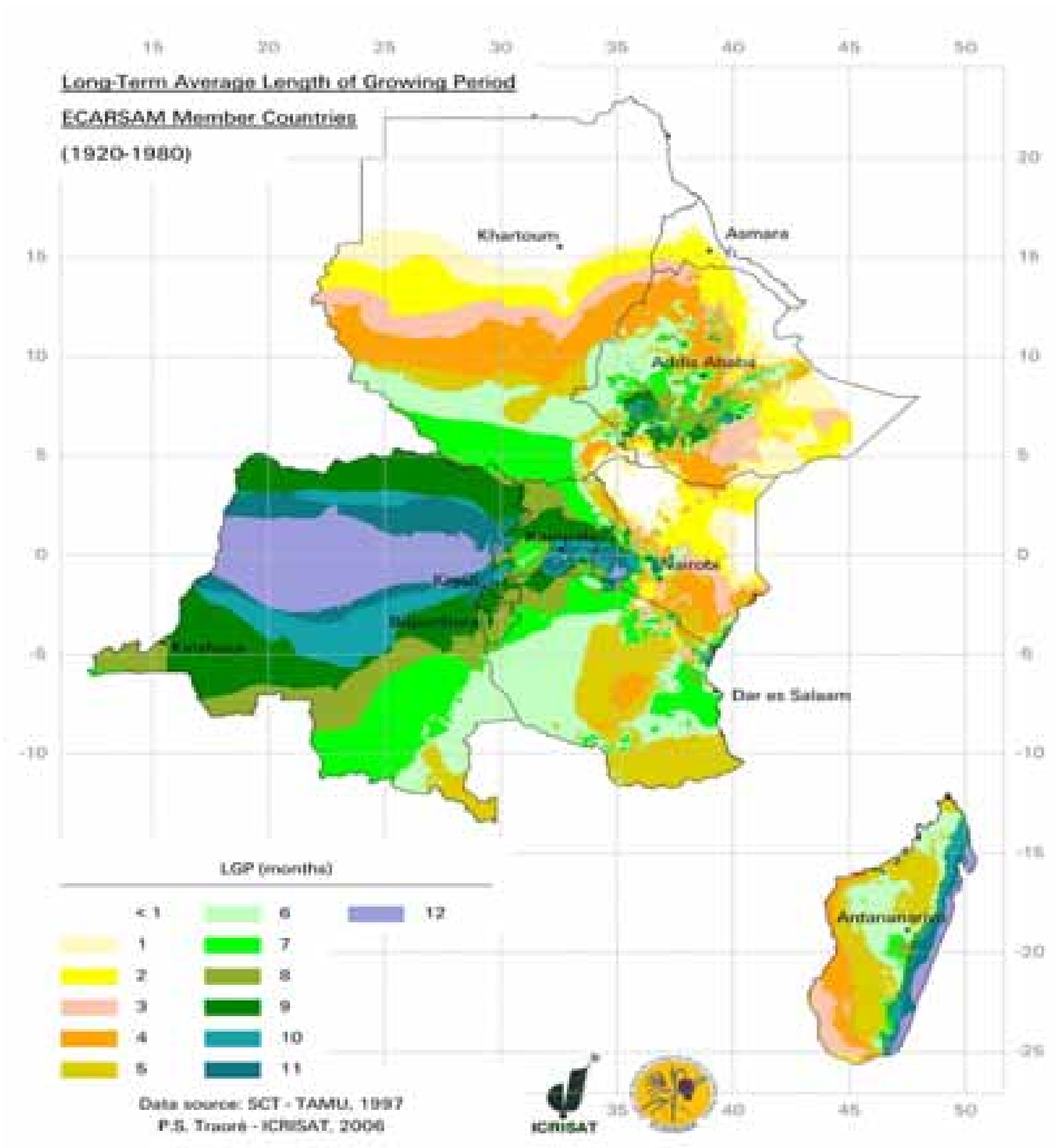

Figure 2.4. Long-term average length of growing period in Eastern and Central Africa.

Activity 2.2.2: Set priorities for a regionalized breeding approach for ICRISAT mandate crops

Milestone: Recommendation domains identified for at least two crops by 2007; Strategic plan and priorities set

Research priorities for legumes and oilseed crops for ASARECA region: The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) has identified legumes and oilseed crops as high priority crops with potential for moving a large number of farmers out of poverty if improved research technologies were easily made available to farmers. ASARECA thus requested ICRISAT to assist in the development of a regional strategy for legumes and oilseed crops. The major oilseed crop in the region is groundnuts. As a member of the team for the development of the regional strategy, we identified four priority areas for groundnuts; yield and adaptation, foliar disease resistance, aflatoxin management and drought. Based on these, we defined priority research issues for non-confectionary groundnuts for the short-duration recommendation domain (which is by far the largest), and confectionary groundnuts for the medium- to long-duration domains. Since the non-confectionary groundnuts the major use is oil extraction, recommendation was therefore for research focus on oil content and quality bearing the following:

- Target development of short-duration cultivars which must incorporate genetic resistance to fresh seed dormancy for short-duration environments.
- For the medium- to long-duration environments need to target yield improvement, quality and confectionary types.
- For all environments improvement of groundnuts for foliar disease (Rosette, ELS, LLS and RUST) resistances and genetic diversity.

The fastest expanding intake of groundnuts is in the confectionary markets – mainly governed by consumers' preferences for taste, seed color, size, shelf life of marketed products and industrial specifications for particular size and shape. For this reason, research priorities should consider the following:

- Low oil content to avoid product rancidity.
- Low Oleic/Linoleic acid (O/L) ratio which favor long shelf life and taste.
- Consumers prefer large seeded nuts hence the challenge to develop large seeded nuts for short duration environments.
- Research efforts are needed to reduce aflatoxin.

For all types, there is need to improve genetic diversity through interspecific/wide hybridization since cultivated groundnuts lies on a narrow genetic base.

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Activity 2.2.3: Assist NARS to pursue regionalized sorghum and pearl millet improvement strategies

Milestone: A range of maturity groups, growth habits and quality characteristics for sorghum, pearl millet, groundnut, chickpea and pigeonpea identified to fit into various agro ecologies and farming systems (2004-2007)

The national programs in the Eastern and Southern Africa are increasingly facing declining human and financial resources for research and development work. In view of this they have had limited capacity to contribute sorghum and pearl millet lines to the regional evaluation programs. It has therefore been necessary to complement the NARS by providing semi finished materials for preliminary evaluation to identify materials adapted to individual countries before recommending them into regional trials.

Improvement of the long season photoperiod sensitive sorghum: The long season photoperiod sensitive sorghums have over the years contributed significantly to the food security of the long season areas of central and northern Mozambique. These areas can be considered as relatively high potential because of the amount of rainfall that is received. From preliminary observations in Mozambique, the genetic diversity of the long season sorghums has declined. The activity therefore looked at the possibility of identifying long season sorghums with higher yield potentials across the targeted areas especially from Tanzania for re-introduction. Further analyses are to provide information on the use of these for developing populations and restorer lines that can be used in hybrid program. A total of 33 long season photoperiod sensitive sorghums from Tanzania, Mozambique and Zambia and two improved long season varieties (Pato and Sima) were evaluated in Nampula (Mozambique) and Naliendele (Tanzania). The number of days to 50% flowering ranged from 136 to 160 days. The improved varieties flowered in 102-110 days. The same materials were also characterized at the University of Zambia by a student form Tanzania. The materials have been assigned the Bulawayo genebank numbers and will be conserved for future crop improvement work including developing experimental hybrids.

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Regional sorghum hybrid evaluation: A regional hybrid trial was conducted in Kenya, Uganda and Zimbabwe. The hybrids originated from the ICRISAT Zimbabwe and Kenya as well as from Pioneer Seed Company. In Kenya these were tested in Alupe and Kiboko and at ICRISAT Matopos in Zimbabwe. Yields in Alupe were higher (mean of 2.78 t ha^{-1}) than in Kiboko (trial mean of 0.81 t ha^{-1}). The yields in Alupe ranged from 1.31 t ha^{-1} to 5.15 t ha^{-1} with IESH22008 yielding the highest. In Kiboko the highest yields of 2.22 t ha^{-1} was obtained from ZWSH1. The combined analysis indicated the highest yields to be from SDSH93025; SDSH98008; DC75; ZWSH 1 and SDSH90003 Table 2.3). Hybrids from Pioneer were extra early and yields were low.

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Ranked according to yield	Variety	Grain yield t ha^{-1}	Days to 50% heading	Days to 50% flowering	Plant height (cm)	Head length (cm)	Exsertion
1	SDSH 93025	2.69	55	60	157.4	34.0	9.0
2	SDSH 98008	2.53	52	57	163.1	34.9	9.2
3	DC 75	2.38	53	58	136.4	31.2	8.5
4	ZWSH 1	2.38	61	63	163.5	28.2	9.6
5	SDSH 93021	2.13	54	59	149.3	34.2	4.1
6	SDSH 98012	1.81	63	67	142.6	30.1	7.6
7	SDSH 90003	1.76	56	60	135.5	30.0	6.1
8	SDSH 94001	1.73	56	61	147.1	28.5	9.3
9	SDSH 98022	1.64	57	61	142.9	30.7	5.1
10	SDSH 94003	1.64	54	59	144.2	31.8	6.5
11	GV 3017	1.61	50	55	124.4	22.4	4.1
12	SDSH 94011	1.53	56	61	138.2	27.9	11.2
13	SDSH 48	1.51	59	64	152.5	29.3	9.2
14	SDSH 98006	1.19	63	68	152.6	32.1	8.2
15	NS 5511	1.18	57	61	105.5	25.2	4.6
16	BSH 1	1.09	59	63	138.3	27.6	7.7
17	SDSH 98001	1.00	66	72	149.3	28.9	9.9
18	SDSH 409	0.89	55	59	120.4	29.1	8.5
19	SDSH 93024	0.35	55	60	143.0	31.4	7.5
20	S4-8601	0.25	54	60	138.0	32.0	7.6
Grand mean		1.63	56.7	61.5	142.4	29.9	7.7
SE		0.54	2.31	2.32	10.38	2.38	2.80
CV (%)		33.1	4.1	3.8	7.3	8.0	36.5

Table 2.3. Combined analysis – sorghum hybrid evaluation in Kiboko and Alupe, Kenya, 2005.

Sorghum cultivar evaluation in Mozambique and Kenya: Twenty five cultivars including some high yielding, large grain sorghum varieties and restorers acquired from ICRISAT India (and tested in Zimbabwe for three years) were evaluated in Nampula province of Mozambique to identify new materials for in-country evaluation. The line SDSL98018 was the highest yielding, followed by some of the new high yielding bold grain variety SP993527 (Table 2.4). Macia and Sima were not among the top ten varieties. Sima was the lowest performer and it was also the latest to flower, an indication that it did not fit the length of growing period for the site.

Ranked from highest to lowest yielder	Name	Grain mass (t ha^{-1})	Initial plant stand	Days to 50% flowering	Plant height (cm)
1	SDSL98018	2.01	27.35	65.66	122.2
2	SP993527	1.57	21	69.46	111.5
3	ICSV89094	1.47	27.82	69.79	145
4	SDSL98021	1.47	19.76	69.61	216.6
5	SP993529	1.40	22.37	67.25	126.1
6	SP993442-1	1.37	23.43	67.38	114.1
7	ICSV89106	1.35	19.26	70.6	129.4
8	ICSV89117	1.13	23.86	69.66	142
9	ICSV93041	1.13	18.61	67.06	146.8
10	ICSR161	1.11	16.33	67.99	116.5
11	SP993371-3	1.04	25.93	73.17	125.7
12	SP993532	0.93	28.83	65.29	126.6
13	Macia	0.91	21.33	66.33	122.2
14	SP993522-1	0.86	16.8	72.33	113.5
15	SP995214	0.67	14.39	65.73	96
16	ICSV500	0.65	22.75	68.59	146.2
17	SP993515	0.62	9.21	72.33	97.3
18	SP993314	0.61	20.12	67.68	145.7
19	ICSV547	0.56	13.01	68.93	148.9
20	SP993520-1	0.54	6.93	71.74	111.6
21	ICSV91010	0.48	14.75	68.33	98.8
22	ICSV492	0.42	22.45	67.75	127.9
23	SP993531	0.40	3.37	68.1	93
24	ICSV382	0.32	8.77	69.21	147.6
25	Sima	0.12	9.24	74.68	165.4
Grand mean		0.926	18.31	68.99	129.5
SE		0.5061	8.393	4.22	18.27
CV (%)		54.7	45.8	6.1	14.1

Table 2.4. Sorghum cultivar evaluation in Nampula Mozambique, 2005.

In Alupe, Kenya, 25 cultivars were evaluated for performance to identify varieties and hybrids that could be incorporated into the regional trials. The IESV92036-SH had the highest yield 5.15 t ha^{-1} followed by SDSH93025 (4.64 t ha^{-1}) and Wagita 3.79 t ha^{-1} (Table 2.5). The hybrids SDSH93021, SDSH 98008, and varieties Seredo and IS8193 had yields above 3.2 t ha^{-1}. There are some varieties which are very competitive and can yield as well as the hybrids. There is need to identify hybrids that are much more superior to the hybrids if hybrids are to be taken up by the farmers and the industry.

Table 2.5. Sorghum cultivar evaluation in Alupe, Kenya, 2005.

Ranked from highest to lowest yielder	Name	Grain yield (t ha^{-1})	Establishment count/plot	Days to 50% flowering	Plant height (cm)
1	IESV 92036-SH	5.15	50	66	224.2
2	SDSH 93025	4.64	47	59	205.2
3	WAGITA	3.79	46	67	196.1
4	ASINGE	3.60	49	71	250.5
5	SDSH 98008	3.58	48	58	199.8
6	SDSH 93021	3.54	30	59	194.0
7	IS 8193	3.36	47	66	175.0
8	SEREDO	3.26	46	61	163.6
9	SDSH 98012	3.10	45	65	179.7
10	DC 75	3.03	40	56	170.8
11	ZWSH 1	2.92	36	59	206.7
12	IESV 93042-SH	2.80	44	69	197.1
13	SDSH 94011	2.74	29	60	168.9
14	SDSH 94003	2.73	31	58	169.7
15	SDSH 98022	2.59	39	60	195.5
16	SDSH 90003	2.54	22	57	159.9
17	SDSH 94001	2.44	29	58	183.2
18	GV 3017	2.08	43	54	144.5
19	NS 5511	2.06	47	58	139.0
20	SDSH 98006	1.98	22	67	192.2
21	SDSH 48	1.81	31	59	183.0
22	BSH 1	1.55	47	59	183.2
23	SDSH 93024	1.48	23	63	170.6
24	SDSH 409	1.43	7	57	144.9
25	SDSH 98001	1.31	37	69	204.9
Grand mean		2.781	37.4	60.4	184.1
SE		0.673	5.20	1.70	12.11
CV (%)		24.20	13.90	2.80	6.60

MA Mgonja, P Kaloki and J Kibuka

Milestone: 5–10 high-yielding short-duration groundnut varieties with confectionary market traits identified for promotion to on-farm testing in ESA region

Short-duration groundnut varieties with improved grain and grading qualities for the domestic and export markets: The ICRISAT ESA program maintains groundnut lines of varying maturity range and seed qualities (Fig. 2.5). In the short-duration category our focus is on incorporation of dormancy, large seeded, high yield and adaptation, and selecting for drought resistance with a focus on the confectionary market. Rainfall at Chitedze Research Station ended pre-maturely (673.3 mm). The crop was therefore subjected to severe end of season drought. At Ngabu Research Station the main drought screening center, effective rain was less than 400 mm, also ending first week of February just when the nurseries were beginning to flower. The nurseries were thus severely stressed. No variety survived the heat (temperatures easily reaches 40 deg.) and long extended drought at Ngabu Research Station in Southern Malawi. This location provides for an excellent natural environment for drought screening. Zero yields were recorded for most entries. However, entries that at least survived death were identified for further observation. Ngabu Research Station provides for an excellent heat and drought screening natural environment for ESA region.

At Chitedze Research Station, several short-duration high-yielding varieties – some with yields ≥ 200% over the standard check JL 24 were identified.

Advanced adaptability and quality groundnut variety trial (Spanish): Some lines outperformed those of the control varieties (JL 24, Nyanda and Sellie). The top five varieties (out of 33 test lines) were ICGV-SM 03552, ICGV-SM 03573, ICGV-SM 03564, ICGV-SM 03559, ICGV-SM 03560 (yields 2794–3043 kg ha^{-1} vs 1299 for JL 24) under low disease pressure. All entries showed susceptibility to ELS with scores ranging from 6–9. Sellie had the highest ELS score (9). Though susceptible to ELS, yields were not affected much because of short-duration.

Figure 2.5. Evaluating elite groundnut varieties for performance and adaptation at Chitedze Research Station in Malawi.

Elite aflatoxin resistance groundnut variety trial (Spanish): Thirteen short-duration genotypes were evaluated and compared to three controls, J11, JL 24 and Nyanda. ICGV 95456 performed exceptionally well in pod yield (3222 kg ha^{-1}), haulms weight (1819 kg ha^{-1}), kernel yield (2028 kg ha^{-1}), 100 seed mass (43.05 g), compared to J11 the resistant check (pod yield 1611 kg ha^{-1}, haulms yield 832 kg ha^{-1}, and kernel yield 1192 kg ha^{-1}). Results from germination tests conducted prior to harvesting showed 0% germination indicating fresh seed dormancy which is not normally the case with most Spanish varieties. ELS incidence was severe and none of the materials tested showed resistance to the disease. Nyanda was the worst hit with an ELS score of 9.0.

Elite very short-duration groundnut variety trial (Spanish): Fourteen short-duration test lines and two controls which included JL 24 and ICG 12991 were evaluated. With the exception of two lines, all the varieties evaluated performed better that the controls. The best five varieties were ICGV 94536, ICGV-SM 99598, ICGV-SM 98543, ICGV-SM 00528 and ICGV-SM 98544 with kernel yields ranging from 2464–2681 kg ha^{-1} compared to the control JL 24 (1616 kg ha^{-1}). In all the entries, ELS incidence was severe.

Elite short-duration drought tolerance and dormancy groundnut variety trial: Twenty breeding lines were evaluated and compared to 4 controls (ICG 12991, Malimba, Nyanda and JL 24). The best five entries in terms of yield performance were ICGV-SM 95598, ICGV-SM 98519, ICGV-SM 86021, ICGV-SM 95599, and ICGV 94139 with kernel yields ranging from 2633-3080 kg ha^{-1} (compared to 1662-2101 kg ha-1 for the controls). ICGV-SM 95599 and ICGV-SM 98519 also showed good levels of resistance to ELS (score 5.0).

ES Monyo

Milestone: At least 2 groundnut varieties with resistance to rosette, ELS, LLS and rust incorporating market desired traits identified for release in ESA

Evaluation and promotion of varieties for food security and market traits: Various breeding lines and varieties were evaluated at Chitedze Research Station, Malawi for rosette and ELS under high and low disease pressure. High rosette and ELS disease pressure was induced using the infector row technique.

Elite rosette resistance groundnut variety trial (Spanish): Twenty three elite breeding lines and 2 controls were evaluated under high rosette disease pressure. The top five entries were ICGV-SM 99543, ICGV-SM 99566, ICGV-SM 01513, ICGV-SM 01514 and ICGV-SM 01506 with kernel yields ranging from 929–1183 kg ha^{-1}. The susceptible control JL 24 produced just 202 kg ha^{-1}, while the resistant control ICG 12991 managed 942 kg ha^{-1}. Rosette disease incidences for the resistant varieties ranged from 0–2.2% while incidence on JL 24 was 81%. The resistant control ICG 12991 had 1.5% incidence. Unfortunately all materials were susceptible to ELS.

The Malawi national program released a new rosette resistant line ICGV-SM 99568 in August 2005. As can be seen from the performance results above, better higher yielding lines are in the pipeline ready for release in the next 2-3 years.

Elite early leaf spots resistance groundnut variety trial: Fourteen elite breeding lines were evaluated under high ELS disease pressure. Among the best five lines were ICGV-SM 93541, ICGV-SM 96678, ICGV-SM 95714, ICGV-SM 95695, ICGV-SM 95740 with kernel yields ranging from 705–947 kg ha^{-1}, compared to the best resistant control Valencia R2 (600 kg ha^{-1}) and the susceptible check JL24 (428 kg ha^{-1}). We therefore have elite germplasm in the pipeline that are ≥25% superior to the current best.

ES Monyo

Milestone: Evaluate a range of chickpea genotypes fitting various agro-ecological and farming systems

Adaptation of chickpeas: There is a growing demand for chickpeas particularly *kabuli* types on the international markets. In ESA, both *desi* and *kabuli* types are popular with smallholder farmers partly because of their ability to utilize residual moisture. Two field trials of chickpeas were conducted in Kenya and Mozambique. In Kenya both *desi* and *kabuli* types flowered with 60 days (Table 2.6). The *desi* type cultivar ICCV 00108 attained the highest grain yield (3.5 t ha^{-1}) while ICCV 00302 achieved the highest grain yield among the *kabuli* types.

Similarly in Mozambique, ICCV 97128 (*desi* type) attained the highest grain yield (4.3 t ha^{-1}) which was 25% higher than the mean grain yield (3.5 t ha^{-1}) of the trial. The highest grain yield among the *kabuli* types was 3.6 t ha^{-1}. The *kabuli* cultivar ICCV 92318 attained the largest grain size (100 grain weight = 42.3 g). The results of the two trials indicated very good grain yield potential for chickpeas in ESA as represented by the two locations. ICRISAT-Nairobi with partners in the Ethiopia national program conducted on-farm technology demonstration [under the using five pilot learning sites (Ude, Hidi, Qurqura, Dire and Godino)] located in Ada district (Fig. 2.6). In addition, smallholder chickpea farmers in the ESA region generally lack adequate inputs such as pesticides.

SN Silim and E Gwata

Figure 2.6. Chickpea cultivar 'Ejeri' row-planted in a demonstration plot at Ude in Ada district (Ethiopia).

Table 2.6. Agronomic performance of chickpea experimental cultivars during the 2005 cropping season at Kabete Research Station, Kenya.

Cultivar	*Kabuli/Desi*	Days to 50% flower	Seed weight (g 100 seed^{-1})	Grain yield (t ha^{-1})
ICCV 00108	D	63	26.9	3.5
ICCV 97125	D	65	23.8	3.1
ICCV 97107	D	64	22.3	2.8
ICCV 97201	D	62	25.5	2.7
ICCV 97110	D	62	23.3	2.7
Ngara local	D	63	19.9	2.5
ICCV 97031	D	64	24.0	2.4
ICCV 97114	D	69	27.4	2.4
ICCV 97126	D	65	25.7	2.4
ICCV 97128	D	67	24.1	2.4
ICCV 00302	K	59	29.3	2.3
ICCV 92311	K	59	31.4	2.2
ICCV 97306	K	57	35.6	2.0
ICCV 97206	D	70	25.8	2.0
ICCV 97406	K	67	23.9	1.9
ICCV 97115	D	69	21.4	1.9
ICCV 92944	D	61	26.2	1.9
ICCV 00402	K	59	27.7	1.9
ICCV 95311	K	54	36.5	1.9
ICCV 97033	D	64	23.8	1.9
ICCV 00104	D	61	30.4	1.9
ICCV 97105	D	63	24.6	1.8
ICCV 96329	K	54	33.7	1.8
ICCV 00305	K	58	26.9	1.6
ICCV 95423	K	63	35.3	1.4
ICCV 92318	K	54	33.3	1.3
Mean	-	62.2±2.5	27.3±2.1	2.2±0.8
CV (%)	-	4.0	7.6	37.0

Output 2.3: Participatory methods and technologies for crop improvement and IPM developed and tested

ICRISAT, in collaboration with the Tanzania NARS, provided seed of improved long-duration pigeonpea cultivars for on-farm trials in the northern region particularly in Babati district, Tanzania. On-farm variety evaluation and farmer participation resulted in wide adoption of ICEAP 00040 and ICEAP 00053 in the district.

Activity 2.3.1: Evaluate and promote through participatory methods, new improved pigeonpea, sorghum and pearl millet varieties, hybrids and seed parents, and groundnut varieties with resistance to major pests and diseases

Milestone: IPM options in field, and plant products efficacy in storage pests of pigeonpea, sorghum and millets evaluated (2007)

Farmer participation and technology dissemination: ICRISAT in collaboration with the Selian Agricultural Research Institute (SARI) and Ilonga Agricultural Research Institute (Tanzania) distributed seed of improved long-duration pigeonpea cultivars for on-farm trials in the northern region, particularly in Babati district. The varieties were evaluated on-farm through farmer-participatory methods. On-farm meetings between ICRISAT scientists and pigeonpea farmers were conducted in the Babati district (Fig. 2.7). ICEAP 00040 and ICEAP 00053 have been adopted widely in the district partly because of their acceptable agronomic, market qualities and resistance to *fusarium* wilt disease.

Figure 2.7. Enthusiastic pigeonpea farmers learn about* fusarium *wilt in Babati (Tanzania).

SN Silim and E Gwata

Output 2.4: Technical backstopping provided to regional networks and projects

The information on the regionally released sorghum cultivars in the SADC region has been published, providing description of the varieties and breeding history and characteristics. More than 200 copies were distributed to NARS partners in ESA. We contributed in the SADC-SSSN meetings to finalize the protocol for regional variety testing and registration. Adequate seed quantities have been multiplied for sorghum varieties Sima, Macia and ICSV112 as well as for two pearl millet varieties Okashana1 and PMV3 to meet the requirements on seed quantities prior to regional variety registration.

A template for a web-based seed catalog to support regional variety registration in the Southern Africa Development Community (SADC), the East African Community (EAC), and in West Africa (a joint initiative involving the West African Economic and Monetary Union (WAEMU), the Economic Community of West African States (ECOWAS), and the Institut du Sahel (INSAH)/Comité Inter-Etat de la Lutte Contre la Secheresse au Sahel (CILSS) was *designed. This catalog will contain information generated from Distinctness, Uniformity, Stability (DUS) tests and results obtained from Value for Commercial and Use (VCU) tests needed for regional registration.*

A Foundation Seed Unit in Mozambique – Unidade de Sementes Basica (USEBA) –addresses the lack of availability of publicly developed varieties. In 2005 a detailed business plan was drawn up for USEBA to become self-sustaining. Based on estimated demand for foundation seed it was showed that full-cost recovery was possible after three years. The Mozambique and Malawi examples are being used to learn about how the seed supply constraint limiting adoption of public-sector developed varieties can be overcome, and to apply these lessons in the development of more sustainable seed supply systems that are urgently required in many countries of sub-Saharan Africa and indeed elsewhere. The harmonization of seed policies is being pursued independently in three sub-regions of sub-Saharan Africa (SSA) under different auspices, and with funding support from different donors.

Technical backstopping and implementation strategies, capacity building, and information were provided to regional networks: ECARSAM, SMINET SADC –FANR and SSSN.

Activity 2.4.1: Provide technical backstopping and implementation strategies, capacity building, and information to regional networks: E*CARSAM, SADC–FANR, SSSN*

Milestone: By 2007, at least 3 sorghum (Macia, ICSV112 and Sima) and 2 pearl millet (Okashana1 and PMV3) varieties with regional adaptation and multiple release status published in the Regional Variety catalogue

The information on the regionally adapted sorghum and pearl millet in the Southern Africa Development Community (SADC) region has been published, providing description of the varieties and breeding history and characteristics. More than 200 copies were distributed to NARS partners in ESA. We participated in the SADC Seed Security Network (SSSN) meeting deliberating on finalizing the protocol for regional variety testing and registration. The protocol will be submitted to the policy makers in the SADC region for ratification. Adequate seed quantities have been multiplied for sorghum varieties Sima, Macia and ICSV112 as well as for two pearl millet varieties Okashana1 and PMV3 to meet the requirements on seed quantities prior to regional variety registration.

MA Mgonja and S Kudita

Seed catalog: A template for a web-based seed catalog to support regional variety registration in the Southern Africa Development Community (SADC), the East African Community (EAC), and in West Africa (a joint initiative involving the West African Economic and Monetary Union (WAEMU), the Economic Community of West African States (ECOWAS), and the Institut du Sahel (INSAH)/Comité Inter-Etat de la Lutte Contre la Secheresse au Sahel (CILSS) was designed. This catalog will contain information generated from Distinctness, Uniformity, Stability (DUS) tests and results obtained from Value for

Commercial Use (VCU) tests needed for regional registration. It is also planned to include maps indicating zones of adaptation of specific varieties based on a common set of mega environments that is sufficiently flexible to cater for the broad range of crops that are being considered for regional registration in each of the three regions.

Catalog management will be the responsibility of the designated authority in each region, and will be done through a web-based management content system only accessible by the designated authority with administration privileges. The catalog will list both commercial and public-sector developed varieties; and information on availability of commercial seed and of basic and foundation seed of public-sector developed varieties produced by Foundation Seed Enterprises (FSEs) will be allowed for a fee to offset the costs of maintaining the seed catalogs.

RB Jones

Foundation Seed Enterprises

In 2003 ICRISAT was asked to establish a Foundation Seed Unit in Mozambique – Unidade de Sementes Basica (USEBA) – to address the lack of availability of public-sector developed varieties. This unit was established as a project under ICRISAT management drawing upon lessons from the seed revolving fund previously established in Malawi for the dissemination of improved groundnut and pigeonpea varieties developed by ICRISAT's regional groundnut and pigeonpea breeding programs, which has achieved considerable success in raising adoption levels of improved varieties. In 2005 a detailed business plan was drawn up for USEBA to determine the likelihood of this unit becoming self-sustaining and based on estimated demand for foundation seed showed that after three years full-cost recovery was possible. Detailed costings were developed for procurement of seed processing equipment and for its operation and management that were then presented to the Mozambique Government and accepted.

The Mozambique and Malawi examples are being used to learn about how the seed supply constraint limiting adoption of public-sector developed varieties can be overcome, and to apply these lessons in the development of more sustainable seed supply systems that are urgently required in many countries of sub-Saharan Africa and indeed elsewhere.

R B Jones

Harmonization of seed policies

The harmonization of seed policies is being pursued independently in three sub-regions of sub-Saharan Africa (SSA) under different auspices, and with funding support from different donors. The regions, countries, regional economic communities (RECs), and institutions involved in these initiatives are listed in Table 2.7.

Table 2.7. Regions, countries, regional economic communities (RECs), and supporting organizations involved in harmonization of seed policies.

Region	Southern Africa	Eastern and Central Africa	West Africa
Regional Economic Community	Southern Africa Development Community (SADC)	East African Community (EAC) and the Common Market for Eastern and Southern Africa (COMESA)	West Africa Economic and Monetary Union (WAEMU)
Countries	13 countries: Angola, Botswana, Democratic Republic of Congo, Lesotho, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe	3 countries under phase one (1999): Kenya, Tanzania and Uganda (EAC) 7 countries under phase two (2001): Burundi, Eritrea, Ethiopia, Rwanda and Sudan (2003) the Democratic Republic of Congo and Madagascar	8 countries: Benin, Burkina Faso, Cote d'Ivoire, Guinea Bissau, Mali, Niger, Senegal, and Togo
Supporting organization	SADC Seed Security Network (SSSN)	Eastern and Central Africa Program for Agricultural Policy Analysis (ECAPAPA)	The International Fertilizer Development Center (IFDC)

A four-day workshop was jointly organized by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Iowa State University (ISU) with support from the "Agricultural Policy Harmonization Project (APHP)" and the program for the Sustainable Commercialization of Seed Systems in sub-Saharan Africa (SCOSA) to review the status of seed harmonization efforts in the three sub-regions of SSA, and then to develop detailed work plans.

The synthesis of the seed policy situation is that all three regions are working on the development of a regional variety testing and release system and common seed certification standards (both field and laboratory) of selected crops. The SADC and EAC regions are in addition pursuing quarantine pest lists based on available scientific knowledge and WAEMU would like to initiate this effort. With regard to Plant Variety Protection (PVP), the EAC region is working toward the development of PVP laws for Uganda and Tanzania, while SADC is interested in developing draft PVP laws for their member countries. The states of West Africa have already drafted a model PVP law intended for regional use and this is expected to be adopted by member states in the near future. With respect to accreditation, the EAC has initiated discussions on this topic. SADC also appears very interested, while WAEMU needs to have additional consultations, given the limited level of seed industry development in their region.

R B Jones

Milestone: Agreement on initiation of regional testing for cereals (sorghum and pearl millet) and legumes (groundnut, pigeonpea and chickpea) (2006)

Sorghum hybrid development has not been an integral part of the sorghum and pearl millet research work in ICRISAT-Nairobi. In southern Africa, however, there has been substantial work of developing and testing of hybrids. The release of hybrids by NARS breeders in SADC has been relatively minimal compared to release of OPVs. Private seed companies have developed and released comparatively more hybrids. Recently, there has been an increasing interest from the NARS and private company breeders to conduct hybrid evaluation. NARS collaborators in Uganda, Zimbabwe and Kenya were provided with a set each of sorghum regional hybrid trials. The model currently in operation in India will be adopted for the ESA region to enhance crop improvement efficiency and also to exploit genetic gains from hybrids. The last regional cultivars evaluations were done during the time of the former network EARSAM in the 1990s. After that there has not been any regular formalized germplasm sharing and comparison of breeding materials developed by different breeding institutions. Based on experiences from the 15 years regional cultivars evaluation in southern Africa, a format has been designed for NARS breeders to provide geographical, climatic and biophysical characteristics of their test sites for sorghum and pearl millet. The information has been provided to the GIS expert to help map target areas for breeding and to stratify test sites for use variety evaluation in Multi Environment Trials (MET).

MA Mgonja and B Mitaru

Activity 2.4.2: Strengthen linkages and partnerships between projects, activities and networks operational within and beyond the ESA region

Milestone: ECARSAM priorities set

Sorghum and millets are the third most important crops in the region, cultivated over 13 million hectares of land. Productivity of these crops is, however, low because of constraints affecting the production to consumption continuum, and limited resources of the national agricultural research systems (NARS) in the region. The East and Central Africa Regional Sorghum and Millet Network (ECARSAM) was initiated in 2003 as one of the networks of the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA), building on the achievements of the former network, the Eastern Africa Regional Sorghum and Millet Network (EARSAM), which ran from 1982 to 1993. The principal goal of the network is to achieve increased economic growth and improved livelihoods in the Eastern and Central Africa (ECA) while enhancing the quality of the environment.

The national systems in ECA cannot simultaneously address all the research needs hence the need to prioritize the constraints and address them accordingly through networking to achieve efficient utilization of resources. The priority setting document is thus an outcome of several consultations involving participation of stakeholders at different levels. The major constraints were identified and these formed the ECARSAM research themes.

1. low productivity;
2. high post-harvest handling losses;
3. limited processing and utilization;
4. limited market for sorghum and millets;
5. unfavorable terms of credit and policy framework;
6. limited capacity-building and institutional development; and
7. limited knowledge and information exchange.

Researchers in ECARSAM are implementing research and development activities in the seven themes funded through ASARECA competitive grants.

B Mitaru

Milestone: Contribution to the annual ECARSAM steering committee meetings and activities and information sharing 2005

ECARSAM is one of the networks/programs and projects (NPP) in the ASARECA region specifically responsible for sorghum and millet research and development for Eastern and Central Africa covering 10 countries. It was revived in September 2003. The ICRISAT–ESA cereal improvement program network work very closely with ECARSAM stakeholders and the ICRISAT cereal breeder provides technical backstopping to the ECARSAM network. Collaboration has also continued with the SADC–FANR. Some of the backstopping activities for 2005 included:

ICRISAT scientists have provided technical backstopping support to ECARSAM and SADC–FANR as follows:

- Participation in stakeholder and Steering Committee meetings for ECARSAM
- Backstopping support to develop competitive proposals for the ASARECA Competitive Grant System in June 2005
- Reviewing of Concept Notes and Proposals that were to be funded under CGS stream B (ECARSAM) in November 2005
- Participated in a proposal development on diversified uses of sorghum targeting funding by the Volcani Institute in Israel
- Supported in the design and implementation of on-farm research demonstration for promoting improved sorghum and blast resistant finger millet varieties in Kenya and Uganda
- Organized an International Finger Millet Workshop in September 2005 to share results on the promotion of blast resistant finger millet varieties and articulate future finger millet research and funding
- Participation at the ECARSAM stakeholders workshop 8-12 November where the ECARSAM priorities and strategies were finalized and documented
- Assisted the ECARSAM network in developing the Finger Millet proposal on "*Facilitating the promotion of improved and blast resistant finger millet varieties to enhance production*" targeting Kenya and Uganda that was submitted and approved for funding by DFID as a collaborative activity between NRI, ICRISAT and the Kenya and Uganda NARS partners
- Assisted and provided technical backstopping to SADC-FANR in organizing a Task Force that deliberated on identification of Sub Regional Organization - Pilot Learning Sites for the Sub Sahara Africa/FARA Challenge Program
- Germplasm for sorghum and millets has been provided to Sudan, Republic of South Africa, Mozambique, Botswana, Madagascar, Ethiopia, NGOs in Zimbabwe, Tanzania, Kenya and Uganda
- Information on the regionally adapted sorghum and pearl millet in the SADC region has been published, providing description of the varieties and breeding history and characteristics. Adequate seed quantities have been multiplied to meet the requirements on seed quantities prior to regional variety registration

- Attended SADC Seed Security Network (SSSN) meeting deliberating and finalizing the protocol for regional variety registration for submission to the policy makers in the SADC region.

MA Mgonja and B Mitaru

Milestone: Capacity and training workshops

- In collaboration and with support from ECARSAM, 26 NARS scientists from 6 countries of the ECA region participated in a training workshop on "Developing winning proposals and technical writing".
- A Tanzanian student graduated at the University of Zambia (MSc Plant Breeding) having worked on the characterization of the long season sorghum varieties using both morphological and molecular markers.
- Sorghum and Pearl millet Seed Production raining was provided to 12 farmers is Eastern Kenya.
- A training workshop for 35 extension staff, farmers and NGO collaborators was conducted at Matopos, Zimbabwe in November 2005 to enable them in implementation of the on-farm and on-station trials in Zimbabwe. This project takes the Integrated Genetic and Natural Resource Management (IGNRM) approach where improved drought tolerant crop varieties for sorghum, maize and pearl millet are integrated with soil fertility and rainwater management technologies for increased productivity.

MA Mgonja and B Mitaru

Milestone: Establish a management framework for the Challenge Program on Water for Food – Project No.1 (CPWFPN1) on crop varieties, soil fertility and water management

ICRISAT is leading and managing Challenge Program Project no.1 (CPWFPN1) for the Limpopo Basin. The Project takes the approach on "Integrated Genetic and Natural Resource Management (IGNRM)". A number of tasks were accomplished in 2005:

- Completed negotiations between ICRISAT and CPWF and finalized MOUs between ICRISAT and the partners institutions
- Organized the inception workshop for the CPWFPN1 in January 2005 at Polokwane, South Africa
- Established project management team and held planning meetings in March and October 2005
- Facilitated development of workplans and strategies for implementation
- Drafted proceedings for the inception workshop
- Milestones for year 1 achieved and report submitted in December 2005
- Assisted in planning and setting up on farm demonstration that integrate crop varieties, soil fertility and water management techniques in Zimbabwe and Mozambique

- Completed the agro-ecological analysis and stratification of sites and an abstract of the paper is given

Agro-ecological Analysis and Stratification of Research Sites of the Limpopo Catchment for Verification of Crops, Soil Fertility and Rainwater Management Technology Options

ICRISAT is collaborating with CIAT, CIMMYT, IWMI and NARES partners of Zimbabwe, South Africa and Mozambique in the implementation of the CPWFPN1. The project is building on past investments and achievements for developed technologies in the areas of crops, soil fertility and water management. It is on the premise that diversified cereal and legume crops, soil fertility and rainwater management options can be combined to reduce risks and improve productivity. Public and private institutional arrangements that allow for output market linkages can be used to enhance profitability and sustainability of smallholder agriculture in the Limpopo basin. Options for participatory technology dissemination and model-based decision support tools can be deployed to promote the benefits more widely.

Identification of benchmark representative test sites was considered an important factor for accurate and efficient technology verification. Participants in the CPWFPN1 proposed 25 sites from which to choose representative sites. The major problem was how to cover the maximum diversity of agro-ecological environment in the Limpopo catchment. Agro-ecological analysis and stratification of research sites was conducted in order to have a minimum coverage of existing experimental sites that would be representative of farmers' fields.

The climates of 25 existing experimental sites within the Limpopo Basin (Table 2.8) were clustered using FloraMap. The extent of the adaptation range for each cluster and site was determined using Homologue. The soil characteristics, land cover, and population were determined from existing data sets. Local access to major markets was mapped using the CIAT Accessibility Wizard. Protected areas were eliminated from the analysis. The length and reliability of the growing season was mapped for the whole catchment using MarkSim. A water balance model was used to calculate potential growing season for rainfed crops over 100 simulated years and the proportion of failed season was mapped.

The 25 sites were stratified into 5 clusters (Fig. 2.8) and each site was processed to give a map of its climatic influence. An example for cluster 4 is in Figure 2.9.

Each site was carefully chosen to represent the maximum environmental range. The exercise quickly eliminated non-representative sites. A consensus was reached on the favored sites where environmental representativity and research infrastructure were maximized. These results provided an objective basis for selection of a few representative benchmark test sites for crop-soil fertility-water productivity technology and also for wide dissemination of results within and beyond the basin.

MA Mgonja

Table 2.8. Stratification of the proposed test sites for the Challenge Program Project No.1.

Site	Latitude	Longitude	Agency[1]	Country[2]	Cluster
Chokwe	-24.53	32.98	CP17	MOZ	1
Mabalane	-23.80	33.60	CP1+17	MOZ	1
Macia	-25.03	33.10	*	MOZ	1
Massingir	-23.80	32.20	CP1+17	MOZ	1
Xai Xai	-25.10	33.50	CP1+17	MOZ	1
Xilembene	-24.60	33.20	CP1+17	MOZ	1
Giyani	-23.33	30.73	LDA	RSA	2
Makulele	-22.86	30.92	LDA	RSA	2
Matibi	-22.08	30.65	*	ZIM	2
Mbahela	-22.81	30.45	LDA	RSA	2
Mopane	-22.60	29.85	*	RSA	2
Mtetengwe	-22.00	30.00	CP17	ZIM	2
Musina	-22.34	30.04	LDA	RSA	2
Filabusi	-20.80	29.30	CP17	ZIM	3
Insiza	-21.42	29.42	*	ZIM	3
Mwenezi	-21.42	30.73	*	ZIM	3
Bochum	-23.30	29.12	LDA	RSA	4
Burgersfort	-24.62	30.33	MDA	RSA	4
Mafefe	-24.17	30.08	CP Wet	RSA	4
Mashushu	-24.32	29.65	LDA	RSA	4
Nebo	-23.03	29.85	*	RSA	4
Sikororo	-24.20	30.42	CP17	RSA	4
Strydkraal	-24.47	29.74	LDA	RSA	4
Tzaneen	-23.77	30.16	LDA	RSA	4
Spitzkop	-23.77	29.85	LDA	RSA	5

1. The Codes with CP are Challenge Program on Water for Food Project Nos (CPWFPN) – CP1=CPWFPN1(ICRISAT), CP17=CPWFPN17(WaterNet), CP Wet=CPWFPN30(Wetland), LDA=Limpopo Department of Agriculture, MDA=Mpumalanga Department of Agriculture.
2. MOZ=Mozambique, RSA=Republic of South Africa, ZIM=Zimbabwe.

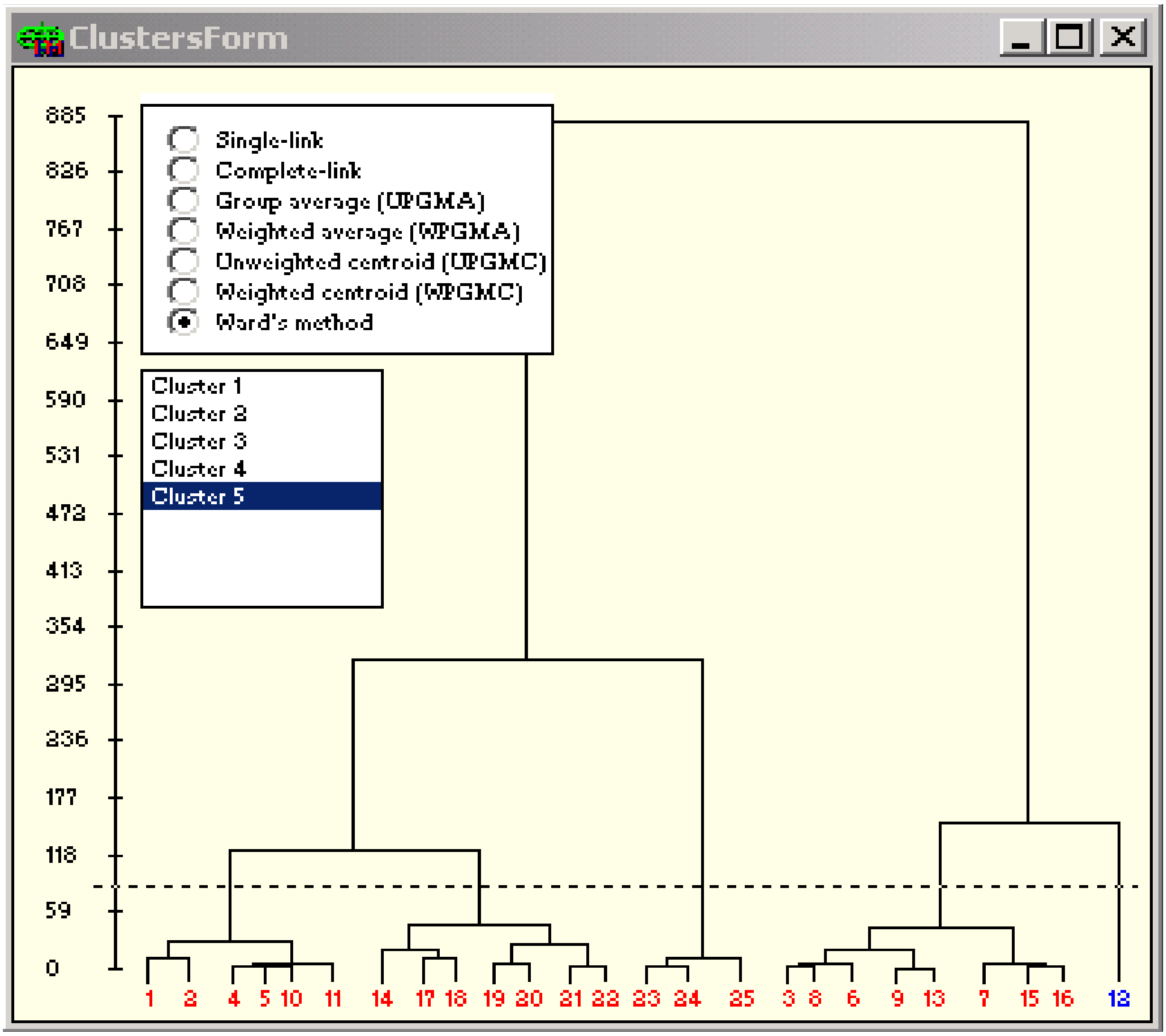

Figure 2.8. Stratification of Limpopo Basin sites into five major groups according to climatic variables.

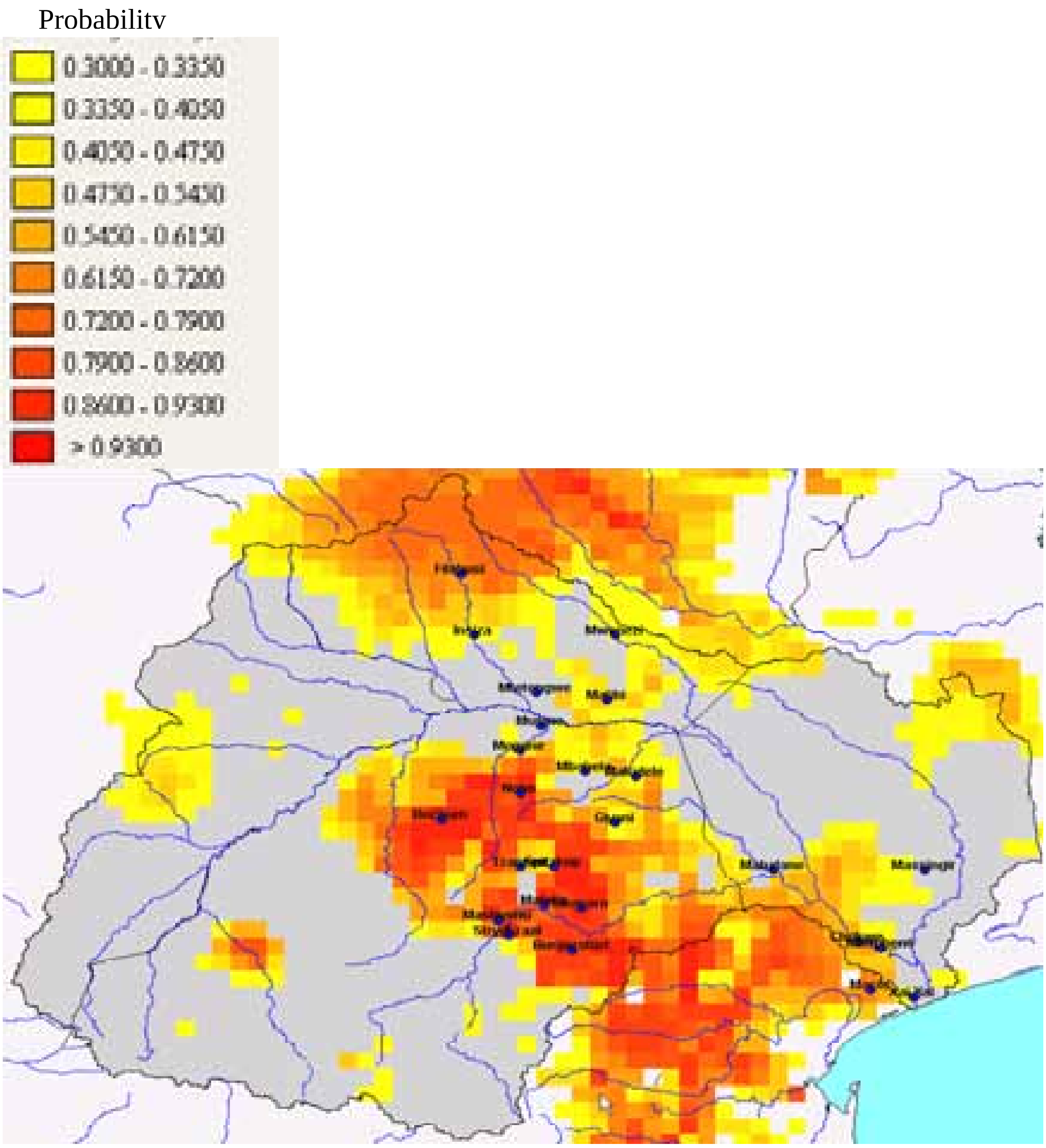

Figure 2.9. Areas of influence for cluster 4 site grouping.

Output 2.5: Regional/sub-regional genebanks maintained

ICRISAT Zimbabwe: *Genebank upgrading and germplasm rejuvenation was completed in Kenya. The Tanzania sorghum landraces have been assigned Bulawayo Genebank numbers and preserved. Cluster analysis based on morphological characters revealed two major distinct groups with two subgroups in each. Molecular marker analysis using SSR revealed variations among 41 genotypes, which were grouped into 11 clusters and was able to separate all the landraces. Three sorghum controls, N13, Ochuti and Adiwo each formed independent clusters. Markers Xgap84 and Xtxp320 had high number of alleles than other markers (7 and 8 alleles, respectively). There were no genotype specific makers with the exceptions of Ochuti and N13 controls. Analyses showed significant variations among landraces, clustering was not by area of collection and molecular markers were more efficient.*

ICRISAT Kenya*: 106 accessions of sorghum and 529 accessions of African finger millet germplasm were characterized. Accessions for 1081 sorghum, 144 accessions of pigeonpea and 36 chickpea have been rejuvenated and seed is being processed for storage.*

Pigeonpea germplasm, originally collected from Tanzania, was characterized for morphological and agronomic traits in Kenya (at Kabete and Kampi yaMawe field stations) and Tanzania (at Ilonga research station). The accessions collected from all the four regions in Tanzania generally flowered later when grown in Kenya (at Kabete and KMRS) compared with Ilonga. The germplasm from the northern region flowered significantly late at all three locations.

Activity 2.5.1: Complete upgrading of regional/sub-regional genebanks

Milestone: Genebank upgrading and germplasm rejuvenation

- Purchased additional equipments required in the genebank and to facilitate operationalization of the installed drier in Nairobi, Kenya
- A medium term storage room for germplasm has been completed at Kiboko, Kenya
- A seed drying room and a drier installed for drying seed for medium storage
- Equipped the Nairobi (Kenya) storage facility with trays for holding storage bottles for ease of tracking the accessions

MA Mgonja and E Muange

Activity 2.5.3: Rejuvenate, characterize, and share information with partners in the region to enhance utilization of the germplasm and usefulness of the genebanks

Milestone: Rejuvenation, collection in identified gaps, and characterization of sorghum, pearl millet and pigeonpea accessions

Bulawayo:

- The Tanzania sorghum landraces have been assigned Bulawayo Genebank numbers and preserved
- 702 sorghum and millet accessions were moved from Bulawayo to Nairobi for rejuvenation in 2006
- Monitored viability of 800 sorghum germplasm accessions. Variability was >85%.

Germplasm sharing: 36 sorghum lines to Mozambique; 86 sorghum and pearl millet entries to Kenya; 32 sorghum breeding lines to Zimbabwe; 66 pearl millet landraces to Zimbabwe**.**

MA Mgonja and S Kudita

Nairobi:

- 106 accessions of sorghum were characterized and seed was processed for storage
- 529 accessions of African finger millet germplasm were characterized and materials with some good performance will be organized for preliminary yield evaluation
- Accessions for 1081 sorghum, 144 accessions of pigeonpea and 36 chickpea have been rejuvenated and seed is being processed for storage
- 575 accessions of sorghum were rejuvenated and 83% produced seed. Seed multiplication will have to be repeated to get adequate quantities for storage

- Number of accessions preserved: Finger millet (379); chickpea (90); groundnut (19); pearl millet (33); sorghum (1243); pigeonpea (203)
- Number of accessions requiring further rejuvenation due to limited seed amounts has been determined for each crop species

MA Mgonja and E Muange

Milestone: Rejuvenate pigeonpea germplasm for medium-term storage

Rejuvenation of pigeonpea germplasm: A total of 227 pigeonpea genotypes in short-, medium- and long-duration maturity groups were rejuvenated at Kiboko (Kenya). For each genotype, approximately 50 g of seed were harvested and processed for medium-term storage at Kiboko.

Characterization of introduced accessions: Pigeonpea germplasm originally collected from Tanzania was characterized for morphological and agronomic traits in Kenya (at Kabete and Kampi yaMawe Research Stations) and in Tanzania (at Ilonga Research Station). At Kampi yaMawe, the accessions were raised in insect pollinator-free conditions in order to avoid cross-pollination associated with pigeonpea. The germplasm was evaluated in the open field at Kabete and Ilonga.

The accessions collected from all the four regions in Tanzania generally flowered later when grown in Kenya at Kabete and Kampi yaMawe compared with Ilonga (Table 2.9). The germplasm from the northern region flowered significantly late at all three locations. This information is useful, particularly for synchronizing prospective parental lines for hybridization in pigeonpea breeding. The grain yield of the accessions did not exceed 0.5 t ha^{-1} at both Kiboko and KM. However, at Ilonga, the mean grain yield ranged between 0.5-2.1 t ha^{-1} (Table 2.9). This could be attributed to the combined effect of genetic and environmental factors. Similarly, the grain size as measured by 100-seed weight, was higher at Kabete than at both KMRS and Ilonga (Table 2.9). Grain color among these accessions was largely white but speckled grains were also observed. The number of branches was highest (11) at Ilonga and lowest (5) at Kampi yaMawe. Similarly, a reduction in the number of pods was also observed at Kampi yaMawe. Likely, this was due to the moisture stress conditions prevailing at the location.

Table 2.9. Duration to 50% flowering (days), seed weight (g 100 seed^{-1}) and grain yield (t ha^{-1}) of pigeonpea germplasm originating from Tanzania evaluated during 2005.

	Duration to 50% flower (days)			Seed weight (g 100 seed^{-1})			Grain yield (t ha^{-1})		
Origin	Kabete	KYM[1]	Ilonga	Kabete	KYM	Ilonga	Kabete	KYM	Ilonga
Coastal belt	97-125	100-149	92-105	14.5	13.2	11.8	1.7	0.3	1.7
Eastern region	99-150	104-223	95-118	15.8	14.7	13.4	2.2	0.3	2.1
Southern region	95-139	103-195	90-123	16.2	14.9	14.8	1.6	0.3	1.7
Northern highlands	118-176	127-234	212-160	16.2	15.2	10.0	2.9	0.2	0.5
Medium duration (Check)	106	92	96	16.5	15.4	14.2	1.9	0.3	1.5
Long duration (Check)	91	202	122	15.5	18.7	14.7	1.9	0.8	1.2
Mean±S.E.	103±5	133±16	108±5	15.7±1.1	14.8±2.1	13.0±1.6	2.1±0.6	0.3±0.1	1.5±0.5

1. KYM=Kampi yaMawe.

SN Silim and E Gwata

Global Theme on Crop Improvement and Management

Archival Report 2005

Regional Project 3

Increasing productivity and utilization of SAT crops in Western and Central Africa

Regional Theme Coordinator: Eva Weltzien

Regional Project Members:

**B Clerget, SS Boureima, BIG Haussmann,
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R Tabo, F Waliyar and E Weltzien**

Regional Project 3: Increasing productivity and utilization of SAT crops in Western and Central Africa

The crop improvement team in WCA achieved a very welcome diversification during 2005. A new pearl millet breeder has strengthened activities on a wide scale, and increased our presence and ability to work with farmers, especially in the Sahelian zone of WCA substantially. Similarly a Striga ecologist joined the team in Samanko, Mali, to focus on research efforts on evaluating options for integrating Striga management measures in collaboration with farmers, in both sorghum- and millet-based systems.

Highlights of the 2005 season were the high levels of heterosis found in a wide range of Guinea race sorghum hybrids, tested for the first on a wide scale. For the first time, we succeeded in producing Guinea race hybrid seed in isolation plots, under natural pollen shedding conditions.

Groundnut seed of a wide range of new varieties continues to be in great demand, from research partners, from farmers, and for the first time, from an emerging private seed sector. Thus the first signs of changes in the supply of improved varieties through targeted commercial activities are encouraging. Efforts to develop national Foundation Seed Units are underway that can support these developments in a sustainable way.

Pearl millet improvement research started off with a large-scale germplasm evaluation and multiplication. The germplasm originates from the West-African region, and represents a wide range of agro-ecological zones. New populations are in preparation, and plans underway to classify this material into heterotic groups.

Research on micro-nutrient nutrition of sorghum and pearl millet was established more broadly with support of the Harvest Plus Challenge Program. Nutritionist input is strongly required to achieve appropriate targeting of the work.

Output 3.1: Regionally adapted diverse breeding materials, varieties and hybrids developed

New source materials provide the basis upon which new varieties and hybrids can be developed. Progress is being made on developing new and improved source materials for sorghum in several respects. The original Guinea-race sorghum population has been and continues to be diversified, targeting specific climatic zones and their adaptation requirements, including for the longer-season Guinea zone, in collaboration with Institute of Agricultural Research (IAR), Nigeria. This intensified collaboration with Nigeria was the outcome of intense interactions between Nigerian officials and the ICRISAT team in WCA. Plans for intensifying this collaboration further are underway, along with plans for new projects.

Participatory variety testing, especially for new groundnut and sorghum varieties, is becoming institutionalized among NARS partners. Methodologies are being refined for use in Mali, Niger, Burkina Faso, Nigeria, and Senegal, and for different systems, as well as crop uses. The team has been able to put together major publications on this issue, and more is in the pipeline.

Results of multi-location sorghum trials indicate that progress in increasing grain yields over local varieties, while retaining adaptive characteristics, is actually possible. Most promising are novel shorter height guinea race sorghum varieties, and guinea race sorghum hybrids.

Activity 3.1.1: Develop and improve trait specific populations and breeding lines of sorghum, pearl millet and groundnut

Milestone: Later maturing guinea-race random-mating population of sorghum developed for Northern Guinea zone

A random-mating population was created by crossing a Nigerian Guinea-race sorghum accession IS 7978 with the Guinea Population containing the male-sterile gene ms3. IS 7978 is late maturing (flowering October 18 at ICRISAT-Mali) with large grain size (3.5 g/100 seeds). This new population was included in a five-variety on-farm trial in Kaduna state, Nigeria in 2005. Results obtained from a total of 8 villages indicated that although the grain was often appreciated, the flowering was often too early (dates between 30 September and 18 October frequently recorded). Farmers indicated this population to be of interest in for the more northerly Sudanian zone. Original F_2 seed of this population will be used in 2006 to cross to Kaura and Fara Fara varieties from the Northern Guinea zone to create a later-maturing population.

HFW Rattunde and E Weltzien

Milestone: Guinea sorghum hybrid parents tolerant/resistant to midge identified

Several Guinea-race germplasm accessions from Cameroon have shown consistent high levels of resistance to midge, both *per se* and in the hybrids they produce. Results from the 2005 Hybrid trial indicated no loss due to midge (0 to 1%) for accessions IS 15302, IS 15629 and IS 30804, all from Cameroon, whereas other accessions of similar maturity had near total loss (IS 26320 (Togo) and IS 7978 (Nigeria) had 84 and 75% losses, respectively). Likewise the hybrids produced with the Cameroon accessions as male parents also showed very high levels of resistance (0 to 2% loss), despite the female parent (IS 3534A) showing 24% loss.

HFW Rattunde and E Weltzien

Milestone: Diversified agronomically superior dual-purpose groundnut breeding lines with improved resistance to foliar diseases and rosette

Groundnut is an important crop for resource-poor farmers in Semi-arid West Africa, who rely on it for their economic prosperity and nutritional welfare. Nutritionally groundnuts are an excellent source of dietary protein, oil/fat, and vitamins such as thiamine, riboflavin and niacin.

Foliar diseases such as rust, early and late leaf spots and groundnut rosette disease cause significant yield losses in groundnut in WCA. In order to stabilize yields and enhance productivity development of high yielding resistant varieties is the most economic approach.

We evaluated 36 advanced groundnut-breeding lines with multiple attributes (dual purpose, tolerant to Aflatoxin contamination and resistant groundnut rosette disease) for resistance early leaf spot. Among 14 early maturing rosette resistant lines, one was highly tolerant to early leaf spot (score of 5 on 1-9 scale) at Samanko in Mali. For the dual-purpose lines, 10 had a score of 4-5 compared to the susceptible check with a score of 8. The six aflatoxin resistant lines were also tolerant to early leaf spot.

We also advanced 71 rosette resistant F_2 populations to F_3 and 47 to F_4. Bulk progenies were selected for further selection and generation advance. These populations were also scored for early leaf spots. Among the F_2 populations, 7 had a score of 5 while in the F_3 populations, 12 had a score of <5. Varieties with high pod and fodder yield with resistance to foliar diseases are expected from these improved breeding lines and populations.

BR Ntare and AT Diallo

Milestone: Multiplication and characterization of pearl millet genebank accessions of diverse geographic origin

One of the objectives of WCA pearl millet improvement program at ICRISAT-Niamey is to better exploit and to enhance access of NARS breeders and farmers to the genetic diversity of pearl millet [*Pennisetum glaucum* (L.) R. Br.] in its center of origin in West Africa. Therefore, 281 pearl millet accessions from nine countries of West and Central Africa, assembled during joint IRD/ICRISAT pearl millet collections in 1976 and 2003 and geographically covering longitudes from 8.44E to 17.28W and latitudes from 6.49N to 20.26N, were grown for seed multiplication and initial characterization in the rainy season 2005 at ICRISAT, Sadoré (Niger).

The multiplication of materials was performed by controlled pollination ("sibbing") within each accession, aiming at a minimum effective population size of 60 plants contributing to the next generation. Pollen donors were simultaneously selfed to obtain S_1 seed as an initial step of further inbred line development out of the most promising accessions. Characterization data include days to 50% flowering, plant height, panicle length and diameter, exsertion, form and compactness of the panicle, numbers of selfed and sibbed panicles, and grain weights of selfed and sibbed panicles. The determination of 100-seed weight and grain color is still underway.

Raw data indicate that the germplasm reveals significant variation for all morphological and phenological traits studied: e.g., observations ranged from 40 to 155 days to 50% flowering, 153 to 405 cm for plant height, 18 to 115 cm for panicle length, 1 to 6 cm for panicle diameter, and from minus 23 to plus 12 cm for panicle exsertion. These accessions are therefore a gold mine of variability for future breeding.

Seed multiplication through sibbing was achieved for 248 out of the 281 accessions, with the amount of seed produced ranging from 22 to 2474 g. The effective population size of ≥60 was achieved in 117 accessions (minimum of 30 sibbed panicles). Twenty five accessions were multiplied with an effective population size of less than 20 (<10 sibbed panicles), due to poor germination or lack of adaptation of the accessions. Selfed seed was produced from 232 accessions, with the seed quantities obtained ranging from 14 to 2901 g.

Small amounts of the regenerated seed will be returned to the IRD-Montpellier and ICRISAT-Niamey genebanks for long-term conservation. The complete characterization data shall be linked to the gene banks information systems. The data will mainly be used for further diversity analysis and studies of heterotic grouping of West African pearl millet genetic resources with the final aim of significantly improving pearl millet yield performance and stability in West Africa. The cooperation from IRD-Montpellier and IRD-Niamey (Drs Y Vigouroux, G Bezançon) in providing the original seed of the accessions and extra-large pollination bags is highly appreciated.

BIG Haussmann, SS Boureima and A Boubacar

Activity 3.1.2: Develop hybrid parents adapted to specific zones of cereals cultivation in WCA

Milestone: Superior Guinea-race sorghum R-lines identified

A set of 29 restorer lines of diverse geographic origin was established for creating experimental hybrids. These R-lines were identified based on prior testcross results and chosen to represent geographic and morphological diversity. Twenty restorer lines were identified from accessions in the Guinea-race Core Collection, and nine landraces or bred varieties from Mali. The restorer lines were used to produce hybrids on newly developed A-lines FambeA, IPS001A, and IS3534A. Hybrid trials were conducted in 2005 at ICRISAT-Mali (two dates of sowing), IER-Sotuba, Mali and Bengou, Niger. Later maturing restorer lines of humid West Africa (Nigeria, Cameroon, Togo) origin produced hybrids with the highest grain yields (Table 3.1). Restorer lines of intermediate maturity, although not producing the highest yielding hybrids, still provided significantly significant yield superiority over highly adapted check varieties.

Table 3.1. Mean grain yields of hybrids over four locations in West Africa, 2005, with diverse restorer lines crossed onto a common female parent FambeA.

Hybrids	Origin of male	Yield (t ha^{-1})
FambeA*Fara Fara-17	Nigeria	3.0
FambeA*IS 26320tg	Togo	2.9
FambeA*IS 23206za	Zambia	2.8
FambeA*IS 7978na	Nigeria	2.8
FambeA*IS 27113zi	Zimbabwe	2.7
FambeA*GPN01 267-9-1	Mali	2.6
FambeA*Seguetana CZ	Mali	2.3
Check Varieties		
CSM335	Mali	1.8
Seguetana CZ 24/25	Mali	1.6
CSM388	Mali	1.5
SE ±		0.19

A restorer line database with agronomic characterization information and combining ability results of both Guinea-race and inter-racial restorer lines developed by IER, is being compiled jointly with IER. Origin, days to heading and plant height of identified restorer lines used for experimental hybrid production are being documented.

Activity 3.1.3: Participatory testing and release of improved sorghum, pearl millet and groundnut varieties

Milestone: Advanced yield testing of new breeding material evaluated jointly with Malian partners, and with farmer participation

Organized variety testing with farmer participation started in 2003 in 11-12 villages and on 2-3 research stations. The same 32 varieties were grown at each location.

Eight (in 2003) and seven (in 2004, 2005) of the villages were situated in Dioila district, an area of more intensive agricultural production. Many farmers are literate and well organized at a local level. Five sites were managed by the farmer organizations which form part of the Union of Cereal Producers in Dioila district (ULPC). Three were managed by village organizations which were initially formed for the management of cotton production in the respective villages, with whom the researchers had developed good working relationships through a close collaboration with the extension service of the cotton parastatal (CMDT= Compagnie Malienne du Developpement des Textiles). In the Mandé area, villages were suggested by the extension partners, who had longstanding relationships with many villages.

The participating farmers were primarily chosen by the farmers' organizations (Dioila) and the extension services (Mandé). The farmers were responsible for choosing the field for the trial and two local control varieties: one common for the whole village and one of specific interest to the farmer who provided the field. Four farmer participants together with the person providing technical assistance chose the village level check variety, usually one of the dominant varieties in the village used by many farmers. The farmers were involved in the choice of the test entries in the following manner:

1. Some varieties were retained from a precursor trial. They were retained based on farmers' choice and the yielding ability in the trials.
2. Farmers involved in the trials came to visit the ICRISAT research station during the pre-harvest period. They were shown the S2- progeny trials from the diversified Guinea-race populations, from which entries for the farmers' trials were to be selected. They scored each plot, using a score from 1-3 with color-coded paper pieces. The preference of farmers was one main criterion to choose varieties for the trials.
3. Farmers did not, however, visit the IER breeding stations, and thus experimental varieties from IER were chosen by researchers primarily. However, IER also conducts some of its selection program in close collaboration with farmers, and thus some materials have been selected by farmers in other areas of sorghum cultivation. These entries were fixed lines, which had previously been tested in multi-location station trials.

Farmers were responsible for managing the trial field and for visual evaluation for a range of traits identified previously together with them. Farmers received a basal dose of N and P fertilizer, which they applied at sowing time. The seed was treated (if the chemical was available in the local market). Each farmer grew one replication of the 32-entry trial. The 6 row plots of 5 m length were arranged in 4 ranges of eight plots each, and randomized as alpha-lattice designs with 4 plots per block. Students and local extension officers supported the farmers, particularly with sowing, plot identification, recording of observations, decision-making about management, and at harvest. Weighing the yield of each individual plot was a key responsibility of the technical support staff. They further organized the visits of other farmers to the field trials and their evaluation of the test varieties. The researchers contributed to the organization of these visits and organized the testing for processing and culinary qualities

In the other region (Mandé), where agriculture is more extensive and less cotton is grown, the same trials with 32 entries were grown in four villages. Extension agents of a local NGO and the government extension service supported the farmers. The responsibilities were shared in the same manner as described above.

Farmers' visits to the trials were organized at one research station and in at least 10 villages each year. All visiting farmers scored all varieties for their overall performance and acceptability, using a 1-3 scale and paper slips with different colors to signify each score (Christinck et al., 2005, p.96). After harvest, a two-day workshop was organized for each pair of neighbouring trial sites in order to discuss the yield results and evaluate grain and culinary qualities. On the first day the results of the yield evaluations, the farmers' selection, and other key observations were presented to the farmers who had participated in the trials as well other interested farmers from the villages concerned. The results were discussed and four varieties were chosen for the culinary trials the following day. The key activity on the second day was the evaluation of processing qualities and the culinary quality of the four best varieties in each village. All participants could also evaluate the grains of each variety visually, using the same 1-3 scoring system using different colored paper slips.

The four entries selected by the workshop participants for the culinary testing were considered to enter the second stage of testing, but only if their processing and culinary characteristics were found to be acceptable.

After harvest, and after completing the tests for culinary quality, a workshop with all farmers who had participated in the trials and other project activities was organized for each project zone (Dioila and Mandé). Yield data were discussed and varieties finally selected for further testing. Furthermore, changes with regard to trial management, monitoring and responsibilities for the diffusion of results were discussed and decided jointly.

Results of yield trials

The results of the yield trials were very encouraging in all years (2003, 2004, 2005), in the sense that all trials could be harvested and evaluated. Only individual replications of trials had to be abandoned in a few cases.

The seasons were markedly different; in 2003, the rainy season was very good, started early and continued until mid-October in all the project areas. This even led to some difficulties caused by excessive rainfall, such as water logging. In 2004, however, the rainy season started late and ended earlier than expected, as a consequence terminal drought stress occurred, particularly in fields with lower water holding capacities. In 2005, the season started some what earlier than in 2004 and ended earlier than normal, but later than in 2004.

In 2003, varieties could be identified in each village which were more preferred by the farmers than the local check entries. The yield superiority, however, was fairly low, between 10-20% on a variety mean basis for individual villages. A number of new dwarf lines performed relatively well in these trials, and as these are not yet finished varieties, the remaining variability could be exploited in order to further improve the grain yields.

In 2004, some of the new improved varieties showed clearly superior grain yields over the farmers' check entries in both project areas, and also reached high values in the farmers' preference scoring. This was partly due to earlier maturity, an advantage under the end-of-season drought conditions encountered this year. Mean grain yield varied widely between locations, and there was also considerable variability between individual replications within the same village. This made the data evaluation more difficult. The flowering dates were only recorded at the research stations. Table 3.2 gives the results of one of the villages in the Doila area.

Table 3.2. Yield (t ha^{-1}) and preference of the best performing varieties and the controls in Wacoro village, 2004 rainy season. (The names of the best varieties are given in brackets)

Variety	Rep 1 Nonkon Dembele	Rep 2 M'Pie Dembele	Rep 3 Moussa Bengaly	Rep 4 Tiecoura Traore	Overall Wacoro	
					Yield	Preference
Mean	1.4	1.1	1.2	1.0	1.17	48%
Village Check	1.5	1.1	1.2	0.9	1.19	68%
Farmer check	1.2	1.3	1.2	1.1	1.21	85%
Best variety	**2.3** (Bolibana)	**1.7** (Lafia)	**2.2** (Kalaban)	**1.6** (Coni)	1.50 (Kalaban)	41%
2nd variety	**2.3** (Coni)	**1.6** (Quinzen)	**1.9** (Sebekoro)	**1.6** (Kalaban)	1.50 (Lafia)	51%
3rd variety	**2.0** (Magnan)	**1.5** (Koura)	**1.7** (Grinka)	**1.5** (Weli)	1.48 (Coni)	48%

There is now increasing interest in the shorter sorghum varieties, as they exhibit better stover quality than the tall varieties that are highly lignified. Farmers are also experiencing that they are easier to harvest, and tend to give higher grain yields.

E Weltzien, HFW Rattunde, I Sissoko and A Christinck

Milestone: Synthesis report on participatory variety selection in groundnut available

Investments by ICRISAT and partners have resulted in the development of a broad range of groundnut varieties. However, farmers have limited access to these varieties. The key is to make available a range of modern varieties and train farmers to efficiently produce seed of selected varieties, using appropriate technologies leading to increase rural incomes.

Over 200 participatory varietal selection (PVS) trials were conducted in 45 locations across four countries: Mali, Niger, Nigeria and Senegal. In each country farmers have selected at least one or two new groundnut varieties. Seed production schemes were initiated in each country to ensure availability of seed of these varieties. The synthesis report will document the PVS process, pathways to adoption of improved varieties, lessons learned and perspectives.

BR Ntare, J Ndjeunga, AT Diallo, HY Bissala and F Waliyar

Milestone: A synthesis report on groundnut seed systems in WCA

The availability and uptake of seed of high quality by farmers is fundamental to the transformation of predominant traditional agricultural production practices to achieve increased stability and sustainable food production in West Africa. New seeds with higher yield potential or ability to relieve constraints faced by farmers in using traditional varieties form part of the improved inputs required to increase crop production.

This technical paper summarizes information on the structure, conduct and performance of formal and informal groundnut seed supply systems in 4 countries in West Africa namely Mali, Niger, Nigeria and Senegal. It highlights a range of technical, socio-economic, institutional and policy constraints facing the groundnut seed industry in West Africa. Low and inconsistent supply of breeder seed, poor seed demand estimation, lack of or non-functional national variety release committees, inappropriate institutional arrangements and the biological features of groundnut have limited private sector entry and the performance of the groundnut seed industry. Options likely to be sustainable should focus on local village seed schemes whereas small-scale private seed entrepreneurs or community based seed systems should be encouraged to become seed entrepreneurs or engaged in the seed industry. There is evidence of vertical integration between inputs and product markets. Appropriate linkages between seed and grain producers, and grain producers and processors are necessary to drive the private sector entry in the seed industry.

J Ndjeunga, BR Ntare, F Waliyar and M Ramouch

Milestone: **Technical paper on market prospects for groundnut in WCA published**

This is a result of a study commissioned by ICRISAT, with financial support from the Common Fund for Commodities. The paper documents the principal groundnut producing countries in the international markets, global market status trends and quality requirements, recent trends in production and consumption, and strategies for increasing groundnut production in West Africa.

BR Ntare, F Waliyar, M Ramouch, E Masters and J Ndjeunga

Output 3.2: Methodologies for enhancing productivity, adaptation of sorghum pearl millet and groundnut cultivars developed

Basic research into adaptive mechanisms of the local guinea races sorghums is showing more explicitly that not only phonological changes are affected by sensitivity to the *photoperiod, but also growth rate changes. However these changes do not affect the whole plant, but rather the above ground dry-matter. It seems that root growth continues unchanged during the various phenological changes of the sorghum plant, in contrast to maize. Research was started to understand better the differential responses of pearl millet varieties to different flowering dates, but also its pattern of root growth.*

During 2005 a handbook on Priority setting with farmers for breeding programs and seed system activities was finalized. The book provides basic insights and concepts, but also practical tools for the field, described in sufficient detail, that they can be used directly.

Activity 3.2.1: Design sorghum and pearl millet ideotypes for a regional selection strategy for increasing productivity under production system-specific conditions

Milestone: Testing and grouping Guinea race sorghum and pearl millet, for photoperiod-sensitivity under the newly shown categories

A regional sorghum core-collection of 214 accessions was sown on the 26 June 2004 and characterized for their phyllochron during the life cycle. The goal of the study was to estimate the variability of the rate of development in sorghum, since this character and its evolution during the life cycle of the plant could give insights into how to increase the yield potential of photoperiod-sensitive varieties. The sorghum core-collection managed and studied by CIRAD has been used in this study. This study has largely demonstrated the generality of bilinearity of the leaf appearance rate for long-duration varieties producing more than 22-23 leaves, while the leaf appearance rate remained always constant for short-duration varieties. It showed also that, for sowing dates at the end of June, varieties of the guinea race (including *margaritiferum*, *gambicum* and *conspicuum*) acquired a shorter phyllochron at emergence, than varieties from the *caudatum* race which were intermediate and varieties from the *durra* and *kafir* races which had the longest phyllochron. This suggests that varieties from the guinea race expand their first leaves faster than varieties from the other races, when sown late.

A new series of monthly sowings of 12 pearl millet varieties with a large range of photoperiod-sensitivity was initiated in June 2004. The 18^{th} sowings has been done in December 2005. Current results show patterns similar to sorghum: (i) the duration of the vegetative phase of 9 varieties varies slightly with the sowing date, corresponding with a quantitative photoperiod-sensitivity, while for the 3 other varieties this vegetative phase has been very long for sowings done during the beginning of the year, corresponding with a qualitative or absolute photoperiod-sensitivity; (ii) when more than 25 leaves have been produced by the apex, the rates of development and growth of the plants slowed down considerably and simultaneously; (iii) the rates of development acquired at emergence doubled from sowings done on the summer solstice to those done on the winter solstice. On the other hand, the vegetative phase of the 12 pearl millet varieties tested in Bamako has been minimal for sowings done at the end of June-beginning of July, while this minimum generally occurs for sowings done in October with sorghum. This last observation is contradictory to the current theory, established under artificial lightings, which predicts that pearl millet, a short-day species, must flower later when days are the longest.

B Clerget, HFW Rattunde and B Siaka

Milestone: Enhance knowledge on dwarfing and panicle size x photoperiod-sensitivity interactions

Panicle size x photoperiod-sensitivity interactions in experimental guinea hybrids

Ten experimental guinea sorghum hybrids and their parents were sown on the beginning of June and July to assess the contribution of the yield components responsible for the heterosis observed. The hypothesis is that the heterosis is due to a larger panicles size. Harvest data showed significant heterosis for grain yield of hybrids based on the parent Fambé A. These hybrids had more grains per panicle than their male parents. For July sowings, this larger number of grains clearly results in a better harvest index, thus a larger number of grains per unit of biomass. For the June sowing, on the contrary, the harvest index of the hybrids was generally not better than the parents and the larger grain number appears to be only related with an increase of the total biomass produced by the hybrids. In June sowings, the grain size (100-grain weight) of the hybrids was also slightly larger than that of the parents. On the other hand, no difference was observed between hybrids and parents in the rates of development of the panicle nodes. They remained always equal to the rate of leaf initiation at the time of the panicle initiation. These results show that heterosis depends on the sowing date, as the expression of the yield improvement of photoperiod-sensitive varieties and hybrids varies with the sowing date. It is necessary to understand these variations in order to find better combinations.

B Clerget and S Dagnoko

Comparing the rates of aerial and root development of sorghum and maize

Tropical maize has a much better yield potential than photoperiod-sensitive guinea race sorghum. To compare their developmental strategies, a parallel study of the developments of the aerial plant and of the horizontal and vertical root fronts were carried out with locally cultivated varieties. The rates of development acquired at emergence were similar for both species. Maize expanded 22 leaves at a constant rate of leaf appearance, against 28 leaves for sorghum with a bilinear kinetic. Maize has produced 15.4 t ha^{-1} of total biomass and 7 t ha^{-1} grain within 90 days against 18 t ha^{-1} of biomass, 3.5 t ha^{-1} grain in 130 days for sorghum. The horizontal rates of root growth were 1.2 and 1.8 cm day^{-1} for maize and sorghum, respectively. The maximal vertical rates of root growth have been similar and equal to 2.8 cm day^{-1} for both species. But the strategy to conquer the vertical dimension of soil has been very different between the species: the root tip of sorghum descended quickly at a constant rate from emergence to the 62nd day, time of panicle initiation. It continued its descent at a reduced constant rate (1.2 cm day^{-1}) until grain maturity. Consequently there was no link between the rate of descent of the roots and the rate of leaf appearance, which broke on the 41st day. In maize, the vertical progress of the root tip stopped one week after germination at a depth of 20 cm. It started again only on the 21st day, at panicle initiation time, and definitively stopped on the 56th day, when internodes had finished elongating. It thus appears that (i) the rate of descent of the root tip would be related to the phenology of the aerial plant, but differs with species and (ii) the roots of sorghum continue to go down quickly even after the rate of development of the aerial plant has decreased and the stem has started to elongate. This pattern of root growth may explain the better adaptation of late maturing guinea race sorghums to low fertility soils: during its stem elongation phase, the biomass is synthesized at a lower rate using minerals and water extracted from a larger volume of soil in comparison with maize.

B Clerget

Activity 3.2.2: Refine and adapt methodologies for farmer participation in specific stages of sorghum and pearl millet breeding

Milestone: Handbook on farmer participation in priority setting published

The handbook was published, and has been used as a basis for some training courses. The book is in high demand, and the first edition is nearly out of print.

A Christinck, E Weltzien and V Hoffmann

Output 3.3: Impact-oriented eco-friendly IPM technologies developed

During 2005 research on IPM technologies focused on two of the most complex issues faced by farmers: Aflatoxin contamination of groundnuts, and Striga *management in dry-land cereals. For* Striga *control research on integrating control measures in a farmer participatory, joint learning was designed, and discussed with partners. We are looking forward to its implementation in 2006. For aflatoxin contamination results from widespread on-farm testing and evaluation is now available, and is leading to intense discussion on consequences, among farmers themselves, farmers and processors, as well as consumers.*

Activity 3.3.1: Develop and evaluate on-farm integrated *Striga* control strategies in sorghum and pearl millet (in collaboration with GT Agro-ecology)

Milestone: Integrated options for *Striga* control in pearl millet tested and refined in two target production zones

Potential for sesame to contribute to integrated control of *Striga hermonthica* of pearl millet in the West African Sahel

Striga hermonthica is an important constraint to the production of pearl millet, a staple cereal in many parts of sub-Saharan Africa. Sesame is an important oilseed crop well adapted to the sandy soils of the West African Sahel. Intercropping of sesame and pearl millet has been reported to reduce emerged *Striga* numbers, but formal research into the potential of sesame to contribute to control the parasite is lacking. Field trials were undertaken to evaluate the potential of sesame grown in rotation with pearl millet to reduce *Striga* infestation. Emerged *Striga* numbers and *Striga* fruiting were strongly reduced on pearl millet following sesame compared to sole millet. To maximize cereal yield, soil fertility enhancement and water conservation are indispensable elements of integrated *Striga* control. The results can guide future research at a time where sesame is being promoted to diversify agricultural production in the Sahel.

DE Hess, H Dodo and E Weltzien

Integrated *Striga* management in farmers pearl millet and sorghum fields

A 6-year on-farm trial with Integrated *Striga* management strategies in Mali and Niger led to very large reductions in the number of emerged *Striga* plants as well as seed bank densities, when compared to the normal farmers' practice. Although not quantified, farmers are known to adopt parts, if not all of the measures in other fields infected with *Striga*. More detailed analyses are underway.

DE Hess, R Tabo and E Weltzien

Milestone: Biology of resistance to Striga in sorghum understood

The role of sorghum genotype in the interaction with the parasitic weed *Striga hermonthica*

The main objective of this study was to find suitable measures for the selection of breeding material (crop genotypes) with superior levels of resistance or tolerance to *Striga*. The relation between *Striga* infestation, infection and yield loss and the effect of host genotype on *Striga* parasitism and reproduction were studied for 4-10 genotypes in agar-gel, pot and field tests. *Striga* parasitism and reproduction, and the detrimental effect of *Striga* on crop yield can be significantly reduced through crop genotype choice. Maximum aboveground *Striga* number is a reliable selection measure for resistance. *Striga* flower stalk dry weight can be used to identify genotypes that reduce *Striga* reproduction. The maximum relative yield loss is a suitable selection measure for tolerance in susceptible genotypes, while for genotypes that are more resistant the relative yield loss per *Striga* infection seems more appropriate. For these tolerance measures, yield assessment of nearby uninfected controls is indispensable. Chlorophyll fluorescence, more precisely photochemical quenching and electron transport rate, may enable screening for tolerance without this requirement.

J Rodenburg, E Weltzien and D Hess

Combining the strengths of marker-assisted backcrossing and farmer-participatory selection to improve *Striga* resistance in sorghum

Striga-resistant sorghums would be an important component of integrated *Striga* management if resistance was available in locally adapted farmer varieties. The application of marker-assisted selection in *Striga* resistance breeding would greatly accelerate progress since field screening is difficult, complex, and often unreliable; *Striga* seed is quarantined thus confining tests to areas where *Striga* is endemic; and because some *Striga* resistance genes are recessive, increasing the time required for conventional backcrossing. QTL mapping for resistance of sorghum to S. hermonthica was performed using a population of F3:5 lines developed from the cross N13 x E36-1, where the resistant sorghum line N13 is characterized by "mechanical" resistance (Haussmann et al., 2004). Composite interval mapping detected five QTL common across five environments over two years of *Striga* resistance evaluation, with the resistance alleles deriving from N13. Since their effects were validated across environments, years and independent genotype samples, these robust QTL are excellent candidates for marker-assisted selection. In a three-year project, launched in April 2004, *Striga* resistance of farmer-preferred sorghum varieties in Eritrea, Kenya, Mali and Sudan will be enhanced through a combination of marker-assisted backcrossing and farmer-participatory selection. The impact of gene flow on the stability of the achieved *Striga* resistance will be investigated in a complementary study. Simultaneously, a socio-economic study of the sorghum seed supply systems in these countries will be undertaken to guide the design of effective seed interventions by partner institutions so that improved materials efficiently reach farmers. Linkage with technology exchange will boost promotion of the improved varieties as component of integrated *Striga* control.

RT Folkertsma, BIG Haussmann, HK. Parzies, D Kiambi, V Hoffmann and H H Geiger

Milestone: Quantification of the *Striga hermonthica* life cycle as a tool for seed bank management

Studies on weed management in cropping systems have shown there are economical advantages in managing long-term weed population dynamics in addition to short-term management to control weeds and prevent crop yield loss. An important component of integrated weed management is monitoring and attempting to predict how cropping systems and control strategies affect long-term population dynamics of weeds. In order to be able to model long term *Striga* seed bank dynamics, steps in the life cycle such as seed bank replenishment (seed production) and seed bank depletion (seed mortality in the soil), were quantified.

In six field experiments, we tried to: (i) develop a reliable, standardized method for monitoring seed production; and (ii) determine the effect of rainy season length, seed density, host cycle length and several control strategies on aboveground demography leading to seed production. Seed bank germination and depletion of *Striga* was also measured at a site in Mali and a site in Niger during one rainy season under different crop and fallow systems.

Seed production was affected by rainy season and host cycle length, as well as by different control strategies. A five-fold increase in initial seed density did not affect seed production and data indicated possible density dependence in underground stages, although with a very high variability. There were striking differences in above-ground *Striga* appearance between years and sites considering small differences in infestation or inoculation levels of (germinable) seeds. Finally, a relation was found between allometric seed production estimates and soil seed content to a depth of 3 cm. Seed production and seed bank dynamics of *Striga* are affected by season length, host characteristics and should therefore be incorporated into population modeling to support choices of integrated control methods.

Until now it is not clear what influences emergence levels considering certain densities, although rainfall distribution in the first weeks after sowing are suggested to play an important role.

Seed bank depletion was determined using two seed burial and retrieval methods, namely (i) mesh seed bags filled with sand and *Striga* seeds and (ii) soil inoculation and sampling after which seeds were extracted by means of wet sieving and flotation. Fate of exhumed seeds was assessed by a seed press test in which empty seeds were considered to have germinated.

Seed germination contributed most to seed bank depletion under a variety of vegetative cover types including host crops, non-host trap crops, intercrops of hosts and trap crops and weedy fallow. The soil sampling method and the seed bag burial method yielded similar percentages of seed bank depletion and treatment effects showed similar trends. Combining data from previous studies on seed production with these data on seed losses indicated that seed bank reduction by suicidal germination would only be achievable if seed production and seed bank replenishment are completely prevented. The results raise questions on the specificity of trap crops and whether differences reported previously in seed bank depletion between trap and host crops are simply caused by the prevention of seed production, rather than increased (suicidal) seed germination in the soil.

With the information obtained in this study and from literature, a population model was constructed and parameterized to explore the long-term effects of management strategies on the *Striga* seed bank through scenario study. The results from this study will aid in assessing and developing promising management strategies for *Striga*.

TA van Mourik, E Weltzien and R Tabo

Activity 3.3.3: Test options to reduce Aflatoxin contamination in groundnut

Milestone: Integrated technologies to minimize aflatoxin contamination in groundnut out scaling trials established in four countries

Aflatoxin is a toxic substance produced by mold fungi (*Aspergillus flavus and A. parasiticus*) that can grow on poorly managed agricultural crops, particularly groundnuts. If eaten in sufficient quantities aflatoxin can cause serious sicknesses that can lead to liver and several other cancers. Groundnuts for sale and export should be free from aflatoxin. Therefore appropriate crop management is essential at pre-and post harvest times.

ICRISAT and its partners have developed several technologies that can contribute to reducing risks to aflatoxin contamination. These include genetic resistance and integrated crop management practices, agronomic practices, biological control, and biotechnological interventions. A number of these technologies have been tested on-farm with farmers in Mali. ICRISAT has also developed inexpensive quantitative methods for the detection of aflatoxin in groundnut-based products and feed. The ELISA based diagnostic test is reliable, cost effective and easy to carry out. This can help NARS, NGOs, traders and exporters to undertake large scale testing of groundnut-based-foods and feed for aflatoxin.

Resistant/tolerant varieties

Past research has identified and developed groundnut varieties that are tolerant to *Aspergillus flavus* invasion and subsequent Aflatoxin contamination. The first task was to expose these varieties to groundnut farmers through participatory on farm trials/demonstrations. In such trials in the district of Kolokani and Kayes, the main groundnut procuring regions in Mali, low levels of aflatoxin contamination were recorded (Table 3.3). Similar trials/demonstrations have been extended to Niger, Nigeria and Senegal.

Table 3.3. Ranges and means of Aflatoxin content in the kernels (ppb) in tolerant varieties evaluated by 10 farmers in Kolokani during the 2004/2005 cropping season.

Variety	Range (ppb)	Mean (ppb)	Pod yield ($t\ ha^{-1}$)	Haulm yield ($t\ ha^{-1}$)
ICG 6101	0.22-1.46	0.86	0.82	1.15
ICG 7	0.02-0.96	0.36	0.92	0.89
ICG 6222	0.51-4.27	1.86	0.82	1.13
ICGV 88274	1.64-11.29	5.87	0.72	1.07
ICGV 92093	2.17-12.45	6.71	0.86	1.07
Res check: 55-437	0.06-2.45	1.02	0.93	1.07
Susc Check Fleur 11	70.89-118.18	92.49	0.94	0.93
Local (47-10)	7.96-25.19	16.95	0.87	0.93
SE ±		1.920	0.064	0.066
CV (%)		39	23	20

Integrated management practices

Infection of groundnut pod/kernel by the mold fungi occurs both in pre-and post-harvest conditions. In the pre-harvest conditions, end-of season drought is a major predisposing factor. Technologies to mitigate the effect of drought have been developed. These have been tested in two major groundnut regions of Mali (Kolokani and Kayes). The technologies are: application of lime, crop residues and farmyard manure and their combination. These treatments were applied to a resistant (55-437) and a susceptible (JL 24) variety with farmer participation. Results are presented in Tables 3.4 and 3.5. All treatments, especially, application of lime and farmyard manure significantly reduced aflatoxin contamination, especially in the susceptible variety. On average the application of lime reduced aflatoxin contamination by 84%.

Table 3.4. Aflatoxin content (ppb) in the kernels under various agronomic practices, averaged over 5 farmers in Kolokani, Mali, 2004/2005.

Treatment	Variety		Pod yield ($t\ ha^{-1}$)	
	55-437	JL24	55-437	JL24
Lime 50DAP	1.90	52.34	1.16	1.06
2.5 $t\ ha^{-1}$ FYM	2.07	64.07	1.27	1.09
2.5 $t\ ha^{-1}$ Residue	3.28	126.59	1.14	1.03
Lime + Residue	2.76	79.53	1.24	0.96
FYM + Residue	4.20	90.64	1.39	1.18
No treatment	6.21	190.84	1.00	1.07
SE ±	1.22		0.087	

Table 3.5. Aflatoxin content in the grain (ppb) under various agronomic practices, averaged over 5 farmers in Kayes 2004/2005.

Treatment	Aflatoxin content (ppb)		Pod yield (t ha^{-1})	
	55-437	JL 24	55-437	JL 24
Lime 50DAP	0.12	4.20	2.208	2.204
2.5 t ha^{-1} FYM	0.26	6.76	2.460	2.468
2.5 t ha^{-1} Residue	0.79	36.71	1.952	2.080
Lime +Residue	0.36	7.36	2.004	2.081
FYM + Residue	0.94	12.10	2.576	2.460
No treatment	2.83	82.32	2.83	82.32
SE ±	1.564		0.082	

Best-bet harvesting and drying technique

Groundnuts need to be harvested at the correct time. Delays in harvesting result in over maturity leading to fungal infections and subsequent aflatoxin contamination.

Poorly dried groundnuts enhance fungal growth and aflatoxin contamination. Good storage with kernel moisture <10% does not permit fungal growth and aflatoxin contamination. Poor curing can induce fungal growth (aflatoxin contamination) and reduce seed quality for consumption, marketing and germination.

Groundnuts that are allowed to dry well immediately after harvesting tend to develop negligible levels of contamination, where as groundnuts left out but covered with haulms and leaves tend to develop alarming levels of aflatoxin contamination (Table 3.6 and 3.7). The most effective control was achieved through immediate removal of pods from the harvested plants, but this has labor constraints at the time when other farm activities are at their peak. There is a need to explore cheap dryers that can be used by farmers during the harvest period.

Table 3.6. Effect of method of drying on aflatoxin contamination (susceptible variety 47-10) averaged over 10 farmers in Kolokani, Mali, 2004/2005.

Name of the farmer	Drying method		% Reduction
	Traditional	Improved	
Bagui	17.94	2.22	88
Mory	13.73	1.78	87
Seba	15.93	4.97	69
Demba	14.61	3.89	74
SE ±	1.373		
CV (%)	29%		

Table 3.7. Effect of method of harvesting and drying on aflatoxin contamination (susceptible variety, 47-10) in Kayes, Mali, 2004/2005.

Name of the farmer	Harvest/drying method		% Reduction
	Traditional	Improved	
Madou	71.31	20.02	72
Savadogo	60.08	18.01	70
Yaya	58.01	21.53	63
Mamadou	79.52	28.31	64
Coumba	59.62	15.73	74
Djenaba	74.48	27.01	64
Kande	44.86	14.28	68
Seydou	12.32	1.96	84
SE ±	2.999		
CV (%)	43%		

Results indicated that proper handling of groundnut during and after harvest will reduce fungal growth and aflatoxin contamination thereby increasing the marketability of groundnuts and increasing sales and income by local groundnut farmers. There is a need for increased awareness for aflatoxin contamination and health hazards.

BR Ntare, AT Diallo, F Waliyar and O Kodio

Global Theme on Crop Improvement and Management

Archival Report 2005

Appendix 1:
List of special projects funded and project proposals submitted for funding during 2005

GT-Crop Improvement: List of Special Projects funded during 2005

Sl. No.	Title of the Project	Donor	Amount (US$)	Scientists involved
1	Diversification of pearl millet hybrid parents	ICRISAT-Private Sector pearl millet hybrid parents research consortium	333,000	KN Rai, CLL Gowda and Team
2	Diversification of sorghum hybrid parents	ICRISAT-Private Sector sorghum hybrid parents research consortium	158,000	BVS Reddy, CLL Gowda and Team
3	Diversification of pigeonpea hybrid parents	ICRISAT-Private Sector pigeonpea hybrid parents research consortium	89,500	KB Saxena, CLL Gowda and Team
4	Development of salinity-tolerant sorghum and pearl millet cultivars for enhanced productivity on saline lands	OPEC Fund for International Development	35,000	BVS Reddy, KN Rai, Vincent Vadez and CT Hash
5	Development of micronutrient and ß-carotene-dense for sorghums	HarvestPlus	55,000	BVS Reddy and Team
6	Improved livelihood opportunities through watersheds	APRLP/TATA Sujala	139,000	SP Wani, BVS Reddy and others
7	Enhancing yield and stability of pigeonpea through heterosis breeding	ISOPOM	415,996	KB Saxena and Team
8	Enhanced utilization of sorghum and pearl millet grains in poultry feed (CFC/FIGG/32)	CFC/FAO	1,509,000	BVS Reddy, P Parthasarathy Rao, KN Rai, CLL Gowda and F Waliyar
9	Protecting crops and Promoting businesses: Eco-friendly materials for protecting crops of SAT farmers in partnership with Private-sector Biopesticides Manufacturers	ICRISAT-Private Sector Biopesticides Research Consortium	22,000	OP Rupela, GV RangaRao and CLL Gowda
10	Exploring soil biology to understand high yields due to SRI method of cultivation	WWF-ICRISAT Dialogue Project	12,300	OP Rupela and SP Wani

Sl. No.	Title of the Project	Donor	Amount (US$)	Scientists involved
11	Introduction, promotion and efficient seed support system of ICRISAT 'Asha' peanut variety in Region 02, Philippines	BAR, Philippines	56,000	WD Dar, SN Nigam and Team
12	Unlocking the genetic diversity in peanut's wild relatives with genomic and genetic tools	Generation Challenge Program	155,000	Vincent Vadez, SN Nigam and Team
13	Improved rural livelihoods and better health: Promoting and improving groundnut for poor farmers in Asia	OPEC Fund for International Development	100,000	SN Nigam and Team
14	Building on strengths towards sustainable management of sterility mosaic disease for enhanced pigeonpea production in the Indian Subcontinent.	Crop Protection Program of DFID, UK	69,000	F Waliyar, P Lavakumar
15	Assessment of aflatoxin contamination in maize production systems in Andhra Pradesh and Karnataka: a step towards developing aflatoxin-free maize production technologies	Effem India Pvt. Ltd.	22,570	Farid Waliyar and Team
16	Safer and better groundnut production for southern India.	Crop Protection Program of DFID, UK.	131,000	Farid Waliyar and Team
17	Aflatoxins in Cereals and Pistachio	Agricultural Research and Education Organization (AREO), Iran	20,000	Farid Waliyar and Team
18	UGA Subgrant No RC710-014/2265137	Peanut CRSP	20,000	Farid Waliyar and Team
19	Traditional Technology with a Modern Twist (Bio-pesticide production)	World Bank	150,000	GV Ranga Rao and Team
20	Utilization of Intelligent Systems for Plant protection	ICT-KM program of CGIAR, ICARDA	18,000	GV Ranga Rao and V Balaji
21	Improvement of salinity and boron toxicity tolerance in chickpea	COGGO-Australia	112,000	Vincent Vadez, L Krishnamurthy, and PM Gaur

Sl. No.	Title of the Project	Donor	Amount (US$)	Scientists involved
22	Support for sustainable conservation and enhanced utilization of genetic diversity in foxtail millet collection held in trust by ICRISAT and support for global plan of action on the conservation and sustainable utilization of plant genetic resource	Food and Agricultural Organization of the United Nations (FAO)	32,000	HD Upadhyaya and CLL Gowda
23	Completing genotyping of composite germplasm set of chickpea	CIMMYT-Generation Challenge Program	103,400	HD Upadhyaya, D Hoisington, RK Varshney, PM Gaur, CLL Gowda and S Chandra
24	Supporting distribution of reference germplasm	CIMMYT-Generation Challenge Program	30,000	HD Upadhyaya and C.LL Gowda
25	Molecular characterization of Finger millet	CIMMYT-Generation Challenge Program	18,000	HD Upadhyaya, CT Hash, D Hoisington, RK Varshney, CLL Gowda and S Chandra
26	Molecular characterization of Groundnut	CIMMYT-Generation Challenge Program	23,000	HD Upadhyaya, D Hoisington, RK Varshney and S Chandra
27	Molecular characterization of Pigeonpea	CIMMYT-Generation Challenge Program	30,000	HD Upadhyaya, D Hoisington, RK Varshney, S Chandra and KB Saxena
28	African bio-fortified sorghum	The Bill and Melinda Gates Foundation	954,000	MA Mgonja and ABS Consortium
29	Promotion of improved and blast resistant finger millet varieties in eastern Africa ICRISAT/NARS and University of Warwick	DFID/CPP	29,000	MA Mgonja and Team
30	Program for the Sustainable Commercialization of Seeds in Africa (SCOSA)	USAID	850,000	RB Jones and Team
31	Using markets to promote the sustainable utilization of crop genetic resources	FAO	70,000	RB Jones and Team

Sl. No.	Title of the Project	Donor	Amount (US$)	Scientists involved
32	Lucrative legumes	Techno Serve	743,000	RB Jones and Team
33	Immediate development activities related to facilitating access to improved seed for farmers in Mali	USAID-Mali/ PRODEPAM	52,500	BR Ntare, B Clerget and Team
34	Environmental risk management of genetically engineered sorghums in Mali	USAID	484,000	F Sagnard
35	Identification of micro-nutrients and Vitamin A precursor (B-Carotene) dense-sorghums for better health in Western and Central Africa (WCA) and Central India	IFPRI/CIAT – HarvestPlus CP	20,000	F Rattunde
36	Genetically enhanced micro-nutrient-dense pearl millet grains for improved human nutrition in the Western Africa region and India	IFPRI/CIAT – HarvestPlus CP	14,000	B Haussmann
37	Developing sustainable seed systems to support commercialization of small-scale agriculture in sub-Saharan Africa	USAID	20,000	E Weltzien and B Haussmann
38	Improved sorghum hybrids for Africa and methods for large-scale production of hybrid sorghum seed	Rockefeller Foundation	289,000	F Rattunde, E Weltzien and Team
39	How can sorghum farmers in Mali benefit from producing and disseminating seed of varieties bred with their input?	IDRC	8,000	E Weltzien and Team
40	Farmer participatory germplasm utilization	IFAD TAG to IPGRI	15,000	B Clerget and E Weltzien
41	Striga management	WOTRO	45,000	E Weltzien and Team
	Total		**7,452,266**	

GT-Crop Improvement: List of project proposals submitted for funding during 2005

Sl. No.	Title of the Proposal	Donor	Amount (US$)	Scientists involved
1	Development of extra-large seeded *kabuli* chickpea varieties	Ministry of Agriculture, government of India	92,000	PM Gaur, S Pande, CLL Gowda
2	An innovative approach for rehabilitation of marginal lands of Uttaranchal by introducing an eco-friendly legume-based technology	Ministry of Agriculture, Government of Uttaranchal	828,500	KB Saxena
3	Exploring soil biology to understand high yields due to SRI method of cultivation	WWF-ICRISAT Dialogue Project	16,200	OP Rupela, SP Wani
4	Building self-reliance in seeds of choice: Improving legume productivity in Asia	Commission of the European Communities (EU)	*	SN Nigam and Team
5	Farmers' participatory groundnut improvement in rainfed cropping system	TMOP, Ministry of Agriculture, Govt. of India (ISOPOM)	214,000	SN Nigam and Team
6	Improving rural livelihoods and sustainability of crop-livestock system through better dual-purpose legumes (groundnut and grass pea)	CGIAR System Wide Livestock Programme (SLP)	50,000	SN Nigam, Michael Blummel and Team
7	Mapping root traits and water use efficiency in chickpea and groundnut to mitigate drought effects	Government of Andhra Pradesh	*	David Hoisington, Vincent Vadez, SN Nigam and Team
8	Establishment of aflatoxin testing laboratory at Anantapur	Department of Agriculture, Government of Andhra Pradesh	51,280	Farid Waliyar
9	Developing strategies for allele mining within large collections	Generation Challenge Program	19,470	HD Upadhyaya and RK Varshney
10	A dataset on allele diversity at orthologous candidate genes in GCP crops (ADOC)	Generation Challenge Program	64,600	D Hoisington, RK Varshney, CT Hash and HD Upadhyaya

Sl. No.	Title of the Proposal	Donor	Amount (US$)	Scientists involved
11	Genotyping of composite collection of tier 2 (orphan) - crop Finger millet [*Eleusine corcana* (L.) Gaertn].	Generation Challenge Program	20,000	HD Upadhyaya, D Hoisington, RK Varshney, CLL Gowda, CT Hash and S Chandra
12	Development of composite collection and genotyping of tier 2 (orphan) crop – Foxtail millet [*Setaria italica* (L.) Breauv].	Generation Challenge Program	25,016	HD Upadhyaya, D Hoisington, RK Varshney, CLL Gowda, CT Hash and S Chandra
13	Development of composite collection and genotyping of tier 2 (orphan) crop – Pearl millet [Pennisetum glaucum (L.) R. Br.].	Generation Challenge Program	60,042	HD Upadhyaya, CT Hash, S Senthilvel, D Hoisington, RK Varshney, KN Rai, RP Thakur and S Chandra
14	Genotyping of composite collection of tier 2 (orphan) crop – Pigeonpea	Generation Challenge Program	30,000	HD Upadhyaya, D Hoisington, RK Varshney, S Chandra and KB Saxena
15	Safeguarding ICRISAT Genetic Resources for future food security in the semi-arid tropics	Government of Japan	2,059,020	HD Upadhyaya and CLL Gowda
16	Gene flow between transgenic pigeonpea and its wild relatives: Risk assessment for testing and deployment of transgenic cultivars	IFPRI	475,000	HD Upadhyaya, KK Sharma, HC Sharma and CLL Gowda
17	Enhancing the availability of cereals and legumes genetic resources for use in crop improvement in Iran	AERO, IRAN	483,000	HD Upadhyaya and CLL Gowda
18	Comparative genomics of Drought Stress Response in Underrepresented Legumes	USDA, USA	43,658	HD Upadhyaya RK Varshney and Vincent Vadez

Sl. No.	Title of the Proposal	Donor	Amount (US$)	Scientists involved
19	Market-led development for poverty reduction in Malawi - Legumes and oilseed crops for improved food security, nutrition and incomes	IFAD (for 2006-2011)	4,225,652	ES Monyo and Team
20	Developing short- and medium-duration groundnut varieties with improved yield performance, acceptable market traits and resistance to foliar diseases	McKnight Foundation (for 2006-2010)	398,200	ES Monyo and Team
	Total		**9,155,638**	

* = At the time of concept notes preparation, the budget is not included.

Global Theme on Crop Improvement and Management

Archival Report 2005

Appendix 2:
List of publications

List of Publications – 2005

Books/Book Chapters

Ahmad F, Gaur PM and **Croser J.** 2005. Chickpea (*Cicer arietinum* L.). Pages 187-217 *in* Genetic Resources, Chromosome Engineering, and Crop Improvement - Grain Legumes, Vol. 1 (Singh RJ and Jauhar PP, eds). CRC Press, USA.

Christinck A and **Weltzien E.** 2005. Identifying target regions and target groups. Pages 25-40 *in* Setting breeding objectives and developing seed systems with farmers. A handbook for practical use in participatory plant breeding projects (Christinck A, Weltzien E and Hoffmann V, eds.). Margraf Publishers, Weikersheim, Germany and Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. 188 pp.

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Christinck A, Weltzien E and **Dhamotaran M.** 2005. Understanding farmers' seed management strategies. Pages 63-82 *in* Setting breeding objectives and developing seed systems with farmers. A handbook for practical use in participatory plant breeding projects (Christinck A, Weltzien E and Hoffmann V, eds.). Margraf Publishers, Weikersheim, Germany and Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. 188 pp.

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Sastry DVSSR, Upadhyaya, HD and **Gowda CLL.** 2005. National information sharing mechanism on the implementation of the PGA – Information of ICRISAT PGRFA. Second Regional Workshop of FAO Sponsored Project on Establishment of National Information Sharing Mechanism on the Implementation on the Implementation and Monitoring of the Global Plan of Action (GPA) for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture, 9-10 November 2005, Hyderabad, Andhra Pradesh, India.

Upadhyaya HD and **Gowda CLL.** 2005. The science of plant genetic resources for effective conservation and efficient use in crop improvement. In Inter Center Working Group on Genetic Resources, 28 February-5 March 2005, ICRISAT, Patancheru, Andhra Pradesh, India,

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Oral Presentations

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Thakur RP, Rao VP, Krishnappa K, Agarkar GD, Solunke RB and **Bharati Bhat.** 2005. Variability among the sorghum grain mold fungi. Invited paper presented at the National Symposium on "Crop Disease Management in Dry land Agriculture" and Annual meeting of Indian Phytopathological Society, New Delhi, 12-14 January 2005, Marathwada Agricultural University, Parbhani, Maharashtra, India.

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Thakur RP. 2005. Scientific communication. At the Annual Meeting of Plant Protection Association of India, 2 March 2005, Rajendranagar, Hyderabad, India.

Thakur RP. 2005. Sorghum Pathology Research Imperatives in India. An invited paper for discussion at the 35th Annual Group Meeting of AICSIP, 21-23 April 2005, ANGRAU, Hyderabad, Andhra Pradesh, India.

Posters/Flyers/Success Stories

Aruna R, Nigam SN and **Waliyar F.** 2005. Current status of folair diseases resistance breeding in groundnut at ICRISAT Center, India. International Peanut Conference, “Prospects and emerging opportunities for peanut quality and utilization technology”, 9-12 January 2005, Kasetsart University, Bangkok, Thailand.

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Public Awareness Articles

Killing me softly! An eco-friendly solution for cotton pests. Published by a farmers-focused magazine, Appropriate Technology, in UK. It was based on a submission from Rupela OP in the SAT Trends of August 2004, and was picked-up by editor of the Magazine. Rupela OP participated in its final draft.

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Dadi L, Regassa S, Fikre A, Mitiku D, Gaur PM, Gowda CLL and **Bantilan MCS.** 2005. Adoption studies on improved chickpea varieties in Ethiopia. Addis Ababa, Ethiopia:

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Student Theses

Bucheyeki TL, Gwanama C, Mgonja MA, Chisi M and **Folkertsma R.** 2005. Characterization of Sorghum [*Sorghum bicolor* (L) Moench] landraces collected from Central and Southern Tanzania. MSc Thesis submitted to the University of Zambia.

Hameeda Bee (PhD). Studies on plant growth promoting bacteria and recycling of crop residues for sustainable agriculture. Submitted to Osmania University, Hyderabad.

Harini G (MSc). Vermicompost enriched in phosphate-solubilizing bacteria and its effect on growth of maize. Submitted to Osmania University, Hyderabad.

Kranthi M (MSc). Microbiological properties of soil samples from rice fields using SRI method of cultivation. Submitted to Jawaharlal Nehru Technological University, Hyderabad.

Lakshminarayanamma V (PhD). 2005. Genetics of resistance to pod borer (*Helicoverpa armigera*) in chickpea (*Cicer arietinum*). Submitted to Acharya NG Ranga Agricultural Univrsity (ANGRAU), Rajendranagar, Hyderabad 500 030, Andhra Pradesh, India.

Rama J (MSc) Microbiology and efficacy of extracts of some botanicals known to kill insect-pests. Submitted to Bharathidhasan University, Tamil Nadu.

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Global Theme on Crop Improvement and Management

Archival Report 2005

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About ICRISAT®

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a nonprofit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. ICRISAT belongs to the Alliance of Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR).

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