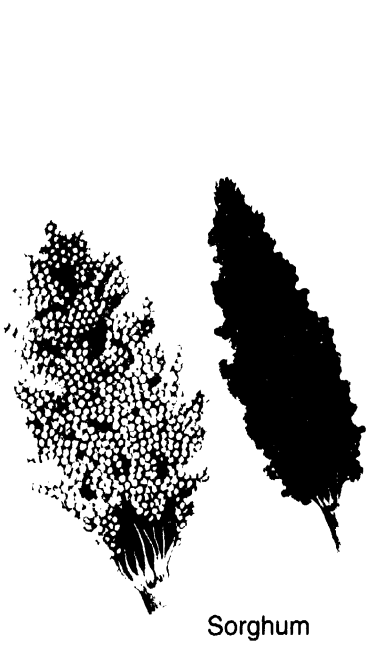
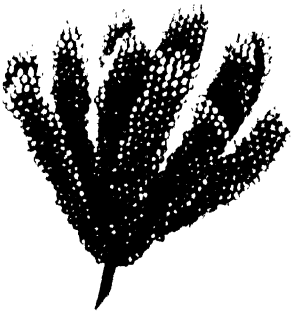
Genetic Resources and Enhancement Program



Sorghum

Pearl millet



Finger millet

Archival Report for 1998 and 1999

Groundnut

Pigeonpea

Chickpea

International Crops Research Institute for the Semi-Arid Tropics

Limited circulation

Genetic Resources and Enhancement Program

Archival Report for 1998 and 1999

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
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Contents

Genetic Resources and Enhancement

Rodomiro Ortiz

Research and technology development, ensuing from genetic improvement, is organized at ICRISAT according to major topical thrusts, rather than crop mandates, to create more flexibility. In 1997 the Genetic Resources and Enhancement Program (GREP) was established at ICRISAT to help developing countries to:

I. Rescue and preserve endangered crop biodiversity;
II. Introduce and apply new biotechnological tools to the needs of the semi-arid tropics;
III. Identify valuable new traits for resistance to biological and environmental stresses; and
IV. Improve breeding populations as a vehicle for sharing new traits with national agricultural research systems (NARS).

The director of the program is based at ICRISAT's facilities in India, where the center's genebank and biotechnology labs are located. Particular problems will require special strategies involving partners throughout the semi-arid tropics (SAT), especially in Sub-Saharan Africa. The development of breeding populations will emphasize vigorous NARS partnerships with greater direct ICRISAT involvement in Africa. Genetic resources conservation and delivery of improved germplasm are the focus of GREP activities in Africa. Likewise, GREP scientists are conserving and enhancing crop genetic resources applying conventional and new tools at our headquarters in India. Other scientists are also identifying useful characteristics to improve crop adaptation in the SAT.

ICRISAT has decided to implement its medium term plan (MTP) 2000-2002 considering as a partnership-based plan for renewal. Accordingly, GREP has developed its research agenda with the aim of "building tomorrow" together with its partners worldwide. For 1999, research projects of GREP have been streamlined and consolidated by integrating activities in four research areas. This consolidation was a direct evolution from the nine GREP research areas originally included in the previous rolling MTP. Experience accumulated during 1998 showed that sets of independent projects within each of these research areas formed an operational continuum, thus a separate structure was not needed. One of the most important features of this consolidation is the focus in sub-Saharan Africa with the corresponding strengthening in both staff and resources.

GREP scientists are expected to continue building partnerships and submitting targeted proposals to apply molecular and bioinformatic tools for the genetic betterment of most important crops of the SAT, which have been included in our research agenda. Likewise, our scientists continue applying conventional and innovative cross breeding methods for the genetic enhancement of ICRISAT mandate crops. In this way, we are working along the lines suggested by the last CGIAR Systemwide Review and ICRISAT External Program and Management Review, which advocated an integrated gene management approach. Furthermore, the partnership-based refinement and exchange of useful breeding materials balances the GREP strategy.

The four research areas advocated in the new MTP by GREP are a logical progression from an appropriate conservation, management and utilization of plant genetic resources and the genes available in the different crop gene pools. GREP scientists expect that our work will culminate by sharing products with our local research and technology transfer partners and making impact together in the fields of our farmer clients.

The four research areas coordinated by GREP are:

- Rescue, analyze and conserve biodiversity to sustain crop productivity
- New tools: adapt and apply new science methods to SAT crop improvement
- New traits: the biology and improvement of disease and pest resistances, stress tolerance and quality
- Partnerships to share breeding materials in farmer-ready forms.

The conservation of genetic resources of important SAT food crops for the long-term benefit of humanity is the most important goal of our research in biodiversity. We expect that biotechnological outputs help to obtain a more effective and durable resistance to biotic and abiotic stresses, which may stabilize production of food crops of the poor in the SAT. Likewise, with an enhanced ability to manipulate genes, improved nutritional quality may be achieved that will benefit human health and household for food security. The identification of new traits will allow ICRISAT and its partners in the national programs to develop a more stable, diversified germplasm with improved resistance to diseases and pests, stress tolerance, better quality, and higher productivity. The research in conventional breeding and seed delivery of improved genotypes integrates outputs from other research areas. Likewise, reduced crop cycle or modified plant structure will provide opportunities for new cropping systems. Finally, with the utilization of new cultivars, we expect to enhance and stabilize agricultural production, farm income and farm-family welfare in the SAT.

There are in excess of 50 core, special project and affiliate scientists working at GREP, who are supported by technical and administrative staff in India, Kenya, Malawi, Mali, Niger, Nigeria, Senegal, and Zimbabwe. These scientists are applying their professional skills in agronomy, biometry, biotechnology, breeding, crop physiology, entomology, genetic conservation, genetics, information management, plant pathology, virology, technology transfer, research networking and project management to accomplish ICRISAT goals in the conservation and enhancement of crop genetic resources of the SAT.

GREP scientists are also supporting research of graduate students from both developing and developed countries, whose investigation focuses on crop improvement for the SAT.

RESEARCH AREA I

Research Area I: Rescue, analyze and conserve biodiversity for utilization to sustain crop productivity

Goals

Conserve biodiversity of important SAT food crops for the long-term benefit of humanity.

Purposes

ICRISAT assembled a large collection of germplasm of the five mandate crops and six small millets. ICRISAT need to ensure that the assembled germplasm is maintained in a safe, secure and cost-effective manner and distributed to the bona fide users for utilization in crop improvement. The collections held in genebank need to be monitored regularly and regenerated with appropriate plant population and pollination controls to ensure genetic integrity. The agreement between FAO and ICRISAT under which ICRISAT holds its germplasm collections in trust for the benefit of international community, requires the accessions to be maintained in long-term conditions and duplicated in another country. Research on genetic resources is aimed at adding value to germplasm collections and enhance their utilization in crop improvement for food security, and developing methods to maximize seed longevity and make *ex situ* conservation more efficient, sustainable and cost-effective. The specific goals of the project are: help NARS collect, conserve and document endangered germplasm; securely maintain, manage and distribute the ex *situ* collections; and study the value and understand the patterns of diversity to enhance its use in crop improvement.

Objective 1.1: Assist national programs to collect traditional landraces and farmers' information on mandate crops and their wild relatives from threatened and unexplored areas of wide biodiversity

Rationale: Assembly of germplasm is of fundamental importance for crop improvement and conservation of biological diversity. It has been the key activity for ICRISAT since inception. ICRISAT germplasm collections, the largest in the world for sorghum, pearl millet, groundnut, pigeonpea and minor millets have been assembled through donations from NARS and by collecting in various targeted missions. The existing collections are estimated to represent 70-80% of the diversity in these crops, but there are still gaps which need to be filled. Many of these are for wild relatives or landraces in areas where the diversity is threatened by political strife or environmental degradation.

Activity 1.1.1: Germplasm cultivars of mandate crops collected from threatened areas of wide diversity in Africa and Asia

Collection of germplasm in Vietnam and Bangladesh (L J Reddy)

Minor millets and pigeonpea are in danger of extinction due to replacement by commercial crops in Vietnam. We collected 19 samples of foxtail millet, 15 samples of proso millet, and four

samples of pigeonpea together with information from 13 provinces of north Vietnam, jointly with the Vietnam Agricultural Science Institute (VASI), Hanoi.
Pigeonpea had been one of the main components of *Jhum* cultivation as a vegetable crop in Bangladesh. However, the introduction of short duration vegetables has relegated this crop to kitchen gardens. We collected 80 samples with remarkable range of seed color variability from 23 districts in collaboration with Plant Genetic Resources Centre, Bangladesh Agricultural Research Institute, Joydebpur.

Activity 1.1.3: Farmer management of genetic resources documented for ICRISAT mandate crops

Documenting farmers' information (P J Bramel-Cox and A Chrisnick)

A questionnaire to better document farmers' traditional knowledge was prepared containing – farmers' name, description of environment, description of the characteristics of the variety, description of the end use and specific properties of the variety, description of normal cultural practices used with the variety or landrace, and discussion of the history of the variety with the farmer.

Documentation of farmer management of genetic resources in western Rajasthan (E Weltzien, P J Bramel-Cox, K van Brocke and A Chriscnick)

Understanding farmers' strategies for selecting, processing, storing and using seed of different varieties forms the basis for developing sustainable strategies for *in-situ* conservation. Seed and food grain samples were collected from farmers in four different villages for three consecutive years. They were compared for standard agronomic traits at three locations in western Rajasthan, India. Selected populations were analyzed for intra-population variability using AFLP markers, and conducting progeny-based field trials. The study revealed that farmers who used new varieties to broaden the genetic base of their seed stocks possessed populations with higher yield, lower levels of nodal tillering, lower incidence of downy mildew, and usually more variable seed stocks than farmers who primarily used the landrace based seed stocks alone. Farmers in two villages were able to maintain relatively pure seed stocks of a preferred modern variety for the entire three years period. Farmers' selection of panicles was clearly effective in maintaining earlier dates of flowering in their seed stocks.

Documentation of farmer management of genetic resources in Mali (E Weltzien)

In Mali, several of the main races of sorghum are cultivated, and the variety diversity within each race is extremely high. Variety development efforts for this country and the region as a whole will need to address the dual goals: Increasing productivity of the crop, while maintaining variety diversity available to farmers. Farmers' participation therefore, will be key to achieving this dual goal. A basic understanding of farmer's variety management is therefore fundamental to the variety development program. We conducted in depth discussions about variety issues, seed selection and storage practices as well as the origin of specific varieties. We used semi-structured interviews, and some PRA-type tools to enhance visualization of the on-going discussions. The initial results indicate that most farmers cultivate more than one variety of sorghum. Usually the

different varieties grown by one farmer differ in their growth duration, adaptation to specific growing conditions, and possibly for grain storage and consumption qualities (Table 1). Most farmers normally produce their own seed, by selecting panicles from the field before the general harvest begins. Farmers pursue traits that are linked to grain productivity and adaptation. Many farmers are interested in new varieties, and changed their varieties considerably during the past 10-20 years. We are focusing on obtaining more precise information on this issue, and to understand the channels for acquisition of new varieties by the farmers.

Table 1. Description by one farmer from Tioribougou, Mali (Moustapha Diarra) of the strengths and weaknesses of the six sorghum varieties he currently grows.

Variety	Strengths	Weaknesses
Kenikeba	Large panicle, good storage, good processing qualities	Long growth duration, drought susceptibility
Tiemarifing	Productive, medium growth duration	Slightly susceptible to drought
Badjouloudjan	Productive, medium growth duration	Slightly susceptible to drought
Nitélini	Short growth duration, harvest during hunger period, production assured	Poor grain storage
Dagassigui	Short growth duration, harvest during hunger period, production assured	Poor grain storage
Gadiabani	Later date of sowing, harvest during hunger period, productive, drought resistant, production assured	Poor grain storage

Activity 1.1.4: Wild and cultivated genetic resources of ICRISAT mandate crops and small millets assembled from donors

Registration of new germplasm (N Kameswara Rao, P J Bramel-Cox, L J Reddy and H D Upadhyaya)

During 1998-99, we registered 820 new germplasm accessions, including 348 sorghum, 102 pearl millet, 344 pigeonpea and 26 groundnut samples. With this the total number of accessions conserved in the genebank raised to 113,170. We have updated the list of accessions of the mandate crops and small millets designated to the Food and Agricultural Organization (FAO). All the ICRISAT developed lines and genetic stocks registered earlier as genebank accessions are now placed under the auspices of FAO to provide unrestricted access to users for crop improvement and de-designated 842 germplasm accessions (3 sorghum, 141 chickpea and 211 pigeonpea and 487 groundnut) without any seed stock. With these revisions, the percentage of germplasm collection designated to FAO has gone up to 97% (Table 2).

We received 946 finger millet germplasm accessions from Zimbabwe and 50 foxtail millet germplasm accessions from Bangladesh. These were grown in Post-entry Quarantine Isolation Area (PQIA) for quarantine inspection and subsequent release.

Table 2. Summary of the germplasm collections in ICRISAT genebank and their 'FAO in-trust' status.

Crop	Total	No. of accessions designated		No. of accessions undesignated	
		Cultivated	*Wild*	*Cultivated*	*Wild*
Sorghum	36,719	35,366	414	936	3
Pearl millet	21,392	20,562	688	80	62
Small millets	9,060	9,051	-	9	-
Chickpea	17,250	16,845	48	270	87
Pigeonpea	13,544	12,385	314	604	241
Groundnut	15,342	14,065	292	825	160

Germplasm acquisitions (L J Reddy)

During 1998, we acquired 100 accessions of wild *Cicer* from the Genetic Resources Unit, ICARDA, Syria.

Objective 1.2: Characterization and evaluation of existing and new germplasm collections for utilization in national conservation and breeding programs

Rationale : Botanical characterization and evaluation for specific traits of interest are necessary to facilitate the utilization of germplasm. While these have been done for most of the assembled germplasm of cultivated species, many of the wild accessions in the collections still remain to be characterized and evaluated. In the cultivated species, the traits of interest included stable botanical characters and a few environmentally influenced agronomic and quality traits. Evaluations are conducted in collaboration with scientists from different disciplines or in the national programs. New collections are jointly characterized in the country of origin, before they are acquired for genebank. The data collected from these characterizations and evaluations represent the reaction of the germplasm in an environment more closely related to that of its evolution.

Activity 1.2.1: In-country characterization and evaluation of new germplasm collections conducted with farmer's and NARS participation

In-country characterization and evaluation of new germplasm collected in Vietnam (L J Reddy)

Fifty-five groundnut accessions collected from 11 northern provinces of Vietnam were characterized using 28 internationally agreed descriptors and evaluated for rust and late leaf spot resistance. Nine collections resistant to rust and three collections resistant to late leaf spot in the early maturity background were identified which will be obtained for ICRISAT genebank.

Activity 1.2.2: Botanical characterization and morpho-agronomic evaluation conducted of the assembled germplasm

Characterization of germplasm accessions for traits of agronomic importance is essential for adequate analysis of data. Several of the germplasm accessions have missing data for one or more traits and attempts were made to fill those gaps.

Characterization of sorghum and pearl millet germplasm (P J Bramel-Cox)

Missing data were obtained for 781 sorghum and 197 pearl millet germplasm accessions for various morpho-agronomic traits. In addition, data were recorded for 2,000 sorghum accessions for grain characteristics. We also characterized and classified 498 sorghum germplasm accessions received earlier from South Africa. In pearl millet, missing characterization data were recorded for 197 accessions in the 1998 rainy season, for 315 accessions in the 1998 post-rainy season, and 1,500 accessions in the 1999 post-rainy season.

Characterization of groundnut germplasm (H D Upadhyaya)

In the 1997/98 postrainy season, we characterized 225 groundnut accessions for days to emergence and 50% flowering, 941 for plant height, 933 for number of primary branches, 20 for growth habit, and branching pattern, 25 for stem pigmentation, 23 for stem hair, 21 for leaf color, leaflet shape, leaflet hair, and peg color, 43 for leaflet length and width, 20 for standard petal color and markings, 675 for days to maturity and 979 for reaction to *Spodoptera litura*. The post harvest data on pod beak (1243 accessions), pod constriction (1239 accessions), pod reticulation (1238 accessions), seed color pattern (1329 accessions), primary seed color (782 accessions), and secondary seed color (47 accessions) were recorded. The information recorded on protein content (2341 accessions), oil content (4656 accessions), rosette reaction (3000 accessions), and early leaf spots reaction (3000 accessions) was entered in to the records.

In the 1998 rainy season the accessions characterized were, 799 for days to emergence and 50% flowering, 1998 for plant height, 1914 for number of primary branches, 20 for growth habit and branching pattern, 274 for stem pigmentation, 264 for stem hair, 16 for leaf color, 90 for leaflet shape, 109 for leaflet hair, 400 for leaflet length and width, 207 for standard petal color and markings, 305 for peg color, and 700 for days to maturity. The post harvest data on pod length (1706 accessions), pod width (1707 accessions), seed length (1799 accessions), seed width (2178 accessions), seed weight (2141 accessions), and shelling percentage (7718 accessions) were recorded in the 1998 rainy season and entered into the records.

In the 1998/99 postrainy season, the number of groundnut accessions characterized included, 900 for days to emergence and 50% flowering, 931 for plant height, 854 for number of primary branches, 2 for growth habit and branching pattern, 72 for stem pigmentation, 70 for stem hair, 28 for leaf color and leaflet shape, 38 for leaflet hair, 1300 for leaflet length and width, 81 for standard petal color and markings, 102 for peg color, and 385 for days to maturity. In this season the post harvest data on pod length (1469 accessions), pod width (1470 accessions), seed length (1569 accessions), seed width (1566 accessions), seed weight (1727 accessions), and shelling percentage (6383 accessions) were recorded and entered into the records.

In the 1999 rainy season we characterized 1500 groundnut accessions for days to emergence and 50% flowering, 303 accessions for plant height, 506 for number of primary branches, 20 accessions for growth habit and branching pattern, 32 accessions for stem pigmentation and stem hair, 29 accessions for leaf color, 33 accessions for leaflet shape, 29 accessions for leaflet hair, 737 accessions for leaflet length and width, 30 accessions for standard petal color and markings, 28 accessions for peg color, and 1500 accessions for days to maturity.

During 1998, we characterized 66 chickpea accessions on which data were not available for different traits. We also characterized 388 pigeonpea accessions, recently obtained from USA, using 29 descriptors and the data were added to the database.

Characterization of Arachis and Cicer accessions (L J Reddy)

Wild *Arachis* species conserved at ICRISAT have not been adequately characterized in the past. Eighty four accessions belonging to 25 species under five sections were planted in a three-replicate field trial. Characterization data using 70 descriptors were collected and added to the data base. In 1999, seventy four accessions belonging to 15 species under section *Arachis* were planted in the glasshouse and characterized using 70 descriptors. In addition, 49 accessions of 8 wild *Cicer* species grown in the field, and another 100 accessions received from ICARDA and grown in the glasshouse were characterized under extended day length conditions using 22 descriptors.

Activity 1.2.3: Wild and cultivated genetic resources evaluated for resistance to biotic and abiotic stresses

Evaluation of wild relatives of Sorghum bicolor for resistance to shoot fly (*Atherigona soccata*), and spotted stem borer (*Chilo partellus*) (H C Sharma)

Shoot fly: On hundred and twenty two accessions of wild relatives of sorghum belonging to *Stiposorghums*, *Heterosorghums*, *Parasorghums*, and *Chaetosorghums* were screened for resistance to sorghum shoot fly, (*Atherigona soccata)* under uniform insect pressure using the cage technique, along with appropriate resistant (IS 1054, IS 18551, and IS 2146), and susceptible (CSH 1 and ICSV 112) checks, during the 1998 rainy season. Data were recorded on the number of plants with eggs, number of eggs laid, and deadheart formation. Eleven accessions showed resistance to shoot fly (<20% deadheart formation compared to 30% in the resistant check IS 18551, and 100% in the susceptible check CSH 1). There was considerable variation in the accessions within a species for susceptibility to shoot fly.

A set of 70 diverse shoot fly resistant and susceptible lines selected from the above, including four controls from *Sorghum bicolor* (IS 18551 and IS 2146 - resistant checks, IS 1054 - moderately resistant commercial check, and CSH 1 - susceptible check), was evaluated under field conditions during the 1998-99 rainy season. The material was planted in two row plot, 2 m long, with three replications in a Randomized Complete Block Design (RCBD). The data were recorded on egg laying and dead heart formation.

Accessions belonging to *Sorghum laxiflorum, S. australiense, S. brevicallosum, S. dimidiatum, S. matarkense, S. nitidum, S. purpureosericeum, S. timorense, S. versicolor, S. angustum, S. ecarinatum, S. extans, S. interjectum,* and *S. intrans* did not suffer any shoot fly damage under multi-choice conditions in the field over two season. These accessions are also being evaluated under no-choice conditions in the glasshouse to identify lines with high levels of resistance and understand the mechanisms of resistance. *Sorghum aethiopicum, S. arundinaceum, S. verticilliflorum, S. virgatum,* and *S. halepense* showed high levels of susceptibility to the shoot fly, and these sorghums possibly play a major role as alternate hosts of this insect under natural conditions. Among the cultivated sorghums, IS 2146 and IS 18551 suffered 30.2 to 51.8% deadheart incidence compared to 93.3 to 96.7% deadhearts in CSH 1.

Spotted stem borer: The same set of germplasm accessions evaluated for resistance to shoot fly was also evaluated for resistance or susceptibility to spotted stem borer (*Chilo partellus)*. Three genotypes of *S. bicolor* were included as controls (IS 2205 - resistant check, ICSV 700 - improved resistant line, and ICSV 1 - susceptible check). The material was planted in two row plots, 4 m long, with three replication in a RCBD. The test material was infested artificially with first-instar larvae at 20 days after seedling emergence (@2 to 5 larvae per plant). Data were recorded on leaf and deadheart formation.

Wild species, *Sorghum laxiflorum, S. australiense, S. brevicallosum, S. dimidiatum, S. matarankense, S. nitidum, S. purpureosericeum, S. timorense, S. versicolor, S. angustum, S. ecarinatum, S. extans, S. interjectum, S. stipoideum,* and *S. intrans* showed leaf damage rating of <1, and did not suffer any deadheart formation. These accessions are also being evaluated in the greenhouse to identify lines with high levels of resistance, as well as to understand the mechanisms of resistance. *Sorghum aethiopicum, S. arundinaceum, S. verticilliflorum, S. virgatum*, and *S. halepense* showed high levels of susceptibility to the stem borer, and these sorghums possibly serve as alternate hosts of this insect. Among the cultivated sorghums, IS 2205 and ICSV 700 suffered 27.8 to 55.0% deadheart incidence compared to 69.8 to 90.0 deadhearts in ICSV 1. Lines showing high levels of resistance will be used in wide-hybridization to increase the levels and diversify the basis of resistance to these insects.

Evaluation of chickpea germplasm for disease resistance (S D Singh)

Collar rot (*Sclerotium rolfsii*), dry root rot (*Rhizoctonia bataticola*), ascochyta blight (*Ascochyta rabiei*) and botrytis gray mold (BGM) (*Botrytis cenerea*) are major diseases of chickpea for which genetic resistance is yet to be found. A total of 1409 accessions from two core collections of cultivated chickpea were tested to identify sources of resistance for these diseases. For collar rot, screening was done in artificially infested pots in glasshouse and for ascochyta blight and BGM, 10-day old seedlings were inoculated in growth room. Spore concentration for the two diseases was maintained at 5 x 106 spores mL^{-1}. The inoculated seedlings were incubated at 95-100% RH for 5 days at a temperature of 22°C for ascochyta blight and 25°C for BGM. The results, though preliminary, indicate that high levels of genetic resistance, particularly to collar rot and BGM probably exist in the regional collection for Asia. A diversity analysis will be done on the entire collection to target accessions for further analysis.

Resistance to collar rot: Two accessions (ICC 14391 and ICC 1698) developed <10% collar rot, and 13 others (ICC 4709, 684, 9934, 618, 8469, 344, 542, 14282, 14207, 205, 89, 10183, and 11273) developed <20% collar rot.

Resistance to ascochyta blight: One accession (ICC 1532) showed high level of resistance (3 score) and five others showed moderate resistance.
Resistance to BGM: Two accessions showed very high levels of resistance (2-3 score) and 10 others showed moderate levels of resistance (4-5 score)

Evaluation of wild chickpeas for botrytis gray mold (BGM) and ascochyta blight (S D Singh)

We screened 74 accessions belonging to nine *Cicer* species for botrytis gray mold. ICC 69977 (*C. cuneatum*) and ICC 17148, -17149, -17150 (*C. judaicum*) remained BGM free. In addition, 17 accessions of *C. judaicum* and one each of *C. microphyllum* and *echinospermum* showed very high levels of resistance (1-2 rating). Among these, *C. echinospermum* can be crossed with cultivated chickpeas. This species has some resistance for ascochyta blight also. One accession, ICC 17212 showed high levels of resistance (2 score), although other accessions were found susceptible. Ten other *C. judaicum* accessions also showed moderate level of resistance (3-4 scores) to acsochyta blight. Several accessions of this species showed high levels of resistance to both BGM and ascochyta blight.

Evaluation of groundnut germplasm for rosette and early leaf spot (P Subrahmanyam)

Rosette and early leaf spot (ELS) are the most destructive diseases of groundnut in the South and East Africa (SEA) region. Yield losses due to rosette approach 100% whenever the disease strikes in epidemic proportions. Some 4,420 (3,000 in 1997/98 and 1,420 in 1998/99 crop seasons) groundnut germplasm lines and 80 (37 in 1997/98 and 43 in 1998/99) accessions of wild *Arachis* species were evaluated for resistance against rosette and ELS in separate disease nurseries at Chitedze, Malawi using the infector row technique. Each entry was assessed for disease incidence/severity at the pod-filling stage and at maturity.
Resistance to rosette: Rosette incidence was almost 100% in most test genotypes in both crop seasons. However, some 20 genotypes in 1997/98 and 28 genotypes in 1998/99 showed low (< 20%) disease incidence. Of these, ICGs 2, 12191, 8517, 13389 and 14785 are short-duration spanish types and others are medium to long-duration virginia types. In preliminary yield trials in 1998/99, ICG 2 gave the highest pod yield (0.79 t ha^{-1}) than the susceptible control, CG 7 (0.10 t ha^{-1}) under high disease situation in Malawi. Among wild species, 15 accessions belonging to *A. pintoi*, *A. appressipila*, and *A. stenocarpa* consistently showed very high degree of resistance to rosette (Table 3). In addition, several of these accessions showed the absence of all three components of groundnut rosette (GRAV, GRV and its satellite RNA) in ELISA tests.
Resistance to ELS: Thirty-five additional sources of resistance to ELS were identified. Of these, 30 of them originated in South America (mostly from Peru and Bolivia) and are valencia types. Eleven accessions of wild *Arachis* species (ICGs 8131, 13211, 13222, 14855, 14856, 14888, 14875, 14907, 14924, 14939, and 14946) were highly resistant (score 2.0 on a 9-point scale) and 15 others were resistant (score 3.0-4.0) to ELS. Thus, several new, valuable sources of resistance to rosette and ELS were identified for possible utilization in breeding programs. High level of resistance to both rosette and ELS diseases hitherto undiscovered in cultivated groundnut were identified in wild *Arachis* species. The information on sources resistance to groundnut rosette disease identified from screening of global germplasm at ICRISAT-Lilongwe will be incorporated into Genebank Information System.

Table 3. Reactions of 18 accessions of wild *Arachis* species against groundnut rosette disease in field screening trials at Chitedze, Malawi, 1998/99 crop season.

ICG No	Species	Section	Origin	Rosette incidence (%)
8190	*A. hoehnei*	*Arachis*	Brazil	6
8945	*A. appressipila*	*Procumbence*	Brazil	0
11558	*A. cardenasii*	*Arachis*	Bolivia	0
13168	*A. villosa*	*Arachis*	Argentina	0
13171	*A. stenosperma*	*Arachis*	Brazil	0
13173	*A. stenosperma*	*Arachis*	Brazil	3
13187	*A. stenosperma*	*Arachis*	Brazil	4
13210	*A. stenosperma*	*Arachis*	Brazil	0
13225	*A. kuhlmannii*	*Arachis*	Brazil	0
14855	*A. pintoi*	*Caulorhizae*	Brazil	0
14856	*A. pintoi*	*Caulorhizae*	Brazil	3
14860	*A. appressipila*	*Procumbence*	Brazil	0
14862	*A. kuhlimanii*	*Arachis*	Brazil	0
14872	*A. sternosperma*	*Arachis*	Brazil	5
14888	*A. pintoi*	*Caulorhizae*	Brazil	0
14875	*A. triseminata*	*Triseminalae*	Brazil	3
14907	*A. pintoi*	*Caulorhizae*	Brazil	0
14946	*A. decora*	*Arachis*	Brazil	0
ICGV-SM 90704	*A. hypogaea*	*Arachis*	Malawi	5
ICG 12991	*A. hypogaea*	*Arachis*	India	9
EC 36892	*A. hypogaea*	*Arachis*	Unknown	15
JL 24	*A. hypogaea*	*Arachis*	India	100
CG 7	*A. hypogaea*	*Arachis*	Malawi	100
Trial mean				10.9
SE				±2.9

Evaluation of wild Arachis species germplasm for aflatoxin contamination (R P Thakur, D V R Reddy and M E Ferguson)

High level of stable resistance to aflatoxin contamination (infection by *Aspergillus flavus* and production of aflatoxin) is not available in cultivated groundnut. Wild *Arachis* species, of which ICRISAT has large number of accessions, have not been explored, except a brief report in 1989 wherein all 16 accessions screened were susceptible to aflatoxin production. We evaluated 35 germplasm accessions of wild *Arachis* belonging to 24 species in six Sections for *in-vitro* colonization by artificial inoculation with a recently identified highly virulent and toxigenic strain of *A. flavus* (isolate *Af* 11-4) and aflatoxin production, using standard methods. Four of the 35 accessions belonging to *Arachis triseminata* (ICG 8131 and ICG 14875), *A. chiquitana* (ICG 11560) and *A. pusilla* (ICG 13212) recorded a score of 1 on a 1-4 colonization rating (1 < 5% seed surface colonized and 4 >50% seed surface colonized). Two of these (ICG 8131 and ICG 11560) recorded very low level of aflatoxin B1 (4 and 21 µg/kg, respectively) compared with very high level (>8000 µg/kg) in susceptible cultivars. Some other promising accessions were ICG 8193, ICG 8904, ICG 13212, ICG 13261, and ICG 15875, which showed variation for *in-*

vitro seed colonization and aflatoxin B1 content between replications. We need to confirm these results by repeated evaluation and also screen more accessions. Further characterization of these accessions for foliar disease resistance and drought tolerance will be useful.

Evaluation of wild Arachis species for resistance to late leaf spot (R Bandyopadhyay, Suresh Pande and M E Ferguson)

Wild *Arachis* species were screened for late leafspot, as adequate level of resistance to this stress is not available within the cultivated *Arachis* genepool. During 1998, 50 wild species accessions along with three susceptible control cultivars (TMV 2, Robut 33-1, and M 13) were screened for late leaf spot reaction under artificial inoculation. We used the detached leaf technique in growth chambers to evaluate the accessions. Detached leaflets were artificially inoculated with a spore suspension (1 x 10^5 conidia mL^{-1}) and placed in moist sand (with petiole inserted in the sand) contained in trays. The trays were covered with polyethylene bags to maintain high humidity and the sand was moistened with a nutrient solution as per needs. The trays were incubated at 25 C for 30 days. Severity of LLS and defoliation were recorded on alternate days. The trial was in a completely randomized design with two replications (two leaflets per replicate) and the experiment was repeated two times. Eight wild species accessions (ICGs 8129, 8138, 8190, 8191, 8904, 8945, 8946, and 8963) highly resistant to late leaf spot and one accession (ICG 8959) immune to the disease were identified. In 1999, we evaluated a further 58 accessions that had not been previously screened. Fifteen accessions were free from LLS. These are ICG 13159, 13187, 13223, 13244,13252, 13256, 14866, 14870, 14882, 14891, 14929, 14938, 14945, 14946, and 15160. Among these, ICG 13159, 13223, 13256, 14866, and 14945 retained all leaflets (i.e., 0% disease and defoliation). Another 12 accessions had less than 2 score. The susceptible check TMV 2 had maximum disease (50%) and 100% defoliation. The results showed that a few wild *Arachis* species have very high levels of resistance, and there is a need to evaluate other species.

Evaluation of wild Arachis species for resistance to Peanut Clump Virus (D V R Reddy and M E Ferguson)

There is currently no adequate resistance to peanut clump virus in groundnut germplasm. The wild species are a potentially valuable source of resistance, but their response to peanut clump virus has never been evaluated. Fifty wild *Arachis* accessions from Section *Arachis* were evaluated in a 'sick-plot' field trial. Entries were planted in a complete randomized block design with 3 replications. Infection was scored visually and using an ELISA test on two separate occasions. Four accessions, ICG 14861 (*A. kuhlmannii*), ICG 13217 (*A. duranensis*), ICG 11555 (*A. duranensis*), and ICG 8206, (*A. ipaensis*) showed no sign of infection in any of the replications in either of the tests. It is interesting to note that *A. duranensis* and *A. ipaensis* are thought to be the wild progenitors of the allotetraploid *A. hypogaea*, and thus exploitation of the observed variation by conventional crossability methods should be feasible.

Evaluation of wild Arachis species for resistance to insect pests (H C Sharma)

A set of 30 accessions of wild relatives of *A. hypogea* was evaluated to identify lines with high levels of resistance to insects for use in wide-hybridization. Five genotypes of *A. hypogea* (TMV 2 - commercial check, FDRS 10 and ICGS 86031 - improved lines with insect resistance, and M 13 and NCAc 343 - resistant checks) were included as controls. The material was planted in 4 row plots, 2 m long during the 1999 rainy season. Data were recorded on leaf miner damage [leaf damage rating,

percentage leaflets with leaf miner damage, and number of mines, larvae and pupae per plant], leaf damage by *Helicoverpa armigera*, leaf yellowing due to jassid damage, and leaf spot severity. Germplasm accessions ICG 8195 ICG 8216, ICG 8963, ICG 11555, and ICG 13212 showed high levels of resistance to leaf miner, *Aproaerema modicella*, cotton bollworm, *H. armigera*, and jassid, *Empoasca kerri* (Table 4). These lines also showed high levels of resistance to leaf spots. Several lines suffered <10% or no damage by the foliage feeders. Eighteen lines showed high levels of resistance to leaf diseases. Among the cultivated types, ICGS 86031, M 13, and NCAc 343 showed moderate levels of resistance to both the leaf miner and foliage feeding by *H. armigera*.

In another trial, 12 derivatives from wild relatives of *A. hypogea* and 8 cultivated types were evaluated in collaboration with breeders for resistance to insects under field conditions, to explore the possibilities of identifying lines with less susceptibility to insects from the wide hybrids. The material was planted in 4 row plots, 2 m long. There were three replications in a Randomized Complete Block Design (RCBD). Data were recorded on leaf miner damage (lead damage rating (DR), percentage leaflets with leaf miner damage, and number of mines, and number of larvae and pupae per plant), leaf damage by *H. armigera*, leaf yellowing due to jassid damage, and leaf spot severity. Data were also recorded on pod yield at harvest. Genotypes Cyto 16, Cyto 73, Cyto 111, and Cyto 502 showed less susceptibility to leaf miner *A. modicella*, cotton bollworm, *H. armigera*, and jassid, *Empoasca kerri*. These lines also showed high levels of resistance to leaf spots. Among the cultivated types, ICGS 86590, ICGS 86699, and FDRS 10 showed moderate levels of resistance to both the leaf miner and *Helicoverpa*. Genotypes Cyto 73, Cyto 111, Cyto 144, Cyto 152, and Cyto 502 yielded 496.7 to 587.3 g per plant compared to 606.7 to 779.0 g per plot in the cultivated types ICGV 86590, ICGV 86699, and FDRS 10; and 212.7 g in TMV 2 - the commercial check. Most of the reduction in pod yield occurred as a result of severe leaf disease incidence.

Screening against Peanut Bud Necrosis Disease (L J Reddy and D V R Reddy)

Information on the reaction of wild *Arachis* species against peanut bud necrosis disease (PBND) will be useful in transferring resistance to this virus into cultivated types. Eighty-four wild species accessions were screened in a three-replicate field trial. PBND was recorded at two stages of crop growth. Three accessions, ICG 8131 (*A.triseminata*), ICG 8144 (*A. villosa*), ICG 8945 (*A.appressipilia*) showed no disease incidence in all the three replications. ICG 11551 (*A. benensis*) showed less than 5% mean disease incidence.

Screening against root-knot nematodes (S B Sharma and L J Reddy)

Complete information on wild *Arachis* species reaction to root-knot nematodes has not been available. Therefore, 55 accessions belonging to sixteen species were evaluated in greenhouse tests. Nine accessions (ICGs 13160, 13237, 13251, 13258, 15147, 15164, 15172, 15175, and 15237) showed resistance to nematode-caused root damage and to nematode reproduction.

Table 4. Relative susceptibility of 30 accessions of wild relatives of *Arachis hypogea* to leaf miner, *Helicoverpa* and jassids under field conditions (ICRISAT, Patancheru 1999. rainy season)

Accession number	LMDR	%leaflet with LM damages	No. of mines/ plant	Larvae / plant	Pupae/ plant	HADR	Collor rot DR	Jassids DR	Leaf spot DR
ICG 8125	3.00	9.27	1.56	-0.20	1.21	1.50	1.00	1.00	0.50
ICG 8130	2.83	22.49	3.08	2.80	0.21	1.00	0.50	0.50	0.00
ICG 8131	2.50	4.70	1.92	0.20	0.79	1.00	1.50	1.00	0.50
ICG 8164	4.14	8.80	1.92	0.20	1.79	1.00	0.00	1.25	0.00
ICG 8190	3.39	8.07	1.92	0.20	1.79	1.00	2.00	1.00	1.00
ICG 8195	1.50	9.36	1.56	0.86	0.69	1.00	3.00	1.00	1.50
ICG 8197	2.50	6.09	1.08	0.17	0.83	1.75	1.50	1.00	4.00
ICG 8201	2.47	3.93	1.58	1.25	0.17	2.25	1.50	1.25	2.00
ICG 8203	4.37	8.43	1.56	0.20	1.29	2.75	3.00	1.16	1.99
ICG 8206	5.25	20.44	1.67	1.33	0.58	1.00	4.00	1.00	2.00
ICG 8215	2.83	24.19	1.00	0.50	0.50	1.00	2.00	1.00	0.00
ICG 8216	1.14	5.18	0.92	1.20	-0.21	1.00	1.00	2.00	1.00
ICG 8904	3.34	10.24	1.56	0.86	0.69	1.00	1.00	1.00	0.00
ICG 8945	4.86	11.35	1.58	0.80	0.96	1.00	0.00	0.50	0.50
ICG 8946	6.64	19.33	1.56	0.86	0.69	1.00	0.00	1.00	0.00
ICG 8959	2.36	6.45	1.08	0.80	1.21	1.00	0.50	1.00	0.50
ICG 8963	1.36	4.00	1.56	0.86	0.69	1.00	0.50	0.50	0.00
ICG 8970	3.36	12.82	1.08	-0.20	1.21	1.25	1.50	1.00	0.00
ICG 11550	2.50	9.70	2.00	1.25	0.25	1.25	3.00	1.34	1.01
ICG 11551	2.75	4.56	2.08	1.80	1.21	1.00	1.00	1.00	1.50
ICG 11555	0.86	7.83	1.56	0.86	0.69	1.00	1.50	1.00	1.00
ICG 11557	3.34	10.24	1.56	0.86	0.69	1.50	1.00	1.00	0.50
ICG 13171	3.25	6.93	1.75	1.75	0.00	1.25	0.50	1.00	3.00
ICG 13173	2.20	5.28	1.08	0.80	0.21	1.00	1.00	1.00	0.50
ICG 13177	4.37	13.43	1.00	0.67	0.67	1.50	1.00	1.00	3.00
ICG 13178	4.15	8.54	1.67	1.33	0.46	3.00	2.00	1.00	4.00
ICG 13212	1.14	6.53	1.56	0.86	0.69	1.00	0.50	2.00	1.00
ICG 13242	3.75	9.19	1.00	0.50	0.50	1.75	1.50	1.00	2.00
ICG 14915	3.34	10.24	1.56	0.86	0.69	1.00	2.50	1.00	2.00
ICG 15171	2.08	7.37	1.92	0.20	0.79	1.25	1.50	1.00	1.75
ICGS 86031	7.20	17.19	2.00	1.42	0.50	2.50	0.00	1.00	6.50
TMV 2	4.00	12.80	1.17	0.67	0.50	5.00	1.24	0.84	0.01
M 13	3.67	6.42	1.17	1.14	0.54	2.00	0.00	3.50	3.50
NCAC 343	4.30	6.91	1.83	1.54	0.13	1.50	0.00	3.50	2.00
FDRS 10	6.20	19.98	1.57	0.83	0.47	2.00	0.50	3.00	5.00
SE	±1.19	±5.08	±0.38	±0.34	±0.3	±0.34	±0.8	±0.29	±0.77

DR = Damage rating (1 = <10% leaf area damaged, and 9 = >80% leaf area damaged), LM = Leaf miner, LMDR Leaf miner damage rating, HADR = *Helicoverpa armigera* leaf damage rating.

Activity 1.2.4: Wild and cultivated genetic resources evaluated for quality traits

Quality analysis of pigeonpea germplasm (L J Reddy)

Protein data are missing for some pigeonpea accessions. Three hundred and seventeen accessions in 1998 and 462 accessions in 1999 were analyzed for their seed protein using Technicon Autoanalyser. Protein content for the 779 samples ranged from 14.9- 24.6 % and the data were added to the database.

Quality analysis of wild Arachis species (L J Reddy)

Sources with good quality factors need to be identified among wild *Arachis* species due to limited variability for these traits within cultivated genepool. Fifty five accessions were analyzed for protein, oil, and sugar content and tripsin inhibitors using standard procedures. Fifty-one accessions were assessed for fatty acid composition by preparing fatty acid methyl ester (FAME) and analyzing in a shimadzu GC-9A model gas chromotograph equipped with a flame ionization detector. Six accessions of *A. duranensis* (ICGs 8201, 8202, 13176, 15171, 15178, and 15179), and one each of *A. pusilla* (ICG 13221), and *A. sylvestris* (ICG 14928) showed above 60% protein in defatted samples as compared to 40.2 to 42.7% of control cultivar, ICGS 44. Two species, *A. magna* and *A. sylvestris* showed above 58% oil compared to 49.0-53.9% of ICGS 44. However, none of the wild species were superior in their sugar content (3.9 to 9.5%) compared to 10.4-12.0 % of ICGS 44. *A. villosa* showed very low TUI/mg protein (2.74) as compared to 4.31-7.77 of ICGS 44. The levels of monosaturated fatty acids like oleic acid were significantly lower in members of section *Heteranthae* (*A.pusilla* and *A.sylvestris*).

Objective 1.3: Assist countries to conserve their biodiversity at the national level through training in genetic resources activities

Rationale: The Convention on Biological Diversity (CBD) increased awareness of genetic resources and associated intellectual property rights, especially among developing countries that are the origins of much of the diversity present in important crop plants. This is reflected in a higher profile for genetic resources in national research priorities and the establishment of new genebanks and genetic resources conservation programs. Consequently, the demand for training in all aspects of genetic resources activities is likely to increase significantly. ICRISAT in collaboration with other international and national institutes provides training in genetic resources to meet the needs of new and developing genetic resources programs as emphasized in the Global Plan of Action for Plant Genetic Resources.

Activity 1.3.2: Training conducted in collection of germplasm and farmer information, and in characterization and conservation of genetic resources

Training in germplasm characterization (L J Reddy)

Five national staff from Vietnam Agricultural Science Institute (VASI) were trained in both theoretical and practical aspects of germplasm characterization.

Training in germplasm conservation (N Kameswara Rao)

Short and medium duration training was offered to in-service trainees from NARS in germplasm conservation at Patancheru. The training included practical sessions on seed moisture content determination, viability and vigor tests, seed processing for medium- and long-term conservation, and genebank documentation. A three months training was offered to one scientist from Eritrea on genebank management and one to three weeks training to three scientists form Eritrea, Thailand and Vietnam in seed conservation. Ten in-services trainees from Bangladesh, Brazil and Eritrea received orientation on genetic resources conservation.

Objective 1.4: Maintain *ex situ* collections in a safe, secure and cost-effective manner for continued utilization in crop improvement

Rationale: ICRISAT has a global mandate to conserve and distribute the world collections of sorghum, millets, chickpea, pigeonpea and groundnut. The collections have to be maintained under optimal condition that ensures their safety and long-term viability. Maintenance requires regular monitoring for seed viability by conducting standard germination tests and checking inventory of the seed stocks. Accessions must be rejuvenated to provide fresh seeds for subsequent storage when viability falls below accepted norms or seed stocks get depleted. Rejuvenation must be carried out with appropriate plant population and control of pollination to ensure that the genetic integrity of the original germplasm accessions is maintained and with appropriate crop management to ensure that optimum initial quality is obtained.

Activity 1.4.1: Cultivated and wild germplasm accessions identified for low viability and low seed stock regenerated

Germplasm regeneration (N Kameswara Rao, P J Bramel-Cox, L J Reddy, and H D Upadhyaya)

The quantity of seeds stored in the genebank is reduced due to their distribution and use. The seed viability of the germplasm accessions also decline during storage. It is necessary to regenerate such accessions before the seed stocks get exhausted or viability declines to very low levels. During 1998-99, we identified 7993 germplasm accessions with low viability and low

seed stocks for regeneration. This included 1862 sorghum, 47 pearl millet, 1098 small millets, 1261 chickpea, 1189 pigeonpea and 3526 groundnut accessions. These accessions were regenerated using appropriate population sizes and pollination control, and the harvested seeds were dried, cleaned and processed for medium- and/or long-term conservation. In addition to the cultivated germplasm accessions, we also regenerated 91 wild *Arachis* accessions belonging to 17 species of section *Arachis* during 1998, and 270 accessions belonging to 32 species of 7 sections during 1999, under controlled glasshouse conditions.

Activity 1.4.2: Baseline germination data obtained on all accessions and viability monitoring schedules developed for efficient management of the assembled germplasm

Baseline viability data of active collections (N Kameswara Rao)

A large part of ICRISAT collections is older than 15 years. In the absence of initial germination data, the quality of the seeds in storage was unknown. Therefore, germination tests were conducted to obtain baseline data and identify and regenerate accessions where viability has fallen below acceptable levels and also to draw schedules for future testing of the other accessions. Baseline viability data were obtained on the active collections of sorghum, chickpea and pigeonpea. The percentage germination ranged between 81 and 100 in 93.9% sorghum and 92.7% chickpea accessions (Table 5). The data on pigeonpea collection are being computerized. Germplasm accessions with <75% germination were recommended for regeneration. Based on the available data, a schedule was developed for further viability testing. Accessions with <85% germination will be tested again after 5 years; accessions between 85 and 95% germination after 8 years; and those with >95% germination after 10 years.

Table 5. Range of germination in active collections of sorghum and chickpea conserved at Patancheru

Crop	Germination (%)				
	0-20	21-40	41-60	61-80	81-100
Sorghum	32	49	223	1,906	34,280
Chickpea	3	19	72	693	16,181

Activity 1.4.3: Seed health tests conducted to ensure conservation of healthy germplasm of mandate crops

Seed health testing to detect seed-associated microflora (S D Singh)

Maintenance and supply of healthy seed is the major responsibility of ICRISAT. Seed-associated microflora are the major cause of deterioration of seed health in field and in storage. Therefore, field inspection of seed crops and health tests of harvested seed are essential to insure healthy seed for storage and export.

Groundnut: Three methods - blotter, Potato Dextrose Agar (PDA) and Potato Carrot Agar (PCA) were compared for the expression of associated microflora on groundnut seed of 10 cultivars.

Larger number of fungi and bacteria were obtained on PCA than on PDA and blotter. This medium also restricted growth of fast growing storage fungi like *Aspergillus* and *Penicillium* which, in turn, helped expression of other pathogens. The medium also induced development of teleomorphs and perennating bodies. Therefore, PCA method will now be used for testing groundnut seed health.

Control of *Sclerotium rolfsii* infection in groundnut seed (S D Singh)

Seed treatment with two bacterial cultures (*Pseudomonas fluorescence* and *Ochrobactrum anthropi*) applied at 16.6 x 106 bacterial cells seed^{-1}, successfully controlled *Sclerotium rolfsii* infection in groundnut seed. However, all seed-borne fungi of groundnut were successfully controlled when these cultures were mixed with Thiram, showing a clear synergistic effect.

In Chickpea only one accession ICC 5978, out of the 378 tested for seed health, was found free of all fungal infection, and seven others had <10% fungal infection. *Aspergillus niger*, *A. flavus* and species of *Fusarium*, *Cladosporium* and *Alternaria* were the common fungi that were found associated with the seed.

Field evaluation of crops for obtaining disease-free seed for storage and export (S D Singh)

Groundnut: An effective method of testing of groundnut seed health is now available. Bacterium-Thiram combination can control all seed-borne microflora from groundnut seed. The synergistic effect is significant and we should consider using this method for treating all imported seed and also to use this method as routine method of treating all groundnut seed for sowing at ICRISAT to eliminate seed-carried inoculum. The treatment has no adverse effect on seed. Keeping in view that about 10% of groundnut samples are infected with *S. rolfsii* and *Rhizoctoni bataticola*, routine seed treatment will reduce inoculum in addition to the soil treatment.

Chickpea: Heavy infection of all chickpea samples particularly with storage fungi suggests that we should develop alternative methods of producing chickpea seed.

Biological control of soil-borne diseases of chickpea (linked to Belgian Project) (S D Singh)

Wilt (*F. oxysporum* f. sp. *cicer)* (FOC), collar rot (*S. rolfsii*), and dry root rot (*R. bataticola*) are economically important diseases of chickpea. Resistance to chickpea wilt, though available, is becoming ineffective (e.g. ICVV2 has become susceptible). Cultivars resistant to collar rot and dry root rot are not yet available. Therefore, to supplement genetic resistance to wilt and to manage dry root rot and collar rot alternative control measures are needed. Use of fungi and/or bacteria provides one such alternative. Six fungal cultures; *A. niger* (2), *A. flavus* (2), *A. ustus* (1), *A. versicolor* (1)) and 25 bacterial cultures, isolated from groundnut field/chickpea seed were tested for their *in vitro* antagonistic activities against FOC, *S. rolfsii*, and *R. bataticola* and also against pigeonpea wilt pathogen *F. udum* using dual culture technique on PDA at 25±1°C. In *in vitro* test *Aspergillus sp.* showed some antagonistic activity against *R. bataticola* and *F. udum* but not against FOC and *S. rolfsii*. Among the 25 bacterial cultures, two cultures CP82 (*P. fluoresence*) and CP 5-4 (*O. anthropi*) showed very high antagonistic activities (>2 cm inhibition zone) for all the four test pathogens. In *in vivo* test the two bacterial cultures were

tested for their ability to control collar rot under heavily infested pots. In two consecutive tests, the two cultures (applied as liquid or seed treatment at 16.6 x 106 bacterial cells seed^{-1}) gave 30-40% reduction in collar rot incidence. However, in two subsequent tests, 30-40% control was obtained only when the cultures were mixed with Thiram showing the synergistic effect. Similar synergistic effect was obtained in a field experiment where collar rot incidence was reduced from 29 to <8%. Final results are awaited from the two overlapping field experiments. The two bacterial cultures appear to have potential for the control of collar rot disease in chickpea. The synergism between Thiram and the bacterial cultures is a significant finding and is worth pursuing.

Objective 1.5: Distribution of germplasm to scientists in ICRISAT and NARS for utilization in crop improvement

Rationale: Distribution of germplasm is fundamental to ICRISAT's mission of increasing crop productivity and food security. International attitudes towards germplasm have changed dramatically in recent years and ICRISAT's germplasm distribution policies have been revised to reflect these changes. The germplasm of the mandate crops continues to be freely available to all bona fide users along with information in accordance with the internationally agreed procedures for germplasm movement and exchange. Germplasm accessions are selected according to the requirement of users by querying the crop databases. MTAs are obtained and seed samples taken out from the genebank are carefully packed and dispatched along with passport and other requested information. Seed samples meant for export are sent to Plant Quarantine Unit for exit quarantine certification. Details of seed dispatch are entered into distribution databases and feedback on the utilization of germplasm is obtained from the users.

Activity 1.5.1: Germplasm distributed to scientists in ICRISAT and NARS

Distribution of germplasm from the Genebank at Patancheru (N Kameswara Rao, P J Bramel-Cox, L J Reddy and H D Upadhyaya)

During 1998 and 1999, a total of 18,256 seed samples of the five ICRISAT mandate crops and six small millets were distributed in 319 consignments from the genebank to the users in 40 countries (Table 6). In addition to this, a total of 16,658 germplasm seed samples were also distributed within ICRISAT, which included 5035 sorghum, 1603 pearl millet, 9399 chickpea, and 1004 pigeonpea and 6704 groundnut germplasm accessions.

Table 6. Germplasm distributed from 1.1.1998 to 29.11.1999

Country	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Small millets	Total
Austria					20		20
Bangladesh	34		77	40			151
Belgium	40		1				41
Cambodia	5		5	5	5	5	25
Canada	71	396	25			5	497
China	6						6
Egypt	219						219
France	290	10					300
Germany	3		1				4
Ghana	8	6		5		4	23
India	4062	1062	3337	1211	2963	438	13073
Indonesia				5	2		7
Iran						30	30
Israel			209				209
Italy	10	10	10	10	11	10	61
Japan	9	16	3	12	3	21	64
Kenya	8			13			21
Malawi				3	1502		1505
Mexico			104				104
Myanmar			4				4
Nicaragua				48			48
Niger	15				461		476
Nigeria	20						20
Pakistan	15	25	8				48
Philippines					29		29
Puerto Rico				98			98
South Africa						20	20
Spain			18		20	20	58
Sri Lanka	20						20
Sudan	80	19					99
Thailand	37				13	20	70
Trinidad	15						15
Tunisia		9					9
Turkey			230				230
UAE				25			25
UK	15	59	4	51	25		154
Ukraine			243				243
USA				3			3
Yemen	13	60					73
Yugoslavia	154						154
Total	5149	1672	4279	1529	5054	573	18256

Distribution of germplasm form SEA (A B Obilana)

A total of 1698 kg of 228 germplasm lines was provided to National Agricultural Research Systems (NARS), Non-Governmental Organizations (NGOs), universities, and processing industries in Botswana, Mozambique, Namibia, South Africa, Tanzania, and Zimbabwe against signed Material Transfer Agreements. Twenty five hybrids from seed companies in South Africa and Zimbabwe were accessed through collaboration with SEED Co, Zimbabwe for regional testing. To compliment and diversify the genetic base of sorghum and pearl millet cultivars developed in the East Africa region by ICRISAT, some 322 selected germplasm from South African Development Community (SADC), new lines, hybrid parents and hybrids, were sent to Nairobi from Bulawayo. These are being used in adaptive testing and crossing programs for the semi-arid drought-prone, and humid Lake Zone areas. About 100 kg breeder seed of pearl millet

variety ICMV 221 was made available, on request and at a cost, to GTZ/IFSP, an NGO in Mwingi District of Kenya through the national coordinated program.

Objective 1.6: Documentation of germplasm accessions and development and maintenance of germplasm assembly, inventory and distribution databases for genebank management, analysis and impact assessment

Rationale: The value of germplasm accessions increases, as more information is available about its attributes. From the moment it is collected, a germplasm accession is documented in great detail. This information includes the precise origin, the botanical classification, its characteristics, results of evaluation for agronomic and stress resistance traits, its placement in various types of storage, seed quantity and viability, distribution, etc. The collection of this information and its maintenance is key to the use of the accession. The information can also be used for analysis of germplasm use and for assessing the impact of germplasm collections. To make information on large collections of many thousands of accessions available, its systematic organization in databases that can be searched by users is required. The management of the information on the germplasm accessions requires the use of sophisticated database management techniques.

Activity 1.6.1: Genebank operations and procedures manual published

Manual of genebank operations and procedures (N Kameswara Rao and P J Bramel-Cox)

The maintenance of the *ex situ* collections requires the use of open and transparent procedures, which can be reviewed from time to time to insure the safety and genetic integrity of the collections and adherence to international standards and policies. This documentation can also be used to train NARS on the appropriate procedures to be used in conservation of these crops. The first draft of the ICRISAT Genebank Operations and Procedures Manual was written, documenting the history of the collections, procedures for germplasm acquisition, maintenance, documentation, conservation and distribution. Existing procedures were reviewed and revised to maintain the collections according to international standards. A taxonomic key for the identification of wild species of the mandate crops has been included in the manual.

Activity 1.6.2: Centralized Genebank Information System installed and networking done to share information and provide online search facility of germplasm databases to users across institute

Genebank Information System (V Mahalakshmi)

ICRISAT holds more than 113,000 accession of sorghum, pearl millet, small millets, groundnut, chickpea, and pigeonpea. The genebank operations span from collection and conservation of germplasm to its distribution. The need to adhere to international standards of germplasm conservation and ensure transparency requires that these operations are made online. This will also help in automating the routine operations of the genebank in a work-flow system and in efficient and timely dissemination of information. The online genebank management system, developed in Visual Basic™ 6.0 with SQL Server™ 7.0 as the backend, is structured to query the available information. It will alert the genebank curator for regeneration when either quantity or quality of seed falls below the critical level and facilitates query based germplasm selection to meet seed requests. Operations such as Material Transfer Agreements, and labels, etc. are also automated. The program has been tested and deployed for use.

Sorghum seed dispatches database (Belum V S Reddy)

In sorghum, seed supplies lists were being maintained by individual scientists at projects level prior to 1986. This used to pose problems in report writing because the data could not be retrieved easily. So, efforts were initiated to maintain details of seed supplies in databases in ASCII text format from 1986 onwards in VAX system. VAX-BASIC package was developed to retrieve the information. Since the VAX system was phased out for operational reasons, a need was felt to update, transfer the databases, and place them in a more user friendly environment. Accordingly, the databases of seed supplies were converted into MS ACCESS™ format and a retrieval package is also developed using Visual Basic™ format. Data on the seed supplies were updated up to October, 1999 with the following information: 1) Description of materials, 2) nature of materials (bred or landrace), 3) classes of materials (A/B-lines, R-lines, varieties, etc.), 4) number of samples, 5) date of dispatch, 6) consignee name, 7) consignee location, 8) consignee country, 9) sector (public/private), and 10) purpose of dispatch.

Activity 1.6.3: Inventory databases developed for germplasm collections and breeding lines

Inventory of germplasm collections at Patancheru (N Kameswara Rao)

The genebank maintains databases that assist in their day-to-day management. In particular these databases contain information on the status of seed being conserved, its viability over time, location in genebank and seed quantity. They provide precise information on seed stocks at all time simplify management decisions on rejuvenation of accessions, etc. For the ICRISAT genebank, information of this type that is stored is less than optimal. We developed a standard list of descriptors to document the inventory information on mandate crops. The existing seed quantity, season of harvest, 100 seed weight, location in genebank, status of the collection and

percentage germination were recorded for the active collections consisting of 36,729 sorghum, 17,250 chickpea, 13,202 pigeonpea and 20,450 pearl millet accessions.

Germplasm collections at African locations (A B Obilana)

Cataloguing and viability testing of over 25,000 germplasm accessions in the SMIP genebank at Matopos is in progress. Six accessions with exceptional long-term viability (100% germination after 15 years of storage) have been identified, and will be shared with national breeding programs to improve field germination in new cultivars. A sorghum working collection has been identified and catalogued. The description and listing of 1452 enhanced germplasm including breeding lines, hybrids and hybrid parents, and 27 improved cultivars released by NARS in the region, have been completed and submitted for publication by ICRISAT. In Nairobi, viability testing and documentation of 556 sorghum germplasm accessions, breeding lines and varieties/populations kept at Alupe; 3847 sorghum, 49 pearl millet and 561 finger millet accessions stored at Kiboko are continuing. Those materials with <60% germination would be rejuvenated.

Activity 1.6.4: Information on past evaluations of germplasm for pest and disease resistance and quality characters incorporated into Genebank Information System

Data on past evaluations of pigeonpea (L J Reddy)

Large amount of disease screening data on pigeonpea generated in the past at ICRISAT still needs to be incorporated in the ICRISAT database. Scanning of ICRISAT Legumes/Pulses Program Reports of last 17 years has resulted in availability of screening data on wilt (5407 records), sterility mosaic disease (7240 records) and Phytophthora blight (5176 records) and data entry is completed for 8000 records.

Data on screening for resistance to sorghum midge (H C Sharma)

Data on screening for resistance to sorghum midge has been tabulated for 1980 to 1990. This involved evaluation for resistance to sorghum midge at ICRISAT Center, Patancheru (1,449 lines), Dharwad (18,367), and Bhavanisagar (3,719). Data on evaluation between 1992-95 on germplasm accessions originating from eastern Africa for resistance to sorghum midge have also been summarized. Data on screening for resistance to sorghum head bug has also been entered for final analysis and tabulation. These data will be put in a format to be finally linked with sorghum germplasm database, to enhance utilization of the germplasm.

Data on past evaluations of pearl millet (P J Bramel-Cox)

In the past, a number of evaluations have been done of the ICRISAT pearl millet collections. Most of the data was only available for those lines identified as resistant and in the original raw data sets. The computerization of these records is important for fully documenting our knowledge of the collections. Thus, the screening results of 6400 accessions for four diseases were made available. The seed protein content was added to the records for 1334 accessions.

Activity 1.6.5: Second phase of SINGER database development and internet access completed

SINGER Phase II Workplan (N Kameswara Rao)

At the end of the first phase of the System-wide Information Network for Genetic Resources (SINGER) project, not all available data could be computerized and made available within the time frame for Phase I. Furthermore, the documented information could not be validated thoroughly, therefore the quality of data replicated for SINGER required further improvements. The hardware and software also needed upgrading in order to meet the increased needs for database management and dissemination of information on germplasm held by the center. The SINGER Secretariat in Rome approved a workplan costing $24,000 for SINGER Phase II. The funds were used to buy a new Server to host germplasm data, and additional workstations to strengthen the client-side capacity to undertake data entry, validation and compilation. The additional Server and computers will help ICRISAT meet the growing needs for germplasm documentation and enhance the quality and availability of the data on mandate crop's genetic resources. A new documentation lab has been established in Genetic Resources premises to accommodate the new equipment and facilitate centralized data handling.

Activity 1.6.6: Pedigree information of elite ICRISAT and NARS breeding lines and genetic map information entered into ICIS and linked to germplasm databases

International Crop Information System (ICIS) (V Mahalakshmi and Belum V S Reddy)

Knowledge is critical for development. The need to disseminate and share information with partners through Internet was recognized as a priority and crop based on-line information system for sorghum was developed as the maiden attempt. The details (pedigrees and evaluation data) of the varieties, hybrids and their parents (A/B-lines and R-lines) are made accessible through ICRISAT internet and intranet.

Objective 1.7: Safety duplication of germplasm collections under long-term conditions at Patancheru and other centers

Rationale: ICRISAT's agreement with FAO requires that all the designated germplasm is maintained in accordance with International Genebank Standards in respect of storage. This requires that germplasm accessions are stored at sub-zero temperatures, preferably at -18°C, with 3-7% seed moisture content. Currently only 40% of the total collection is stored under these conditions. Chapter 14G of Agenda 21 and ICRISAT agreement with FAO which places the germplasm collections under the auspices of FAO, requires all genebanks to duplicate collections of germplasm in order to ensure its safety. ICRISAT is therefore committed to ensure adequate long-term conservation of the collections and to their safety duplication in similar facilities in

other countries. Safety duplication in other countries involves identification of suitable host countries and institutions, which can and are willing to provide safe storage. A Memorandum of Understanding exist with ICARDA for safety duplication of chickpea germplasm and with National Bureau of Plant Genetic Resources / Indian Council of Agricultural Research) (NBPGR/ICAR) for pigeonpea germplasm. Under these agreements, we have already transferred 2000 chickpea and 2482 pigeonpea accessions, respectively.

Activity 1.7.1: MoU developed for off-site duplication of germplasm

A formal agreement for safety duplication of germplasm that meet the requirements under ICRISAT/FAO agreement is available only for the chickpea collection. The agreement with NBPGR for duplication of pigeonpea collection does not meet the requirement since the collection is held in India. Therefore, there is a need to reconsider the on-going arrangement in pigeonpea. A strategy needs to be developed to fully explore the various options and to find a cost effective, secure and long-term strategy for safety duplication of our mandate crops.

Duplication of ICRISAT mandate crops at other locations (P J Bramel-Cox)

Sorghum, groundnut and pearl millet germplasm databases of Plant Genetic Resources Conservation Unit (PGRCU), Griffin, USA and ICRISAT, Patancheru, were cross referenced to assess duplication. Over 20,000 sorghum, 5417 groundnut, and 788 pearl millet accessions were found to be in common between the two collections. A request was made to PGRCU for transfer of 886 sorghum accessions to fill gaps in the Rockefeller collection acquired by ICRISAT in 1975. The sorghum germplasm database from Bulawayo genebank was cross-referenced with ICRISAT sorghum germplasm and 4527 accessions were identified as duplicates. Similarly, though a caparison of the databases, we identified 547 duplicates in the sorghum collection held at Bamako, Mali.

Activity 1.7.2: Germplasm collections of ICRISAT mandate crops duplicated under long-term conditions at IAC

Long-term conservation of germplasm accessions at Patancheru (N Kameswara Rao, P J Bramel-Cox, L J Reddy and H D Upadhyaya)

The increased drying capacity, due to the addition of new seed drying facility and the availability of baseline viability and seed stock inventory data accelerated the movement of germplasm for long-term conservation. Thus, we processed 11,778 sorghum and 1834 chickpea germplasm accessions with >90% viability and sufficient seed stocks from medium-term storage. About 80 g of sorghum and 200 g of chickpea seed samples drawn from medium-term storage were dried to 6-7% moisture content in a drying room maintained at 15°C and 15% RH. They were vacuum-sealed in laminated aluminum foil packets and transferred to long-term storage at -20°C. In addition, 128 sorghum, 1265 chickpea, 69 pigeonpea and 554 groundnut accessions grown for regeneration and other trials were processed for long-term conservation.

Activity 1.7.3: Germplasm collections of ICRISAT mandate crops duplicated in other countries

Off-site duplication of chickpea and pigeonpea germplasm (N Kameswara Rao, H D Upadhyaya, L J Reddy)

During 1998-99, we prepared 1084 chickpea accessions for safety duplication. These accessions were identified from the material grown for regeneration and other trials. About 300 seeds per accession with >85% viability were dried at 15°C and 15% RH and vacuum packed in aluminum foil envelopes. About 120 g of 43 pigeonpea accessions were similarly processed for transfer to NBPGR genebank, India. The chickpea samples will be exported to ICARDA after obtaining special permission, bypassing the routine quarantine examination. The pigeonpea samples will be transferred to NBPGR in year 2000, along with 400 other accessions currently being regenerated. During 1998, we repatriated 250 accessions each of sorghum and chickpea to NBPGR, New Delhi. Another set of 1000 chickpea accessions is currently being regenerated at ICRISAT for repatriation to NBPGR.

Objective 1.8: Research on germplasm collections to evolve safe and cost-effective strategies for conservation

Rationale: ICRISAT mandate crops produce orthodox seeds, which remain viable for extended periods at low temperatures. Therefore they are well suited for *ex situ* conservation. The efficiency of the conservation system however depends upon using appropriate rejuvenation and storage procedures. The rejuvenation procedure should adequately maintain the genetic integrity of the collected germplasm. Similarly, storage environment that maximizes seed longevity clearly contributes to optimizing the efficiency of genebanks. The current practices and assumptions in the secure conservation of these crops needs to be investigated to both insure their adequacy and to research safer alternatives. While there has been widespread interest in collecting and conserving genetic diversity, very little effort has been made to understand the factors that shape the formation and diversity of local landrace populations. Understanding these factors is critical when developing strategies to improve the productivity of framer's traditional varieties and to develop appropriate *in situ* strategies for conservation of agricultural biodiversity.

Activity 1.8.1: Descriptor lists developed for characterization of wild species

Descriptors for *Pennisetum* species (P J Bramel-Cox)

ICRISAT genebank hold about 750 accessions of 24 species of *Pennisetum* and related genera. Some of these are reported to be excellent sources of resistance to biotic and abiotic stresses in addition to their fodder value. However, non-availability of characterization data limits the use of these species in crop improvement. To date, no studies have been conducted to assess the diversity within and among these species. The first step to enhance the utilization of these

species is systematic characterization and a set of descriptor for 64 traits was developed for this purpose.

Activity 1.8.2: Factors affecting seed quality and longevity studied and improved strategies developed for *ex situ* conservation of mandate crops

Effect of seed drying methods on longevity of groundnut (L J Reddy)

Effective seed drying procedures need to be developed for enhancing the seed viability and seed health of groundnut. Four drying methods, 1) shade drying of pods for six days immediately after harvest, 2) windrow drying of whole plants in the field for 2 days followed by shade drying of detached pods for 4 days, 3) windrow drying of whole plants in the field for 6 days, and 4) field drying for 6 days using DOR method (drying of whole plants in heaps in such a way that the pods are not directly exposed to sunlight) were tried on 3 virginia groundnut varieties, ICGS 76, M 13, and Kadiri-3 grown during the 1997-98 postrainy season. Initial moisture content in all the samples was determined before transferring the pods to short term storage conditions (18-20^{0} C temperature; 30-35% RH) on the seventh day. Moisture content, viability, and pest incidence of the seeds were determined on all the samples at 6, 12, and 18 months after storage. The samples drawn at all the three different storage periods, under the first three drying treatments did not differ much with regard to the mean percentage germination across the 3 genotypes, which ranged from 93-100%. However, under DOR drying method, all the 3 genotypes' samples drawn at 6, 12, and 18 months storage showed 100% seed germination. Similarly, the bruchid damage was negligible in the DOR method (0.0 - 0.3%), whereas the mean damage for the first 3 drying methods, bruchid damage ranged from 0.56-83.8%. A significant correlation between seed moisture content and bruchid damage was evident at the 6 months storage (r = 0.90**), 12 months (r = 0.84**), and on the combined data from 6-18 months storage (r: 0.94**). Of the 4 different methods of seed drying tried, DOR method was superior over the other 3 methods with regard to maintaining the seed viability of the post-rainy season harvested groundnut.

Activity 1.8.3: Secure regeneration procedures established for germplasm of mandate crops

Floral biology of low seed producing Arachis species (L J Reddy)

Pod setting has been observed to be very poor in some *Arachis* species. We studied the floral morphology of 54 accessions belonging to four different sections of *Arachis* with low seed production, using two control cultivars (TMV 2 and M 13). In all the wild species accessions studied, the anthers were far below the stigmatic surface and the distance between the level of anthers and stigmata is much wider than that of cultivated species. In the cultivated varieties, the level of anthers is slightly higher than that of stigma, thus the latter is fully surrounded by the anthers ensuring better pollen deposition on the stigma. In the wild species accessions, the stylar hairs were long and dense compared to the sparse and short hairs in the cultivated varieties. The differences between stigma and anther levels and the long and dense stylar hairs in the wild

species are responsible for their low seed production. Hand tripping might help in increasing the pod formation.

Composition of trait-based pigeonpea genepools and their maintenance in isolation and their diversity assessment (L J Reddy)

There is a need to assess alternative ways to maintain pigeonpea for use in crop improvement programs in a safer and cost-effective way. The world germplasm collection was stratified into six groups based on their maturity, growth habit, utilization, and pest reaction. They are; i) early maturity determinate group (341 accessions), ii) early maturity indeterminate group (551 accessions), iii) medium and late maturing determinate group (188 accessions), iv) medium and late maturity indeterminate group (10,846 accessions), v) vegetable type group (810 accessions), and vi) disease and insect resistant group (664 accessions). These will be maintained for four seasons in isolation and their diversity assessed across the various number of multiplication generations along with the originally composed groups to see whether there is any genetic drift over generations.

Activity 1.8.4: *In vitro* methodology developed as an alternative conservation procedure for perennial *Cicer* and wild *Arachis* species

***In vitro* propagation of wild *Cicer* and *Arachis* species (Nalini Mallikarjuna)**

In vitro propagation procedures were developed for perennial *Cicer* species, *C. montbretii*, *C. macranthum* and *C. microphyllum*. Encapsulation and synthetic seed production techniques were standardized for *C. pinnatifidum* using immature embryos. The technique for encapsulation and synthetic seed production was standardized using immature embryos of *Arachis hypogaea*. Synthetic seeds of aborted immature embryos from the cross *A. hypogaea* x *A. stenosperma* conserved for 4 weeks at 7-8°C produced hybrid plants upon germination.

Activity 1.8.5: Ultra-dry seed storage experiment concluded and critical moisture level that extends storage time and reduces the requirement for regeneration determined

Optimal moisture content for storage of pearl millet and chickpea seeds (N Kameswara Rao)

Although temperature and seed moisture content are known to influence longevity, the optimum conditions that maximize seed longevity have been a subject of debate. For example, while Ellis et al. (1990) (Ann. Bot. 63: 601-611) reported that moisture contents in equilibrium with 10-12% relative humidity (RH) provide maximum longevity, Vertucci and Roos (1990) (Pl. Physiol. 94: 1019-1023) recommended equilibrating seeds between 19-27% RH to achieve the critical moisture level for long-term storage. They also reported that the RH that gives maximum longevity increases with decrease in temperature and that aging rates accelerate when seeds were dried at RHs, below the optimum. We designed an experiment to resolve the controversy on critical moisture content which has a consequence for both refrigerated and nonrefrigerated

storage of orthodox seeds. Pearl millet (cv. Sadore local) and chickpea (cvs. ICC 7228, ICC 15964) seeds were held over saturated salt solutions to adjust seed moisture contents from 2-14%. The seeds were hermetically sealed in laminated aluminum foil packets and stored at three temperatures 20°C, 35°C and 50°C along with a control at -20°C. The moisture content, rate of germination, radicle length, and percentage germination were measured before storage for each treatment. Subsequent assays for germination and vigor were made at regular intervals based on the seed moisture content and storage temperature. In pearl millet, at 50°C, seeds stored with >8% died after 64 weeks. While storage of seeds stored with 4 and 6% moisture content resulted in significant deterioration, seeds with 2% moisture content retained 92% germination even after 160 weeks of storage. At 35°C, storage with >10% moisture died within 160 weeks. However, germinability was >94% in seeds stored with 2, 4, 6 and 8% moisture, the differences among treatments being only marginal. At 20°C seeds stored with 14% moisture content lost germinability by 144 weeks of storage, while no deterioration occurred at other moisture contents. In chickpea, at 50°C, seeds stored with >8% survived for 20 weeks, while storage with 6% moisture content resulted in complete deterioration by 120 weeks. Significant deterioration occurred at 4 and 2% moisture contents in the kabuli cv. ICC 7228, but germinability was still high in the desi cv ICC 15964. At 35°C, seeds stored with >10% moisture died within 60 weeks in the kabuli cultivar and after 120 weeks in the desi cultivar. Although no significant deterioration was observed in germinability of seeds stored at 8 and 6% moisture content, storage at lower moisture content (4% and 2%) accelerated seed deterioration. The rate of loss of viability was found to be high in the kabuli cultivar and in the driest (2%) treatment, more so in the kabuli cultivar. At 20°C, seeds of ICC 7228 stored with 12% moisture content started to deteriorate after 120 weeks. These data indicate that critical moisture content for storage varies with temperature and storage at very low moisture contents could accelerate seed deterioration.

Activity 1.8.6: Genetic base of mandate crops broadened for ready use in breeding programs

Diversification of pearl millet germplasm (F R Bidinger)

Accessing new pearl millet genetic diversity can be difficult for small NARS breeding programs because of cost of evaluation of large amounts of often poorly adapted germplasm. This activity will offer millet breeders globally the opportunity to evaluate new genetic variability, in their own environments, in the form of population diallel F1s, made from crosses of elite, global populations and varieties. F1s selected by collaborators will then be random-mated to produce targeted base populations for local exploitation. At the same time the activity is quantifying the basic characteristics and genetic variances in the parent populations/varieties to assess the relationships of these to their general and specific combining abilities. During 1998 and 1999 we a have introduced through Indian quarantine and multiplied seed of 50 elite breeding and landrace populations/varieties from both western and southern Africa, to complement a similar set of 36 Indian parents. All potential parents have been characterized (at Patancheru) for plant growth rate, biomass distribution, yield components and panicle characteristics (a total of 130 variables, both means and within-population variances, based on a 36 plant sample). The 1998 evaluation initially classified the Indian parents into three types: *Iniari* x Indian/ICRISAT material, African x Indian derived material (mainly at ICRISAT), and Rajasthan landrace and landrace-derived material. There were significant differences in growth rate among the three types of materials (ranging from 2.4 g/plant/day to 3.5 g/plant/day), with consequences for

biomass (178 to 260 g/plant) and grain yield (59 to 100 g/plant) and many of its components. Additional data on panicle characteristics, partitioning between main stem and tiller, dry matter distribution among plant parts, etc. are available to classify parental types.

Activity 1.8.7: Strategy for research on *in situ* conservation developed through partnerships with farmers, NGO and NARS

On-farm conservation of pearl millets in Rajasthan, India (E Weltzein, P J Bramel-Cox and A Christinck)

In western Rajasthan local landrace varieties are still widely used, and represent the majority of germplasm cultivated by farmers. In eastern and central Rajasthan, local landrace varieties have been largely replaced by modern varieties, largely hybrids. Thus in the two sub-regions very different issues are at stake, when considering to promote *in-situ* conservation. In eastern Rajasthan, were local landrace variety are threatened, the project has identified villages and individual farmers who strive to maintain specific local landrace varieties. Semi-structured interviews were used to better understand the farmers' motivations for maintaining specific varieties. In western Rajasthan, where landraces are still widely used we investigated farmers' practices for selection of seeds and their strategies for assuring conservation of their varieties even through extended drought periods. In eastern Rajasthan, four villages were identified that still produce seed of each one specific, famous landrace variety. Usually the varieties carry the names of the villages, which indicates that village communities co-operate in the maintenance, and possibly further development of a specific variety. A strategy to promote conservation of these varieties in their villages of origin was developed, based on integrating support to individuals, who are specifically keen, as well as community level support. Farmers in western Rajasthan near bigger market centers, and who own more and better land tend to use small quantities of seed from modern varieties to widen the adaptability of their seed stocks to include more productive, more fertile conditions. Since these farmers are most commonly the main local seed providers, farmers who primarily cultivate relatively less fertile land perceive the availability of pure landrace seed as a serious problem. On a small scale a project was developed in collaboration with NGOs to support a local effort at identifying good sources of local variety seed, and to develop a village level plan for seed production and distribution. Another strategy, that is supported by the Rajasthan pearl millet breeders who work for eastern Rajasthan, is a strong commitment to using local landrace germplasm as a base material for the development of improved varieties, that maintain good adaptation to the more unfavorable growing conditions for pearl millet in this state.

On-farm conservation of sorghum in Mali (E Weltzein)

The management of sorghum genetic resources by farmers in Mali appears to be very dynamic. Farmers frequently adapt and adopt new varieties and abandon others. Indications are that in the cotton zone of Mali, were agriculture is rapidly intensifying, maize is rapidly replacing sorghum. Semi-structured interviews with farmers who are conducting variety evaluations are helping us to identify major causes for potential genetic erosion in the major sorghum growing regions. The role of sorghum in the cotton zone of Mali is changing, i.e. delayed sowings are frequent, and crop husbandry is more often done after tat of the cash crops. However, sorghum is also benefiting from the increased levels of soil fertility resulting from inputs given to the cotton crop.

Sorghum is the preferred food in these areas, and it generally has better storage characteristics than maize. A strategy is being developed in collaboration with Malian breeders, genetic resources specialists and physiologists to introgress traits conferring enhanced yield potential and responsiveness to increased fertility into a range of local varieties. Selection and testing will be decentralized, and will involve farmers' at several stages in the variety development process.

Objective 1.9: Define core collections of mandate crops based on available characterization and evaluation data

Rationale: Germplasm collections often comprise many thousands of distinct accessions and their sheer size presents problems for both conservation and utilization. Core collections identify a much reduced number of accessions that represent the diversity of the entire collection and serve as an entry point to the whole collection. Identification of core collections also simplifies the process of multiplication and distribution to potential users by substantially reducing the number of accessions that need to be maintained in active collections. Core collections can be formed on the basis of characterization information available on germplasm accessions, which can be used for multivariate analyses which cluster groups of similar accessions together.

Activity 1.9.1: Core collections of mandate crops established and validated based on characterization and evaluation data

Development of core collections of chickpea and groundnut (H D Upadhyaya)

For developing chickpea core collection we used 13 quantitative traits for which data was available on > 16 000 accessions. We stratified chickpea collection by the country of origin. The accessions from the small and adjacent countries with similar agro-climatic conditions were grouped together. The traits used were days to 50% flowering, plant height (cm), plant width (cm), days to maturity, number of basal and apical primary branches, number of basal and apical secondary and tertiary branches, number of pods per plant, seeds per pod, seed yield (kg ha^{-1}), and 100-seed weight (g). In case of groundnut we developed core collection from 14 310 accessions using 14 morphological descriptors traits. The traits were stem color, stem hair, branching pattern, leaf color, leaf shape, leaf hair, flower color, streak color, peg color, pod beak, pod constriction, pod reticulation, number of seeds per pod, and seed color pattern. The entire collection was stratified by country of origin in a botanical variety in groundnut. The accessions from smaller countries with similar agroclimatic conditions were grouped together. As these traits were measured on different scales, they were standardized using the range of trait in each group to eliminate scale differences. The standardized data was used for clustering by Ward's method using SAS program. From each cluster about 10% accessions were randomly selected for inclusion in the core subset. At least one accession was selected even from the clusters, which had less than 10 accessions. Using the above criteria, core collection consisting of 1956 accessions in chickpea and 1704 accessions in groundnut were selected. In chickpea, the mean, median, and standard deviation for the 13 traits used in the selection of core subset were similar for both core and entire collections. For the 11 of 13 traits, 83.7 to 100% variation range of entire collection was represented in the core collection. For basal and apical primary branches the range variation included was 62.3% and 72.5%, respectively, indicating that the core subset was

representative of entire collection. In groundnut, also the mean, median, and standard deviation for the 14 traits were similar in both the entire and core collections. The range of variation represented in the groundnut core subset was 100% of the entire collection for all the traits except for branching pattern for which 50% range was captured in the core. The Chi-square and Wilcoxon non-parametric rank-sum tests indicated the homogeneity of distribution between entire and core collections in both chickpea and groundnut core collection for most of the traits. Also, in the core collections, the phenotypic associations observed in the entire collection were preserved. This clearly suggested that the co-adapted gene complexes controlling these traits were adequately sampled in both chickpea and groundnut.

Development of core collections of sorghum (C Grenier and P J Bramel-Cox)

ICRISAT maintains a large *ex situ* collection of sorghum. A series of studies were established to compare various procedures to define a core collections and to compare sampling procedures to establish a core collection. An assessment was also made of the pattern of diversity maintained in the landrace collection and its adequacy. The comparison of the sampling strategy indicated the logarithmic sampling strategy was the best to represent the diversity in the collection. Three core collection procedures were compared for morph-agronomic characters and DNA level diversity using SSR markers. The three methods were a principal component maximum likelihood procedure (PC) using quantitative traits; hierarchical stratification based upon adaptation and race classification; and taxonomic knowledge based on experience with the collection. The comparison indicated that there are differences in the representation of the ICRISAT collection found in each core. The PC method resulted in the best representation of the landrace collection. This also would include all the various redundancies and gaps. When the cores were compared for their representation of species level diversity, the other two procedures were equally adequate to sample the species level diversity . This was particularly prevalent in the SSR level diversity assessment. To assess the adequacy of the sorghum landrace collection, an analysis of the pattern of diversity was done based on geographical and taxonomic classification. This assessment indicated that the collection maintained at ICRISAT was underrepresented for the bicolor race and for accessions from China. The assessment highlighted redundancies as well, especially in race Caudatum and Durra, and in germplasm acquired from East Africa and Indian Sub-continent.

Development of regional core collections in chickpeas (P J Bramel-Cox)

Many of the statistical procedures used to assess diversity or establish core sub-sets have been used on large, very diverse collections. The appropriateness of these techniques to establish regional core collections were assessed for the ICRISAT chickpea collection from the Indian Sub-continent. The two most appropriate cores were also assessed for morph-agronomic diversity and DNA level diversity using RAPD markers. The two best core sub-sets were both defined with a proportional sampling strategy with both the hierarchical stratification and principal component analysis. The two cores sub-sets were planted during the 1998 and 1999 rabi season. The accessions were planted in an unreplicated augmented design using three checks per block. The trials were analyzed to determine the impact of genotype by year on the seven qualitative and thirteen quantitative characters. The genotype by year interaction was found to effect the mean for traits but not the rankings. Thus the relationships between the traits and

accessions were not influenced by the differences in years. The comparison between the molecular level diversity using RAPD markers found 39 bands in Core 2 and 34 bands in Core 5.

Development of core collections in Pearl millet (P J Bramel-Cox)

Pearl millet is a highly cross pollinated species where the germplasm is conserved as individual accessions using a closed population breeding procedure. Characterization data has been collected for the 25,000 accessions based upon the mean for the various quantitative traits and the median for the qualitative traits. These traits are typically used to assess the diversity within a collection based upon the among accession diversity. The structure of the diversity with pearl millet has not been investigated to date. Thus the value of the among accessions estimates of diversity to establish core sub-sets is unknown. Thus the objective of this study was to define a core collection for pearl millet and then to evaluate the adequacy of the mean characterization data to assess diversity in pearl millet. A core collection of 504 accessions was defined using a hierarchical cluster analysis of Ward's minimum variance based on plant height, days to flower in rainy season, spike length, spike thickness, spike exertion, and 1000 grain weight. The original collection of 16,100 landrace accessions were reduced to 1600. The 504 accessions in the core were defined using the tree joining technique. A field evaluation was established in the post-rainy and rainy season of 1998/1999. The trial was planted in a modified augmented block design. The central sub-plot was assigned to a well adapted hybrid to determine the influence of environmental heterogeniety. Observations were taken on characterization traits based on 60 plants per plot. The analysis of the control plot indicated that there was little impact of the environment on the traits measured. The preliminary assessment of the means calculated with 5 versus 60 plants found significant differences in the means and rankings. Further analysis will be conducted.

Objective 1.10: Develop new tools to describe diversity in mandate crops and assess completeness of collections

Rationale: Biodiversity studies aim to describe the variation within a crop in relation to known parameters. These might be taxonomic, geographical, or other factors for which there are differences among germplasm accessions. The aim of these studies is to understand the variability found in the collections in ways that will help predict the performance and acceptability of particular germplasm accessions for use in specific situations. The availability of modern biotechnological tools particularly molecular markers provides an opportunity to characterize germplasm for traits like yield, days to flowering, resistance to pests and diseases, controlled by a number of genes interacting in complex ways.

Activity 1.10.1: Core collections of mandate crops refined based on molecular diversity

Use of molecular markers for diversity analysis in chickpea (Jagdish Kumar)

A major reason for slow progress of improvement in chickpea is its narrow genetic base. Diversity of parents for hybridization is generally based on geographic origin. Molecular

techniques can help identify sources based on genetic differences. The DNA extracted from Asian core and germplasm selected for various resistance traits from 10 countries was used for diversity analysis through RAPD markers. Using nearly 600 RAPD and operon primers we found 588 polymorphic bands on 35 germplasm accessions. We also studied diversity of about 220 germplasm accessions using three RAPD markers based on our selection from over 200 RAPD primers tested on chickpea germplasm and confirmed that RAPD primers show low polymorphism on chickpea. Geographic origin does not appear to always show genetic diversity. Other types of primers such as STMS that show increased polymorphism in chickpea are now available and will be used for further analysis.

Activity 1.10.2: Genetic diversity in germplasm collections assessed using molecular markers

Genetic diversity in germplasm collections assessed using molecular markers (M E Ferguson)

Co-dominant Polymerase Chain Reaction (PCR) based markers are required for efficient diversity assessment and for gene discovery in wild and cultivated species. Advantages of PCR based markers are the small quantities of DNA required for extraction and the potential high-throughput. A workplan was devised with specific objectives of determining an efficient PCR based extraction protocol and screening available Simple Sequence Repeats (SSR) and Sequence Tagged Microsatellites (STMS) markers from *A. hypogaea* and the genus *Stylosanthes* for amplification and polymorphism in wild *Arachis*. Three different variants of a CTAB based mini-prep extraction protocol were tested across a set of 10 *Arachis* species, together with extraction using Amersham's Nucleon extraction kit which purifies DNA via centrifugation through a resin. The quality of DNA from the kit was much higher than the CTAB-based method according to a quantification gel, although was worse according to spectrophotometer readings. Spectrophotometer readings were likely to have been influenced by DNA colour, a poor determinant of DNA quality. Experiments on CTAB based methods are continuing, but the extraction kit appears a good, relatively inexpensive option for wild species where polysaccharides and polyphenolics are a problem. Good quality DNA was successfully extracted from 14 day old wild *Arachis* seedlings. Thirty-five SSR and STMS primer sets have been obtained for screening purposes. In order to conserve maximum genetic variation it is important to have an understanding of the geographical distribution of variation, so that sites for future collection can be objectively prioritised. An initial objective under this milestone was to determine a 'core' set of wild *Arachis* species, which contained no duplicates or selections and had adequate passport data for determining latitudes and longitudes. A 'core' of 308 accessions has been identified from the wild *Arachis* database of 452 accessions. The latitudes and longitudes of the 'core' have been determined. A report on the current status of the wild *Arachis* collection at ICRISAT has from the above studies.

Assessment of variation in wild and cultivated species of pigeonpea (S Sivaramakrishnan)

Variations in chloroplast DNA (cpDNA) and mitochondrial DNA (mtDNA) have been used to study the diversity of cytoplasm in crop species. RFLP analysis of mtDNA is found to be useful for studying phylogenetic relationships within species. We have used this method to quantify the genetic diversity of wild and cultivated species of pigeonpea collected from various regions.

Genomic DNA was extracted from twenty-six accessions (22 *Cajanus* and 4 *Rhynchosia* species) of pigeonpea. DNA was digested with three restriction enzymes (*Eco*RI, *Eco*RV, and *Hind* III) and Southern blot hybridization was carried out with five maize mtDNA probes (*cox* I, *atp6*, *cox* II atp 9 and *atpα*). Polymorphic bands on the autoradiograph were scored and the similarity index data obtained was used to construct the dendrograms. All the twenty-six accessions showed highly polymorphic hybridization banding patterns with maize mtDNA probes. Cluster analysis of the hybridization data placed the twenty-six accessions into nine major groups. Four of the accessions in each of the *C. scarabaeoides*, and *C. platycarpus* species formed two groups and the single *C. volubilis* and *C. sericeus* accessions formed two separate groups by themselves. Other accessions belonging to *C. mollis*, *C. grandifolius*, and *C. rugosus* formed one group along with one accession of *C. acutifolius*, whereas *C. latisepalus* and two accessions of *C. acutifolius* formed another group. Among the cultivated species ICP 7119, ICP 7220, and ICP 2376 formed a separate group from those of ICPL 87 and WR 15.All the 4 species belonging to section *Rhyncosia* formed one major group with two subgroups. The results indicate the use of heterologous mtDNA probes in assessing the diversity in wild species and selected cultivars of pigeonpea using RFLP analysis

Activity 1.10.3: Completeness of germplasm collections assessed and genetic diversity mapped using GIS tools

Mapping the distribution of wild Arachis species in South America using GIS (L J Reddy)

Using the geographic coordinates of 1905 wild species collections in South America, distribution maps were constructed. Of the five countries where collections were made, Brazil comprises the widest diversity with seven sections and 58 species represented in its collections and Uruguay represents the least diversity with only two species.

Objective 1.11: Maintain and distribute microbial germplasm collections

Rationale: Collection of rhizobia, their maintenance and distribution have been regarded as an important support activity for those concerned with research on biological nitrogen fixation at ICRISAT. Initially, collection and maintenance of rhizobia of several legumes of interest in the semi-arid tropics were attempted. But this activity was subsequently restricted to ICRISAT's mandate legumes, chickpea, pigeonpea and groundnut. Thus, Rhizobium strains of mandate legumes that were isolated or received are being maintained and distributed by ICRISAT.

Activity 1.11.1: Collections of agriculturally beneficial microorganisms conserved, regenerated and distributed

Multiplication and distribution of rhizobia (O P Rupela)

ICRISAT has a large collection of the root-nodule bacteria of its mandate legumes and receives request for their supply. In 1999, (effective period June 1998 to May 1999), 131 units of

rhizobial strains or peat inoculants were supplied to 19 requesters from seven countries. In addition, 98 units of rhizobial inoculants were provided to ICRISAT scientists to support their field/greenhouse experiments. In addition, we spent some resources on evaluating two methods (Agar 'slope' and Agar 'stab' culture) for short-term storage of rhizobia. Thirty mL screw cap tubes (glass) were used for slope cultures and 5 mL plastic tubes for the stab cultures. The study involved five strains of groundnut, six of pigeonpea and seven of chickpea. At least three units of each of the 18 strains were prepared on 14 June 1998, using standard procedures, and stored in a refrigerator at 6°C. All the strains were purified and tested for nodule formation before starting the experiment. Survival of the strains was tested after about 54 weeks, using plate-culture method. In the set stored as 'slope', two of the 18 strains died and six were either associated with contaminants or were doubtful (as judged by culture characteristics) and required nodulation test. All the 18 cultures, except one (IC 4062 of pigeonpea) survived well and were pure when stored as 'Stab'. The stab culture seemed economical and more reliable short-term storage system for rhizobia than the slopes.

Plant Quarantine Activities

A. Export of pest-free seed of mandate crops, microbial and pest cultures, soil and plant material (S D Singh)

Seed: A total of 6952 samples (groundnut, 2665; pearl millet, 1600; chickpea, 1466; sorghum, 1014; pigeonpea 182; and minor millet 25) were tested for quarantine clearance and sent to 49 countries against 134 phytosanitary certificates. One hundred nineteen samples (1.71%) were detained. The largest detentions (7.6%) were in pigeonpea followed by sorghum and groundnut and the least detentions were in pearl millet (0.25%). There was no detention in minor millet. Seed-associated fungi were the major cause for detention. The largest number of fungi were found associated with chickpea and pigeonpea (7 fungi each) followed by groundnut (4 fungi). *Rhizoctonia bataticola*, *R. solani*, and *Macrophomina phaseolini* appeared to be the major cause of loss in seed viability in legume crops.

Other material: A total of 1456 samples (1284 pearl millet leaf samples to Netherlands, 13 dead insect cocoons to Kenya, 29 pearl millet and sorghum spikes to UK and 12 Rhizobia cultures to Sudan) were exported for various research purposes.

Domestic seed dispatches: A total of 14,500 seed samples of mandate crops under 323 consignments were dispatched. The largest seed dispatches were for sorghum (8570 samples in 123 consignments) followed by pearl millet (4885 samples in 92 consignments). The least seed dispatches were for chickpea (121 samples in 7 consignments).

The postcard acknowledgement system introduced in 1998, has been the most cheapest and effective system; we have so far received about 80% domestic acknowledgements this year.

B. Import of pest-free seeds of ICRISAT mandate crops, microbial and pest cultures, soil and plant material imported (S D Singh)

A total of 540 seed samples were imported during 1998-99. The largest imports were for sorghum (456 samples) followed by pearl millet (56) and chickpea (26). No pigeonpea and minor millet seeds were imported this year.

During grow-out tests in the PEQIA, fusarium wilt, sterility mosaic on pigeonpea, and maize stripe virus on sorghum were recorded. All the infected plants were uprooted and incinerated. Rhizoctonia sheath blight on sorghum and bud necrosis in groundnut were also noticed and these diseases were controlled by spraying with appropriate fungicide/insecticide. No control measures for diseases like zonate leaf spot and leaf blight were taken.

Import permits: We requested 11 permits from the NBPGR this year; as against 36 permits in 1998.

No exotic disease/pest was recorded in any crop grown in PEQIA this year. Also, no seed sample was detained by NBPGR this year.

C. Post-entry quarantine isolation area (PEQIA) management (S D Singh)

To reduce soil-borne diseases, and some weed problems in PEQIA fields, three steps were taken:

A 3-year crop rotation: The six fields were grouped into three blocks. All the sowing in 1999 will be done in fields E and F; in 2000 fields A and B, and in 2001 in fields C and D.

Solarization: This operation which began in 1998 will end in 2001, after solarizing each field for two consecutive years. An analysis of soil samples collected from pre-, and post-solarized B and C fields showed that none of the 15 fungi that were present prior to solarization could survive solarization, except *Fusarium udum* in one of the samples. The operations will reduce soil-borne inocula of all the soil-borne fungi particularly downy mildew oospores.

Green manuring: All the fields were sown to *Sesbania* sp. during the rainy season and this will be a common practice in future. This operation will reduce some weed problem and increase fertility. All the grow-out tests are planned from October - April months in future.

RESEARCH AREA II

Research Area II: New tools: adapt and apply new science methods to SAT crop improvement

Goals

More effective and durable resistance to biotic and abiotic stresses will increase and stabilize production of the food crops of the poor. Improved nutritional quality will benefit human health and household food security. Improved ability to manipulate genes determining nutritional quality for both humans and livestock will contribute to greater household food security and economic gains.

Intermediate Goals

Development and adaptation of biotechnology tools to effectively exploit germplasm resources and provide efficient technologies for the genetic enhancement of ICRISAT crops.

Purposes

The rapid pace of global innovation in biotechnology provides enormous opportunities for breakthroughs in improvement of the food crops of the SAT. ICRISAT has a unique comparative advantage as a bridge between advanced research organizations and the NARS of the SAT, helping its partners to identify, adapt, and apply these tools to improve the neglected crops of the poor. Acting in concert with advanced institutions and NARS partners, this Project leverages the continuing rapid advances in the field of molecular marker-based and genome mapping research to better conserve and improve the food crops of the SAT poor. This Project serves the following specific purposes:

- Improve the quantification and analysis of genetic diversity for new trait identification and biodiversity conservation
- Increase the targeted, efficient, and effective transfer of genes for important traits
- Enhance NARS partners skills to use these new tools and methods

Outputs

- Practical, effective gene transformation and cell/tissue regeneration protocols for ICRISAT crops
- Genetic maps and mapping systems with increasing genome coverage and saturation over time
- Cost-effective marker-assisted selection procedures for chickpea, pigeonpea, groundnut, sorghum, and pearl millet
- Identification and isolation of novel genes for deployment through conventional and transgenic approaches
- Identification of pathogen races prevalent in the crop growing areas of SAT
- More durable resistance to variable pathogen populations

Objective 2.1: Develop anther and pollen culture techniques for ICRISAT crops

Rationale: Doubled haploid production is a useful intermediary biotechnological tool for plant breeders and geneticists as it can quicken the development of inbred lines and facilitate several basic studies. There are no suitable protocols for *in vitro* doubled haploid production in pearl millet [*Pennisetum glaucum (L.) R. Br.*], and therefore it was important to develop the necessary protocols at ICRISAT.

Activity 2.1m: Development of pearl millet doubled haploids

Methods for developing pearl millet doubled haploids (N Seetharama)

The results from the study of physical, chemical, and physiological and genotypic factors affecting in *vitro* development of dihaploids from different explants (anthers, isolated microspores, spikelets and dissected ovary) are presented below:

Suitable methods were developed for *in vitro* culture of different types of explants following appropriate pretreatment of harvested panicles. Media and growth conditions were standardized with each type of explants (see below), and maximum success was obtained only with spikelet culture. This method now provides a working protocol for development of doubled haploids in pearl millet. This technology was transferred to both public and private sectors.

- *Microspores:* Microspore-derived embryos were obtained at a frequency of 8.3%, but fully developed plants were albinos. Microspore embryogenesis was confirmed with extensive light, electron, and fluorescence microscopy studies.
- *Anthers:* Sterile androgenic plants were regenerated at a frequency of 14 -18 % depending on the genotype in our protocol. Again plantlets were albinos, but with a few exceptions (e.g., only green stunted shoots with profound rooting observed in 7042 DMR).
- *Isolated ovaries*: This type of explant failed to respond under *in vitro* conditions.
- *Spikelets:* From spikelet cultures, fertile (gynogenic) plants were regenerated at a frequency of 6.7%. Out of 21 regenerants, 97 % were green plants. Cytological analysis of gynogenic haploid (sterile) and doubled haploid (fertile) plants confirmed their ploidy levels. Further, molecular analysis of the doubled haploids using RFLP and RAPD techniques confirmed the homozygous status (absence of allelic segregation among progeny) of the fertile regenerants. Uniformity and homozygosity within doubled haploid populations were further confirmed by morphological evaluations under greenhouse and field conditions.

Objective 2.3: Develop and apply transformation techniques for production of transgenic plants of ICRISAT crops

Rationale: It is essential to develop efficient tissue culture methods for the genetic transformation of sorghum, chickpea, groundnut and pigeonpea to introduce novel genes for enhanced resistance to various biotic constraints. Regeneration after transformation appears to be

genotype specific and the techniques are being refined to address this problem. In our search for genotype-independent protocols, we constantly improve existing tissue culture protocols or develop new ones. Regeneration following genetic transformation needs to be specifically addressed, as this is a major limiting factor for producing transgenics. Some of the genes targeted for genetic transformation include those for resistance to insect pests *viz Bt*., protease inhibitor (SBTI), lectin, etc., fungal pathogens *viz*. chitinase. Attempts are being made to improve the nutritional quality of pigeonpea by increasing the essential amino acids like lysine and threonine. Bioassays with artificial diet are carried out to test the efficacy of various insecticidal proteins before the transgenics are made. Some of the transgenic tobacco plants containing the insecticidal proteins are used as model systems for evaluating their efficacy on insect pests. Most of the present work is now confined to the laboratories and specified greenhouses and these will be expanded later to the field only after obtaining the necessary clearance from the Bio-safety committee.

Activity 2.3c: Develop transformation technologies for the production of transgenic chickpea

Transformation technologies for chickpea (K K Sharma)

Seedling explants (embryo axis and leaflets) from mature seeds of chickpea cultivars C 235 and ICCV 2 were used to optimize shoot regeneration in tissue culture. Genetic transformation was carried out by using the biolistic device and plasmid DNA carrying marker genes like *NPT II*, *HPT* and *GUS*.

Under optimal conditions, embryo axis explants either produce multiple shoot buds or somatic embryos. Though only a small proportion (<1%) of the somatic embryoids undergo spontaneous maturation (it has so far not been possible to obtain higher frequencies of embryo maturation) large number of shoots can be obtained from embryo axis-derived shoot buds. However, these multiple shoots are formed from both adventitious as well as axillary meristems. The system has been successfully used for biolistic-mediated transfer of marker genes. However, most of the shoots are chimeric that need to be selected on antibiotics over several passages (3 - 4 months). While most of these shoots can be elongated, the rooting frequencies are low (50%) and transplantation to the glasshouse has not yet been successful. Work is underway to further optimize various components (shoot induction, elongation, rooting, and transplantation) of this system for routine applications in genetic transformation.

Chickpea tissue culture has remained problematic due to the possible recalcitrant nature and genotypic variability. Recent success with the embryo axis explants where multiple shoots buds can be produced using the phytohormone thiadizuron (TDZ) is very promising in the utilization of this system for transformation studies.

Activity 2.3g: Develop transformation technologies for groundnut and apply them to improve resistance to viruses, defoliating insect pests, and nematodes

Transformation technologies for groundnut (K K Sharma)

Explants (cotyledons and embryo axes from mature presoaked seeds and leaflets from 1-3 days-old germinating seedlings) of cvs. JL 24 and ICGS 44 were used in tissue culture and transformation experiments. Binary vectors carrying marker and coat protein genes of Indian peanut clump virus (IPCV) in *Agrobacterium tumefaciens* strain C58 were used for in vitro transformation.

Tissue culture methods have been optimized to obtain high frequency (80 - 90%) shoot regeneration from cotyledon and leaflet explants and somatic embryogenesis from leaflet and embryo axis explants of groundnut. These protocols have been optimized for obtaining transgenic plants of groundnut from cotyledon and leaflet explants by using *Agrobacterium tumefaciens*-based binary plasmids carrying genes of interest. The method has been successfully utilized to obtain a large number of independently transformed transgenic plants with marker genes (*NPT II* and *GUS*) and coat protein gene of IPCV (IPCVcp). The putative transformants (in T_0 to T_3 generations) growing in the containment glasshouse are being characterized at the molecular and genetic level. In general it takes about 6-9 months to successfully transfer the plantlets to the glasshouse with over 90% success.

The development of tissue culture and transformation methods for groundnut is almost complete and is generally applicable to several Spanish type genotypes tested. A large number of putative transformants carrying the coat protein gene of Indian peanut clump virus (IPCVcp) have been generated and transferred to the glasshouse where over 40% of the putative transgenic plants have tested positive for the introduced genes. This is the highest frequency achieved so far with groundnut.

Activity 2.3p: Develop transformation technologies for pigeonpea to produce transgenic plants with improved resistance to *Helicoverpa armigera* and other insect pests, and enhanced lysine and threonine levels

Transformation technologies for pigeonpea (K K Sharma and H C Sharma)

Explants from *in vitro* germinated seeds of pigeonpea cultivars ICPL 87, ICPL 88039 and ICPL 87119 were used to optimize tissue culture regeneration protocols. Genetic transformation was carried out by using either the biolistic device (Bio-Rad, USA) or *Agrobacterium tumefaciens* strain C58 carrying marker genes (*NPT II*, *HPT*, *GUS*) or insecticidal genes like *Bt Cry IA (b)* and soybean trypsin inhibitor (*SBTI*) on binary vectors.

The tissue culture system involving a unique region present near the axillary buds of two week-old seedlings have been optimized to produce a large number of adventitious shoot buds from almost

100% of the explants. These explants can be easily transformed with both biolistics and *Agrobacterium*-mediated genetic transformation with the recovery of high frequency of transgenic shoots. So far, this system has been tested with constructs carrying marker genes and two different insecticidal genes, viz., Bt Cry IA (b) and SBTI. The putative transformants grown under the selection pressure of kanamycin or hygromycin have shown positive histochemical reactions for *GUS* gene. These will be further characterized once the plants are transferred to the glasshouse in 3-4 months. An amplicon of Bowman-Birk type trypsin inhibitor from pigeonpea was cloned by PCR.

Transgenic tobacco plants containing *Bt Cry IA(b)* and *SBTI* genes have been generated and are being used to optimize insect bioassays to test their efficacy against important insect pests of ICRISAT crops. Preliminary results with these plants and recombinant SBTI protein produced in *E. coli* have shown their anti-feedant and antibiosis effects on *Helicoverpa* and *Spodoptera* larvae.

An efficient system for the tissue culture regeneration of pigeonpea has been developed. A transformation protocol for pigeonpea to incorporate novel genes is in the final stages of development. Insect bioassays with tobacco transgenics having *Bt* or SBTI genes have shown the potential of the available *Bt* and SBTI genes for insect control.

Activity 2.3s: Develop transformation protocols for sorghum (and pearl millet)

Protocols for tissue culture and genetic transformation of sorghum developed (N Seetharama)

In vitro plant regeneration from different explants was tried using different media, and genotypes. Genetic transformation technology is being perfected using particle-inflow gun (PIG) and a gene construct containing both GUS and the *basta* resistance genes.

Tissue culture: A method was developed to isolate and culture mesophyll protoplasts of sorghum from which plants were regenerated. We achieved a yield of 6.45×10^5 protoplasts per gram of young leaf tissue with a viability of >95% in two cultivated genotypes. Micro-colony formation was observed within 60 - 65 days with a plating efficiency of 4.8%. A simple procedure for establishing cell suspension cultures of sorghum was established using *S. dimidiatum* as a model system. The ability of fine cell clusters to develop into somatic embryos, to regenerate plantlets in the liquid medium and to yield protoplasts makes the system highly efficient. We were able to demonstrate even direct regeneration of normal plants from plated cell clusters. With the above two protocols, one can attempt to transfer insect resistance from wild sorghums to cultivated types using an asymmetric protoplast fusion technique, as conventional inter-specific crosses are not possible because of pre-fertilization reproductive barriers.

Plant regeneration protocols based on both scutellum (from developing seed) and inflorescence were developed. Further, a new protocol has been developed to generate sorghum plants rapidly from the shoot tip cultures, thus dispensing the need to grow plants for few months to harvest developing panicles or seeds.

Genetic transformation: The effectiveness of transformation varied with the particular explant and genotype. In contrast to shoot tip derived calli and the calli derived from immature embryo, immature inflorescence-derived calli were effective in terms of both regeneration and transformation frequency. Of the three sorghum genotypes (M 35-1, BTx 623 and 296B), M 35-1 was found to give better *in vitro* response. So currently we are concentrating on the use of immature inflorescence-derived callus of M 35-1 for transformation following an already established protocol for complete plant regeneration from the transformed calli.

While establishing the kill curve for control (non-transformed) explants using the herbicide basta, it was found that 3 mg l^{-1} was sufficient to kill all explants. However, in the case of transformed calli, basta interfered with the process of regeneration at 3 mg l^{-1} concentration probably due to high levels of ammonia, and the explants showed adventitious rooting and stunted shoots. During initial phase of selection (with 1 mg l^{-1} basta) the transformed explants survived and showed normal rate of development and produced embryogenic calli. Therefore, we are planning to regenerate plants following selection at lower concentration of basta (1 mg l^{-1}) and confirm the genetic transformation by conducting leaf swab tests with basta using regenerated plants. At present, from a total of 1425 bombarded explants, 3 are surviving on regeneration medium with 3 mg l^{-1} basta, 571 explants are on regeneration medium with basta (1 mg l^{-1}) and 871 are on callus induction medium (1 mg l^{-1} basta). Alternatively phosphenothricin (50% of the explants die at 4 mg l^{-1}, and 75% die at 8 mg l^{-1}) can be used as a selection agent as used by others.

A new protocol was developed for *in vitro* plant regeneration using shoot meristems by direct organogenesis without any callus induction phase. From nearly a thousand shoot meristems bombarded so far, a great majority produced normal plantlets. Among these, 25 plants survived in jiffy cups, 80 plants survived in magenta jars, 108 plants are at rooting stage, and 709 are in the differentiating medium (post bombardment).

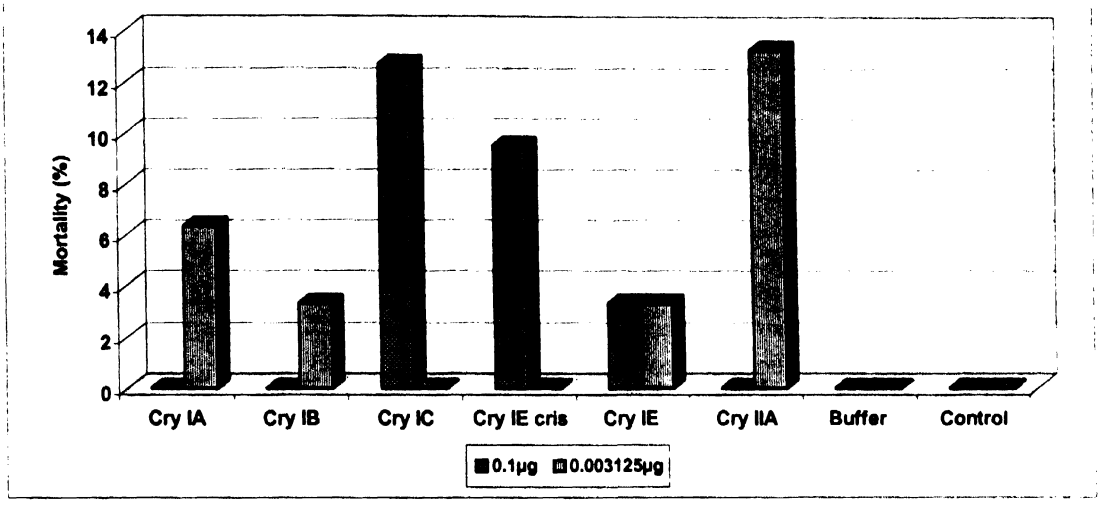
Considerable progress has been made in developing protocols for sorghum tissue culture and genetic transformation. The current limitation for the production of transgenic sorghum is the difficulty in regenerating plants in the media containing *basta*, and this is now being adequately addressed.

Effectiveness of Bacillus thuringiensis toxins against *Helicoverpa, Spodoptera, Chilo, and Atherigona* (H C Sharma)

To bioassay Bt toxins, we tested six artificial diets for rearing the sorghum shoot fly, *Atherigona soccata*. Shoot fly larvae were successfully reared on a diet containing wheat flour. The females reared on artificial diet laid 11 eggs per female compared to 35 eggs laid by those reared on sorghum. Further experiments for improving this diet are in progress.

To identify virulent strains *of Beauveria bessiana* for use in biological control of *Chilo partellus*, we evaluated 29 strains of *Beauveria bassiana*. Isolates 3u, 22u, and BbW of *Beauveria bassiana* were found to be highly pathogenic to the third-instar larvae of stem borer, resulting in >80% larval mortality in contrast to 3% mortality in the untreated control. Twenty isolates tested could be placed under two main groups based on RAPDs.

Fig.1. Spotted stem borer - larval mortality (5 days)



For the bioassay of *Bt* toxins artificial diet in a vial was treated on the surface with the test chemical. Twenty eggs were released in each vial 4-h after treatment, and observations were recorded on larval mortality and larval mass 5 days after treatment. Commercial *Bt* formulation (Biolep®) at 0.0625 and 1.0 mg per ml concentration, the resulted in 62 and 91% mortality, respectively 9-days after treatment. Toxins from *B. thuringiensis* var *morrisoni* showed appreciable biological activity against the shoot fly larvae. In a diet treated on the surface with 1 µg per ml toxin, <5% larval survival was recorded compared to 75% survival in the untreated control diet.

Five ml of chickpea based artificial diet in 15 ml glass vials [used for rearing *Helicoverpa armigera*] treated on the surface with 100 µl of the test chemical has been found to be suitable for bioassay of *Bt* toxins against *Chilo partellus*. Observations were recorded on larval mortality at 5 days after treatment. Bt toxins *Cry*1Aa *Cry* 1C, *Cry*1E, and *Cry* 2A showed activity against the spotted stem borer larvae (Figure 1). At 0.05 and 0.80 µg per ml, *Cry*1A (a) resulted in 35 and 80% mortality of the third-instar larvae, respectively.

One ml diet in 7 ml glass vials was treated with 25 µl of the test chemical on the surface, and one *Helicoverpa armigera* larva was released in each vial. Observations were recorded on larval mortality 5 days after treatment. *Cry*1A was most effective against the first-instar larvae, followed by *Cry*2A.

Bioassay of transgenic tobacco plants for resistance to *Helicoverpa armigera* and *Spodoptera litura* (H C Sharma and KK Sharma)

To standardize the transformation protocols and test the efficacy of transgenic plants against damage by insects, we evaluated purified soybean trypsin inhibitors (SBTI) from *E. coli*, induced and un-induced cells, and transformed plants against *Helicoverpa armigera* and *Spodoptera litura*. Leaf discs were treated with 25 µl of 10 ug purified SBTI, 17 µg *E. coli* induced and un-induced cells, and 15 µg of recombinant SBTI from *E.coli*. To evaluate the antibiotic effects of SBTI, artificial diet was impregnated with SBTI from induced and un-induced cells of *E. coli*, two transformed plants (15-2 and 9-3), and pure SBTI. Five ml of artificial diet was placed in 96 well plate, and treated with 2.5 ug/ml of pure SBTI, and SBTI from induced and un-induced cells of *E. coli*. SBTI acted as a phago-stimulant to the third-instar larvae of *Helicoverpa* at the dosage tested. Transformed plants showed anti-feedant effects against the third-instar larvae. Larval mass was lower in diet containing pure SBTI and SBTI from transformed 15-2 plant.

Table 2.3s Relative resistance/susceptibility of transgenic tobacco plants with *Bt* and SBTI genes towards the first-instar larvae of *Helicoverpa armigera* under no-choice conditions

Treat	DR[1] 72	Larval mortality (%) 72 hrs	Larval mass (g)
723 BT 1	0.4	93	0.100
723 BT 3	1.3	38	0.500
723 BT 4	1.6	60	0.425
723 BT 7	0.7	88	0.100
723 BT 8	1.0	75	0.325
723 BT 10	4.2	30	1.125
723 BT 12	0.2	65	0.150
737 SBTI 1	2.0	38	0.575
737 SBTI 5	1.5	48	0.575
737 SBTI 11	2.3	42	0.475
737 SBTI 12	0.8	58	0.325
Control	6.3	25	1.125
SE	±0.40	±1.10	±0.1000

1. Damage rating (1 = <10% leaf area damaged, and 9 = >80% leaf area damaged)

In another experiment, 11 tansgenic tobacco plants with *Bt* gene and soybean trypsin inhibitor (SBTI) were tested against *Helicoverpa armigera* and *Spodoptera litura*. Leaf discs from the mid portion of the third and fourth leaves from the terminal end were fed to *Helicoverpa* and *Spodotera* larvae in dual or no-choice tests. In dual-choice tests, one leaf disc from the non-transformed control plants was fed to the larvae along with a disc from the transformed plant under test. Ten first-instar larvae were placed in the Petri dish in no-choice tests, whereas only one third-instar larva was released inside the Petri dish in dual-choice tests. The level of resistance of the transgenic plants was measured in terms of leaf disc feeding (1 = <10% leaf disc area consumed, and 9 = >80% leaf disc area consumed), larval mass, and larval survival at different intervals. Leaf feeding by the first-instar larvae of *H. armigera* was lower in the *Bt* and SBTI transformed plants as compared to the control (Table 2.3 S). Larval mortality was higher and larval mass was lower on these transgenic plants as compared to the larvae fed on control plants three days after initiating the experiment. There was a significant reduction in leaf disc consumption by the third-instar larvae on all the transformed plants (1.10 - 2.69 cm^2 unconsumed

leaf disc area) compared to the non-transformed control (0.52 cm^2 unconsumed leaf disc area). Similar trends were observed in the larval mass two days after initiating the experiment. Visual damage rating was lower in transgenic plants (723 *Bt* 7, 737 SBTI 1, 737 SBTI 11, and 737 SBTI 12) than in the control. Under dual-choice conditions, leaf disc feeding was lower in 723 BT 3 and SBTI 12 transgenic plants compared to the control. In case of tobacco caterpillar, *Spodoptera litura* the transgenic plants (723 *Bt* 3, 723 *Bt* 4, 723 *Bt* 7 and 737 SBTI 12) showed anti-feedant activity against the third-instar larvae. There was no apparent effect of the transgenic plants on larval survival and larval mass three days after initiating the experiment. Transgenic plants 723 *Bt* 3, 723 Bt 7, 723 *Bt* 12, 737 SBTI 1, 737 SBTI 5, 737 SBTI 11, and 737 SBTI 12 showed anti-feedant activity against the third-instar larvae 24 h after initiating the experiment. Mass of the larvae was reduced on all the transgenic plants as compared to the control plants. In dual-choice tests with the third-instar larvae, the transgenic plants 723 *Bt* 1, 723 *Bt* 4, 723 *Bt* 10, 723 *Bt* 12, 737 SBTI 5, 737 SBTI 12 showed anti-feedant activity. Mass of the larvae fed on transgenic + control discs was significantly lower than those fed on the control discs only.

Objective 2.4: Discovery, isolation and characterization of genes from ICRISAT mandate crops

Rationale: Isolation and characterization of agronomically important genes from both cultivated and wild species of mandate crops will facilitate crop improvement by both marker-assisted and transgenic approaches. Of the many methods available to isolate potentially useful genes from crops of interest the important ones are i. use of degenerate primers for isolation of putative resistance genes by PCR, ii. heterologous probes to identify corresponding genes from genomic libraries, and iii. differential display techniques using appropriate template cDNA from crops exposed to specific stress treatments. Majority of the plant disease resistance genes cloned so far shows conserved DNA sequences and amino acid domains irrespective of whether they confer resistance to viral, bacterial, or fungal diseases. The similarity in the resistance genes among the plant species has made it possible to isolate such resistance gene candidates (RGC's) from any plant species using PCR with oligonucleotide primers to the conserved domains. Differential display of RNA from has been described as a powerful technique for the isolation of tissue-specific or stage-specific genes. To analyze host-pathogen interactions and to understand the signaling events that occur between pearl millet and the downy mildew pathogen, *S. graminicola*, differential display reverse transcriptase PCR (DDRT-PCR) is the most ideal technique especially where the pathogen cannot complete its life cycle without the host plant.

Resistance gene candidates (RGCs) isolated and mapped in pearl millet (S Sivaramakrishnan)

Degenerate primers used were designed from the motifs within sequence encoding the nucleotide-binding site NBD). PCR was performed with the different primer combinations in a total volume of 35 ul. PCR products cloned into pGEM vector. About 12-16 clones were sequenced from each successful amplification consisting of about 80 clones using the ABI 377 PRISM automated sequencer. BLAST searches were performed via the National Center for Biotechnology Information (NCBI) web site.

Though we obtained many clones only 12 of these were sequenced. Seven of these clones pulled out known disease resistance gene sequences on BLAST search. Six of these clones including the representative RGC labeled M9-2 had almost identical aminoacid sequence showing the conserved motifs in the NBD. Both M-9-2 (M1) and M11-1 (M2) was mapped by sending it to JIC, UK. Of these, M 9-2 was mapped on to linkage group-1 (LG-1) close to the RFLP marker Xpsm567 and on LG-7 close to Xpsm 518. The LG-1 accounts for one of the major QTL for downy mildew resistance. The two RGCs were deposited in the GenBank with accession numbers M1: AF186631 and M2: AF186632. Further work is needed to establish their usefulness in marker-aided selection.

This PCR approach with degenerate oligonucleotide primers has great potential for amplifying numerous resistance genes from diverse species. With the isolation of more resistance genes, it is becoming possible to design primers that will be highly selective in amplifying resistance genes

Putative genes involved in host-pathogen interaction in pearl millet downy mildew isolated (S Sivaramakrishnan and R P Thakur)

Highly virulent pathotype (IC 7042) was used in this study. RNA samples of healthy 10-day-old seedlings of 7042 with no pathogen inoculation were used as negative control. After inoculation of the spores leaf tissue was harvested at 9-time intervals upto 72 h and one sample on the 6^{th} day. RNA isolated from the various samples was used for cDNA synthesis using anchored primers, random oligomers (10-mer) and degenerate oligonucleotide primers of R genes in a PCR reaction. The PCR products were run on sequencing gels and the differentially expressed bands were eluted and cloned in pGEM vector.

About 35 clones were identified as differentially expressed DNA fragments from the pathogen-infected pearl millet seedlings and these were cloned. The authenticity of the clones was verified by using them as probes in Northern hybridization with RNA isolated from the control, infected and sporangial RNA. Some of these fragments are being sequenced and BLAST search will be done to establish their homology with other known genes in the database.

DDRT- PCR is an excellent tool for the identification of differentially expressed transcripts during the process of infection which will help us in the understanding the molecular basis of disease resistance.

Objective 2.5: Characterization of genetic variability in important pathogens of ICRISAT crops

Rationale: The major cause for "breakdown" of a crop variety is the existence of variable pathogen population which makes it necessary to replace cultivars due to disease susceptibility. Several factors contribute to the breakdown of resistance in the field and it is essential to understand some of the environmental factors that contribute to this breakdown which can be used in successful screening of cultivars for resistance. It is now possible to assess the variability in pathogen populations using molecular methods that can help in deploying cultivars that are resistant to the prevailing pathotypes in a crop growing area. Molecular technologies will permit enhanced virulence monitoring, characterization of the fungal genome, and understanding the

genetics of the host-pathogen interaction. Simple PCR-based method like RAPDs is commonly used for assessing variability in the pathogen population. We have also used the hybridization - based DNA fingerprinting using microsatellites to detect polymorphism among the different isolates which can be tedious and time-consuming. Therefore, we are constantly improving our molecular methods to assess the variability in pathogens in a precise and cost-effective way.

Activity 2.5d: Characterization of genetic variability in the pearl millet downy mildew pathogen

Characterization of genetic variability of downy mildew pathogen isolates from Africa and India (D E Hess)

The International Pearl Millet Downy Mildew Virulence Nursery (IPMDMVN) is a collaborative nursery permitting monitoring of variability in pathogen populations and contributing to understanding of the mechanisms of variability. The West and Central African Downy Mildew and Smut Observation Nursery (WADMSON) is a collaborative regional trial permitting the testing of pearl millet lines and varieties from national programs and ICRISAT-Niger for reaction to downy mildew (*Sclerospora graminicola*) and smut (*Tolyposporium penicillariae*).

IPMDMVN was conducted at Sadoré (Niger), Samanko and Cinzana (Mali), and Bagauda (Nigeria) in 1998. The pathogen populations from Cinzana and Bagauda were the most virulent, inducing more than 10% disease in all 13-test entries. Considering mean disease incidence across test entries over past years, the population from Bagauda appeared most aggressive (58% incidence), followed by those from Bengou, Sadoré, Cinzana, and Kamboinsé (Burkina Faso) (38-39% incidence), with the least virulent population from Bambey (Senegal) (9-20% incidence).

Summary reports for the 1995 and 1996 WADMSON trials were completed and distributed to partners contributing seed and/or conducting the trial (Burkina Faso, Ghana, Mali, Niger, Nigeria, and Senegal). 1996 entries performed extremely well at all locations. At the end of the season most entries were resistant (□10% disease severity) with the exception of Samaru, where only 4 entries were resistant (SO x SAT and Synth 16 C_1 from Mali, CS1-C1-R-5 from Burkina Faso, and SOSAT C88 from ICRISAT/Mali NARS). No IPMDMVN line exhibited stable resistance across locations and over years.

Virulence monitoring in pearl millet downy mildew in India (*Sclerospora graminicola*) (R P Thakur and S Sivaramakrishnan)

Field surveys and a collaborative International Pearl Millet Downy Mildew Virulence Nursery (IPMDMVN) were used to monitor spatial and temporal virulence patterns in *S. graminicola* populations. Isolates were collected from different pearl millet cultivars in farmers fields during surveys in Maharashtra, Rajasthan, and Gujarat and some of these were characterized for pathogenicity and virulence by artificial inoculation under greenhouse conditions and for genetic diversity using molecular markers. About 50 sporangial collections from different cultivars in farmers' fields in Maharashtra during the 1999 crop season were sent to Clint Magill (Texas A&M University) to study population genetics of S. *graminicola*.

Field surveys: Downy mildew incidence on some of the private sector hybrids (MLBH 104, -267, -287, GK 1004, -1014, Proagro 7501, -7701, -9330, Pioneer 7686, Bioseed 8421) and public sector hybrids (BK 560 and ICMH 451) was very high (>50%) in farmers' fields during the past 2-3 years. These hybrids have been in cultivation for 3 years or more and have succumbed to downy mildew, primarily due to virulence shifs in the pathogen population. There has been cultivar diversification, but not for disease resistance diversification. In contrast to F_1 hybrids, open-pollinated variety, ICTP 8203 that occupies about 50% area in Maharashtra has recorded only 0-2% incidence over 6-7 years.

Virulence pattern: Results of IPMDMVN from 23 locations in seven countries during 1992-1998 indicated that the pathogen populations from Cinzana (Mali) and Bagauda (Nigeria) were the most virulent inducing more than 10% disease in all 13 test lines. These were followed by populations from Kamboinse (Burkina Faso), Durgapura, Jodhpur and Mandor (India) and Sadore (Niger). Other populations that were virulent, in descending order, were those from Samanko (Mali), Mysore, Pune, Dhule and Patancheru (India). The least virulent population was from Bambey (Senegal).

Host resistance: No line was highly resistant and stable across locations over years. Line IP 18292 that was resistant (<10% incidence) at Bambey, Bengou, Samanko and several locations in India showed susceptibility at Nioro, Kamboinse, Sadore, Cinzana and Bagauda in Africa, and at Durgapura, Jodhpur and Mandor in India.

Molecular characterization: DNA fingerprinting using the microsatellite $(GATA)_4$ revealed high levels of polymorphism among the six field isolates. Both virulence and DNA fingerprinting analyses showed that isolate Sg021 from a popular hybrid MLBH 104 was quite distinct from those of MBH 110, BK 560 and others. The cluster analyses of virulence data and DNA fingerprinting classified the isolates into four groups, although there was no complete agreement between the two groupings.

The global virulence pattern of S. *graminicola* populations could tentatively be identified into 15 putative pathotypes. This, however, will need confirmation. Seven test lines (IP 18292, IP 18293, 700651, P 310-17, P 7-4, MBH 110 and 852B) that provided differential reactions at 22 locations might possess different resistance genes. The results of disease survey and IPMDMVN have been found useful for breeders and seed industries for their breeding program and seed marketing. DNA fingerprinting using microsatellites is a better method for detecting genetic variability among the pathogen though it is tedious and time-consuming.

Activity 2.5f: Characterization of molecular and pathogenic variability in *Fusarium* wilt pathogens of chickpea and pigeonpea

Characterization of genetic diversity in chickpea wilt pathogens (S D Singh)

Though wilt resistant cultivars are available in both chickpea and pigeonpea, resistance in some of these cultivars (e.g. ICCV 2 of chickpea, ICPL 8863 of pigeonpea) is becoming ineffective due to the presence of variable populations of the pathogens among locations. Soil type, inoculum concentration, and temperature etc., may also adversely affect the longevity of resistance. New genes for resistance are needed for a long term control of these diseases.

Thirty-four isolates of pigeonpea wilt pathogen (*Fusarium udum*) from Andhra Pradesh and Maharashtra were assessed for biological diversity following standard procedures. Four cultures

(Races 1, 3, 4, V2) of chickpea wilt pathogen (*F. oxysporum* f.sp. *ciceri*) were compared for the production of conidiospores and conidia, and their shape, size, and number. For pathological differences, two sets of differential lines were tested with each race in artificially developed sick-pots maintained in growth chambers at 2.8±1°C. Effects of chickpea growing media, inoculum concentration, and temperature were studied on chickpea wilt development on susceptible and resistant cultivars in growth chambers and in a glasshouse. The wide crosses progenies of chickpea were screened for ascochyta blight resistance in growth room conditions at 23-25°C and 95-100% RH.

Most of the isolates *F. udum* grew well at 15-30°C. Colonies were from white to creamy-white and had floccose to powdery texture. Sclerotial formation that took place within 5-27 days, occurred only in 17 (50%) isolates, and half of these isolates produced sclerotia at 20°C, and none at 35°C. Sporodochial formation occurred in 75% of the isolates at 20°C. Only 10 isolates produced both sclerotia and sporodochia.

The V2 race of *F. oxysporum* f.sp. *ciceri* differed from race 1, 3, and 4 in inducing susceptibility on ICC 11324 and ICC 7509 (>50% wilt) which were resistant to moderately susceptible to races 1, 3, and 4. Also, ICC 12237, which was free from race 1, 3, and 4 infection, developed 10% disease with V2. In another differential set, V2 race produced 68-100% wilt in nine of the 10 differential lines. Only CPS 1, which is resistant to race 1 and 4 and moderately susceptible to race 3, developed 20% wilt with V2 race. The microconidia of V2 race are more curved than the microconidia of other races and are produced in larger number. Chickpea grown in sand medium developed more wilt than when grown in sand and soil mixture or soil alone. Growing medium containing 20-30% inoculum (inoculum multiplied on sand and chickpea flour, 9:1 ratio) produced more wilt than when lower and higher inoculum concentrations were used. Wilt development was more at 25-28°C than at lower temperatures and no wilt occurred at 35°C.

The differences in the production of sclerotial and sporodochia showed the presence of genetic diversity in pigeonpea wilt pathogen (*F. udum*). Temperature more than 30°C was unfavorable to the growth of *F. udum*. The V2 race of chickpea pathogen is distinctly different from other races.

Molecular characterization of genetic variation in isolates of pigeonpea *Fusarium* wilt pathogen (S Sivaramakrishnan and S D Singh)

DNA was isolated from 36 isolates of *Fusarium* collected from the pigeonpea growing regions of Andhra Pradesh and bordering Karanataka, and Maharashtra. Four isolates from ICRISAT fields and one from Uttar Pradesh were also included for analysis. About 20 random oligonucleotide primers (10-mer) from Operon Technologies (USA) were used in a PCR reaction using standard temperature cycle. The four ITS primers were also tested in a PCR reaction similar to the random primers.

All the 15 oligonucleotide primers tested and the ITS primers detected varying levels of polymorphism among the 36 isolates. Cluster analysis of the data based on similarity index data from ITS placed the 36 isolates in different groups. The isolates form Kanpur formed a separate group and those from ICRISAT formed separate groups with isolates from other regions. Thus both RAPDs and ITS primers could detect polymorphism among the various isolates of *Fusarium* pathogen.

Activity 2.5s: Molecular characterization of the pigeonpea sterility mosaic virus

Molecular characterization of the pigeonpea sterility mosaic virus (D V R Reddy)

A special purification procedure was designed to obtain sufficiently pure samples of the sterility mosaic virus for detailed characterization. A highly flexuous rod shaped particle-containing RNA was isolated; the genome was divided and contained one single polypeptide of 32kDa. Production of polyclonal antibodies is in progress.

Twelve pigeonpea genotypes with differential reaction to sterility mosaic were sown in three locations, Patancheru, Bangalore and Varanasi, to assess the likelihood of variation the virus in different locations. The twelve genotypes reacted differently at Patancheru and in Bangalore, indicating the possibility that the isolate of the causal virus in Bangalore may be different from that in Patancheru. At both the locations ICP 7035 was rated as resistant to the virus, based on the absence of visual symptoms

Objective 2.6: With advanced institutions, develop and apply genetic linkage maps for improvement of ICRISAT mandate crops

Rationale: Genetic linkage maps facilitate genomic studies, and especially identification of Quantitative Trait Loci (QTL) that can be used for marker-aided selection (MAS). Existing genetic linkage maps for sorghum and pearl millet developed in collaboration with ARIs are not sufficiently saturated, and no satisfactory maps are available for the legumes. Many new DNA markers will be added to the existing maps of sorghum and pearl millet using the various mapping populations whereas in legumes new mapping populations will be made and use those already available to identify of polymorphic DNA markers, to facilitate the identification of QTL for many of the economically important traits that can be used in MAS. In pearl millet we have made considerable progress in MAS for downy mildew resistance and other traits like drought tolerance and stover quality are being addressed now. Although several genetic linkage maps of sorghum are published, no suitable maps are accessible for identifying QTLs related to priority traits of interest to ICRISAT (like QTLs for *Striga* resistance or drought tolerance). Therefore, we need to continuously work to saturate existing maps, and develop new ones using appropriate parental lines so that eventually marker-assisted selection can be initiated in all the mandate crops.

Activity 2.6c: Develop and apply genetic linkage maps for improvement of chickpea

Use of molecular markers for genome mapping in chickpea (Jagdish Kumar)

Chickpea recombinant inbred line (RIL) sets from a variety of crosses (base mapping population from a across of ICCV 2 x JG 62, six mapping populations for earliness, one for root volume,

one for *Ascochyta* blight resistance, two for cold tolerance, and one from an interspecific cross) were advanced by single seed descent (SSD). Collaboration was initiated with Washington State University, Pullman for genome mapping. The German collaborators sent us 10 pairs of primers and the US collaborators allowed the use of about 100 pairs of STMS primers. It was possible to screen about 700 RAPD primers on chickpea lines ICCV 2 and JG 62 and select those that were polymorphic. About 400 F_3 and F_4 SSD individuals were advanced to enlarge the ICCV 2 x JG 62 RIL population for fine mapping and genetic analysis. This population was genotyped for many traits.

Collaboration with ARIs and NARS was established. A skeleton genome map of chickpea was developed with about 75 markers which links a few genes with molecular markers. We confirmed that only 2-3% RAPDs elicited polymorphism in cultivated chickpea. We therefore, look forward to using STMS primers which are reported to show much higher levels of polymorphism in chickpea compared to RAPDs.

Phenotyping of RILs, for drought resistant traits, as inputs for identification of QTLs for root traits in chickpea (N P Saxena and Jagdish Kumar)

Two parents and 129 RILs (derived from the cross *C. arietinum* x *C. reticulatum*) were received from our cooperator in Washington State University, USA. for initial phenotyping. These were grown in controlled environment facilities. In the first set, the photoperiod was maintained at 11 h, and day/night temperature at 25°/18° C. In the second set, the photoperiod was changed to 18 h to better synchronize flowering of the lines. Observations were recorded on shoot and root traits at the time of flowering.

In the first set (11 h photoperiod) large differences in time of flowering, between the two parents and between RILs, were observed. ICC 4958 and one RIL were the first to flower 35 days after sowing, whereas *C. reticulatum did* not flower. Only half of the RILs (65 in numbers) flowered by 90 days after sowing and the remaining 66 continued to grow vegetatively. Contrasting differences in growth habit, from prostrate to erect types and in basal and terminal branching, were apparent. A large variation in shoot growth (shoot mass, branch number, and root traits, total nodes) and root growth (root length, volume, and root weight), and root/shoot ratio were observed in the RILs that had flowered in the first 90 days after sowing. Equally large were the differences in root volume (cc), root weight and shoot weight (g) and root/shoot ratio in the RILs which had not flowered, Large difference in shoot weight, root weight, and root/shoot ratio were also observed. In the second set (18h photoperiod) where flowering was more synchronous, occurring in 30 days after sowing. Measurements commenced 45 days after flowering showed that the differences between RILs were very large. Leaf area ranged from 10-105 cm per plant, root volume 2-19 cc/plant and root weight 0.1-1.6 g/plant and root/shoot ratio from 0.1-2.7.

The data are being provided to our collaborators. A large variation in shoot and root traits among the RILs and the parents is expected to be useful for identifying QTLs for some of the root traits.

Activity 2.6g: Develop and apply marker-assisted selection tools for improvement of groundnut

Identification of molecular polymorphism among selected germplasm and interspecific derivatives of groundnut (S L Dwivedi)

PCR-based markers were used to study polymorphic variability among groundnut germplasm lines with resistance to rust, leaf spots, bacterial wilt, rosette, aflatoxin, and drought, in order to identify candidate parental lines to use in mapping population development. Genetic similarity among lines was estimated by the method of Nei and Li (1979).

The RAPD data revealed 47 - 69% genetic similarity in DNA profiles of MK 374 and U4-7-5 among 82 groundnut germplasm lines evaluated. The SSR data revealed no genetic similarity in DNA profiles of the few germplasm lines resistant to bacterial wilt (ICG 1609 with ICGs 1703 and 1705; ICGs 1703 and 1705 with ICGs 5313, 15220,15227, and 15230), drought (ICGV 86031 and TMV 2 NLM with ICGs 1471 and 1823), and late leaf spot (ICG 13922 with ICGs 2716, 4747, 4995, 6022, 7013, 11321, 11485, 13919, and 13920). The rosette resistant germplasm (ICGs 10183, 10543, and 12876 with ICGs 6326, 7346, 7458, 7469, 7492, 7637, 7728, 7753, and 7760) showed 40% similarity in DNA profiles. JL 24 and Mani Pintar, susceptible to rosette, revealed genetic similarity of 40 to 50% with the resistant germplasm studied.

The AFLP data revealed less than 50% genetic similarity in DNA profiles among the germplasm belonging to rust and leaf spots (TMV 2 with ICG 10890, 10881, 1705, 405, 6284, 6886, ICGVs 99001, 99002, 99003, 99004, and 99005), drought (TMV 2 NLM with Chico), bacterial wilt (Chico with ICG 7893 and 15222), and rosette (JL 24 and Mani Pintar with ICGs 3436, 6323, 6466, 9558, 9723, 10347, 11968, 11044, and 12876).

Evaluation of F_1, F_3, and F_2BC_1 progenies from crosses between wild *Arachis* species and cultivated groundnut for foliar disease resistance (R Bandyopadhyay and N Mallikarjuna)

Several wild *Arachis* species posses high levels of resistance to late leaf spot and rust. A program is underway to transfer the resistances from the wild species to cultivated groundnuts through an appropriate crossing program. We evaluated 50 F_1, 9 F_3 progenies, and 6 F_2BC_1 progenies for resistance to late leaf spot and rust using the detached leaf technique in growth chambers. The wild species *A. glabrata* and *A. stenosperma* were free from both LLS and rust whereas *A. kretmarie* was highly resistant (<2% disease). The cultivated parents ICGS 44 and MK 374 were as susceptible to LLS as the susceptible check TMV 2 (46 to 50% disease). Five F_1 progenies of the cross ICGS 44 x *A. stenosperma* and one F_3 and F_2BC_1 progeny each of (MK 374 x *A. stenosperma*) x MK 374 had less LLS; all other F_3 and F_2BC_1 progenies were susceptible. The results showed that a few interspecific derivatives have higher levels of resistance compared to some of the popular cultivars, but the resistance level is not as high as the parental wild species.

Identification of molecular markers associated with rosette resistance (P J van der Merwe)

Hybrid populations between resistant and susceptible parents have been developed. Six F_0 generations, five F_1 generations as well as the back cross populations between susceptible and resistant parents have been developed. Single plants of the F_2 will be separated into highly

resistant and susceptible bulks for implementing a bulk segregating analysis. Both parents and the bulks will be subjected to the AFLP and RAF techniques for identification of genetic markers.

The F_1 and F_2 generations were planted at the hybridisation block at the Chitedze Research Station. These populations will be used to identify markers for aphid resistance. These are the first materials to be developed for the identification of marker genes associated with aphid resistance. Populations to identify GRV resistance marker genes will be developed during the next cropping season.

Host-plant resistance to diseases is considered as a major form of disease control, and an important factor for the application of integrated disease management. Identifying the resistance is important, but understanding the genetics of the resistance and the mechanism of resistance operating against the disease, and in some cases against the vectors, is also important. Such an approach is being followed with rosette virus disease at ICRISAT-Lilongwe. A multi-disciplinary team, with scientists from ICRISAT, the Natural Resources Institute (UK), and the University of Georgia, USA is working on different aspects of the rosette virus disease complex. A student (Ph.D.) will be involved with the identification of markers linked to genes for groundnut rosette virus and aphid resistance.

Activity 2.6m: Develop and apply linkage maps for improvement of pearl millet

Evaluation of Pearl Millet for phosphorus uptake ability (K Anand Kumar and A Batiano)

Nine pearl millet genotypes were evaluated under two applied P treatments (13 and 26 kg P ha^{-1}) and control (no applied P) over three years to determine phosphorous utilization efficiency (PUE = units of grain produced per unit of phosphorous applied).

There were significant differences between genotypes for grain and stover yield and for their response to applied P (Figure 2). PUE at 13 kg applied P ha^{-1} varied among the nine genotypes from 25 kg grain kg P^{-1} for varieties ICMV-IS 85333 and ICMV-IS 86330 and 80 kg grain kg P^{-1} for Haini-Kiréi. The relationship between PUE with applied P ha^{-1} and grain yield achieved with no application of P was not significant. Only 15% of the yield variation without P was explained by PUE, indicating that a genotype with a high PUE will not necessarily perform better under low applied P conditions than a genotype with low PUE. This lack of relationship also suggests that genotypes selected for high grain yield under low P situations will not necessarily have high PUE in applied P conditions. However the PUE with 13 kg applied P ha^{-1} was significantly correlated with grain yield in this same treatment. PUE explained 77% of the total variation in this relationship, indicating that cultivars with a high PUE can first be identified using their grain yield performance at 13 kg P ha^{-1}.

Results reported here indicate that phosphorous efficient genotypes can be identified at low P application levels. However, before undertaking genetic enhancement for phosphorous use efficiency, it is recommended that the effect of increasing PUE, with and without P fertilizer application, be evaluated.

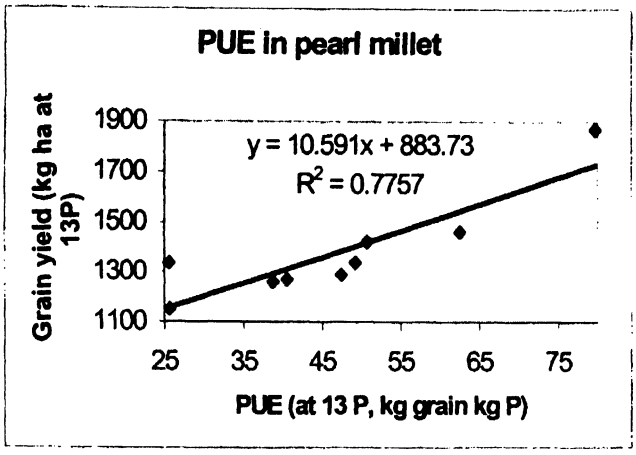


Figure 2. Relationship between Phosphorous Use Efficiency (at 13 kg P ha^{-1}) and grain yield (kg $^{ha-1}$, at 13 kg P ha^{-1}) for nine pearl millet genotypes, Sadoré, ICRISAT-Niger, Rainy seasons 1991-93.

Identification and evaluation of QTL for field tolerance of terminal drought stress and seedling heat tolerance in pearl millet (R S Yadav, F R Bidinger, C T Hash, C Howarth, G P Cavan and X Qi)

This activity is aimed at the identification of putative drought tolerance QTL, by conducting field experiments to provide data for phenotyping of mapped populations, both in managed stress environments in Patancheru and in natural stress environments in Rajasthan.

Field evaluations of 104 testcrossed progeny (tester = 843A) from mapping population 2 (H77/833-2 x PRLT 2/89-33) for drought response in the dry season and under the rainout shelter in 1998 (irrigated control and terminal stress). Both trials have yielded good data. This completed a set of 5 different evaluations of this population begun in 1996. The material was also sown for evaluation in two locations in Rajasthan in 1998, but neither trial was successful because of loss of plant stand due to early stress. Data analysis is essentially complete for four stress environments and their paired irrigated controls.

Trial mean grain yield reductions under stress ranged from 28 to 61%, while stover yield reductions ranged from 8 to 55%. Grain yields in each of these stress environments were not correlated with grain yield or flowering time in the paired irrigated control environments, so most of the QTL analysis has been based directly on phenotypic means from the terminal stress environments. However, data from the most severe stress environment and its irrigated control revealed putative QTL from linkage group 2 of PRLT 2/89-33 for superior ability to maintain grain yield, straw yield, total above-ground biomass, harvest index, 100-seed mass, and productive panicle numbers under stress. These QTL accounted for 15 - 23% of observed phenotypic variation in maintenance of these yield components under stress. The incompletely inbred structure and small size of the mapping population used in this study have prevented determination of whether these effects on various yield component traits are due to pleiotropy or

due to linkage. Marker-assisted backcross transfer of a series of contiguous segments from linkage group 2 of PRLT 2/89-33 into the background of H 77/833-2 is currently underway and should permit us to separate the effects of individual linked QTL. In addition, three topcross pollinators were developed from individual F4 lines from mapping population 2, selected on the basis of homozygosity for the major QTL on linkage group 2 associated with superior grain yield performance under severe terminal drought stress conditions, field performance of testcrosses, and a random set of F4s to serve as a control. These will allow evaluation of the effectiveness of this QTL as a selection criterion.

Field evaluations of 80 testcrossed progeny (testers = H 77/833-2 and PPMI 301) from mapping population 3 (841B x 863B) for drought response in the dry seasons of 1998 and 1999 at Patancheru (irrigated control and both late and early onset terminal stress) and under the rainout shelter in the rainy seasons of 1998 and 1999 (irrigated control and terminal stress). All trials have yielded good data. The material was also sown for evaluation in two locations Rajasthan in the rainy season of 1999, but neither experiment provided useful data because of stand loss due to early stress. Initial analyses of the successful experiments confirm the presence of one or more major QTL on linkage group 2 that are associated with distribution of grain yield components and hence with grain yield performance under terminal drought stress. Marker-assisted backcrossing to transfer terminal drought tolerance alleles from 863B into the 841B background, and terminal drought sensitivity alleles from 841B into the 863B background is underway.

Identification of molecular markers for seedling heat tolerance in pearl millet (F R Bidinger and C Howarth)

Five field evaluations of 104 testcrosses of mapping population 2 (H77/833-2 x PRLT 3/89-3) for seedling heat tolerance were conducted in Rajasthan in 1988 and 1999. The two 1998 trials were severely affected by stress during emergence, but yielded useable data, whereas all three 1999 trials were affected by unseasonal rainfall, which resulted in very little heat stress.

Analyses of the heat tolerance phenotyping results are being done by a collaborator in the UK. The topcross pollinators will be used (in hybrid combination) to quantify the benefits of marker-aided selection, in comparison the original population (represented by the random control), and to conventional selection based on field performance.

Identification and evaluation of QTL for stover productivity and quality in pearl millet (F R Bidinger, E Zerbini, X Qi and C T Hash)

Field evaluations of 80 testcrossed progeny (testers = high tillering, small panicle line H 77-833-2 and low tillering, large panicle line PPMI 301) from mapping population 3 (841B x 863B) for stover quantity and quality under irrigated conditions were conducted in the dry seasons of 1998 and 1999 at Patancheru, and again under dryland conditions during the 1999 rainy season in two sowing dates at Patancheru. All trials were successful. Dryland field evaluations of these testcrosses for stover yield and quality were also attempted in Rajasthan during the rainy seasons of 1998 and 1999. The 1998 Rajasthan trial was not harvested due to severe effects of early stress on plant stands; the 1999 trial will yield useful data.

Initial QTL analyses of the 1998 Patancheru data set reveal several tester-dependent associations of QTL for testcross flowering time and stover yield. For example, with tester H 77/833-2, 2 QTL for

flowering time were detected that collectively accounted for 46% of observed phenotypic variation for this highly heritable trait. The alleles for delayed flowering came from linkage groups 5 and 7 of 841B. One of these alleles for delayed flowering testcrosses mapped to a position indistinguishable from that for a QTL on linkage group 5 for superior stover yield with this tester. A second QTL for superior testcross stover yield mapped to linkage group 3, with 863B providing the superior allele. These flowering time and stover yield QTL mapped independently of a single QTL for superior in vitro gas production (a measure of digestible energy content) of ground leaf blade samples, that accounted for >20% of the observed two-fold variation in this trait among mapping progeny testcrosses with H 77/833-2. Thus it appears possible to combine QTL for superior testcross stover yield with those for superior ruminant nutritional quality of that stover, at least for this tester.

With tester PPMI 301, three independent QTL for flowering time were detected (on linkage groups 5, 6 and 7). Together, these accounted for 46% of observed variation between mapping progeny testcross means. Alleles from 841B were associated with delayed flowering time (1 day each) at each of these QTL. All three of these QTL mapped to positions indistinguishable from those for QTL detected for stover yield (with 841B alleles in each case associated with a 10-25% increase in testcross stover yield). No QTL for stover quality have yet been detected with this tester. It will be necessary to regress out the effects of flowering time on stover yield before detection of other types of QTL contributing significantly to the remaining 50-75% of stover yield variation will be effective in this data set.

Identification and evaluation of QTL for downy mildew resistance in pearl millet (C T Hash and S D Singh)

Downy mildew resistance gene transfer from source ICML 22 (7042DMR) to the background of elite early seed parent maintainer line 843B by conventional backcrossing, initiated in 1991, yielded its first homozygous product lines in 1998 and 1999. A total of 14 near-isogenic downy mildew resistant versions of 843B have been produced (ICML 98004 and ICML 99011 to ICML 99023). Each of these new backcross derivatives (BC3F3 to BC5F4) is homozygous for 1, 2, or in some cases perhaps 3, dominant resistance gene(s) from ICML 22 that individually are highly effective against the Patancheru field population of the pathogen (0-5% disease incidence in severe greenhouse seedling screens compared to >80% disease incidence on recurrent parent 843B). All of these lines are similar in plant height, flowering time, and other plant architectural traits to recurrent 843B, although genetically tall sub-selections of several are also available. Seed of ICML 98004 and its A-line counterpart have been multiplied for distribution (as ICMB 98004 and ICMA 98004) as short-term alternatives to 843A and 843B having improved downy mildew resistance.

Identification of molecular markers for downy mildew resistance in pearl millet (C T Hash, W A Breese, M Kolesnikova-Allen, T Pittaway, C Howarth, G P Cavan and R P Thakur)

During 1998 and 1999 a large number of pearl millet mapping population x downy mildew pathogen population screens were conducted at ICRISAT-Patancheru and by our UK-based collaborators (Table 2.6 M 1). QTL analysis has been completed for only part of the extensive data sets produced. The following brief summaries of results from two of these mapping populations gives an idea of the problems and prospects to come.

For the (ICMP 451 x H 77/833-2)-based mapping population, a minimum of 6 putative downy mildew resistance QTL have been detected, each effective against 1 or more of the 9 pathogen populations from 6 locations for which screening data (including two field screens from Patancheru) were analyzed. The parent expected to be more susceptible, H 77/833-2, contributed the allele conferring greater resistance at 2 QTL each on linkage group 3 (effective against pathogen populations from Nigeria, Sudan, and India) and linkage group 7 (effective in only one of four screens against the Patancheru pathogen population). At the remaining 4 QTL, the allele from parental line ICMP 451 conferred the higher level of resistance. Optimized multiple QTL models based on 1 to 3 of these 6 loci accounted for 10% (a single QTL effective against a Mysore pathogen population) to 88% (two QTL effective against a Sudanese pathogen population) of the observed phenotypic variation in mapping progeny mean disease incidence for a given pathogen population.

For the (PT 732B x P 1449-2)-based mapping population, a minimum of 7 putative downy mildew resistance QTL have been detected, each effective against 1 or more of the 7 pathogen populations (from 6 locations) against which screens have been conducted. Optimized multiple QTL genetic models based on 3 to 5 of these loci accounted for 57 to 97% of the variation in disease incidence between F2-derived mapping progeny F4 self bulks, depending on the pathogen population considered. For 2 of the resistance QTL detected, susceptible parent PT 732B provided the allele conferring greater resistance. However, each of these resistance alleles from PT 732B was effective against only pathogen populations from only a single location (Sadore, Niger for the QTL on linkage group 7 and Patancheru, India for the QTL on linkage group 2). Parent P 1449-2 (previously identified as having stable resistance across years and locations) consistently provided alleles conferring greater resistance at 3 of the remaining 5 putative resistance QTL detected. The P 1449-2 allele at 1 of 2 QTL detected on linkage group 4 proved effective in reducing (but certainly not completely preventing) disease incidence for all 7 pathogen populations studied.

Table 2.6m1: Greenhouse downy mildew screens completed against pearl millet mapping population progeny sets during 1998 and 1999 (or earlier *)

Mapping population	Pathogen populations used in screens conducted at	
	Bangor, Wales	ICRISAT-Patancheru
81B x ICMP 451	---	Sg139 (Jodhpur), Sg140 (Jamnagar), Sg150 (Jalna) and Sg151 (Durgapura)
841B x 863B	---	Sg139 (Jodhpur), Sg150 (Jalna) and Sg153 (Patancheru)
H 77/ 833-2 x PRLT 2/89-33	---	Sg139 (Jodhpur), Sg150 (Jalna) and Sg153 (Patancheru)
ICMP 451 x H 77/833-2	Samanko, Mali; Sadore, Niger; Maiduguri, Nigeria; Kordofan, Sudan; and Patancheru, India	Sg150 (Jalna), Sg151 (Durgapura), Sg153 (Patancheru) and Mysore*
PT 732B x P 1449-2	Sadore, Niger Maiduguri, Nigeria; Kordofan, Sudan; and Patancheru, India	Sg139 (Jodhpur), Sg150 (Jalna) and Sg153 (Patancheru)
W 504-1-1 x P 310-17	Kordofan, Sudan	Sg139 (Jodhpur), Sg140 (Jamnagar), Sg150 (Jalna) and Sg151 (Durgapura)

Characterization of downy mildew resistant versions of an early-maturing pearl millet male-sterile 843A for performance *per se* and combining ability (K N Rai, C T Hash and R P Thakur)

A number of popular commercial millet hybrids are based on 843A, which has now become highly susceptible to downy mildew (DM). DM-resistant versions of 843A, if developed, would make significant contribution to continued cultivation of hybrids based on this male sterile line. 843B and six DM-resistant versions (three each developed by backcrossing—conventional or marker-assisted—and by pedigree breeding) were evaluated for grain yield, agronomic traits and DM resistance *per se* as well as in hybrid combination. Hybrids were produced by crossing the A-line counterparts of the seven B-lines with the restorer lines of three released hybrids on 843A. Downy mildew (DM) incidence in 843B was generally very high in the seedling inoculation test in green house, ranging from 30% against MLBH 110 pathotype to >86% against the pathotypes from Patancheru, Jodhpur and Durgapura. Three DM resistant versions (ICMB 95555, ICMB 97444 and ICMB 98004) had much lower DM incidence levels against all these pathotypes. Of these, ICMB 98004 (homozygous for two dominant resistance genes from ICML 22 = 7042DMR) was more resistant than the other two B-lines. However, under field conditions at Durgapura (where resistance of ICML 22 is no longer effective), ICMB 98004 had 20% DM incidence, compared to 3 to 5% in ICMB 95555 and ICMB 97444. This shows the need for field testing in the target areas against local pathotypes, as these can change rapidly. There was no significant difference for grain yield among the hybrids made on counterpart A-lines of these seven B-lines with any of the three pollinators. Differences among hybrids made with individual pollinators were generally significant for plant height and time to 50% flowering. However, these differences were of the order of 1 to 3 days and hence of little practical significance except in conditions of severe early-onset drought stress where earlier flowering is most favorable.

Preliminary evaluation showed that at least three DM-resistant versions of 843B had higher levels of resistance than 843B against a range of pathotypes, and hybrids made on their respective A-lines had similar yielding ability and general morphological characteristics.

Identification of downy mildew resistant A-lines of pearl millet (K N Rai and R P Thakur)

Fifty-four A-lines developed during 1986-1999 and retained as potentially useful, after repeated evaluations over seasons and years, were screened against five diverse pathotypes (Patancheru, Jalna, Durgapura, Mysore and Jodhpur) using seedling inoculation test in the greenhouse.

High disease pressure developed against all pathotypes, with DM incidence in the susceptible control (7042S) ranging from 71% against Jalna pathotype to 98% against Jodhpur pathotype. Thirty-five A-lines had <5% disease incidence, with 24 of these being free of DM against Patancheru pathotype. Jodhpur pathotype was most virulent with 31 A-lines registering 50-100% incidence. During the course of breeding, these lines had never been exposed to Jodhpur pathotype. Yet 13 A-lines had <10% incidence to this pathotype, with 8 of these being resistant to other four pathotypes as well (Table 2.6.M 2). This indicated that lines identified as resistant against Jodhpur pathotype are likely to be resistant against the other four pathotypes as well. This hypothesis needs to be tested with a range of currently available breeding lines and by conducting selection experiment in composites.

Activity 2.6p: Develop and apply genetic linkage maps for improvement of pigeonpea

Development of CMS lines of pigeonpea (K B Saxena)

Identification of molecular markers for fertility restoration genes (s) in cytoplasmic male-sterility will enhance the process of developing heterotic hybrids in pigeonpea. The first step in developing molecular marker is the selection of stable fertility restorers. The more promising pigeonpea cytoplasmic male-sterile lines are regularly crossed with elite breeding and germplasm lines. The F_1 generation were grown and individual plants were identified for pollen fertility and pod set.

Thirty-eight F_1 hybrids were evaluated in 1998. The pollinators used were from India, Iran, Kenya, Tanzania, Canada, Australia and ICRISAT. ICP 6308, ICP 8744, 2 Tanzania, 7 Tanzania, PI 396279, ICPL 86102, ICPL 88039, and HPL 24 were found promising fertility restorers.

In 1999, 22 new crosses are being evaluated for fertility restoration. F_1 hybrids showing promise in 1998 are being re-evaluated to confirm their fertility restoration. The promising fertility restorer lines will be purified further to develop populations for genetic linkage maps.

Genes (s) for fertility restoration of CMS line is available in the breeding populations/ germplasm. Selfing of good restorer lines is being done to produce pure lines before proceeding with genetic mapping.

Purification of wilt resistant lines to develop marker linked to resistance against *Fusarium* wilt in pigeonpea (K B Saxena and S D Singh)

Known *Fusarium* wilt resistant and susceptible lines need to be purified for 2-3 seasons before developing mapping populations. Due to improper maintenance of wilt resistant lines in the past, these have become genetically mixed due to natural out crossing. In 1998 as well as in 1999, efforts were made to develop pure genetic stocks by selfing individual plants. After confirming the disease reaction of the selections to the *Fusarium* pathogen set of crosses will be made to develop mapping populations for *Fusarium* resistance.

Activity 2.6s: Develop and apply genetic linkage maps for improvement of sorghum

Selection of sorghum materials for development of mapping populations (Belum V S Reddy and N Seetharama)

To identify molecular markers for resistance/tolerance to a range of yield limiting factors in sorghum, it is necessary to create mapping populations consisting of a large set of recombinant inbred lines from crosses of resistant/tolerant and susceptible parents. Populations are under development for the following constraints:

Acid soil and Al toxicity: Seven acid soil tolerant lines (REAL 60, ICARAVAN, SBL 107, ICSR 110, ICSB 28, ICSB 499 and ICSB 543), were crossed with three susceptible lines (ICSR 43, ICSB 89 and ICSB 338) and their F_1s were obtained in 1999 rainy season.
Shoot fly: Two resistant lines (SPSFPR 94006B and IS 18551) and two susceptible B-lines (296B and BTx 623) were chosen as mapping population parents and crossed in 1995 post-rainy season. They were advanced to $F_{3.5}$ stage in the 1998 post-rainy season. These $F_{3.5}$ are being grown in 1999 post-rainy season.
Stem borer and midge: Two midge resistant but stem borer susceptible lines (ICSV 745 and ICSV 88032), and four stem borer resistant but midge susceptible lines (PB 15520, PB 15881-3, ICSV 700, and ICSV 714) were crossed in 1998 post-rainy season and their F_1s were advanced to F_2 in 1999 rainy season.
Grain mold: Nine grain mold resistant lines [PKV 801 (SPV 1333), KR 194, PMS 7 B, SPV 1403, B 58586, IS 23599, IS 25017, C 43 and RS 29] were crossed with four susceptible lines (Bulk-Y, 296B, KR 188, and AKMS 14B), and their F_1s were developed in 1999 rainy season.

The $F_{3.5}$ lines produced for MAS for shoot fly resistance ranged from 117 to 229 in the seven crosses (four crosses and their reciprocals excluding the reciprocal of BTx 623 x IS 18551). The $F_{3.5}$ progenies (shoot fly) are being advanced to $F_{3.6}$ in 1999 post-rainy season. Four F_1s and their reciprocals were obtained by crossing the individual plants of stem borer and midge resistant and susceptible lines. They were advanced to F_2 generation in the rainy season of 1999. The F_2s are being advanced to F_3 generation in 1999 post-rainy season. Twenty-seven F_1s and their reciprocals were made for developing RILs to identify DNA markers to grain mold resistance, and 17 F_1s and their reciprocals for developing acid soil tolerant populations. These F_1s (stem borer/midge. grain mold, and acid soil tolerant groups) will be advanced to F_2 generation in the following post-rainy season.

Identification of polymorphic DNA markers for the construction of sorghum genetic linkage map (N Seetharama and V Mahalakshmi)

This activity is intended to identify suitable polymorphic DNA markers for sorghum and map these with the existing populations, and to develop new populations for specific traits, and phenotype populations under selected environments.

PCR-based markers: Use of AFLP and STMS markers to reveal polymorphism between parental genotypes for developing different mapping populations was evaluated. AFLP revealed only 3-4 polymorphic bands between cultivated sorghum genotypes, compared with nearly 10-fold more polymorphism detected by automated fragment analysis at Keygene (work funded by the GTZ *Striga* project). Similarly, use of published primer-combinations (PC) for STMS detected little polymorphism. Although radio-labelling improved the detection of polymorphism, this method is very expensive. Therefore, it was decided to use automated procedures for genotyping with these markers. A procedure for STMS analysis with acrylamide gels and silver staining was successfully tried.

Considering the low costs, RAPD method was extensively used. A total of 221 primers (Stage I) were initially used for parental screening. Of these, only 105 primers could reliably amplify the genomic DNA with 1-5 clear bands per sample. The polymorphism ranging between 24 - 40% among different parental combinations.

In stage II, the pairs of genotypes showing polymorphism and a small subset of their progeny (RILs) were screened again with the useful primers identified during stage I to confirm consistency in amplification and polymorphism among parents and the segregation pattern of polymorphic bands in the sample set of progeny. Only those primers that showed consistent polymorphism at both stages I and stage II were used for further extensive screening of whole mapping populations (stage III). Such screening successfully identified 17 markers with a mapping population from N13 x E36-1. A preliminary genetic linkage map was constructed for with AFLP markers. Primer OPH4 was located half way between a gap of 9.4 cM on the proximal end of Linkage Group J. Similarly, OPL2 extended the length of linkage group L by 5.8 cM toward the telomere. Such RAPD markers qualify for cloning and subsequent use as RFLP probes or for conversion into SCARs.

RFLP markers: Considering the cost, time and efforts required for RFLP markers, these will be used initially only to facilitate comparative mapping. Towards this end, a set of 148 anchor probes (DNA) was received from the rice-mapping project at Cornell University. Fifty-two were cloned in *E. coli*, and RFLP probes were developed to screen a panel of sorghum mapping parents, and other cereals including rice, maize, and sugarcane. Results obtained so far with rice anchor probes have showed extremely limited polymorphism with sorghum genotypes in which we are interested, and polymorphism was hard to detect in spite of hybridizing with 5 different restriction-enzyme digests of plant DNA. We also used few putative disease resistance genes as RFLP probes and found limited polymorphism with one of them (S8-2 from sorghum).

Development and phenotyping mapping populations: Recombinant inbred lines (F_8) were obtained from both the *Striga* tolerant mapping populations based on crosses of E36 with N13 (115 lines), and IS 9830 (103 lines). Seeds were shared with collaborators in India who are evaluating these populations for drought tolerance (E36-1 is a staygreen genotype) and others traits of local interest such as charcoal rot resistance and fodder quality. We have made crosses with stay green line B35 and E36 for the elite lines we assembled and the ones contributed by Asian NARS and the first backcross is also done. We also evaluated two of the collaborators' mapping populations for terminal drought tolerance and have supplied data to them.

The prospects for use of PCR-based markers and automation for saturating maps of sorghum are improving. With several mapping populations already developed, it should be soon possible to identify markers/QTLs for several priority traits so that effective marker-assisted selection can be initiated at ICRISAT.

Identification of molecular markers for *Striga* resistance components in sorghum (D E Hess)

Transfer of resistance to *Striga* into adapted varieties has been limited due to inadequate information on the genetics of resistance, and the difficulty of evaluating resistance in the field. This work was conducted to identify and map genes for qualitative and quantitative resistance to *S. hermonthica* in sorghum.

The agar-gel assay was carried out in the laboratory at Samanko with recombinant inbred population (RIP) 1, using *Striga* seeds from Samanko and Bengou. Field resistance tests involving two recombinant inbred populations (RIPs), derived from the crosses: (1) IS 9830 x E 36-1, and (2) N 13 x E 36-1 were carried out in *Striga*-infested fields at three locations in West

Africa (Samanko and Cinzana in Mali and Diapaga in Burkina Faso), and in East Africa (Kibos and Alupe in Kenya in the long rainy season and Alupe in the short rains). The evaluation involved a new sample of 110 F3:5 lines of each population plus the three most resistant and three most susceptible F3:5 lines from 1997 plus parents and checks. Pot screening trials were also conducted at Samanko, Sadoré, (Niger), and at Kibos in the long rains.

In the agar-gel assay, estimated heritability for the 110 new F3:5 lines was 95.2% for the mean maximal germination distance, across the two West African *Striga* sources. (RIP 2 was not evaluated in the agar-gel assay since last year's results revealed no useful genetic variation for low stimulant production present in this cross.). Data analyses revealed significant genetic differences among the tested entries in all experiments, and entry means have achieved the accuracy required for the mapping study. AFLP marker analyses performed by Keygene (Netherlands) resulted in the creation of genetic maps with 10 and 11 linkage groups, and genome lengths of 810 and 759 cM in RIP 1 and RIP 2, respectively. The QTL analyses are still to be carried out. Genetic research is supplemented by investigations into mechanisms of resistance. A preliminary pot trial suggested antibiosis as an additional resistance factor in the parent line N 13. Infection sites were isolated for use in histochemical studies.

The *Striga* resistance data collected with the two RIPs during 1998, in combination with the 1997 data set, will provide an excellent data base for the mapping study.

Development of RILs for mapping resistance to spotted stem borer and sorghum midge (H C Sharma and N Seetharama)

A set of 20 genotypes with known resistance and susceptibility to the spotted stem borer, *Chilo partellus*, was evaluated at several ICRISAT locations, to identify lines with stable, global resistance to stem borer for developing recombinant inbred lines (RILs). At ICRISAT Patancheru, data were recorded on leaf feeding, deadheart formation, stem tunneling, tiller production, and grain yield. Genotypes PB 15520, PB 15520-2-2-2, PB 15925, PB 15833-1-1-2, and PB 14698-2 showed <8% deadheart formation compared to 9% in the resistant check, IS 2205, and 33% in ICSV 88032. Midge-resistant genotypes ICSV 745, ICSV 93046, and ICSV 88032 showed high levels of susceptibility to the stem borer. These lines can be used to develop RILs for molecular markers associated with resistance.

Individual plant selections from the F_2s of the crosses ICSV 745 x PB 15881-3, and ICSV 88032 x ICSV 714 were advanced from F_3s to F_4s during the 1997/98 post rainy season. These lines were advanced to F_5s during the 1998/99 post-rainy season, and to F_6s during the 1999 rainy season. These will be ready for phenotypic and molecular marker evaluation by 2000.

Identification of parents for mapping fertility restoration in sorghum (Belum V S Reddy)

Several different cytoplasms cause male-sterility in sorghum when they interact with a specific nuclear gene(s). These male-sterility cytoplasms (CMS) have the potential for increasing cytoplasmic diversity among parental lines and hybrids, but the number of lines that will restore fertility more than or other than the A_1 (milo) CMS system are limited. DNA markers for restoration ability to specific CMS systems would enable us to exploit the diversity in CMS systems.

Research was initiated to identify specific and cross-cytoplasm fertility restoration as a base for selecting parental lines for marker identification. Forty eight known restorers were testcrossed to A_1, A_2, A_3 and A_4 CMS systems and the fertility of the F_1's evaluated. Results showed that 41 lines restored fertility on both the A_1 and A_2 CMS systems, two lines (Swathi -22, and IS 5631-24) on the A_4 CMS system, but none on A_3 system. The dual restorers will be useful to determine the relative roles of A_1 and A_2 CMS systems.

Objective 2.7: Technology Exchange

Rationale: The major emphasis of this objective was to transfer the technologies developed at ICRISAT to NARS. The best platform for this activity are the various workshops and short-term training to participants from NARS and those in ICRISAT who would like to update their skills in new areas of research. Another important activity is to write project proposals that can be submitted to suitable donors for funding so that the core and collaborative research can be well supported with special project funding. Special project funding is also being sought to expand the Applied Genomics Lab that will cater to the changing needs of our research to capitalizes on the developments that are taking place in the field of biotechnology.

Workshops and Training Courses: A training course on "*Genetic transformation using particle inflow gun (PIG)*" was conducted from 16-21 April 1998 at Patancheru under the ACIAR project. Training was conducted in two batches to 20 participants from Indian universities, NARS institutions, and private sector. The course content included general principles of genetic transformation, construction of a particle inflow gun (PIG), preparation of DNA for bombardment, selection of explants, and assay for transgene expression. The main emphasis was on hands-on experience in the use of PIG. The resource person was Dr. C. Rathus, University of Queensland, Australia and technical and organization support was provided by Dr. N. Seetharama. Arrangements were also made to construct additional PIG by a local private sector company.

A training course on "Identification of *Aceria cajani*, the Mite Vector of the Agent of Pigeonpea Sterility Mosaic Disease Based on the Analysis of Ribosomal DNA Internal Transcribed Spacer Sequences" was held from 24 Aug - 2 Sep, 1998, at ICRISAT Patancheru. The main objective was to acquaint NARS from India, Nepal and Myanmar, with nucleic acid-based technology, and its application for identification of eriophyid mites and other plant virus vectors. The training course comprised various sessions of lectures and laboratory exercises covering all the relevant topics. Dr Brian Fenton, SCRI, UK acted as the main resource person and he was helped by Dr. Lava Kumar and others. This course was sponsored by DFID, UK.

A training workshop on " Advances in sorghum and anthracnose research " was held from 23-25 Sep 1998 at Patancheru. Dr. R. P. Thakur was the coordinator for the workshop. The main objectives of the workshop were to i. understand pathogenic and genetic diversity in *Colletotrichum graminicola* populations; ii. learn molecular and statistical techniques/methods for virulence analysis; iii. learn more about epidemiology, resistance utilization and disease management; and iv. discuss the future collaborative research. The workshop provided theoretical insight, practical observations and hands-on experience in several areas of sorghum anthracnose research.

A one-day meeting was held to discuss the current developments in biotechnology with special emphasis on transgenics was held on 11 December 1998. The participants included NGOs (M.S. Swaminathan Research Foundation), private sector (Monsanto, Novartis, and Proagro), Indian NARS, representative from Department of Biotechnology, GoI and ICRISAT scientists. The main objectives of the meeting were i) to identify specific areas in the field of biotechnology for future collaboration, ii) visit ICRISAT laboratory, greenhouse and field facilities, and iii) discuss various issues affecting collaboration, and bio-safety.

A project-planning workshop was held from 23-26 February 1999 to review the progress of the ICRISAT-VUB collaborative project on biotechnology (funded by ABOS/BADC-Belgium). The meeting was coordinated by Dr. K.K. Sharma. The project involves the application of plant biotechnology for the sustainable improvement of productivity of ICRISAT mandate legume crops. The project is divided into four sub-projects on specific aspects of individual crop constraints: i. improvement of the nutritional quality of pigeonpea; ii. development of transformation techniques for pigeonpea and chickpea; iii. anti-nutritive factors in chickpea and pigeonpea and expression of lectin genes in transgenics; iv. utilization of rhizosphere *Pseudomonas* as bio-control agents. The participants were scientists from VUB, Belgium, Indian NARS, and ICRISAT. The major outcome of this workshop was to formulate concrete outputs for the remaining period of the project based on the progress made so far.

An International workshop was held during March 8-9, 1999 to review the progress on sorghum tissue culture, transformation, and genetic engineering. The workshop was coordinated by Dr. N. Seetharama. The main purpose was to review the progress in these fields in the context of developments that have taken place in other crops (particularly rice, maize and model species like *Arabidopsis*) and to examine the implications for future research in sorghum. The workshop was sponsored by ACIAR, Australia, ICAR, India, AP-Netherlands Biotechnology Program, IPE, Hyderabad, CLAN, ICRISAT. Forty-five participants from four countries representing both the public and private sectors participated and disciplines ranging from molecular biology to socio-economics and policy research were covered in the meeting.

In-house training course was held from 19-30 July1999 at ICRISAT, Patancheru campus on the application of QTL mapping and marker-assisted selection in crop improvement. The resource persons for this workshop were S Chandra, C T. Hash, Maria Kolesnikova-Allen, and RP Thakur. Of the twenty ICRISAT participants, sixteen were from Patancheru and four were from other African locations. The course consisted of both lectures and demonstrations in the lab. The main focus was on the QTL and MAS for downy mildew resistance in pearl millet. Some of the topics covered include, statistical theory of QTL mapping, mapping of QTL, composite interval mapping; practical demonstrations ranged from plant tissue collection, DNA extraction, Southern blot hybridization, scoring of autorads.

An International workshop on "Breeding for Striga resistance in cereals" was held from 18-20 August 1999 in IITA, Ibadan, Nigeria. It was organized by IITA, ICRISAT, University of Hohenheim, Tubingen, Germany, and the Rockefeller Foundation. The objective of the workshop was to summarize the state of the art of cereal breeding for *Striga* resistance including biotechnological approaches, and to develop, together with NARS scientist, future strategies for *Striga* resistance breeding in sorghum, maize, millet and rice.

Applied Genomics Laboratory: One of the long -standing need for biotechnology research at ICRISAT was the development of an Applied Genomics Laboratory (AGL) to carry out various DNA-related work that will support the research of all those scientists working in this area. Dr. Stephen Kresovich, Cornell University, USA was brought as a consultant to prepare a plan for the development and operation of the AGL facility. He spent two weeks at Patancheru, studied the functioning of the present biotechnology labs, discussed research needs with various scientists, and prepared a set of recommendations. The report identifies five essential operational components for the AGL: i. Genomic DNA isolation, preparation, and quantification, ii. DNA cloning, iii. DNA amplification, iv. DNA genotyping and sequencing, and v. database development, analysis, and bioinformatics. The plan of action is intended to support a cost-effective, high throughput DNA laboratory for use by the laboratory team and an approved group of allied scientists and staff. A capital allocation of about US$600, 000 was made for developing the AGL. A new position for Head, Applied Genomics Laboratory was created, suitable candidates were called for interview and Dr J H Crouch, UK, was selected for the position. Appropriate space and equipments were identified for setting up the laboratory. The essential equipment in the AGL is the automated DNA sequencer which can be used for genotyping, fragment analysis, and sequencing.

Project Proposals: Several project proposals were submitted to the various donor agencies viz. DFID, ABOS, USAID, the Rockefeller foundation, etc. for funding. One of the major project proposals is "Rapid Crop Improvement for Poor Farmers in the Semi-Arid Tropics in Asia" submitted to ADB for funding. Sorghum, chickpea, and groundnut crop were chosen as the focus for the proposal because of their importance to food security and their potential to increase income of poor farmers in Asia. The research emphasis is on the identification and mapping of QTLs for diseases and pests resistance of economic importance in these crops. Using the tools of biotechnology, it will be possible to pyramid the genes to increase the levels of resistance. The research is also targeted to six Asian countries, Bangladesh, China, India, Nepal, Pakistan, and Vietnam that collaborate with CLAN.

Other activities:

- Training was provided to three NARS scientists on molecular markers in chickpea
- Two of our scientists (N. Seetharama and S. Sivaramakrishnan) served as resource persons in the UNESCO sponsored workshop on Biotechnology held from 8-18 Feb 1999, University of Peradeniya, Sri Lanka.
- Many of GREP scientists participated in the All India Coordinated Research Project meetings on sorghum, pearl millet, chickpea, pigeonpea, and groundnut organized by ICAR, India.
- Modification of the greenhouses was undertaken to meet the bio-safety requirements related to transgenic work.

RESEARCH AREA III

Research Area III: New traits: the biology and the improvement of disease and pest resistance, stress tolerance and quality

Goals

Make available to farmers more stable, diversified germplasm with enhanced resistance to diseases and pests, improved stress tolerance, better quality, and higher productivity.

Intermediate Goals

Identify sources of resistance, tolerance and quality/productivity traits; understand the mechanisms and genetics of these traits; and develop/improve screening and breeding methods to transfer such traits into adapted genetic backgrounds. Classes of traits include resistance/tolerance to pests, diseases, drought, heat, and soil nutrient stresses; greater productivity, and enhanced quality for diversified food and fodder uses.

Purposes

Continued progress in plant breeding requires that new and enhanced traits be available for incorporation into gene pools and into parental lines. New and diversified traits are discovered through the application of improved screening methods on broader genetic collections and in special environments (e.g. hotspots) that enable the detection of useful differences among lines. The development of these screening techniques, in turn is only possible through a better understanding of trait mechanisms, ecology, and genetic control. To achieve this objective, this project specifically aims to:

- Improve analytical tools and understanding of trait mechanisms
- Improve screening methods for resistance, tolerance, adaptation, etc.
- Identify valuable new and enhanced traits for use by collaborators

Outputs

- Elucidated mechanisms and genetics of resistance to disease and pest constraints to crop production (fungi, viruses, bacteria, insects, *striga*, nematodes) and effective selection procedures for resistance
- A better understanding of the mechanisms and genetics of tolerance to abiotic constraints to crop production (drought, extreme temperatures and inadequate nutrients) and the establishment of effective selection procedures for tolerance
- An evaluation of the value of novel crop traits with the potential to improve adaptation, yield, quality or utility of mandate crops, and the establishment of effective selection procedures for useful traits
- The identification, improvement, and/or transfer to adapted genetic backgrounds, of effective sources of biotic stress resistance, abiotic stress tolerance and desirable plant traits, and the supply of theses improved sources to NARS and other users

Objective 3.1: To understand the mechanisms and genetics of resistance to disease constraints to crop production (fungi, viruses, and bacteria) and to establish effective selection procedures for resistance

Rationale: It is necessary to have a basic knowledge of the biology of the pathogen or virus and the epidemology of the disease it causes, the nature and genetics of host plant resistance, and the effects of environment and genotype by environment interaction on disease expression, in order to design effective selection procedures for resistance. This objective focuses on the understanding of these basic requirements, and the development of effective screening procedures for resistance, where this is needed, in order to make progress in identifying and using genetic resistance

Activity 3.1.1: Refine resistance-screening techniques and model risks of sorghum grain molds.

Relationship between headbug damage and grain mold in sorghum (A Ratnadass)

In West and Central Africa, panicle-feeding bugs are a major threat to increasing sorghum production through the extension of improved caudatum cultivars, while grain molds are major problems with introduced genotypes maturing during relatively high rainfall periods. There is a need to identify sources of resistance to both stresses, and to elucidate the relationships between weather parameters, sorghum head-bug population dynamics and grain mold epidemics.

A combined analysis of variance was carried out on data from the WCASRN regional head-bug/grain mold conducted nursery in 1996 in a total of 28 site-year combinations in 10 countries. Correlations between both head-bug and grain mold damage scores, and nine weather variables were used to evaluate relationships among these parameters.

Cultivars IS 14384 and CGM 39/17-2-2 consistently exhibited very low head-bug damage and grain mold infection levels. Insecticidal protection of the panicles significantly reduced both head-bug and grain mold damage, thus confirming the role of head-bugs as factors aggravating mold infection. The analysis of correlation coefficient matrices highlighted that mold incidence is strongly correlated with high relative humidity both during early plant growth (5-40 days after sowing) and during the grain filling period (65-125 das).

This suggests the existence of both a "primary" infection from the inoculum on senescent leaves, and of a secondary "head-bug-assisted" infection.

Development of techniques to evaluate sorghum lines for grain mold resistance under variable disease pressure (R Bandopadhyay)

The resistance screening technique for grain mold resistance currently being used imposes very high selection pressure because wet conditions are maintained throughout the post-flowering growth stages. Although wet conditions are the overriding factor determining grain mold epidemics, the specific effect of wetness at different post-flowering stages on grain mold infection and severity is

not clear. Better information on these relationships will allow design of a realistic wetness regime with the variable mold pressure necessary to identify genotypes with moderate levels of resistance.

We conducted field experiments during the 1997-99 rainy seasons to determine the effect of wet and dry conditions during different post-flowering stages until grain maturity, using a moderately resistant and a susceptible genotype. All treatments, except a treatment for natural conditions, were maintained under rain-free conditions under polyethylene shelters over plots. Panicles were wetted at required stages with a wetness-sensor-linked misting system. Severity of different mold fungi was recorded individually at 3-5 day intervals. Grain infection was monitored by plating developing grains on fungal growth medium several times during grain filling.

Results of the experiment during the 1999 rainy season, a low rainfall year, are reported here (Table 3.1.1). Irrespective of genotype, the least mold developed in non-wetted plants under the shelter (T2) and the maximum mold developed when panicles were wetted from hard dough stage until harvest two weeks after maturity (T8). Dry conditions after black-layer formation (T3, T4 and T6) stopped further development of mold in the moderately resistant genotype. In the susceptible genotype, however, mold continued to increase albeit at a much lower rate compared to wet conditions (T5, T7 and T8). In both genotypes, less mold developed when panicles were wetted from milk stage to black-layer formation and then not wetted after black-layer formation (T4) than when panicles were not wetted from milk stage to black-layer formation and then wetted after black-layer formation (T7).

Table 3.1.1. Field grain mold rating of all fungi on panicles of a susceptible (Bulk Y) and a moderately resistant (IS 18758C) sorghum genotypes exposed to different wetness treatments, rainy season, 1999, Patancheru.

Treat-Ment	Description [2]	Grain mold score[1]			
		Bulk Y		IS 18758C	
		PM	PM+14	PM	PM+14
T1	Natural conditions throughout	7.1	8.7	3.7	4.6
T2	Shelter (no rain) throughout	3.2	3.7	2.0	2.0
T3	E – mist; L1 and L2 – shelter	4.4	4.4	2.3	2.3
T4	E and L1 – mist; L2 – shelter	8.6	8.6	3.5	3.5
T5	E – mist; L1 – shelter; L2 – mist	7.0	8.7	2.3	5.7
T6	E –shelter; L1 – mist; L2 – shelter	8.8	8.9	3.4	3.5
T7	E and L1- shelter; L2 –mist	3.8	7.6	2.0	5.5
T8	E – shelter; L1 and L2 –mist	8.7	9.0	3.4	6.8
	SE(±)	0.34	0.11	0.08	0.26

1. Grain mold scored on a 1-9 scale where 1 = no mold, and 9 = >75% mold. Data recorded at physiological maturity (black-layer formation, PM) and 14 days later (PM+14).
2. E = milk to soft dough (SD) stage, L1 = SD to PM, and L2 = PM to post-PM.

Grain mold severity is thus controlled primarily by the extent of wetness at and after black-layer formation. It should be possible to induce different levels of moldiness on sorghum genotypes in the field by varying duration of wetness at post-flowering stages. Treatments T8 (maximum mold), T7

(moderate levels of mold) and T3 (less mold) are good candidate treatments that can be used further to identify mold resistance under variable disease pressure.

Activity 3.1.2: Characterization of variability in the anthracnose pathogen and identification of resistance to panicle anthracnose.

Characterization of the genetic and pathogenic variability and virulence pattern among pathogen isolates from India (R P Thakur)

The sorghum anthracnose pathogen, *Colletotrichum graminicola* (Ces.) Wilson, infects leaves, stalks, peduncles and panicles causing substantial loss to both grain and forage production. Host plant resistance, the best strategy to control this disease, has been difficult to achieve because of large genetic variability in pathogen populations. Understanding temporal and spatial virulence shifts should help develop strategies for identifying and deploying resistance to better manage this disease.

Virulence monitoring in the pathogen was done by analyzing field isolates for virulence, and through the collaborative International Sorghum Anthracnose Virulence Nursery (ISAVN). Field surveys were undertaken in India and Nigeria. Isolates were analyzed for morphological and cultural variability, and for virulence. Some of the Indian isolates were also analyzed for genetic diversity using RAPD markers. Surveys indicated large variation in symptom types and susceptibility levels of cultivars in farmers' fields. We collected about 200 samples (isolates) in India and 50 in Nigeria for determining pathogenic and genetic diversity. Detailed analysis classified 50 isolates collected in Nigeria (from Sahel, Sudan, northern Guinea and southern Guinea zones) into nine morphological groups and seven pathogenic groups. These were further grouped into five putative pathotype groups based on host differential reactions. These results indicate the existence of five pathotypes or putative races of *C. graminicola* in major sorghum growing zones of Nigeria and support the results of ISAVN (1992-1998).

The ISAVN consisted of 15-18 sorghum lines, originating from different geographical areas of the world, that had shown differential reactions to the existing populations of the pathogen in earlier nurseries. The ISAVN data over 7 years across 19 locations revealed that at the global level, *C. graminicola* populations could be classified into five major virulence groups; the most virulent being populations at Pantnagar (India) and Griffin (USA), followed by populations at Mansa (Zambia), Bagauda and Samaru (Nigeria), Alupe (Kenya) and Surat (India), Udaipur, Kovilpatti, Indore (India), and avirulent at Dharwad (India) and Bangkok (Thailand). Sorghum line IS 18758 was resistant at all locations and thus it seems to possess stable resistance, and likely multiple genes for stable resistance. Several other lines exhibited resistance to local pathotypes and these could be potential sources of resistance for utilization in local resistance breeding programs.

Although virulence characterization through field surveys and the collaborative nursery has proved useful, identification and characterization of resistance genes, and development of near-isogenic lines will provide a more powerful tools for monitoring virulence change in *C. graminicola* populations. Use of molecular techniques to identify anthracnose resistance genes against different pathotypes would help resistance breeding and strategic deployment of resistance to manage this disease.

Activity 3.1.3: Quantification of components of resistance to late leaf blight in inter-specific derivatives of groundnut

Components of resistance to late leaf blight in groundnut (S Pande)

Current levels of heritable resistance to late leaf spot *(Phaeoisariopsis personata)* in cultivated groundnut are considerably inferior to the resistance available in certain wild species. In order to better focus our search for improved resistance, we compared the disease development in five resistant inter-specific groundnut lines (ICGVs 86699, 94108, 94118, 96283, and 96284) derived from *A. Cardenasii, A. batizocoi*, and *A.durranensis*, along with that in two known *A. hypogaea* susceptibles (TMV 2 and Robut 33-1) in both field and greenhouse environments. The components of resistance evaluated were incubation period (IP), latent periods from infection to first lesion sporulated (LP_1), and 50% lesions sporulated (LP_{50}), lesion number (LN), lesion frequency (LF), lesion diameter (LD), sporulation index (SI), percentage of leaf area damage (LAD) and percentage of defoliation (DF).

All five inter-specific derivatives showed significant longer IP, LP_1 and LP_2 (Table 3.1.3). Additionally the inter-specific lines had lower LN, lower LF, smaller LD, lesser SI, lesser LAD, and lesser DF than the susceptible cultivars in both environments. Correlation analysis in both the environments, indicated highly significant ($P< 0.005$) positive correlations among IP, LP_1, and LP_{50}, and highly significant negative correlations between these three components and LN, LF, LD, SI, LAD, and DF for all inter-specific derivatives.

Table 3.1.3. Least square means (of 3 replications) for components of resistance to late leaf spot disease for selected medium-maturing inter-specific derivatives of groundnut genotypes in field and greenhouse environments. Components (measured in days) incubation period (IP), latent period from inoculation to first sporulating lesion (LP_1) and latent period from inoculation to 50% lesions sporulated (LP_{50})

Genotype	IP (d)		LP_1 (d)		LP_{50} (d)	
	Field	Greenhouse	Field	Greenhouse	Field	Greenhouse
ICGV 86699	16.7	15.2	25.0	24.8	34.2	32.2
ICGV 94108	14.2	13.2	19.8	17.8	25.5	22.2
ICGV 94118	14.2	12.0	20.2	18.0	26.2	22.7
ICGV 96283	16.8	15.0	25.5	25.2	34.2	31.8
ICGV 96284	16.7	15.2	25.8	25.5	34.0	32.3
Robut 33-1	10.7	8.0	16.8	16.0	20.0	19.8
TMV 2	9.8	10.0	14.3	14.5	17.5	17.5
SE	±0.35		±0.55		±0.4	

These studies confirmed the availability of higher levels of resistance to LLS in the wild *Arachis* species, due mainly to the extended period of incubation and latent period that restricts the colonization of LSS pathogen and the progress of the disease. Possibly a similar form of resistance operates with respect to *Puccinia arachidis* (rust disease) of groundnut.

Activity 3.1.4: Development of cost effective tools for quantification of aflatoxins and components of integrated aflatoxin management in groundnut

Development of cost-effective tools for quantification of aflatoxins (D V R Reddy)

The standard laboratory methods formerly used for aflatoxin analysis are time consuming, require extensive processing of samples and are relatively expensive. For large scale analysis of groundnut samples it is essential to have rapid and cost-effective tools, such as immunological analyses, for the quantitative estimation of aflatoxins. Additionally, the technology should be readily applicable to situations that exist in developing countries.

Aflatoxin B1 conjugated to bovine sum albumin (BSA-aflatoxin) was injected in to rabbits at different intervals. The serum was drawn at various intervals and the titer measured by ELISA. Bleeds were collected after the titer were found to be adequate for performing ELISA tests. Indirect competitive ELISA was used. Wells were coated with BSA-aflatoxin. Competition with antiserum was done in the wells of ELISA plate. Aflatoxin B1 standards were used starting from 0.1 ng to 100 ng/ml. Antibodies attached to the aflatoxin-BSA were detected by goat antirabbit IgGs labeled with alkaline phosphatase. Substrate for the enzyme was p-nitrophenyl phosphate. Absorbance values were recorded at 405 nm in an ELISA reader, for aflatoxin B1 standards as well as for test samples.

Concentrations of Afl-BSA, for coating the plates dilutions of antisera and enzyme conjugates to obtain optimum reaction were worked out. Afl-BSA at 150 ng/ml was found to be optimum for coating the plates. Antiserum diluted to 1:25,000 gave the most satisfactory regression curves with different concentrations of AfB1. In order to test the consistency of results, each sample was replicated at least three times. Results were compared with analysis done independently at ANGRAU, Rajendranagar, by HPLC, to assess the reliability of the procedure There is good agreement between ELISA and HPLC tests.

We have been undertaking analysis of samples for aflatoxin content, on payment, from external sources. During 1998 and 1999 we analyzed more than 550 samples of groundnut seed and cake, maize, rice, cotton seed cake and feed mixtures for both public and private agencies.

Identification of biocontrol agents for *Aspergillus flavus* (R P Thakur, V Anjaiah and O P Rupela)

Biological control of aflatoxin contamination is one of the potential components of integrated aflatoxin management in groundnut. Identification and characterization of fungal and bacterial antagonists to *A. flavus* and determining their potential as biocontrol agent is the focus of this research.

We screened 70 isolates of *Trichoderma* species against four selected strains of *A. flavus* using dual-culturing methods in petri plates . Four isolates, two each of *T. harzianum* and *T. viride* were found to be promising antagonists. Several bacterial isolates obtained from groundnut rhizosphere soils at ICRISAT were screened against selected *A. flavus* isolates and five potential

antagonists identified. These are being evaluated for their effectiveness in suppressing *A. flavus* populations in pot experiments.

Five of the 12 bacterial isolates tested on groundnut plants were confirmed as non-pathogenic and safe for use as biocontrol agents. Morphological and physiological characterization of these strains indicated that all are non-sporulating, gram-negative rods. Three strains were identified as fluorescent *Pseudomonas*. The analysis of PCR amplification of *oprI* gene and iso-electric focusing of siderophores confirmed these as group I fluorescent pseudomonads. These strains were identified as *P. fluorescens*, *P. fluorescens* biotype F and *P. aurantiaca* on the basis of biochemical and molecular analyses. Further, biochemical analysis is in progress for identification of other two bacterial strains. The antifungal compounds produced by all these strains were isolated from the culture supernatants and tested to confirm for *in vitro* antagonism. All these are being evaluated for their effectiveness in suppressing *A. flavus* population in pot experiments.

Effectiveness of biocontrol agents to suppress *A. flavus* populations (R P Thakur and V Anjaiah)

The effectiveness of antagonists is determined from their ability to suppress soil populations of the test pathogens and reduce subsequent infection to the host. Pre-harvest aflatoxin contamination in groundnut occurs at the seed development stage by the toxigenic *A. flavus* population inhabiting the field soil. Experiments were conducted to determine the effect of antagonists in reducing *A. flavus* population in soil.

A preliminary pot experiment was conducted in the greenhouse using *A. flavus*-infested soils and two antagonists, *Pseudomonas fluorsecens* (TNAU) and *Trichoderma* sp. (ICRISAT). The antagonists were applied at sowing and peg formation stages of cvs. J 11 and JL 24 resistant and susceptible, respectively, to *A. flavus* colonization, and *A. flavus* populations were monitored.

The rhizosphere population of *A. flavus* in cv. JL 24 was higher than in cv. J 11. Inoculation of antagonists resulted in significant reduction of *A. flavus* population in the rhizosphere. Bacterial inoculation at sowing was more effective than at pegging in both cultivars. The effectiveness of *Trichoderma* inoculation was similar at both stages of application. The overall seed infection by *A. flavus* was reduced significantly in antagonist-applied treatments, compared to controls in both cultivars. The experiment will be repeated in greenhouse to confirm the results before it is taken to the field.

Activity 3.1.8: Characterization of a novel virus involved in the etiology of pigeonpea sterility mosaic disease, and description of the mechanism(s) of differential host reaction

Characterization of casual virus in pigeonpea sterility mosaic disease (D V R Reddy)

After 25 years of research at ICRISAT we have made the break through in identifying the causal agent of pigeonpea sterility mosaic disease, which has been estimated to cause over 90 million dollars worth crop losses annually. The disease is widely distributed in India; many pigeonpea

lines identified as resistant in 1980's have now become susceptible presumably due to the appearance of new virus isolates. The only method currently available for disease identification is by symptoms and mite transmission. Symptomatology is unreliable because the pathogen can cause wide variation in symptoms. Mite transmission is laborious. Therefore only viable option for detecting the pathogen is by the characterization of the causal virus (we know now it is a virus) and subsequent development of ELISA-based diagnostic tools.

Purification protocols for the causal virus, pigeonpea sterility mosaic virus (PPSMV), are being developed. A total of 32 samples on infected pigeonpea, obtained from five different locations, were subjected to the purification protocols. Virus obtained following gradient analysis was examined under an electron microscope. All of them contained flexuous rod shaped particles and in gels a 32 kDa protein was detected.

Monitoring of breeding populations and various pigeonpea genotypes will be undertaken following the development of diagnostic tools. Twelve differential pigeonpea types were sown in three locations, Patancheru, Bangalore and Varanasi. The twelve differentials produced reacted differently at Patancheru and in Bangalore, indicating the possibility that the isolate of the causal virus in Bangalore may be different from that in Patancheru. At both the locations ICP 7035 was found resistant to the virus on the basis of absence of visual symptoms.

Activity 3.1.9: Epidemiology of groundnut clump and bud necrosis diseases

Identification of alternate hosts for peanut bud necrosis virus (D V R Reddy)

Weedy plants collected in and around the groundnut fields were tested by ELISA. *Euphorbia hirta, Amaranthus virdis, Indigofera linifolia, Abutilon indicum, Acalypha indica, Evolvules alsinoides* and *Chrozophora rottleri* have been shown to contain the peanut bud necrosis virus (PBNV) antigens. In nucleic acid hybridization tests, in addition to these hosts, *Mukia maderaspatana, Brachiaria eruciformis, Commelina bengalensis* and *Aristidia adsensionis* were also shown to be infected with PBNV. All the weeds mentioned have also been shown to support the multiplication of the thrips vector, *Thrips palmi*. Thus they have the potential to act as sources of inoculum.

Objective 3.2: To understand the mechanisms and genetics of resistance or tolerance to pest and parasite constraints to crop production (insects, *Striga*, and nematodes) and to establish effective selection procedures for resistance

Rationale: It is necessary to have a basic knowledge of the biology of the pest and the nature, mechanisms, and genetics of host plant tolerance/resistance, and the effects of environment and genotype by environment interaction on pest damage, in order to design effective selection procedures for resistance or management methods for reducing damage. This objective focuses on the understanding of these basic requirements, and the development of effective resistance

screening procedures or IPM methods, where these are needed, in order to make progress in identifying and using genetic resistance and/or IPM technology.

Activity 3.2.2: Selection criteria, mechanisms and inheritance of resistance to sorghum insect pests

Genetics of resistance to head bug and midge (A Ratnadass)

The mirid panicle-feeding bug, *Eurystylus oldi*, is a major threat to increasing sorghum production through the extension of improved, but largely head bug susceptible caudatum cultivars. The genetic basis of resistance to *E. oldi* which is available in a few cultivars, is largely unknown. The elucidation of the inheritance of this resistance could help to determine the appropriate breeding procedure for transferring this resistance into high-yielding backgrounds.

A detailed genetic analysis of sorghum resistance to head-bug (*E. oldi*) and midge (*Stenodiplosis sorghicola*) was done with the help of CIRAD geneticists and biometricians, using an F1-based complete diallel involving four parental lines (head-bug resistant Malisor 84-7 and 87W810, and susceptible S 34 and ICSV 197), conducted at Samanko, Mali, in 1995 and 1996.

Diallel analyses showed that general combining ability (GCA) and thus additive gene effects were very important in the inheritance of resistance to both pests. Specific combining ability (SCA) and maternal effects were generally of minor importance. Mean performance of the parents and their GCA effects were strongly correlated.

Head-bug resistant parents, Malisor 84-7 & 87W810, with high *per se* resistance and negative GCA should be used in breeding for resistance to this pest, while for a similar reason, ICSV 197 should be used in breeding for midge resistance.

Standardization of screening and selection criteria for resistance to spotted stem borer, *Chilo partellus* (H C Sharma)

We evaluated a range of sorghum lines/ progenies for resistance to the spotted stem borer using a paired plot technique, in which two rows were infested artificially with lab-reared insects, and the other two rows were retained as an uninfested control. The performance of the plants in the infested plots was compared with the control plants of the same cultivar to assess the overall effect of borer damage on plant growth and yield. Data were recorded on leaf damage, deadheart formation, tiller production, plant growth at the boot stage, tiller production following borer damage, grain yield, plant height, stem and peduncle tunneling, and borer entry/exit holes

In a set of advanced breeding lines selected for resistance to stem borer, leaf damage rating (LDR) ranged from 3.7 to 7.0, deadhearts (DH) from 5 - 37%, resistance score (RS) (extent of damage in the infested plots relative to the uninfested control) from 4.3 to 7.7, and recovery resistance (RR) from 2.7 to 6.0. Lines ICSV 96070, ICSV 96074, and ICSV 96080 had <10% deadheart incidence compared to 37% in ICSV 1. Genotypes ICSV 93057 and IS 2205 showed the least borer damage and minimum effect on plant growth.

In F_4 progenies derived from a grain mold x a borer resistant line, LDR ranged from 0.3 to 7.7, DH from 21 to 95%, RS from 4.3 to 8.7, and RR from 3.3 to 7.3. The levels of borer resistance in these lines were much lower than in the lines which had earlier been selected under borer infestation. GM 968490 -1, GM 968491-1, GM 966349-1-bk, GM 966049-1-bk, and GM 966459-1-bk had <30% deadheart incidence compared to 61% in ICSV 1.

In an experiment involving sources of resistance to stem borer, and diverse lines from different geographical regions, LDR ranged from, 3.0 to 7.7, DH from 32 to 88%, RS from 2.7 to 7.0, and RR from 2.0 to 6.3. IS 1044 showed <40% deadheart incidence compared to 88% in CSH 9.

These data will be used to develop selection criteria for borer resistance, by assigning weightings to different kinds of damage caused by the borer larvae, based upon their ability to discriminate among test genotypes.

Antixenosis and antibiosis mechanisms of resistance to spotted stem borer (H C Sharma)

To identify sorghum genotypes with diverse mechanisms of resistance to stem borer, Chilo partellus, we evaluated 25 sorghum genotypes under greenhouse and laboratory conditions for antixenosis and antibiosis components of resistance. There was considerable variation among the borer-resistant genotypes tested for nonpreference or antixenosis for oviposition. Genotypes IS 2123 and IS 13100 were highly nonpreferred for oviposition by *C. partellus* females in both the tests. Genotypes showing antibiotic effects included IS 2205, IS 2309, IS 1054, ICSV 714, and ICSV 743. It is suggested that lines showing different combinations of characters associated with resistance can be used in breeding programs to increase the levels and diversify the basis of resistance to stem borer.

Activity 3.2.3: Development of screening techniques for mechanisms of resistance to *Striga*

Description of the reaction of wild millets (subspp. *monodi* and *stenostachyum) to Striga hermonthica* infestation (D E Hess)

Certain wild relatives of pearl millet, notably *P. monodii*, (primary gene pool), *P. squamulatum* (tertiary gene pool) and napiergrass (*P. purpureum*) have been shown to possess resistance to a number of major millet diseases and pests. To determine if wild species are also a potential source of resistance to *Striga hermonthica*, germplasm from the primary, secondary, and tertiary gene pools were evaluated for resistance, along with putative resistant cultivated millet and sorghum germplasm lines and cultivars.

In 1998, 276 wild millet accessions from the primary gene pool (a collection of *P. glaucum* subspp. *monodii* and *stenostachyum*) were screened for reaction to *striga* infestation in the field in Mali (Cinzana and Samanko) and Niger (Sadoré). In addition, a set of crosses between wild and cultivated parents were evaluated at Sadore' and Cinzana. In 1999, nineteen entries from the pearl millet secondary gene pool (crosses between wild and cultivated parents) and 46 entries from the tertiary gene pool were re-evaluated at Niamey and Samanko In both years, 23 cultivated pearl millets with possible resistance were re-evaluated in the field at Sadoré and

Samanko, and a selection of pearl millet and sorghum lines were evaluated for stimulation of *striga* seed germination in the agar gel test.

Across all 1998 trials, maximum *striga* emergence was correlated ($P<0.01$) positively with *Pennisetum* flowering date, and negatively ($P\leq0.05$) with downy mildew incidence and date of *striga* emergence. Resistance indices were developed to account for the relationships between maximum *striga* counts and the other variables. When observed *striga* counts were compared by Fisher's lsd, 84% of the germplasm collection did not differ from the most resistant accession. With different resistance indices, the percentage of the germplasm collection that did not differ from the most resistant accession ranged from 37 to 47%. When all four resistance indices were used for comparisons, only 31% of the collection could be considered resistant. When observed *striga* counts were used, 144 accessions were falsely classified as resistant, while 1 accession was falsely classified as susceptible. Because several variables not directly related to genetic resistance are related to maximum *striga* emergence, use of the resistance indices may allow more consistent identification of resistance to *striga*. All entries tested in-vitro showed low levels of *striga* seed germination stimulation.

Pearl millet lines ICMV IS 85327 and ICMV IS 85333 had a 40% - 56% lower *striga* infestation in the field, compared to the local cultivar at both Cinzana and Sadoré in two years. There was considerable variability for stimulation of *striga* seed germination among the sorghum lines tested in the agar gel test. Twenty one percent of the 34 Guinea sorghum population entries were low stimulant lines and may lend themselves to development of resistant lines; 24% were very high stimulators of *striga* seed germination. Fourteen percent of the 28 farmer-selected varieties were also low stimulant lines (ICSV 1079, Framida, IS 15401 and CMDT 48).

Ten Malian pearl millet lines (selected for improved field reaction to *striga*) provided evidence of genetic variability among the *striga* populations at the three test locations, underlining the need to target host genotypes in *striga* management approaches. All of the millets were high stimulators of *striga* seed from Sadoré (*striga* population adapted to pearl millet); one line (IKMV 8201) showed reduced stimulation of *striga* seed from Bengou (also adapted to pearl millet); two lines (Boboni 98 CZ and Mankakolo 93 CZ) are high stimulators of *striga* seed from Samanko (*striga* population adapted to sorghum).

Activity 3.2.4: Identification, mechanisms, inheritance and utilization of new genetic resistance to *Helicoverpa armigera*

Components of resistance to *Helicoverpa armigera* in wild relatives of pigeonpea (H C Sharma)

To identify germplasm accessions with diverse mechanisms of resistance to *Helicoverpa armigera*, 23 accessions of wild relatives of pigeonpea were tested during the 1998-99 rainy season under natural field infestation. Five pigeonpea cultivars (ICPL 332 - resistant; ICPL 187-1, ICPL 84064, and ICP 7203-1 - moderately resistant; and ICPL 87 - susceptible) were included as resistant and susceptible controls.

No eggs of *H. armigera* were recorded on *A. scarabaeoides* (ICPW accession nos. 68, 90, 94, 116, 125, 130, 137, 141, 152, 278, 280, 281, and *A. scarabaeoides* Sel-1), *A. cajanifolia*, and *A. sericeus* (Table 3.2.4). *Rhyncosia bracteata* and *A. albicans* were, however, as preferred for oviposition as the cultivated pigeonpeas. The range in numbers of eggs per 10 inflorescences was large among the pigeonpea cultivars tested, ranging from only 12 eggs per 10 inflorescences on ICPL 332 to 69 on ICPL 87 in the first observation (Table 3.2.4). In the second observation, there were 2 to 7 eggs per 10 inflorescences on ICPL 187-1, ICPL 332, ICPL 84060, and ICP 7203-1 compared to 23 eggs on ICPL 87. Thus, oviposition preference seems to be one of the components of resistance to *H. armigera* in both the wild and *Cajanus cajan*.

There were no larvae of *H. armigera* on 12 accessions of *A. scarabaeoides* (ICPW nos. 83, 94, 116, 125, 130, 137, 141, 152, 278, 280, and 281), *A. cajanifolia*, and *A. sericeus*. Nine larvae per 10 inflorescences were recorded on *A. platycarpus* (ICPW 68) and *A. scarabaeoides* (ICPW 90) in the second observation. *Rhyncosia bracteata* and *A. albicans* had 7 larvae per 10 inflorescences in first observation and 6 to 60 larvae in the second observation. Among the pigeonpea cultivars tested, there was a low of only 3 larvae per 10 inflorescences in ICPL 332 to 64 on ICPL 87 in the first observation. In the second observation, there were 17 to 27 larvae per 10 inflorescences on ICPL 187-1, ICPL 332, ICPL 84060, and ICP 7203-1 compared to 44 larvae on ICPL 87(Table 3.2.4). Thus, resistance in pigeonpea to *H. armigera* seems to be the function of lower larval density during flowering and pod development, which in turn is a function of oviposition preference by *H. armigera* females. ICPW 90 and *A. cajanifolia* had no damage in the pods collected from the marked portion of the inflorescence

Table 3.2.4. Oviposition and larval abundance of *Helicoverpa armigera* on wild relatives of pigeonpea (ICRISAT, Patancheru, 1998 rainy season). Data are means of observations on 3.11.98 (I) and 4.1.99 (II), between 0 to 29 days after flowering for all species

Genotype	No. of eggs per 10 inflorescences		No. of larvae per 10 inflorescences	
	I	II	I	II
Wild species	0.0	0.0	0.0	9.4
Cajanus platycarpus ICPW 68				
C. scarabaeoides – ICPW 83	0.0	0.0	0.0	0.0
C. cajanifolia	0.0	0.0	0.0	0.0
C. sericeus	0.0	0.0	0.0	0.0
Rhynchosia bracteata	0.0	6.0	0.0	60.0
C. albicans	0.0	1.0	0.0	6.0
Cajanus cajan				
ICPL 332	12.0	4.0	3.0	21.0
ICP 7203-1	43.0	2.0	42.0	17.0
ICPL 84060	29.0	5.0	15.0	27.0
ICPL 187-1	39.0	7.0	24.0	20.0
ICPL 87	69.0	23.0	64.0	44.0
Mean	9.1	2.3	7.1	9.4
SE[1]	±0.88	±0.24	±0.8	±0.41

Activity 3.2.6: Development of the components of integrated pest management systems for major legume pests in eastern and southern Africa

Distribution, origins, host range, and natural enemies of pigeonpea pod borers in Malawi (E Minja)

This activity was conducted as part of the collaborative CABI-Bioscience/International Institute of Entomology/DFID Global Project on legume pod borers. Insect pests constitute one of the major biotic constraints to pigeonpea production in the southern Africa region. Pod borers are among the key pests that damage flower buds, flowers, pods, and seeds. Other key insect pests include pod sucking bugs and pod fly.

Surveys were carried out in the pigeonpea growing areas of southern Malawi during August 1999. Samples of pods, legume pod boring pests, and natural enemies were collected from cultivated and wild hosts. Malaise traps were set at different locations to collect both pests and their natural enemies. Pods, pests, and natural enemies were examined in the laboratory, identified as far as possible, and unidentified samples preserved for identification by CABI/IIE.

Two additional borers that feed on pigeonpea seeds in southern Malawi and in other parts of the region have now been identified as *Leguminivora ptychora* (Tortricidae) and *Pardasena virgulana* (Noctuidae). A parasitoid on *Lampides*, *Neotypus intermedius* (Ichneumonidae) has also been identified for Malawi. *Etiella* sp. and the *L. ptychora* were also collected from pods of the fish bean plant (*Tephrosia vogelii*), and from cultivated and wild *Crotalaria*. *Tephrosia* is a legume shrub that is being promoted in Malawi for green manuring, agro-forestry, and a source of natural insecticide (leaves). The cowpea pod borer, *Maruca vitrata* was collected from *Dolichos*. Damage from *Helicoverpa armigera* was observed on pigeonpea, soyabean, *Dolichos*, *Phaseolus* beans, tomatoes, and *Crotalaria*. *Lampides* was also recorded on cultivated and wild *Crotalaria*, dolichos, and beans.

The legume borer pests, natural enemies, and alternative hosts that are documented comprise the first set of information in the region for the global project. Such information is vital as baseline data towards the search for IPM components.

Host plant resistance to aphids in groundnut (E Minja)

Aphis craccivora (Koch) is a major pest of groundnut (*Arachis hypogaea* L.) causing yield losses by feeding on phloem sap and transmitting groundnut rosette virus (GRV). Host plant resistance to the aphid in groundnut is recognized as the most effective, economic, and sustainable method of limiting the spread of the aphid and the viruses. Breeding lines and elite groundnut varieties with field resistance to rosette virus were screened for aphid resistance during the 1998/99 cropping season.

Seeds of 41 groundnut genotypes were sown in plastic pots in 10 replications in the screen house. A single first instar aphid nymph from a colony reared on a standard genotype was each introduced on to the third leaf of each seedling. The aphids were left to feed and reproduce freely on the plant. The colonies were counted at 10 and 15 days after first instar infestation (DAFI).

The first instar nymphs established on all genotypes tested (Table 3.2.6). The rate of nymph growth and time taken to produce offspring nymphs varied between genotypes. Aphid fecundity counts at 10 and 15 DAFI showed that ICG 12991 had the lowest rate of nymph development, low fecundity, and relatively smaller sized aphids compared to EC 36892, CG 7, and JL 24. The other genotypes showed varying degrees of resistance to *A. craccivora* by reduced aphid growth and fecundity. Among the breeding populations, 60% showed higher levels of resistance than EC 36892. JL 24 was most susceptible.

Screening for aphid resistance should continue in the screen house and fields to evaluate wild *Arachis* species and other potential resistance sources for utilization in breeding programs in the region.

Table 3.2.6. Mean aphid populations on rosette-resistant F_6 groundnut lines and control cultivars at 10 and 15 days after first instar infestation (AFI) in caged posts

F6 groundnut lines	Aphids/plant 10 d AFI	Aphids/plant 15 d AFI
ICGX-SM 94101/P1	14.3	92.7
ICGX-SM 94101/P7	19.7	49.4
ICGX-SM 94104/P5	19.5	72.2
ICGX-SM 94104/P10	18.6	93.0
ICGX-SM 94108/P1	15.0	46.1
ICGX-SM 94108/P3	18.2	69.9
ICGX-SM 94109/P2	20.3	43.0
ICGX-SM 94109/P3	16.8	66.1
Control varieties		
JL 24	42.8	265.6
EC 36892	29.2	209.2
CG 7	32.0	294.7
ICG 12991	9.0	14.8
Mean	25.2	105.7
SE	4.26	22.01
LSD (5%)	11.85	61.28

Objective 3.3: To understand the mechanisms and genetics of tolerance to abiotic constraints to crop production (drought, extreme temperatures and inadequate nutrients) and to establish effective selection procedures for tolerance

Rationale: It is necessary to have a basic knowledge of the effects of environmental stress on crop growth and yield, the nature and genetics of host plant traits which confer useful tolerance to stress, and the effects of environment and genotype by environment interaction on the expression/effectiveness of these traits, in order to design effective selection procedures for tolerance to stress. This objective focuses on the understanding of these basic requirements, and the development of effective screening procedures for tolerance or for its underlying traits, where this is needed in order to make progress in identifying and using genetic tolerance in reducing losses to various environmental stresses.

Activity 3.3.1: Evaluation of adaptive traits for improving yield of sorghum in drought-prone regions

Assessment of the value of stay-green for drought resistance in sorghum (V Mahalakshmi)

The adaptive trait for drought, non-senescence or "stay green" stay green, was evaluated in sorghum in two experiments in the 1997/98 and 1998/99 post rainy seasons. The first experiment, divergent selection for the trait (stay green and senescent lines), was repeated for the second year. The first year data were analyzed for the stay green and grain productivity traits. The divergent groups expressed the selected character (stay green) truly, though there were few crossovers. The second year data is awaiting analysis. The two year's data, including the stover quality data (which is yet to come), will be combined to prepare a conclusive archival report and hopefully a journal article.

The second experiment contained 81 putative stay green source lines, which were evaluated for stay green expression. Percentage green leaf area at 45 days after flowering (approximate physiological maturity) ranged from 0 to 60%. There were a few new source lines with as good an expression of stay green as the standard source line B35. This experiment is being repeated in the current rabi season (1999/2000); a conclusive report on stay green in these two experiments will be available next year.

Activity 3.3.2: Development of drought tolerant groundnuts using novel selection tools and trait-based breeding

Understanding of the gene action controlling transpiration efficiency and harvest index (S N Nigam)

The empirical approach currently being followed in breeding for resistance to drought in groundnut at ICRISAT, although successful, is considered inefficient and slow. Selection efficiency should be improved if physiological traits associated with drought resistance or their simple surrogates can be incorporated in the selection index. The near-term objectives

associated with the milestone are: (1) to compare efficiency of the trait-based selection scheme with that of the empirical approach currently used in drought resistance breeding at ICRISAT, and (2) to study the inheritance of physiological traits associated with drought resistance or their surrogates in groundnut.

The first cycle of selection was done in the post rainy season in $F_{2:3}$ progenies of four crosses between parents differing in specific leaf area (SLA, a surrogate for transpiration efficiency) and harvest index. Empirical selection consisted of visual selection for pod yield under moisture stress conditions. Trait-based selection was carried out under non-limiting moisture conditions, using a selection index that consisted of harvest index (HI), transpiration efficiency (W), and total transpiration (T). The both selection procedures were repeated in the following generations. A replicated trial of various generations (P_1, P_2, F_1, F_2, BC_1, and BC_2) of six crosses for inheritance study was planted in the 1998/99 post-rainy season to record observations on traits associated with W and HI.

From the studies carried out in Australia and India, a strong negative relationship was established between SPAD meter values (a measure of relative amount of chlorophyll present in plant leaves) and SLA (r = -. 87). It suggested that the SPAD meter could be used as a rapid and reliable correlated measure of SLA and, hence the W. The following selection index was developed for use in trait-based selection scheme:

SI = [{HI-med (HI)}/QR (HI)]+[{W-med (W)}/QR (W)]+[{T-med (T)}/QR (T)]
Where med stands for median and QR for quartile range.

In the 1999 rainy season, 50 $F_{2:4}$ progenies form each cross under trait-based selection procedure were sown for further selection to bring the number of selected progenies down to 10 for each cross. The number of selected progenies in the empirical approach was to be brought down to 10 for each cross after the rainy season. However, the severe rust epidemic at the Center interfered with selection process. All the progenies will be grown again in the 1999/2000 post-rainy season for final selection before multilocation evaluation in the 2000 rainy season.

Four crosses were completed to develop recombinant inbred lines for traits associated with water use efficiency. Observations on SLA, SPAD values, and HI recorded at three stages of plant growth and shelling percentage for inheritance study were brought in analysis-ready form.

The rust epidemic at ICRISAT in the 1999 rainy season caused a set back to the time schedule of this project, which is funded by ACIAR. In the 1999/2000 post-rainy season, the experiment is being repeated at all locations (Junagadh, Jalgaon, Tirupati, and ICRISAT) with simultaneous seed increase of promising progenies. It is hoped that this step will enable us to have multilocation trials in the 2000 rainy season. The data on inheritance study will soon be analyzed after the planting of our post-rainy season crop.

Activity 3.3.4: Complete assessment work on selection methodologies for tolerance to seedling heat stress and terminal drought in pearl millet for arid areas

***Selection criteria for terminal drought tolerance and seedling heat tolerance in pearl millet* (F R Bidinger)**

Drought and high temperature stress are characteristic features of more marginal pearl millet growing environments; landraces which evolved in these environments have a degree of tolerance not often found in introduced breeding materials. Breeding programs targeting such environments need to be able to incorporate/retain this adaptation in new products. This activity is the final stage of a long term research on methods of applying selection pressure for tolerance to both terminal drought stress and seedling heat stress.

The project is currently (1) completing evaluation of the effectiveness of panicle harvest index (PNHI) as a selection criteria for tolerance to terminal drought stress in the breeding of hybrid parents, the selection of experimental varieties from composites and the improvement of open-pollinated varieties, (2) completing a comparison of methods for improving seedling heat tolerance with collaborators in the UK. Much of the evaluation data accumulated over the past 6-8 years has now been analyzed and digested and is awaiting formal publication.

Divergent selection for and against PNHI under terminal stress in B- and R- line test crosses produced significant differences in PNHI and grain yield under stress in subsequent evaluations (4 years) of hybrids made with the selected lines. Selection for PNHI under stress had no effect on either PNHI or grain yield in non-stress conditions. Hybrids made with the best of the high PNHI selections had a 9-10% yield advantage under stress over the mean of the trial (combined high and low PNHI selections).

A comparison of experimental varieties based on selection for PNHI under stress with selection for grain yield in the absence of stress demonstrated (1) the importance of selection in stress environments for performance in stress environments (where the variety selected for yield in the absence of stress 5-19% less than an unselected control), and (2) that selection for PNHI under stress had no cost in non-stress test environments and resulted in modest (2-8%) gains in yield in stress environments, compared to an unselected control.

Seven open pollinated varieties have been subjected to one cycle of S1 progeny selection for a high PNHI under terminal stress. Full scale testing will begin in 2000.

Experimental varieties and their test crosses selected for and against seedling heat tolerance in the field, under simulated field conditions in the growth chamber, and selected for membrane thermo-tolerance in the laboratory were evaluated in five different field experiments in 1998 and 1999 in Jodhpur. The stress levels were extreme in 1998, affecting emergence of many test entries; differences in survival between selection alternatives were small. The data from the 1999 experiments, which were affected by unseasonal rainfall, has not yet been analyzed.

Activity 3.3.5: Identification of drought resistance traits and development of selection indices to screen chickpea progenies derived from drought resistant parents

Evaluation of drought resistance traits in chickpea (N P Saxena)

Empirical breeding for drought tolerance using seed yield as a selection criteria, in general, has not been very effective in increasing crop yields in drought-prone conditions. Two traits, a large root system and fewer leaf pinnules (7 compared to 11-13 in normal lines), were found to be associated with drought tolerant chickpea germplasm. Pyramiding these traits is expected to result in genetic enhancement of drought tolerance; incorporating these traits in useful agronomic and disease tolerant genetic backgrounds could result in higher yields and greater stability of yield in rainfed chickpea.

Three pot experiments were conducted in CEC facilities at Patancheru (nine varieties with the drought tolerant traits incorporated and three parents), for morpho-physiological characterization. Two field experiments were conducted, one on a deep vertisol and another on a shallow vertisol during 1998/99 season, to evaluate 52 elite selections for drought tolerant traits. A gradient of drought was applied through a line-source irrigation method. Yield and shoot mass were regressed against the amount of water applied. Linear regression estimates of the slopes and intercepts were used as criteria of drought tolerance. Lower slopes combined with high intercepts are taken as a measure of greater drought tolerance.

The two drought tolerant traits were successfully combined. Eighty percent of the large root system of ICC 4958 was recovered in the best of the selected genotypes, combined with 100% of the fewer pinnule trait of ICC 5680, the other drought tolerant parent. The amount of water transpired in two improved drought tolerant varieties was reduced by 30%, compared to ICC 4958. Water use efficiency was similar to or marginally better than ICC 4958 and superior to Annigeri, the best adapted local cultivar in peninsular India. In field conditions, genotypes that combined fewer pinnules with larger roots maintained a higher mid-day leaf relative water content (80% compared to 74% in ICC 4958). Correlations between the amount of water applied and yield of a number of the genotypes were high (r^2 = 80-90%). Three of the elite selections had lower slopes (of the linear regression of yield on water applied), combined with higher intercepts for yield, indicative of greater drought tolerance, compared to the two drought tolerant parents. Also, some drought tolerant selections had very high levels of resistance to fusarium wilt, Race 1. The field experiment is being repeated during the 1999/2000 chickpea crop season to verify the responses.

It seems feasible to reduce transpiration loss of water with smaller leaves (fewer pinnules) combined with a large root system which seems to help maintain a relatively high mid-day leaf relative water content. Since the amount of dry matter produced and partitioned into seed is directly proportional to the amount of water transpired, further selection for increasing node number, and thereby increasing potential pod bearing sites may be possible.

Activity 3.3.6: Development of selection criteria to identify traits associated with chilling tolerance in chickpea

Methodology for identifying chilling tolerance in chickpea (N P Saxena)

It has been demonstrated that chilling tolerant chickpea genotypes, which set seed under cooler temperatures in winter growing environments, have reduced lodging, higher harvest indices and relatively higher yields. Screening for chilling tolerance in field conditions is difficult because of uncertainty of occurrence of desired degree of chilling stress coinciding with flowering and pod filling stages of crop growth. Use of controlled environment chambers (CEC) to screen breeding material on a large scale is prohibitively costly. Since pod set at chilling temperatures is associated with chilling-tolerant pollen, a simple technique that will identify chilling-tolerant pollen would greatly facilitate the incorporation of this trait into appropriate genetic backgrounds for use in winter environments.

A selected set of 16 chickpea germplasm accessions (originating from chilling-prone areas), five ICRISAT chilling-tolerant varieties, and a freezing tolerant variety from ICARDA, were grown in the CEC at day/night temperatures of 22°/15° C. At bud stage, chilling temperatures of 15°/5° C day/night temperatures were applied. The same genotypes were also grown in field where the thermal regime was favorable for pod set. Flowers were collected from plants grown in the field and plants grown in CEC. Pollen from these was exposed to a range of chilling temperatures in incubators in the laboratory and tested for viability.

As expected, there were no marked differences among the genotypes in either percent germination and pollen tube growth at laboratory (23° C) temperatures. The differences between cold tolerant and cold susceptible genotypes were detectable at 7° C and were markedly visible at 2° C, both in pollen germination and pollen tube length. ICCV 88505 (derived from ICC 8923) was most tolerant and Annigeri most susceptible. The freezing tolerant variety from ICARDA (FLIP 91-120) did not show high degree of chilling tolerance. Experiments are in progress to verify these results.

Five new sources of chilling tolerance were identified in this exercise, three desi (ICC 5033, ICC 9514, ICC 4889) and two Kabuli (ICC 8505 and ICC 8927) types originating from Turkey and the former USSR. Many chilling-tolerant genotypes also had a high to moderate degree of ascochyta blight tolerance. Identification of new sources of chilling tolerance presents opportunities for gene pyramiding to further enhance chilling tolerance. Screening for chilling tolerance can now be simplified, by exposing the pollen of plants grown in field or in glass house at normal temperatures, to chilling temperatures in refrigerator or an ordinary incubator maintained at chilling temperatures.

Objective 3.4: To evaluate novel crop traits with the potential to improve adaptation, yield, quality or utility of mandate crops, and to establish effective selection procedures for useful traits.

Rationale: It is necessary to have a basic knowledge of the relationship between specific traits and crop adaptation, yield or quality, the genetic variability in, and inheritance of, these traits, and the effects of environment and genotype by environment interaction trait expression/ effectiveness, in order to design effective selection procedures for improved adaptation, yield or quality using such traits. This objective focuses on the understanding of these basic requirements, and the development of effective evaluation methods for selected traits, where this is needed in order to make progress in identifying and using trait selection to improve adaptation, yield or quality.

Activity 3.4.1: Evaluation of the genetic variability in sorghum and millet residues for feed intake and feed quality

Evaluation of genetic variability in quality in Asian pearl millet crop residues (F R Bidinger)

Although pearl millet stover is a very important source of animal feed, especially in the arid zone, little is known about the magnitude of genetic variation for stover quantity and feed quality, specific plant factors influencing these, or the possibility of improving them by breeding. This activity (which began only in 1999) is collaborating in experiments intended to provide data and stover samples, to answer some of these questions. The basis of the collaboration is the availability of appropriate experimental facilities in Patancheru and Rajasthan for the following set of baseline data experiments:

- Evaluation of stover productivity and quality of pearl millet cultivars collected from farmers in NW and Central India, to determine the range in quality/quantity differences in currently available cultivars
- Determination of the effects of plant population and nitrogen fertility on the productivity and quality of stover of a range of millet cultivar types, to assess management effects on quantity/quality
- Evaluation of variation in stover quantity and quality in among progenies of two dual purpose millet composites, to estimate the opportunity to improve quality/quantity by direct selection in currently available materials

Stover samples and field data are currently being analyzed.

Assessment of Asian sorghum cultivars for their fodder value (Belum V S Reddy)

Over the years, breeding programs and gene banks have assembled a range of plant types of sorghum, including dwarf grain sorghums, mid-tall dual purpose sorghums, tall fodder sorghums, and multicut forage sorghums. A study was initiated in collaboration with ILRI, on the role of these various morpho-agronomic traits on their fodder value. Five genotypes (G) of

diverse origin (M 35-1, M 35-1-Bulk 3, M 35-1-Bulk 5, NTJ 2 and CSV 13) were grown at two fertilizer levels (F) (80 kg ha-1 N and 9 kg ha-1 N) and at three plant densities (D) (25000, 30000 and 45000 plants ha-1) during 1998 post-rainy season in split-split plot design. Data was collected on 20 different traits that are known to affect fodder value.

Plant density significantly affected seven traits out of the 20 traits studied. Variances due to F were significant for several traits, as were those due to interactions of both F x G and F x D x G. Variances due to G were highly significant for all traits studied.

The average biomass per plant was strongly affected by density; but this effect was not reflected in fodder or grain yield per ha. Stem weight was increased significantly by high fertility while leaf weight was unaffected, indicating that fodder grown under high fertility may not be as palatable to animals as that grown under low fertility. High levels of fertilizer also increased stem sugar percentage, however, possibly compensating to some extent for the reduced palatability of the fodder caused by the increased stem weight.

Selected genotypes for various characters are as follows: Least stem girth (M 35-1 bulk 3), maximum height (M 35-1 bulk 3), large number of tillers plant-1 (NTJ-2), average tiller weight (M 35-1), high sugar % (M 35-1 bulk 5), least senescence (M 35-1 bulk 5 and NTJ-2), early flowering (CSV 13), late flowering (NTJ-2), high average number of leaves (NTJ-2), high average leaf weight plant-1 (NTJ-2), high grain yield per plot-1 (CSV 13), high fodder yield plot-1 (M 35-1 bulk 5).

Gas production, neutral detergent fiber (NDF) and nitrogen content of stover were significantly different between genotypes. These results indicate a clear distinction in gas production and NDF between M35-1 bulk 5 and CSV-13. Values of gas and NDF of other genotypes were intermediate. As expected, there was a negative relationship between gas production - an indicator of stover digestibility - and NDF that represent cell walls, the less digestible component of the stover. While fertility had no significant effect on gas production, plant density did. Both plant density and fertility affected NDF. However, the only significant interaction for NDF was fertility x genotype. These results point out not only the significant variation in stover quality between genotypes but also and possibly more importantly the environmental effects on quality. These results are tentative and will be verified from the results of further experiments in the 1999 rainy season.

Evaluation of the genetic variability in West African sorghum and millet residues for feed intake and feed quality (H F W Rattunde)

Sorghum residues are increasingly being preserved for feeding livestock in the West Africa as fallow lands diminish. Improved nutritional quality of sorghum residues offers major opportunities for achieving impact in the region. Information on the nature of genetic variation for stover quality and on the importance of genotype by environment interactions is required to effectively breed for its improvement.

Field trials were conducted in1999 at three locations, ICRISAT-Samanko, IER-Sotuba and IER-Cinzana. Twelve sorghum varieties that represent the range of guinea and caudatum varieties adapted in the region were tested. The tests were conducted under two plant densities (2.2 and 4.4 plants m^2) using a split plot design with densities as main plot and variety as subplot. Leaf

and stem samples have been harvested and are awaiting laboratory analyses of NDF, ADF, digestibility.

Objective 3.5: To identify, improve, transfer to adapted genetic backgrounds, and supply to NARS, effective sources of biotic stress resistance, abiotic stress tolerance and desirable plant traits

Rationale: The ultimate objective of GREP Research Area III is to provide access to superior sources of disease and pest resistance and environmental stress tolerance and novel traits to collaborators, in adapted genetic backgrounds that they can readily use in their own breeding programs. This may involve the little more that the screening of existing genetic materials for resistance, etc. or may involve a targeted breeding programs to transfer resistance, etc. to adapted or diversified genetic backgrounds to make it more readily useable to scientists in public and private sector breeding programs.

Activity 3.5.1: Identification of genetic resistance to millet head miner and stem borer

Screening techniques for resistance to millet head miner (O Youm)

The millet head miner is one of the most damaging insect pests of pearl millet in Sahelian West Africa. Management of the pest through host plant resistance would be the simplest solution, and require minimal input by farmers. Progress towards identifying sources of resistance has been hindered by the a lack of reliable screening technique, however. The overall purpose of this work is to develop better methods to identify reliable sources of resistance. As a part of this research studies were conducted at ICRISAT-Niamey to optimize infestation procedures to be able to achieve at least a damage rating of 7 (1 to 9 scale) in susceptible millet genotype.

A head-cage technique using white screen cloth was used. Panicles were caged and infected with a known number of eggs placed on stickers and pinned on the surface of the panicle. In one experiment susceptible variety 3/4HK-B78, was subjected to six (6) levels infestation - 20, 25, 30, 35, 40 and 45 eggs per panicle. In another experiment the efficacy of infection with eggs versus larvae in resistance screening was assessed. A number of varieties were also screened to assess reaction to head miner.

Egg infestation was more efficient and reliable than the use of larvae, and damage score using eggs was higher than that using larvae. We also found that eggs were easier to handle than larvae and the infestation process was less time consuming. Although sample size was not very high, we found in all experiments that 40 eggs/panicle produced significantly higher scores of damage rating than other infestation levels (Table 3.5.1). For example, damaged rating on a susceptible cultivar was 2.2 using 20 eggs/panicle versus 8.6 when 40 eggs panicle were used. Infestation using more than 40 eggs did not seem to provide adequate response, possibly due to larvae crowding after egg hatch or other factors which could inhibit larval growth. The Larval Production Index (LPI) values indicate the proportion of eggs that developed to full-grown

larvae or pupae out of the number of eggs infested per panicle. Differences in LPI between treatment levels were not significantly different (although 40 eggs/panicle gave the highest LPI). This could be possibly due to other mortality factors which affect larval survival, or timing of larval collection before they leave the panicles.

In 1998, experimental varieties differing in panicle diameter (cage-evaluated using 40 eggs / panicle) showed some differences in susceptibility, ranging from 5.5 (less susceptible) for HHVBC-PVC3 to 8.3 (highly susceptible) for EC91PVC2 . These results need to be confirmed.

Results of the 1998 and 1999 studies showed that artificial infestations of pearl millet varieties using infestation with 40 eggs per panicle was more efficient and reliable that previous technique using larvae. This is the first time that an improved, reliable technique is developed for head miner resistance screening. The technique should significantly speed up the identification of reliable resistance sources against the millet head miner and is recommended for future use.

Table 3.5.1. Mean(±SE) damage rating and larval production index (LPI) in susceptible variety 3/4HK in 1999. Means with the same letter are not significantly different at 0.5 probability level. Sample size for rated panicles ranged from 5 to 8

No. of eggs per panicle	Damage Rating[1]	Larval production index(%)
20	2.2±0.65	14.2
25	5.5±0.73	23.5
30	4.5±0.90	13.3
35	3.7±0.91	13.5
40	8.6±0.24	35.0
45	5.4±0.67	15.6

Activity 3.5.2: Evaluation of existing, elite pigeonpea genotypes for resistance to pod borers (*Helicoverpa* and *Maruca*), pod fly (*Melanagromyza*) and pod sucking bugs (*Clavigralla*)

Assessments of levels of insect resistance/susceptibility in current varieties of pigeonpea in eastern and southern Africa (E Minja)

Pod sampling was conducted on medium- and long-duration pigeonpea genotypes that mature in July, and August/September in southern Malawi. One hundred pods per genotype (four replicates of 25 pods) were sampled from each trial site of the NRI/DFID/Farming Systems IPM Project. All pods were examined in the laboratory to determine the pests involved, their damage on pods and seeds, and natural enemies associated with these pests.

The results (Table 3.5.2) indicate that pod sucking bugs accounted for 87% of total seed damage in the samples, while pod borers accounted for 9% and pod fly about 3%. The local medium-duration landrace, Chilinga and the wilt resistant long-duration genotype ICP 9145 appeared to be less susceptible to insect pests compared to the new varieties although the differences were not significant. Intercropped long-duration genotypes also showed slightly less (non-significant) damage from pests compared to sole crops in the trials.

Pod sucking bugs (mainly *Clavigralla tomentosicollis*) were common on the medium- and long-duration pigeonpea genotypes. Pod borers consisted of the blue butterfly (*Lampides* spp.), the lima bean pod borer (*Etiella zinkenella*), and the cotton bollworm (*Helicoverpa armigera*) in that order of importance. A small wasp (*Bracon* sp.) was reared from white cocoons collected from pigeonpea pods with pod fly puparia. These results are similar to those obtained in the 1995 and 1996 surveys in farmers' field crops.

Sucking bugs and pod borers appear to be important pests on pigeonpea in Malawi each season. There is therefore a need to concentrate on evaluation of management strategies particularly for the two pest groups.

Table. 3.5.2. Pigeonpea pod and seed damage (%) due to insect pests on medium- and long-duration genotypes in on farm trials at Mangunda , Thyolo in southern Malawi

	%damaged pods	% Seed damage due to:			
		Borers	Sucking bugs	Pod fly	Total
Sole cropped:					
Chilinga	7	2	39	0.5	42
ICEAP 00068	37	7	38	1.2	47
ICEAP 00073	14	2	45	1.2	49
ICP 6927	35	7	52	2.2	62
Mean	23.1	4.7	43.6	1.3	49.9
P-value	<0.001	0.060	0.321	0.333	0.168
Sole cropped:					
ICP 9145	31	10	45	Negligible	55
ICEAP 00040	15	5	54	Negligible	59
ICEAP 00053	26	9	54	Negligible	63
Mean	24.0	8.0	51.0	-	59.0
P-value	0.355	0.485	0.453	-	0.6
Intercropped:					
ICP 9145	13	5	38	Negligible	43
ICEAP 00040	20	7	49	Negligible	46
ICEAP 00053	33	11	45	Negligible	56
Mean	22.0	7.7	44.0	-	48.3
P-value	0.071	0.207	0.217	-	0.110
P. value (cropping pattern)	0.757	0.831	0.344		0.373

Activity 3.5.4: Diversification of sources of groundnut rust, leaf spot and rosette resistance for global use

Diversification of resistance in West Africa (B R Ntare)

Early and late leafspots cause considerable yield losses in all groundnut growing areas, affecting pod filling and reducing the biomass and the feed quality of the haulms used as fodder. Groundnut genotypes with resistance to these foliar diseases would have a dual role of increasing production of fodder for livestock and of pods for human use.

Twenty four F_4 and 30 F_6 breeding populations, derived from crosses of early maturing susceptible varieties and sources of resistance to both early and late leafspot diseases, were evaluated for their agronomic characteristics and reaction to late and early leafspot in Mali in 1998. In 1999, 452 selected F_5 and 872 selected F_7 progenies from these populations were characterized for maturity and reaction to early leafspot which was dominant at Samanko. A total of 513 progenies were selected based on earliness and a disease score of less than 6 on a scale of 1-9.

One hundred interspecific derivatives resistant to late leafspot were grown in an observation nursery at Samanko in Mali. They were mostly medium to late maturing, and appeared tolerant to early leaf spot as well. In addition, 25 interspecific derivatives were characterized for reaction to late leafspot at Bengou, Niger. The majority were in good agronomic background and resistant to late leafspot.

With the identification of these materials, our ability to provide NARS plant breeders with a ranges of improved breeding lines with resistance to leafspots and appropriate maturity should improve dramatically in the near future.

Identification of resistance sources to foliar diseases in West Africa (F Waliyar)

Foliar diseases rust, late leaf spot (LLS) and early leaf spot (ELS) cause significant damage to groundnut, with up to 65 % pod yield loss recorded. One of the most economical means of reducing disease impact on groundnut yield is through improving varietal resistance.

All field screening trials are carried out in "hot spots' under natural disease pressure, using randomized complete block or lattice designs with three replications. Disease severity was visually scored on 1 (resistant) to 9 (susceptible) scale several times during the season and percent leaf area damage, defoliation and at pod harvest, and haulm yields were recorded at maturity. Results are summarized below:

- Germplasm lines, ICG 10450, ICG 11485, ICG 7878, ICG 6022 had a score of 3 for ELS. Some germplasm lines also had good pod and haulm yield. All the resistant lines are being characterized for other traits.
- Trials in Niger, where LLS has been the major foliar disease the last two years, identified a number of germplasm lines with stable LLS resistance, among these were ICG 10936, ICG 10028, ICG 10951, ICG 4747, and ICG 7013. A few breeding lines also had good levels of resistance to LLS: ICGV 87821, ICGV 87836, and ICGV 87862.
- Twenty five breeding populations and 7 checks, tested in a field trial at Samanko, had ELS scores between 3 and 9. All 3 resistant checks had a resistant reaction and a score of 3;

whereas all susceptible checks were highly diseased. A few breeding populations were moderately resistant (score of 5 to 6): ICGVX 97084, ICGVX 97085 and ICGVX 97104 .

- In 1999 100 interspecific derivatives resistant to LLS , which were received from ICRISAT - Patancheru, were grown in an observation nursery prior to further testing in LLS "hot spot" locations in WCA. As ELS is the dominant foliar disease at Samanko, the evaluation was primarily for reaction to ELS. Of 100 lines sown, 32 did not germinate, the remaining 68 spanned the full range of disease reaction, scoring between 2 to 8. Ten were highly resistant (score of 2) and 15 were resistant (score of 3). These lines will be evaluated again next season to confirm their resistance to ELS and to test them for resistance to LLS Identification of interspecific derivatives with resistance to both leafspots will be of significant benefit in the region.

Diversification of resistance in Southern/Eastern Africa (Pala Subrahmanyam)

Rosette and early leaf spot (ELS) are the most destructive diseases of groundnut in the SEA region. ELS alone causes losses of about US $ 5 million to Malawi national income, and yield losses due to rosette approach 100% whenever the disease strikes in epidemic proportions. ICRISAT-Lilongwe therefore places major emphasis on the development of high-yielding varieties/populations with resistance to these diseases in diverse backgrounds. Several hundred breeding lines/populations from crosses made for resistance to rosette and ELS diseases were evaluated by the pathologist and plant breeder in disease nurseries at Chitedze, Malawi using the infector row technique to create severe disease pressure.

Resistance to ELS: During the 1997/98 crop season, a total of 174 F_4 and F_5 progenies, from crosses made for ELS resistance, were screened under high disease pressure conditions. From these, 68 F_5 progeny bulks and 46 single-plant selections, and 117 F_6 progeny bulks and 5 single-plant selections were made for further testing. Some 16 uniform lines were also selected for preliminary trials. In 1998/99, a total of 2,046 F_2 and 30,194 F_4 plants from crosses made for ELS resistance were evaluated under high disease pressure situation 6 and 203 promising plants, respectively selected for further evaluation in 1999/2000. In addition, 11 F_7, 40 F_8 bulks, and 66 advanced generation breeding lines in varietal trials were scored for their reaction to ELS.

Resistance to rosette: During the 1998/99 crop season, 11,319 F_2, 39,791 F_4, 984 F_5, 21,736 F_6, 744 F_7, and 1,550 F_8 plants from crosses made for rosette resistance were evaluated under high disease pressure situation, from which 588 F_3, 191 F_5, 29 F_6 23 F_7, 2 F_8, and 4 F_9, plants were selected for further evaluation in 1999/2000. In addition, 33 advanced generation breeding lines in Spanish and Virginia varietal trials were scored for their reaction to rosette.

Diversification of resistance in Asia (S L Dwivedi)

Groundnut germplasm, including wild species and their derivatives, show varying levels of resistance to rust, leaf spots, and rosette diseases. Knowledge of molecular diversity within the germplasm materials, their effective resistance mechanisms, and the genetic control of their resistance, will speed the development of enhanced germplasm with multiple resistance to rust, leaf spots, and rosette.

mature seeds but no clear effect of maturity on aflatoxin production was discernible. Surprisingly, ICG 1697, which is tolerant to end-of-season drought, had the highest aflatoxin content. It was followed by ICGV 92022 (10.7 ug kg^{-1}), which is tolerant to mid-season drought. The latter also had the highest level of seed infection. In the 1998 rainy and 1998/99 post-rainy seasons, only aflatoxin content was measured. In both the seasons, the aflatoxin content was higher under drought than under irrigated conditions, but the difference was marginal., possibly because these experiments were carried out in a non-infected field. Drought does appear to promote seed infection and aflatoxin contamination but its effect is likely to be more pronounced in a sick plot of *A. flavus*. Tolerance to drought does not appear to be associated with tolerance to aflatoxin contamination, but these are preliminary results that require confirmation.

Identification of sources *of* groundnut aflatoxin resistance in West Africa (F Waliyar)

Aflatoxin contamination of groundnut in West Africa is a significant threat to human health and a major constraint to the groundnut export trade because of its impacts on human health. The fungi *Aspergillus flavus* and *A. parasisticus* are commonly found in groundnut and groundnut products. Only limited sources of resistance are available. A screening program was initiated to test West African germplasm lines to try to identify new sources of resistance.

In 1998, various adapted germplasm and breeding lines were tested in Niger, Mali and Senegal using RCBD design with 3 replications. At harvest, seeds were sampled for laboratory testing. Percent seed contamination by *A. flavus* was counted after plating 100 seed from each plot and aflatoxin content was measured using an ELISA technique developed by ICRISAT. In 1999, a screening trial was conducted in Niger to test new germplasm lines from the West African groundnut germplasm collection. As we have not completed the detection of aflatoxin we present 1998 results only.

- Five germplasm and breeding lines of the 49 lines tested in Mali, had very low levels of seed contamination by *A. flavus*. Lines ICGV 91278, ICGV 91279, ICGV 89104, and CMA 92068 (local line) had less than 5% seed contamination compared to 31% for susceptible lines.
- Three breeding lines of the 16 germplasm and breeding lines tested at Samanko, Mali, possessed resistance *to A. flavus* and/or aflatoxin. These are ICGV 89063, ICGV 87815 and ICGV 87084; these lines also produced 60% greater pod yield than the local check (55-437).
- At Kaolack (Senegal) ICGV 91283, ICGV 89112 and ICGV 89063 were among the least contaminated (1, 2 and 4% seed contamination, respectively) of the seventeen breeding lines tested.

Inheritance of resistance to aflatoxin contamination in groundnut (D V R Reddy)

Two parents, URR 245 (aflatoxin resistant) and JL 24 (aflatoxin susceptible) were crossed and F1 and F2 progenies generated, to produce materials to study the inheritance of resistance to aflatoxin contamination. Initially seed from the two parents were colonized with a toxigenic *A. flavus* isolate and individual seeds were tested for aflatoxin content by ELISA. The concentration ranged from 8 to over 220,000 µg/kg of seed. Because of the tremendous variation among individual seeds in a single line, further research will be done only after standardizing the conditions for evaluating aflatoxin contamination in individual seeds.

Activity 3.5.7: Identification of sources of resistance to wilt, collar rot and dry root rot in chickpea.

Sources of resistance to wilt, collar rot and dry root rot in chickpea (S D Singh)

Chickpea is vulnerable to a variety of fungal diseases from emergence to podding stage, including three important soil-borne diseases - wilt, collar rot, and dry root rot. Collar rot is increasing in occurrence and is becoming a major disease in peninsular India. High levels of genetic resistance to most of the fungal diseases, except wilt, have not yet been identified. Resistant sources and resistant cultivars to all the soil-borne diseases and to the most important foliar diseases (botyrtis grey mold or BGM and ascochyta blight) are vital to control losses from these diseases.

Collar rot screening was done in both *Sclerotium rolfsii* infected soil in pots and in a collar rot infected field plot. Dry root rot screening was done using a paper towel technique in the laboratory. Screening for wilt resistance was done in wilt sick plot. Screening for BGM and ascochyta blight was done in a growth room.

- A total of 456 chickpea lines , including 37 accessions with <20% collar rot, 215 germplasm accessions with <10% wilt, and 138 entries from international trials, were evaluated for dry root rot (*Rhizoctonia bataticola*) resistance. None of the collar rot resistant accessions showed high level of dry root rot resistance. However, 31 wilt resistant accessions showed high levels of dry root rot resistance (2-4 ratings). These include ICC 14396, ICC 14395, CPSI, ICC 14401, ICC 14322, and ICC 14397.
- None of the 250 wilt resistant accessions (which were tested for ascochyta blight , BGM, collar rot and dry root rot) showed acceptable levels of resistance to BGM, and only four of these (ICCX 810800, ICCV 97801, MCK 54, etc.) showed moderate levels of resistance (4-5 ratings) to ascochyta blight. Twelve lines (including ICC 6815, ICC 7489, IC 9035, and ICC 9035) showed <10% collar rot.
- None of the 18 dry root rot resistant lines (<4 rating) showed acceptable levels of collar rot resistance under greenhouse conditions.

We have thus identified one entry, which is collar rot free in greenhouse, wilt-free in two field tests, and has only 1.5% dry root rot in one field test. Freedom from collar rot is significant because of the rarity of genetic resistance to *S. rolfsii*. This resistance, coupled with resistance to wilt and dry root, makes the entry extremely useful. There are 7 other entries - ICC 6815, ICC 8166, ICC 8585, ICC 9035, ICC 9127, ICCX 810737 and ICCX 830264-B4-BH-94 that developed 5 to 10% collar rot in greenhouse test, 0-7% collar rot and wilt in field tests, and 0-2.4% dry root rot infection under field conditions.

Clearly, we have very high level of individual and multiple resistance to wilt, collar rot and dry root rot - the three soil-borne chickpea diseases. However, sources with high levels of multiple resistance to the two foliar diseases plus the soil-borne diseases are not yet available.

RESEARCH AREA IV

Research Area IV: Partnerships to share breeding materials in farmer-ready forms

Goals

Enhance and stabilize agricultural production, farm income and farm-family welfare through the use of improved crop cultivars.

Intermediate Goals

Help NARS in developing countries to more effectively and speedily develop, test and disseminate improved cultivars for adoption by farmers.

Purposes

Valuable new traits identified in Research Areas I to III cannot be directly used in the breeding programs of many of the less-developed NARS. These traits must first be introduced into locally-adapted genetic backgrounds, and then evaluated for performance and stability over time and space. NARS networks continue to request active involvement of ICRISAT in helping them to conduct breeding programs, particularly in technical backstopping, training, fundraising, and information sharing activities. Responding to this need, the specific purposes of this Project are to:

- Upgrade breeding programs of NARS and regional networks by supplying advanced generation breeding material and enhanced germplasm,
- Provide improved male-sterile, restorer, and maintainer lines to develop improved hybrid cultivars,
- Improve the capacity of NARS breeders to develop and test improved cultivars, and to multiply and distribute seed,
- Enhance the role of farmers in participatory-crop improvement, and
- Increase the adoption of new cultivars by farmers.

Objective 4.1: Genetic diversification of breeding populations to enhance productivity and protect against genetic vulnerability

Sorghum

Improved guinea sorghum random mating population (H F W Rattunde and E Weltzien)

The *Guinea* population was mass selected for grain (seed size, absence of grain anthracnose) and panicle characteristics (free threshing, large number of panicle branches, shorter internode length on rachis). The population sizes used for selection were 3,000 plants in 1998 and 13,000 plants in 1999. Every plant was labeled for heading date in 1999 to form narrower-maturity sub-populations. A total of 191 male-steriles were selected in 1998 and 607 in 1999. The selections had excellent grain characteristics with panicles having dense panicle branches and high number of grains per panicle (maximum of 3300). The mean grain size was 2.4 g per hundred seeds with

a maximum of 3.0 g among the selected male-sterile plants of 1998. Despite the large variability for grain size the endosperm was very corneous, with a mean score for vitreousness of 1.06 (1 vitreous to 5 floury). Variability exists for internode length, but there is very low frequency of dwarf plant stature. Undesirable associations of the dwarf phenotype with small grain and panicle size are strong. The maturity based sub-populations now being formed will provide outstanding material for varietal development and for initiating recurrent selection procedures for increased yield and reduced plant height.

Diversified *Guinea* sorghum random mating population available (H F W Rattunde and E Weltzien)

The introgression of an agronomically elite *Caudatum* population (Multifactor resistant population (MFR) from ICRISAT-India) into the well adapted *Guinea* random-mating population will diversify the Guinea germplasm for such important traits as internode length (dwarfing genes), harvest index, stay-green, and stover quality. The introgression of genetic diversity from the MFR population into the *Guinea* population was initiated in the 1998/1999 off-season. Eight F_1s of MFR x *Guinea* varieties (Segou Local, CMDT 48, CSM 388, Bimbari Soumale, Bimbiri Cycle Moyen, Oueni, IPS 0001, Keninkeba) were used as males for crossing onto 10 to 30 male-sterile plants of the *Guinea* population. The resulting 142 population F_1s were sown head to row with two replications in 1999. One to two panicles were selected from each plot. The approximately 200 F_2s harvested in 1999 provide genetic materials possessing the targeted genetic composition of 75% *Guinea* and 25% *Caudatum*. Observation of the F_2 grow-out will determine if one additional population backcross will be required to sufficiently recover the desirable *Guinea* grain and panicle characteristics. The new introgressed population will be valuable source material for diversifying *Guinea* sorghums and developing novel trait combinations.

Diverse *Guinea* lines derived from Guinea random-mating populations (H F W Rattunde and E Weltzien)

Guinea varieties with high yield, desirable grain quality and adaptive characteristics and novel plant types are required for intensification of sorghum production in the Sudanian and North Guinean Zone of West Africa. Progenies from the *Guinea* random-mating Population were selected in each cycle of population improvement. The 1997 series of S_1 progenies were sown in 1998 (single row plots) and 34 S_2 progenies selected for panicle, grain and plant height. Yield evaluations (two replication, three row plots) and an assay for the striga low-stimulant germination character were conducted with these 34 S_2 progenies in 1999. The 1998 series of 81 S_1 progenies were sown (six row plots) in 1999 and 161 S_2 progenies were selected. A total of 407 fertile S_0 progenies were selected from the population to initiate the 1999 series. The S_2 progeny trial of 1999 confirmed that novel plant types with desirable *Guinea* grain can be obtained from the *Guinea* random-mating population. Short statured (2.0m) intermediate to late maturing (87 to 98 d to flower) progenies were obtained, as well as intermediate and tall progenies. The progenies exhibited productive panicles (yield data to be available after threshing). These initial progenies however exhibited undesirable associations between dwarf plant height and small grain size, and erect panicle type and tighter glume attachment. Highly significant variation for the low-stimulant trait was exhibited by the 34 S_2 progenies in the Agar Gel Assay, with some progenies exhibiting extremely low levels of germination stimulant (<5mm considered low-stimulant). One quarter of the S_1 families tested showed segregation for

this trait, indicating considerable frequency of low-stimulant gene(s) in the population. Varieties with desirable and novel characteristics can definitely be obtained from the Guinea population.

Sorghum gene pools improvement (Belum V S Reddy)

Three gene pools, i.e., maintainer genepool (ICSP B), large grain population (ICSP LG), and high tillering population (ICSP HT) are being developed.

ICSP B: We introgressed bold grain lines; and downy mildew, midge, shootfly and stemborer resistant lines into US/B-C_6 *ms3* population during 1991 rainy season and three random matings were achieved by 1993. Selection for dwarf plants with bold grain was carried out until 1997 rainy season. Additionally four boldgrain *durra* maintainer lines and 296B and M35-1 were introgressed during 1997 postrainy season and random mating with mass selection for bold grain, dwarf plants and resistance to shootfly was practiced during 1998 rainy and postrainy seasons and during 1999 rainy season. One hundred twenty open pollinated male-sterile S_1s and 50 male fertile S_1s selected for bold grain, high grain number in dwarf to medium height and for resistance to shootfly during 1998 rainy season were bulked in 3:1 ratio to make the bulk (C_7) for the next cycle. The 1998 postrainy season bulk (C_6) is being evaluated and selected for postrainy season during 1999 postrainy season. The rainy and postrainy season bulks will be selected for the season-specific adaptation.

ICSP LG: The large grain population development was initiated by introgressing nine bold grain landraces by making singlecrosses (4), backcrosses (2), and three-way crosses (15) with US/B-C_6 (*ms3*) bulk during 1990 rainy season. Additionally 10 large grain lines were introgressed during 1991 postrainy season by crossing these onto male steriles found in the F_2s of the earlier F_1 bulk. Random mating was allowed during 1992 to 94 postrainy seasons. Mass selection for bold grain and resistance to shoot fly was practiced during 1995 to 98 postrainy seasons. The population was grown under unprotected (no-spray) conditions and deadhearts due to shootfly were removed before flowering during 1998 postrainy season. We selected one hundred and five male-sterile S_1s, and 72 male fertile S_1s were bulked in 3:1 ratio to make the C_5 bulk, which is being evaluated during 1999 postrainy season.

ICSP HT: Three landraces (IS 1347, IS 3075 and IS 3479) were introgressed into US/B-C_6 (*ms3*) bulk in 1998 postrainy season. The F_3s obtained earlier from the crosses of tillering lines and early lines were introgressed with the male-steriles in F_2 bulk during 1989 postrainy season and 1990 rainy and postrainy seasons. The bulked seed (C_0) from 1990 postrainy season was grown during 1991 rainy season. During 1991 postrainy season, three Sudan grass lines, one downy mildew resistant line, one anthracnose resistant line, and seven sweet-stalk lines were introgressed into the C_0 bulk. After following two random matings and four selection cycles eight sweet-stalk lines and three brown-midrib lines were introgressed during 1993 postrainy season. Following two random matings, and selection for tillering types for over four seasons, a sweet-stalk tillering line, a Sudan grass cultivar, a foliar disease resistant line, and three late maturing high-biomass lines were introgressed during 1997 rainy and postrainy seasons. Two random matings were effected during 1998 rainy and postrainy seasons with mild selection. The resulting C_0 bulk is being evaluated during 1999 postrainy season. In all selection cycles, uniculm plants were removed before flowering and plants with effective tillers were selected and bulked. During 1998 postrainy season, uniculm plants were removed before flowering. Plants with white midrib were tagged and tall and leafy plants with more than three effective tillers having green to brown midrib leaves were selected. This exercise resulted in 180 male-sterile S_1s and 85 male-fertile S_1s and the seed from the selections was bulked in 3:1 ratio to make the C_1 bulk for next cycle of selection.

Development of *guinea*-based maintainer lines in sorghum (Belum V S Reddy)

Guinea lines are well adapted for Western and Central Africa (WCA) conditions. The grains of the F_1 hybrids do not thresh normally when such hybrids are produced by pollinating a non-*guinea* female line with a *guinea* pollinator. In other words, *guinea* glume characteristic is essential in both the parents to produce free threshing F_1 hybrids of *guinea* sorghums. Therefore, work on the development of *guinea* maintainer lines was initiated in 1997. We chose high yielding *guinea*-bred lines from the erstwhile grain mold resistance breeding project. These are: IS 30469C-1187-5, IS 25017, PAB#16, PAB#64, PAB#102, SAL 2177, ICSV 95046, and GM 968284B. These when tested on A_1 cytoplasm showed male fertility restoration. These were crossed with grain mold resistant B-lines (3), bold grain and high yielding B-lines (18), and stem borer resistant B-lines (19) during 1997 postrainy season. The F_1s were advanced to F_2 generation in 1998 rainy season. The F_2s were evaluated in 1998 postrainy season and selection for *guinea*-type grain in dwarf background was practiced. The F_3s (70) were evaluated in the 1999 rainy season. Some of the crosses made in 1998 rainy season were advanced to F_2 generation in 1998 postrainy season. These F_2s (65) were evaluated in the 1999 rainy season. The S_2 selections identified earlier with *guinea* characteristics from the maintainer population (ICSP B) were also evaluated in 1999 rainy season and selection for high yield and *guinea* type glume and grain was practiced. The F_3s (521) obtained from the 36 F_2s introduced from West and Central Africa were also evaluated during 1999 rainy season, and selection for *guinea*-type earhead was also practiced in these (These were also selected upon for *caudatum* type - please see section 4.1.4S). We obtained a total of 298 selections with *guinea* type glume and grain. Of these 184 are in F_3 generation, 224 are in F_4 generation, and 62 are in S_3 generation. Twelve *guinea*-type F_4 selections were obtained from the F_3s of WCA introductions. Plant height in these ranged from 1.5 to 2.2 m and days to 50%flowering from 65-75 days. These lines are high yielding and their agronomic desirability is quite high.

***Guinea* maintainer lines identified from WCA varieties and breeding materials (H F W Rattunde and E Weltzien)**

Testcrosses of *guinea* landrace varieties and partial *guinea* breeding lines developed by the national program in Mali (IER) and CIRAD were evaluated in a three replicate trial in 1998 for fertility reaction and agronomic characteristics. Fertility reaction was observed on six selfed plants per plot using a 1 to 5 score, with 1=100% seed set, 2 = >80% seed set, 3 = 50-80% seed set, 4= 20-50% seed set, and 5= < 20% seed set. The fertility reactions varied greatly. The landrace varieties (Nazangola, CSM 388, and Guinea AE) showed great plant to plant variation, whereas the breeding lines were generally more uniform for fertility reaction. These initial results confirm the possibility of developing *Guinea* maintainer lines. Two testcrosses exhibited desirable agronomic plant and panicle type with shorter plant height (190cm); SP47561A x (Bimb. Soum/S34)-13-22-1 had large corneous grain and open, productive panicles, and SP 47561A x CGM 21/4-4-2 and open panicles with smaller round corneous grain.

Development of *feterita* sorghum maintainer lines for SEA (Belum V S Reddy)

In Southern and Eastern Africa (SEA), particularly in Sudan, *feterita* type bold grain (with thick sub-coat and white pericarp) is preferred. Therefore, it was planned to develop high yielding *feterita* type maintainer lines. The selected *feterita* type lines behaved as restorers on A_1 CMS

system. They are: IS 24756, IS 18759 and ICSV 95046. They were crossed with stem borer resistant maintainer lines (6), bold grain maintainer lines (4), and other germplasm (8) and bred-lines (13) during 1998 rainy season to develop 50 F_2 populations. Additionally, 14 F_3 selections of *feterita* type obtained from crosses of grain mold resistant lines (ICSV 901 and FM 768) and *feterita* lines (IS 921, OSVE 13, and Ajab-Scido). These F_2 populations and F_3 progenies were evaluated during 1999 rainy season. The selection for *feterita* type grain in high yielding, photoperiod insensitive background was continued. We obtained 93 F_3 selections from the F_2 populations evaluated. Evaluation of F_3 progenies resulted in 5 F_4 selections. Also, we selected 14 individual plants with *feterita* type grain from other breeding populations. Variability for grain yield is limited in these populations. Therefore, additional crosses will be made to increase diversity.

Development of improved maintainer lines for resistance to shoot fly, stem borer and grain mold (Belum V S Reddy)

In the first cycle of trait-based breeding, male-sterile lines resistant to shoot fly, stem borer and grain mold were developed. But, several of these are not agronomically good. Therefore, work was initiated on shoot fly resistance during 1995 postrainy season and on stem borer and grain mold during 1998 rainy season.

Shoot fly: The objective is to increase grain yield and boldness in the available resistant male-sterile lines. Therefore, shoot fly resistant B-lines (8) were crossed with high yielding and bold grain B-lines (9), and R-lines (10) during 1995 postrainy season. Individual dwarf shoot fly resistant plants in these F_2 (115) populations were crossed with shoot fly resistant B-lines (62) and R-lines (2), and 1544 (three-way cross) F_1s were obtained during 1997 rainy season. Also, 405 individual shoot fly resistant F_3s were selected from the F_2 (115) populations during the same period. Earlier in 1996, some of the F_1s where 296B was involved, were backcrossed to 296B again. Selection for resistance to shoot fly was carried out both in the rainy and postrainy seasons of 1997 and the rainy season of 1998. From the 1998 postrainy season nursery, we selected 65 F_6s from BxR crosses, 111 F_5s from BxB crosses of F_3x296B and of [(F_3x296B) x 296B], 199 F_4s from the three-way crosses of [(F_3x296B) x shoot fly resistant B-liner], 83 S_6s from ICSP B population and 16 direct selections from 296B. Additionally, 37 F_3s and 7 F_4s were selected from the crosses of shoot fly resistant B-lines (6) x stay-green/bold grain lines (14). All these were evaluated in 1999 rainy season in late planted shoot fly infested nursery. We selected the families with less than 25% shoot fly deadhearts (DH%) (DH% in the resistant check, IS 18551 was 7 to 22, and in the susceptible check, CSH 9 was 54 to 78). The high yielding plants with bold grain were selected from the resistant families (Table 4.1.1). Three types of materials, i) F3 - three-way crosses, ii) population progenies, and iii) resistant B lines x stay green lines exhibited more resistance to shoot fly.

Stem borer: Seventeen stem borer resistant B-lines were crossed with four high yielding B-lines and six improved *guinea* lines, during the 1998 rainy season. A total of 75 F_2 populations of the above crosses were evaluated and selection for agronomic desirability was practiced during 1999 rainy season. We selected 149 F_3 plants from 46 F_2 s based on agronomic desirability, dwarf to medium plant height and good grain quality. The parents that contributed to more than 10 F_3 selections are : ICSBs 468 (31), 469 (13), 476 (21), 477 (24), 486 (17), and 487 (14).

Grain mold: Thirteen grain mold resistant B-lines were crossed with bold grain high yielding B-lines (18). A second set of crosses were made between 10 foliar diseases resistant B-lines and grain mold resistant germplasm lines (7) and improved grain mold R-lines (2). During 1998 postrainy season, we obtained 272 F_2 populations and these were evaluated during 1999 rainy

season. Selection for agronomic desirability and high grain yield was practiced. Selection was practiced for less panicle grain mold, and high agronomic desirability in the F_2 s during 1999 rainy season. A total of 728 F_3 selections were made from 229 F_2 populations. Of these, 280 are colored (red/brown) grain types and the rest (448) are white grain types. Parents contributing to more than 15 F_3 selections are : ICSBs 362 (32), 376 (19), 383 (41), 403 (16), 404 (23), 405 (19), 203 (16), 306 (36), 308 (18), and ICSB 328 (16). Agronomic desirability and grain yield potential is high in shoot fly resistant materials, while it is less in others. Testcrossing should be carried out to determine the male-sterility maintainer ability in these selections.

Table 4.1.1 Selections made from various types of sorghum material in the shoot fly screening block, Rainy season, 1999.

Type of material	Families evaluated		Selections made		
	Generation	Number	Individual plants	Families	%Families selected
BxR Single crosses	F_6	65	19-F_7; 2 B/A_1	16	25
BxB of F_3x 296B and it's backcrosses	F_5	111	45-F_6;23 B/A_1; 17 B/A_2	34	31
F_3 three-way crosses	F_4	199	149-F_5	100	50
Population progenies	S_6	83	81-S_7;11 B/A_1; 23 B/A_2	35	42
296B selections	-	16	3	3	19
Resistant x Stay green	F_3	37	40-F_4	23	62
Resistant x Stay green	F_4	7	1-F_5	1	14

Mass selection in shoot pest/bold grain and head pest populations (H C Sharma)

To increase the levels and diversify the basis of resistance to shoot pests (*Atherigona soccata* and *Chilo partellus*), we tested the head pest population under shoot fly infestation in the field. The shoot pest population was planted in an isolation, and infested by shoot fly during the 1997/98 postrainy season under natural conditions. The shoot fly damaged plants were removed, and the remaining plants were allowed to random mate under natural conditions. This population has been reconstituted for further improvement and utilization.

To increase the levels and diversify the basis of resistance to sorghum midge, *Stenodiplosis sorghicola*, different sources of resistance to this insect were random mated using genetic male-sterility system. From the C_1 cycle random mated population, 350 S_2s were screened for resistance to sorghum midge during the 1997 rainy season, and the S_2s showing resistance to sorghum midge were harvested. The selected S_2s (165) were planted during the 1997/98 postrainy season to recover the plants with male-sterile genes by half-sibbing. The same set of S_2s' was also sent to Kenya for testing for midge resistance. Another set of S_2s' selected as less susceptible to midge in Kenya was planted in the plant quarantine, and the male-sterile plants were sibbed to recover the male-sterile genes. S_2s' (nearly 125) that did not produce male-sterile plants during the 1997/98 postrainy season, were sown during the 1998 rainy season to recover the male-sterile genes. The selected S_2s (250) were planted in isolation during the 1998/99 postrainy season. The male-sterile panicles were tagged, and pollinated with bulk pollen from the fertile plants. All the sterile plants, and nearly 10% fertile plants were harvested. The sterile and fertile plants were threshed

separately, and the population was reconstituted by mixing 5 g seed from each panicle and (from nearly 350 panicles) for future use and distribution to the NARS.

Pearl Millet

Large seeded, medium maturity and high tillering dwarf B composites available (K N Rai)

Large regional differences exist in farmers' preference for seed size, maturity and tillering ability in hybrids. The objective of developing these three trait-specific B-composites is to provide genetically enhanced broad-based populations to NARS to enable them develop seed parents of specific characteristics for their target regions. Sixty-nine advanced generation, dwarf seed parent progenies were recombined to develop Medium-maturity dwarf B-composite (MMDBC). Early generation progenies were identified for further evaluation and utilization to form a Large-seeded dwarf B-composite (LSDBC) and a High-tillering dwarf B-composite (HTDBC). MMDBC that flowers in 52-54 days was constituted. More than 200 selected half-sibs from this composite were planted at CCSHAU, Hisar in 1999 rainy season as a part of ICAR-ICRISAT collaborative project (4.6e). A large number of these displayed good yield potential and are being used for B-line development. At Mandor, this nursery failed due to severe drought. In the year 2000, these half sibs will be evaluated for B-line breeding at RAU Research Station, Durgapura. More than three hundred F_3 and S_4 progenies with >10 g 1000^{-1} seed mass and flowering in 42 to 60 days at Patancheru in the rainy season were identified for further evaluation and utilization to constitute LSDBC. One hundred and eighty dwarf F_3 progenies with tillering potential typical of a high-tillering B-line (ICMB 89111) and flowering in 44 to 50 days at Patancheru in the rainy season were identified for further evaluation and utilization to constitute HTDBC. Some of the most promising progenies from these sources will be converted into A-lines. The progenies identified so far may not have larger seed size than some of the large-seeded A-lines (e.g., ICMA 96555), or higher tillering than some of the high-tillering lines (e.g., ICMA 89111), but they will add to genetic diversity and are likely to have higher grain yield and downy mildew resistance, more compact panicles and better lodging resistance.

Extra-early dwarf B composite available (K N Rai)

Hybrid HHB 67 is the earliest-maturing (<65 days to mature) commercial pearl millet cultivar ever developed anywhere. The objective of developing EEDBC is to increase the utility of this extra-early germplasm for breeding dwarf A-lines that can be used for eventual genetic diversification of hybrids in HHB 67 maturity group. The C_1 cycle bulk of EEBC, developed by mass selection and designated as ICMP 94001, is being converted into dwarf version by backcross transfer of a d_2 dwarfing gene into it. With the initial cross made in 1997, the conversion program advanced to BC_3F_2 stage in 1999. Dwarf plants identified in BC_4F_2 population will be random mated to constitute EEDBC. This dwarf population is unlikely to produce progenies for direct use in A-lines breeding as, like most of the *iniadi* germplasm, it will lack tillering and stalk strength, and most of the plants will have tip sterility. EEDBC will serve as the most valuable broad-based source of extra-early and dwarf germplasm with large grain size and high downy mildew resistance.

Dwarf versions of SRC II and Nigerian breeding lines available for diversification of seed parent breeding materials (K N Rai)

There is substantial morphological diversity in dwarf A-lines developed at ICRISAT-Patancheru. However, they lack long (30-35 cm) and compact panicles. The objective of this research is to mobilize these two attributes from some of the tall composites and breeding lines into dwarf genetic background for more efficient use in A-line breeding. Tall S_3 progenies from Smut-resistant composite II (SRC II) and advanced breeding lines from ICRISAT-Nigeria were crossed with dwarf B-lines and seed parent progenies. Dwarf, compact and long-panicled plants selected from 58 F_2 populations were selected for pedigree breeding with emphasis on long and compact panicles, high grain yield potential, other agronomic traits and downy mildew resistance. Based on visual selection for high grain yield potential, long panicles (mostly 30-40 cm) and other agronomic traits, 75 F_3 progenies out of 149 produced from crosses involving Smut-resistant composite II (SRC II), and 104 F_3 progenies out of 274 produced from crosses involving ICRISAT-Nigeria breeding lines were selected. Since within-progeny variation in these F_3s was large, single plant selections were made, leading to 246 F_4 progenies involving SRC II and 318 F_4 progenies involving ICRISAT-Nigeria breeding lines. Considering a large proportion of promising F_3 progenies from each of these two sets of crosses, backcross breeding program to convert SRC II and Nigeria breeding lines into dwarf versions was dropped. The F_3 progenies derived from crosses involving ICRISAT-Nigeria breeding lines had smaller seeds and more compact panicles than those involving SRC II progenies. These two groups of progenies will be maintained separately until F_4 generation. Decision on whether to form one or two composites will be taken on the basis of inter-group F_1 performance. F_3 progenies of intended panicle length and shape have now been produced. These lines and the composite(s) derived from them may serve as a good source of breeding materials for breeding A-lines of hybrids targeted for the most parts of India and SADC region.

Converted populations of country-specific photoperiod-sensitive gene pools of pearl millet (K N Rai, P J Bramel-Cox and F R Bidinger)

Highly photoperiod-sensitive landraces from several African countries provide a useful genetic resource for hard and lustrous grain and new sources of resistance to downy mildew and rust. Converted insensitive forms of this germplasm would greatly increase the efficiency of its mobilization into breeding programs. Photoperiod-sensitive landraces from Burkina Faso (30), Cameroon (44), Nigeria (43), Sierra Leone (30) and Tanzania (44) are being random mated to develop country-specific photoperiod-sensitive genepools, and converted into insensitive versions by crossing with each of the two extra-early-maturing and photoperiod-insensitive donors (an inbred line ICMP 85410e_1e_1 and a composite EEBC). F_1s made with Burkina Faso accessions in 1997 have been kept on hold, while those made with Sierra Leone accessions were advanced to F_2 generation. Also, F_1s were made in 1998 with accessions from Cameroon, Nigeria and Tanzania. Accessions from Sierra Leone were random mated to initiate the formation of photoperiod-sensitive genepool. Random-mated photoperiod-sensitive country-specific genepools will contribute to cost-effective genetic conservation. The insensitive versions under development will enhance genetic access to this germplasm.

Trait-specific sub-populations of Large Panicle Dwarf B-composites (K N Rai and R P Thakur)

A large number of elite large panicle dwarf progenies produced can be evaluated for direct use in breeding of A-lines or hybridization programs. Trait-specific sub-populations developed from these would provide backup variability for more targeted local selection for productivity and adaptation traits prior to their conversion into A-lines or use as parents in hybridization programs. At the S_3 stage of evaluation, about 1200 dwarf progenies of large panicle size (generally more than 30 cm length and 4 cm diameter) produced from three composites, earlier designated as High head volume B-composites (HHVBC and HHVBC II) and Large panicle dwarf B-composite 97 (LPDBC 97), were further evaluated and classified into eight trait-specific groups. Based on visual evaluation of grain yield potential and agronomic traits during the rainy and dry seasons of 1999 and downy mildew evaluation in 1999 rainy season, 204 S_4 progenies selected out of 455 were grouped into eight trait-specific groups: dwarf (29), medium-dwarf (67), tall-dwarf (19), thick panicles (50), compact panicles (17), upright (32), early maturity (23) and lodging resistant (69). Forty-three of these progenies are already under A-line development, and 64 additional lines were selected as candidate entries for A-line conversion, using the A_4 cytoplasm. Three hundred and fifty F_3/F_4 progenies of medium maturity (about 50 days to flower) and large panicles (somewhat smaller than those from HHVBCs and LPDBC 97) were selected (out of 1450 generated) from diverse crosses involving S_2/S_3 progenies of HHVBCs and LPDBC97, MC94, ICMR 312, and Large-panicled potential B-lines. These will be further evaluated for yield potential, maturity and DM resistance to eventually breed A-lines and possibly develop a Medium-maturity Large-panicle Dwarf B-composite. A-lines developed from this base material will be useful for breeding hybrids targeted to parts of Maharashtra, Madhya Pradesh and Uttar Pradesh in India; and the SADC region. The composites and sub-populations would serve as back-up materials for local selection in these regions.

Groundnut

Selected and non-selected bulks of breeding populations with enhanced resistance to drought and aflatoxin for NARS in Asia available (S N Nigam)

For improving groundnut productivity and its quality in the SAT region, it is important that the new cultivars possess genetic tolerance to drought and aflatoxin. These cultivars will form an important component of the integrated management of these constraints. The main objective is to develop diversified selected and non-selected bulks with enhanced level of resistance to drought and aflatoxin for Asia. Visual selection for high pod yield and other desirable agronomic characters was practised in early generations under imposed mid-season drought condition in the field. Advanced breeding lines were evaluated for pod yield in replicated trials under similar field conditions. Advanced breeding lines, and wild *Arachis* species, were screened for their reaction to mid- and end-of season drought under line-source sprinkler technique which created eight water deficit intensities. Ten new crosses were made in the 1998/99 postrainy season to create diversified populations for selection for drought resistance. In 400 F_2-F_9 populations, 285 selections were made for high pod yield under mid-season drought condition. Of these, 36 were identified for replicated yield trial. Of the 131 advanced breeding lines evaluated in replicated yield trials under imposed mid-season drought condition, 22 significantly out yielded the highest

yielding control in respective trials. The pod yield in these lines ranged from 3.5 t ha^{-1} to 4.3 t ha^{-1}. The range of pod yield in the highest yielding controls was 2.8 t ha^{-1} to 3.2 t ha^{-1}. In the 1999 rainy season, 22 crosses were made to generate populations for selection for drought and heat tolerance. In 250 F_2 to F_9 populations, 176 selections were made for high pod yield under imposed mid-season drought condition. Of the 75 advanced breeding lines evaluated in replicated trials under imposed mid-season drought conditions, 8 significantly out yielded the highest yielding control in respective trials. The pod yield of these lines ranged from 1.0 t ha^{-1} to 2.0 t ha^{-1} and that of highest yielding control from 0.7 t ha^{-1} to 1.7 t ha^{-1}. From the field screening in the 1997/98 and 1998/99 postrainy seasons of 246 genotypes involving 129 advanced breeding lines from different groups, 27 wild *Arachis* species, and 90 drought resistant selections, several were identified as promising for total biomass and pod yield.

The genetic enhancement activities for resistance to aflatoxin contamination were revived in the 1999 rainy season. Five crosses were made to generate populations to combine genes for resistance to pre-harvest seed infection, seed colonization, and aflatoxin production. In 997 F_3 to F_6 populations, retrieved from the cold storage and sown in the field, 652 selections for high pod yield were visually made. Only 1 of the 32 advanced breeding lines evaluated in a replicated trial produced significantly higher pod yield (1.7 t ha^{-1}) than the highest yielding control ICGS 11 (1.3 t ha^{-1}). Several promising breeding lines with high yield potential under mid- and end-of-season drought conditions have been identified

Selected and non-selected bulks of short duration breeding populations with resistance to groundnut rosette virus, early leafspot, rust and late leafspot available for NARS in WCA (F Waliyar)

In collaboration with NARS, advanced breeding lines are tested for their reaction to disease and pod and haulm yields both at the ICRISAT research station and in farmers field, under natural disease pressure. A RCBD design with 3 replications was used. During the season diseases were scored using a 1 to 9 scale, and at harvest pod and haulm yields were recorded. In some regions the trials were managed by farmers but in other regions we provided the technology for the demonstration to farmers during the first year of the trial. Thirty six advanced foliar disease resistant varieties were evaluated for their performance for resistance to early leaf spot in Mali. In 1998, thirteen foliar disease resistant lines were tested in the farmers field in Kolokani region in Mali for their resistance to foliar diseases and yield performance. Three lines showed resistance to foliar disease and produced 30 to 52% high pod and haulm yields. One of the foliar disease resistant germplasm lines, ICG 7878 produced 52% higher yield than susceptible lines. ICGV 92 093, ICGV 92087 and 92082 were among the best.

In 1999, on farm evaluation of advanced foliar disease resistant lines was conducted by 70 farmers in Mali. Several lines showed very good performance under farmer's field conditions in terms of disease resistance and pod yield. Among the lines tested by a womens' group, ICGV 92093 and ICGV 92107 had the highest pod yield. In the Kolokani region ICGV 92093 was among the best and produced 2 times more yield than the local variety. ICGV 92087, ICGV 92082, ICGV 92090, and ICGV 92107 also produced good pod and haulm yields. An IER line (Mossitiga) and ICG 7878 showed good performance in both years in some locations and several other farmers showed interest in testing these lines. Many farmers from these region appreciated foliar disease resistant varieties and requested IER and ICRISAT to help them in producing certified seed. Several germplasm lines possess stable resistance to foliar diseases and

to rust and late leaf spot under natural disease pressure. Only 6 of the 253 medium-duration advanced breeding lines in the postrainy season and 14 of the 157 lines in the rainy season out yielded the highest yielding control in respective trials. Compared with 4.2 t ha^{-1} to 4.9 t ha^{-1} in highest yielding controls, the pod yield in high yielding lines in the postrainy season ranged from 5.4 t ha^{-1} to 6.0 t ha^{-1} . These lines included ICGVs 97098, 97093, 98089, 98088, 98167, and 98177. In the rainy season, the pod yield in high yielding lines ranged from 3.2 t ha^{-1} to 5.0 t ha^{-1} and in highest yielding controls from 2.4 t ha^{-1} to 3.7 t ha^{-1}. Some of these lines included ICGVs 97116, 87118, 97115, 98105, 98104, 98077, 99160, 99162, 99161, 98187, 98180, and 99171. Among others, ICGVs 99160, 99162, 99161, 98180, and 99171 also showed moderate resistance to rust and late leaf spot under natural disease pressure. Eight confectionery varieties produced 7 to 23% greater pod yield than ICGV 86564 (4.0 t ha^{-1}) during the 97/98 postrainy season at Patancheru. Nine other confectionery varieties produced 14 to 33% greater pod yield than Somnath (3.7 t ha^{-1}). Two varieties produced 48 to 52% greater pod yield than ICGV 86564 (pod yield 2.1 t ha^{-1}) during the 98/99 postrainy season. They showed greater 100-seed mass and greater proportion of large seeds. Thirty eight varieties recorded oil content between 50 to 55%. Of these, 22 showed an oleic (O)/linoleic (L) fatty acid ratio of >1.60. ICGVs 96228, 96230, 96231, and 96234 showed O/L ratio between 2.16 to 2.49. In 1998 rainy season at Patancheru, 16 varieties resistant to rust (a score of 3) produced 25 to 58% greater pod yield than ICGV 86590 (1.7 t ha^{-1}). Of these, ICGVs 98372, 98390, 98385, 98384, 98371, 98389, 97164, and 97150 were tolerant to LLS (a score of 6). Control ICGV 86590 showed a score of 7 for LLS and 3 for rust. In 1999 rainy season, 25 varieties produced 52 to 113% greater pod yield than control ICGV 86590 (1.8 t ha^{-1}). They scored 4 to 6 for LLS and 2 to 5 for rust. High yielding bulks/breeding lines with moderate levels of resistance to rust and late leaf spot are now available for use by NARS. For resistance to bacterial wilt, access to locations in southeast/east Asia is required.

Short-duration groundnut breeding populations (H D Upadhyaya)

Short-duration high-yielding groundnut varieties are required for many agroecologies of the world where growing season is short or end-of-season droughts are frequent, and for multiple cropping systems. We used cumulative thermal time (CTT measured in degree days, ^{0}Cd) in selection program in the segregating generations and yield trials. The segregating generations were harvested when crop accumulates 1470 ^{0}Cd (equivalent to 90 days after sowing (DAS) in the rainy season at Patancheru). The yield trials were harvested at 1240 ^{0}Cd (equivalent to 75 DAS in the rainy season at Patancheru) and 1470 ^{0}Cd. We grew 16 F_2 populations, 258 F_3 progenies and 440 F_4-F_{11} bulk populations in the 1998 rainy season. In the 1998/99 postrainy season we sowed 15 F_2 populations and 331 bulks. Further, we evaluated 163 varieties in five replicated trials (plot size 6.0 m^2) in the 1998 rainy and 1998/99 postrainy seasons, and selected (on the basis of high percentage of well filled and mature pods obtained at 1470 ^{0}Cd), 152 single plants from the F_2 populations and 331 bulks from F_3-F_{11} population progenies In the breeding populations, and we selected a total of 246 populations in the 1998/99 postrainy season. In the 1998 rainy season 41 lines yielded significantly more than the best control cultivars in the trials. In two trials harvested at 75 DAS, 37 lines yielded significantly greater than the highest-yielding control cultivars JL 24 (1.89 t ha^{-1}) and TMV 2 (1.67 t ha^{-1}). In the postrainy season 11 lines yielded significantly more than the control cultivars. In two trials harvested at 1240 ^{0}Cd, top five lines were ICGVs 98260, 98240, 96346, 96399, and 98354 producing 2.45-2.63 t ha^{-1} compared to 2.16 t ha^{-1} of J 11 and 2.13 t ha^{-1} of JL 24. In the trials harvested at 1470 ^{0}Cd, ICGVs 97328, 97293, 97297, and 97346 yielded 2.63-2.71 t ha^{-1} compared to the highest-yielding control

cultivar TMV 2 (2.31-2.42 t ha^{-1}). Considering pod yields and shelling percentage in both the seasons, ICGVs 98191, 98226, 98285, and 98210 (2.38-2.49 at t ha^{-1}, 38.4%-44.8% more than JL 24) at 1240 ^{0}Cd and ICGVs 97295, 97245, 97338, and 97293 (2.39-2.46 t ha^{-1}, 25.8%-29.5% more than JL 24) at 1470 ^{0}Cd were found most promising . Short-duration variety ICGV 93382 was released as Sinpadetha 7 by the Central Agricultural Research Institute, Myanma Agricultural Service, Myanmar for general cultivation in country. In the multilocational evaluations in the country ICGV 93382 produced on average 2.55 t ha^{-1}, 16.4% more than the control cultivar Sinpadetha 1.

Selected and non-selected bulks of short and medium duration breeding populations with resistance to groundnut rosette (P J van der Merwe)

Rosette is one of the most important diseases of groundnuts and is endemic to sub-Saharan Africa. Resistance to rosette, especially in short duration material is considered a major form of control. Nineteen F_0 and 27 F_1 were sown at the hybridisation block at the Chitedze Research Station. The F_2 to F_8 generations were sown at Chitedze under high rosette disease pressure. The infector row technique was used to create high disease pressure. Yield trials were sown at Chitedze Research Station under high, medium, and low rosette disease pressures. No rosette disease was observed at the low disease pressure. A total of 2087 resistant breeding lines were selected under high disease pressure during the two cropping seasons, ranging from the F_2 to F_8 generations. The outstanding performance of ICGs 12991 and 12988 under high and medium disease pressures can be ascribed to excellent resistance to rosette disease. Almost 99% rosette infection was observed in the susceptible controls (JL24 and Sellie), compared with 10 % infection on ICGs 12991 and 12988. Unfortunately the pods and seeds are small compared with the control variety JL24. Breeding material (F_6 generation) has been identified in short duration groundnut types. NARS and the private sector requested short duration breeding lines and it was distributed to countries in the SEA region. Breeding lines were also made available for evaluation in West Africa through ICRISAT, Bamako. Short duration groundnut material with resistance to rosette is important for both SEA and West Africa

Selected and non-selected bulks of short-duration breeding populations with resistance to groundnut rosette (B R Ntare)

Breeding populations with resistance to rosette will significantly contribute to the objective of diversification of breeding populations to enhance productivity and reduce genetic vulnerability. Sixty (60) new backcross (BCF1) populations for resistance to groundnut rosette were produced. These involved newly identified sources of resistance to rosette with early maturity but low yielding. These were crossed with high yielding, but susceptible early maturing varieties. Eighty (80) populations and 1831 progenies were screened for resistance to groundnut rosette in Nigeria in 1998, and rosette resistant bulk and progenies were selected for further evaluation. In 1999, 25 F_5 populations for rosette resistance and earliness were advanced under natural rosette infestation at Samaru in Nigeria. Only rosette free plants were harvested. A total of 428 F_4 to F_7 bulk progenies were screened in a rosette disease nursery at Samaru in Nigeria. Resistant lines and bulks were selected. This is a collaborative breeding program with IAR, Nigeria and is making good progress towards development of high yielding short-duration varieties resistant to rosette.

Selected and non-selected breeding populations with resistance to drought and aflatoxin contamination (B R Ntare)

Stable groundnut production in West Africa is imperiled by the frequent end-of season drought. Varieties that are tolerant or escape drought stress are needed. Fifteen F_2 bulk populations for resistant/tolerant to drought were obtained from ICRISAT-Patancheru and advanced to F_3 in 1998. In 1999, 1534 F_3 single plant progenies were sown one month after the establishment of the rains at Samanko, Mali. The aim was to expose pod filling to end-of-season drought. Due to extended rainfall, drought stress conditions were not created. At maturity, 872 progenies with good agronomic characteristics were harvested. Out of these, 103 progenies showed resistance to early leafspot (a score of < 5 on a scale of 1-9).

Selected and non-selected bulks of short duration breeding populations with enhanced resistance to drought and aflatoxin (P J van der Merwe)

Aflatoxin production is often associated with drought stress during pod development. Resistance to drought may also reduce the production of aflatoxin. Trials were conducted to evaluate yield and quality characteristics of the breeding material supplied by ICRISAT, Patancheru. Some material has resistance to drought, some are very short duration for escaping the drought situations and others have resistance to colonisation of *Aspergillus flavus*. Four yield trials were conducted at Kasinthula Research Station during 1997/98 and three trials were conduced the Chitedze Research Station near Lilongwe in 1998/99. Test lines were not subjected to drought because Lilongwe experienced good rainfall during the cropping season. The very short duration variety trial at Chitedze was harvested after 90 days. The normal harvesting time for short duration material in Lilongwe is usually 100 to 110 days after sowing. The trial with lines resistant to colonisation of *Aspergillus flavus* was also sown at Chitedze Research Station in 1998/99. Most of the drought tolerant lines have a disappointing performance compared with CG7 (Virginia) and JL24 (Spanish) at Lilongwe in 1998/99. After 90 days some very short duration material produced yields of more than 100% yield as compared to JL24 at Chitedze. Yields of lines with resistance to colonisation of *A. flavus* were disappointing. The materials identified are of great importance in drought prone environments and should be evaluated for broader adaptation.

Selected and non-selected bulks of short-duration breeding populations with resistance to early leaf spot available for NARS in SEA (P J van der Merwe)

Early leaf spot disease of groundnuts is a major constraint to groundnut production globally. It is a destructive disease in higher altitude areas. The use of resistant varieties provides the most appropriate means of disease control, especially for smallholder farmers. The F_0 generation (19 combinations) and F_1 generation (21 combinations) were planted in the hybridization block at Chitedze. Early leaf spot were controlled using fungicides on the F_0 and F_1 generations. The F_2 and F_5 generation progeny rows (598) were planted under high disease pressure. To create high disease pressure for early leaf spot, the infector row method and a field conducive for early leaf spot infection were used to evaluate advanced lines and segregating generations for resistance. Heavy infestations of early leaf spot were observed. Based on the results of the check row, advanced and elite yield trials were analyzed. Resistant lines with average rating of less than 4 (on a 1 to 9 scale) were identified. The yields of the short duration varieties from the advanced trials under high disease pressure were disappointing. Lines from the elite Valencia trial

performed extremely well. In comparison with the control variety JL24, lines in the Elite and Valencia trials produced yields more than 100% of the control variety JL24. A strong genetic relationship between early leaf spot resistance and poor seed quality is well known. One of the objectives of the breeding project was to break the relationship and to develop populations with both early leaf spot resistance and acceptable grading qualities of groundnut. Some genotypes with early leaf spot resistance and improved grading qualities are now available.

Selected and non-selected bulks of breeding populations with improved seed quality available for NARS in SEA (P J van der Merwe)

Grading quality of groundnuts is important for domestic and export markets. Kernel quality is important factor for determining the grading qualities of both short- and long-duration varieties. Pod and seed size, shelling percentage, maturity, percentage seed above certain grading screens, shelf life of seed, and the presence of aflatoxin determine qualities of groundnuts. The objective was to develop high yielding varieties with marketable qualities, high yield, and adaptability. The F_0 generation (7 combinations) and the F_1 generation (7 combinations) were sown at the hybridization block. The F_2 to F_7 generations (2715 progeny lines) and yield trials were also sown at Chitedze. CG7 was used as control variety for comparing Virginia bunch and JL 24 for comparing Spanish breeding lines. Many short duration varieties out yielded the control variety JL24 in the elite variety trials. In the F_2 to F_6 generations, high yielding breeding lines with improved quality and adaptability were identified. Both short, medium duration and long duration varieties produced excellent yields in trials. Dormancy is common in long duration breeding lines, but sprouting is a problem with short duration varieties and may cause considerable quality deterioration. Very promising, high yielding short duration lines with dormancy were identified at Chitedze research station in preliminary and elite yield trials. Less than one percent sprouting was observed. The shelf life of groundnuts is determined by the ratio of oleic to linoleic fatty acid content of the oil. Sources with very high oleic acid content were used as parents in crosses to introduce genes with high oleic oil to adapted varieties from the SEA region. The populations are now in the F_2 generation. Improving the grading of groundnuts is important for domestic and export markets.

Selected and non-selected bulks of breeding populations with combined resistance to late leaf spot and rust available for NARS in SEA (P J van der Merwe)

The lack of rosette resistant varieties with tolerance to rust and late leaf spot has been an obstacle to groundnut production, primarily in low altitude areas. Fungicides can control the disease, but these are costly. Breeding for resistance is therefore, one of the best means of reducing disease. The F_0 - generation (7) and F_1- generation (22) were sown at the hybridization block at the Chitedze Research Station. The F_2 to F_5 generations (708 progeny rows) of rust and late leaf spot resistant material was sown at Chitala Research Station. Selections were made on basis of growth habit and seed quality traits as well as the disease susceptibility ratings. Rust and late leaf spot disease resistance were evaluated at Chitala in two yield trials, one for Spanish and one for Virginia types. Lines with rust and late leaf spot resistance were introduced from ICRISAT, Patancheru. The trials were rated (using 1 to 9 scales) for rust and late leaf spot diseases. The spreader row technique insured a uniform field infestation of rust disease. At Chitala, the incidences of rust and late leaf spot were high. Varieties with rust and late leaf spot resistance were identified in both Virginia and Spanish botanical types. Some improved varieties produce yields in excess of 100% compared to JL 24 (Spanish) and CG7 (Virginia).

Chickpea

Breeding populations and advanced lines with combined fusarium wilt and botrytis gray mold resistance, and chilling tolerance available to Asia (Jagdish Kumar)

Drought is the most important abiotic and fusarium wilt is a major biotic yield reducer for chickpea. We made crosses involving short-duration parental lines with new sources of resistance to fusarium wilt and drought. The F_2 and F_3 populations were screened in wilt-sick and unirrigated plots at ICRISAT, Patancheru. Multiple crosses for incorporation of resistances to ascochyta blight, chilling tolerance, earliness and/or large seed size were made for desi and kabuli types. The populations made earlier were advanced and elite lines were selected. We made 172 crosses, advanced 393 populations in the normal fields and screened 116 F_2 and 116 F_3 populations in the fusarium wilt-sick plot at ICRISAT and selected 448 plants and 187 progenies in 1997/98 and 1998/99. Five populations and 50 lines were screened for ascochyta blight in the chickpea growth room and 100 lines in an artificially augmented blight nursery at the Punjab Agricultural University, Ludhiana, and 26 advanced lines were found resistant over two years' testing. The development of varieties for sub-tropical environments requires both the earliness gene (s) and genes for chilling tolerance. Therefore, we developed super-early lines ICCV 96029 and ICCV 96030 at ICRISAT. ICCV 96029 was tested at Patancheru (18^0N) and at Hisar (29^0N) during 1997/98 and 1998/99. The two-year data indicated that the super-early line matured about four weeks earlier than the popular controls at Hisar. It flowered earlier and podded through the cool winter. If these results are repeatable over sub-tropical locations and years it may be possible to develop chickpea varieties which will mature early to escape damage by major constraints prevalent during podding in the sub-tropical environments. As many as 26 out of 40 crosses planned for 1999/2000 in the national program involve ICRISAT bred parents, especially super early ICCV 96029.

Breeding populations and advanced lines with combined drought and fusarium wilt resistance available for SEA (N P Saxena)

Drought and fusarium wilt are important constraints of chickpea yield in East African countries. Improving tolerance and resistance to these stresses is expected to increase realizable yield and also render greater stability of yield. A crossing program was established with the following parents; ICC 4958, a drought tolerant germplasm line with a large root system; ICCV 2, a kabuli type which is early and escapes drought; F 91-120, a freezing tolerant, large seeded Kabuli from ICARDA; ICC 5680, a drought tolerant desi type with fewer pinnules (6-7 compared to 11-13 in other geno types); ICC 14303, a fusarium wilt resistant long duration desi type; and ICC 7345, a very large seeded, bold kabuli type from Mexico. The eight crosses were made and F_1 seed was produced in the off-season in conviron in April 1998. F_1s were grown in the postrainy season 1998/99 and F_2s were bulk harvested. The F_2s were advanced to F_3 during off-season (sown 22 June 1999 under extended days) and bulk harvested. F_3s have now been sown in the field and will be advanced and F_4 bulks will be produced by Feb 2000. Four-way crosses were made in postrainy season of 1998/1999. Generation was advanced to F_2 during off-season in 1999. F_2s derived from these four-way crosses have now been sown in postrainy season of 1999/2000. F_4 segregating bulks of two-way and four-way crosses will be supplied to NARS partners in Africa and on request in Asia for planting in 2000, and making selections for specific adaptation in their

target regions. It has been possible to achieve it through rapid generation turnover using both conviron and field facilities with extended day lengths.

Pigeonpea

Mechanism and inheritance of water-logging tolerance completed and documented (K B Saxena)

This is the first ever study on the mechanism and inheritance of water-logging tolerance and its documentation will be useful. Water-logging is an important abiotic production constraint, specially in the short-duration types. At ICRISAT a pot screening technique was developed and a few water-logging tolerant genotypes were identified. In this study, a number of morphological traits were also studied to establish their relationship with water-logging tolerance. Under water-logged conditions the tolerant lines developed prominent lenticels (swelling of stem below the waterline) and adventitious roots. The tolerance was dominant over susceptibility. Additive, dominance, and epistatic effects were found to control the variation. Water-logging tolerance was closely associated to lenticel formation and development of adventitious roots.

Objective 4.2: Evaluation and exploitation of new cytoplasmic male-sterility options to enhance productivity through hybrid cultivars.

Sorghum

Development of A_2 maintainer lines (Belum V S Reddy)

It is important to diversify the male-sterile base not only for nuclear genes but also for cytoplasms. Therefore, some of the progenies in the ongoing A_1 CMS research areas were test crossed on to A_2 CMS to find out their male-sterility maintainers reaction. In a testing of 83 S_0 progenies for resistance to shoot fly, 23 individual plant selections were identified as maintainers on A_2 CMS. Also, 17 individual plants were identified to have male-sterility maintenance reaction from 111 F_5 families derived from BxB of F_3 x 296B and its backcross. Similarly from the bold grain maintainer lines development program, four individual plant selections showed male-sterility maintainers reaction on A_2 CMS.

Sorghum A&B-lines evaluated for resistance to shoot fly and stem borer (H C Sharma)

To identify cytoplasmic male-sterile lines with resistance to sorghum shoot fly, *Atherigona soccata*, we evaluated 50 pairs of A&B lines for resistance to shoot fly under infester row fish meal technique under field conditions. We evaluated 50 pairs of A&B lines in collaboration with breeders during the 1998-99 seasons. There were three replications in a RCBD. Data were recorded on egg laying, deadheart formation, glossiness, plant height, days to 50% flowering, and agronomic desirability. During the 1997/99 postrainy season, 38 pairs of A&B lines were

evaluated for resistance to shoot fly, and there were three replications in a RCBD. Both A and B pairs of SPSFR 94006, SPSFR 94034, SPSFR 94036, and SP 55301 were significantly less susceptible to shoot fly across seasons (<67.7% deadheart formation compared to 99.6% deadhearts in 296A and 78.5 to 98.6% in the susceptible check, CSH 1) (Table 4.2.1). These lines are glossy (glossiness score of <3.0 compared to 5 of the susceptible check CSH 1). These are 121.3 cm in plant height, take 80 to 86 days to flowering compared to 81.7 days in CSH 1, and are agronomically good.

To identify cytoplasmic male-sterile lines with resistance to spotted stem borer, *Chilo partellus*, and agronomic desirability we evaluated 22 A&B pairs of sorghum lines for resistance to stem borer in collaboration with breeders. There were three replications in a RCBD. The material was infested artificially, and data were recorded on leaf feeding and deadheart formation. During the 1998-99 rainy seasons, 10 pairs of A&B lines selected earlier to be less susceptible to stem borer damage were screened for resistance under artificial infestation. Data were recorded on leaf feeding, deadhearts, and stem tunnelling (Table 4.2.2). Overall resistance score of SPSBR 94005, SPSBR 94011, and SPSBR 94017 was 3.7 to 5.3 compared to 7.3 to 7.5 of the susceptible check, ICSV 1. The agronomic score of the stem borer resistant A and B lines was 2.8 to 3.3 compared to 5 of the resistant check, IS 2205, indicating the need to improve these lines for agronomic desirability. The flowering periods of these lines were similar to those of the commercial cultivars. During the postrainy season, five lines (SPSBR 94001, SPSBR 94006, SPSBR 94010, and SPSBR 94011) showed a relative resistance score of <5.0 compared to 6.0 of the susceptible check, ICSV 1. Data on leaf feeding and deadheart formation was not conclusive because of low levels of damage in the initial stages because of cold conditions. The agronomic desirability of the improved lines was 2.4 to 3.0 compared to 4.3 of the resistant check, IS 2205.

Table 4.2.1. Relative resistance/susceptibility of 12 cytoplasmic male-sterile (cms) lines and their maintainers to sorghum shoot fly, *Atherigona soccata* (ICRISAT Center, Patancheru 1998-99)

Genotype	Deadhearts (%)			
	A – lines		B - lines	
	1998	1999	1998	1999
SPSFR 94006	31.0	49.1	16.6	35.9
SPSFR 94010	45.6	61.4	33.5	39.6
SPSFR 94027	15.6	60.6	26.3	74.0
SPSFR 94034	28.2	56.8	9.4	36.3
SP 55301	27.7	60.4	25.6	61.7
296 A - susceptible	-	99.6	-	98.2
IS 18551- resistant	-	-	32.3	66.7
SE	±11.11	±7.00	±11.11	±10.7

a-lines = Male-sterile lines, and B-lines = Maintainer lines

Table 4.2.2 Relative resistance / susceptibility of cytoplasmic male-sterile lines and their maintainers to spotted stem borer, *Chilo partellus* (ICRISAT Center, Patancheru 1998-99)

Genotype	A-Lines						B-Lines					
	Leaf feeding score[1]		Deadheart (%)		Relative resistance[2]		Leaf feeding score[1]		Deadheart (%)		Relative resistance[2]	
	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
SPSBR 94005	5.0	5.3	2.9(7.0)*	0.0(4.8)	5.5	4.5	5.5	5.8	0.0(4.8)	0.0(4.8)	3.5	5.3
SPSBR 94007	4.5	3.7	1.1(6.1)	5.7(8.10	7.5	6.7	4.0	4.7	9.6(10.1)	7.3(8.6)	6.5	5.0
SPSBR 94011	5.0	7.0	3.3(8.0)	4.4(8.5)	4.5	5.0	6.5	5.0	2.9(7.0)	3.3(7.5)	4.0	4.7
SPSBR 94012	7.0	6.7	7.6(9.2)	5.0(8.0)	6.0	5.7	6.0	6.0	12.8(10.6)	6.8(8.2)	5.0	5.7
SPSBR 94017	5.5	5.3	3.8(7.3)	0.9(5.8)	5.0	4.3	6.0	7.0	1.3(6.2)	9.4(10.2)	4.5	3.7
296 B S	-	7.3	-	40.2(14.5)	-	7.0	-	7.0	-	28.7(13.4)		6.3
IS 2205 B R	-	-	-	-	-	-	4.0	4.7	11.8(10.7)	0.0(4.8)	4.0	3.3
SE	±0.9	±0.78	±0.79	±0.67	±0.98	±0.62	±0.9	±0.78	±0.79	±1.71	±0.98	±0.62

1 Leaf feeding score (1=<10% leaf area with shot-holes and scarification, and 9=>80% leaf area damaged

2 Relative resistance (1=no apparent difference in plant height and panicle emergence between infected and uninfected plants, and 9 infected plots with extensive dead hearts formation and drastic reduction in plant height and a few normal panicles)

* Figures in parenthesis are Arcsin (N+0.5) transformed values

Pearl Millet

Cytoplasmic male-sterility (CMS) system diversity and stability (K N Rai)

CMS diversity provides an insurance against potential disease and insect pest epidemics on hybrids. It also expands the scope for genetic diversification of seed parents. Stability of male sterility of A-lines is the most essential feature determining commercial viability of a CMS system. Four isonuclear A-lines (81A_1, 81A_4, 81A_5 and 81A_v) with four CMS sources and in the genetic background of 81B were evaluated for male sterility across three environments for two years. Their hybrids, made by crossing with each of the 11 diverse inbred lines, were evaluated across two seasons for two years for fertility restoration patterns to determine CMS diversity. Ten hybrids of 81A_5, seven of 81A_4 and three of 81A_1 were consistently male sterile in all four tests. Only one hybrid of 81A was consistently sterile in all four tests, while five were sterile in the two dry seasons but partially to highly fertile in the two rainy seasons. This indicated that these four CMS sources represented four diverse CMS systems, and that the sterility of 81A_v was least stable. Evaluation of isonuclear A-lines with these four CMS sources showed that male sterility of 81A_4 and 81A_5 was most stable, as these did not have any pollen shedders across all the six environments. The 81A_v had least stable sterility as it had 0.1 to 0.8% pollen shedders across all the six environments. The 81A_1 (control) had similar pollen shedders as 81A_v in four environments, but none in the other two environments. The degree of selfed seedset in non-shedding plants ranked these A-lines in the same order with respect to stability of male sterility.

CMS differentials and dual restorers in pearl millet (K N Rai)

CMS differentials provide useful testers for classification of new CMS sources. Common restorers of different CMS systems (dual restorers, if they restore fertility of two CMS systems) enable valid assessment of the effect of alternative CMS systems on grain yield and other

characters of hybrids, by eliminating the confounding effect of fertility/sterility on these characters. CMS differentials of A_1, A_4, A_v and A_{egp} systems and dual restorers of A_1 and A_4 systems were identified and purified from individual plants of pollen parents. Two S_6 progenies developed from NCD_2 produced highly fertile hybrids on $81A_4$ and fully sterile hybrids on $81A_1$. Purified versions derived from two pollinators (IPC 319 and IPC 337) produced highly fertile hybrids on $81A_4$ and sterile hybrids on $81A_1$. Similarly, a purified version derived from IPC 390 gave a fully fertile hybrid on $81A_1$ and a sterile hybrid on $81A_v$. From amongst 54 seed parents progenies from diverse sources that had been previously identified to have produced sterile hybrids on both $81A_1$ and $81A_4$, five produced fertile hybrids on $81A_v$, although the level of fertility was just about the average. Evaluation of male fertility restoration in the dry season of 1999 showed that either all or some of the plants of six pollinators produced testcrosses on both $81A_1$ and $81A_4$ that had very high levels of selfed seedset (SSS). Re-evaluation of the most fertile testcrosses of both $81A_1$ and $81A_4$ that involved the same pollinator plants in the 1999 rainy season confirmed the high levels of their SSS. Individual plant testcrosses from the selfed progenies of these pollinator plants have already been made to confirm their uniformity for high levels of fertility restoration ability of both $81A_1$ and $81A_4$.

Isonuclear A-lines in diverse genetic backgrounds of pearl millet (K N Rai)

Fifteen isonuclear A-lines have been under development by backcross transfer of nuclear genomes of three diverse B-lines (81B, 5054B and ICMB 88004) into five diverse cytoplasms (A_1, A_4, A_5, A_v and A_{egp}). During the backcross conversion of B-lines into A-lines, complete male sterility was observed in all the backcross progenies. More than eight backcrosses were completed. Isonuclear A-lines in all the five cytoplasmic backgrounds visually looked similar to their respective B-lines. Morphological evaluation will be done to determine isogenicity of these lines. It would also be worthwhile to examine their isogenicity by RFLP. The isonuclear A-lines produced from this work will be the only stocks available anywhere for studies related to genetics and stability of male sterility, and CMS effect on grain yield and other traits.

Potential advantages of F_1 seed parents over inbred seed parents in pearl millet (K N Rai and Subhash Chandra)

Low seed yield due to inbreeding depression, and rapid breakdown of downy mildew resistance due to homozygosity and genetic uniformity, are the two major disadvantages with inbred seed parents. The F_1 seed parents may provide an alternative option to address both these issues. Eleven diverse inbred seed parents and nine hybrids derived from their crosses were evaluated in 11 year x locations environments for grain yield and other agronomic traits. These were also evaluated for downy mildew (DM) incidence in the DM nursery at Patancheru and against Patancheru pathotype in the greenhouse. Grain yield of F_1 hybrids, averaged over all the environments, was significantly higher than their respective higher-yielding inbred parents, with the better-parent heterosis ranging from 27 to 107%. The yield response to varying productivity levels of environments and yield stability was more a characteristic of a genotype rather than of the genotype class, whether hybrid or inbred seed parent. It is interesting that in some instances, the yield advantage in F_1s was achieved despite their being as early as the early-maturing parental inbred lines. The F_1s were either not significantly different from their early-flowering inbred parents, or were closer to their early-flowering inbred parents than to the late-flowering parents. Under high DM pressure in disease nursery and in greenhouse seedling inoculation test at Patancheru (>70% DM incidence in susceptible hybrid HB-3), the differences between the

DM incidence of F_1s and their less-susceptible (i.e., more resistant) inbred parents were not significant. Thus, F_1 seed parents, besides their grain yield advantages over the inbred seed parents, can provide a useful approach to modify the late-maturing but the otherwise high-yielding inbred lines towards earliness. Similarly, they can help prolong the commercial life of widely used inbred seed parents that might have become susceptible due to their large-scale deployment over time. The extent of seed yield advantage of F_1s and the good opportunities that they provide for maturity manipulation in late-maturing inbreds and downy mildew disease management in susceptible inbreds make them an attractive option for use in 3-way hybrid breeding.

New CMS sources in pearl millet characterized for diversity (K N Rai)

Search for additional CMS sources led to identification and stabilization of 15 sources from EEBC (Extra-early B-composite), 5 from LSGP (Large-seeded genepool) and 1 from EGP (Early genepool). These were evaluated for differences, if any, among themselves and from the classified CMS systems. Nine inbred lines were crossed onto $81A_1$, $81A_4$, $81A_5$, $81A_{egp}$, and on 15 isonuclear A-lines developed from EEBC CMS sources. Seven of these lines were also crossed onto five CMS sources identified from LSGP. Fertility restoration patterns of hybrids evaluated in the 1999 dry season was used to examine CMS diversity. Fertility restoration patterns of hybrids made on $81A_{egp}$ and 15 EEBC sources were similar to that made on $81A_1$, implying that all these 16 new sources were similar to each other as well as to the A_1. Of the five LSGP sources, fertility restoration patterns of hybrids made on isonuclear A-lines with LSGP 22, LSGP 28 and LSGP 43 cytoplasms were similar to that of $81A_1$, and the patterns in hybrids made on isonuclear A-lines with LSGP 33 and LSGP 55 cytoplasms were similar to that of $81A_4$. This preliminary grouping of the cytoplasms indicated the type of tester to be used in further studies to resolve the CMS diversity, if any. For instance, in another study involving hybrids of $81A_1$, $81A_4$ and $81A_{egp}$ made with a set of 16 inbred lines, it was observed that four inbred lines produced fertile hybrids on both $81A_1$ and $81A_4$, but sterile hybrids on $81A_{egp}$. In the light of this observation, the two groups from five LSGP sources will be evaluated with larger tester sets identified for both A_1 and A_4 CMS systems. The EEBC CMS sources will be shelved. The five LSGP sources will be further evaluated with larger tester sets already identified. Hybrids comparing A_1, A_4 and A_{egp} cytoplasms will be re-evaluated to confirm the results obtained so far.

Recurrent selection efficiency for fertility restoration and sterility maintenance with A_1 and A_4 CMS demonstrated (K N Rai)

Selection efficiency for male sterility maintenance and fertility restoration ability is one of the major determinants of relative usefulness of alternative CMS systems in hybrid parents breeding. Recurrent selection based on male fertility or sterility reaction in testcrosses made on $81A_1$ and $81A_4$ was initiated in three composites (ESRC II, SOSAT-C88 and ICMR 312) during 1998 and in Raj 171 during 1999. There were 70% pollen-shedding (F) and 30% non-shedding (S) plants in the topcross hybrid of ESRC II made on $81A_1$, while 39% F and 61% S plants in the topcross hybrid made with the same population on $81A_4$. During the recombination in C_1 cycle to form restorer (R) and maintainer (B) sub-populations with respect to both male-sterile lines (i.e., $81A_1$R, $81A_1$B, $81A_4$R and $81A_4$B), bulk pollen from all S_1s that were being recombined to form a sub-population were crossed onto $81A_1$ and $81A_4$ to produce what can be equivalent to four C_1-cycle topcrosses. In $81A_1$R-topcross, frequency of fertile plants increased to 84%, while in $81A_1$B-topcross, frequency of sterile plants increased to 73%. Similarly, in $81A_4$R-topcross,

frequency of fertile plants increased to 53%, while in 81A_4B-topcross, frequency of sterile plants increased to 93%. This showed that bi-directional selection for fertility restoration and sterility maintenance ability in ESRC II was effective both with A_1 and A_4 CMS systems. Recurrent selection program on SOSAT-C88 was dropped because of poor pollen-shedding characteristics of fertile testcrosses made on 81A_4. This program on ICMR 312 was also dropped because only 2 out of 212 tescrosses made on 81A_1 were sterile. Recurrent selection in ESRC II was effective in both directions in both CMS systems. Gains from further selection cycles in ESRC II will be compared with those made in Raj 171 to examine relative efficiency of A_1 and A_4, and also if genetic background of a population has any influence on it.

A_4 and A_5 restorer versions of elite inbred lines available (K N Rai)

One major advantage with A_4 and A_5 CMS systems for genetic diversification of seed parents is that a significantly higher proportion of inbred lines are maintainer of A_4 than of A_1, and almost every inbred line is a potential maintainer of A_5. Its implication in grain hybrid breeding is that fewer inbred lines will be restorers on A_4 and none on A_5, requiring vigorous restorer development program. Twenty-seven diverse A_1-system restorers were selected for backcross breeding into A_4 restorer version, and 53 into A_5 restorer version. In both cases, restorer gene donor sources in the respective cytoplasmic backgrounds were used as non-recurrent female parent during the entire backcross breeding program. Eleven inbred lines were advanced to BC_5 and 16 to BC_1 stage for A_4-restorer development. In case of A_5-restorer development, 31 lines were advanced to BC_5, eight to BC_2 and 14 to BC_1 stage. Selection of highly fertile plants in backcross progenies to be used as a female parent has proved effective and straightforward in restorer development for both CMS systems. The restorer development methodology proved simple and effective, implying that a wide range of A_4 and A_5 restorer lines can be developed rather rapidly and in a cost-effective manner.

Pigeonpea

Stable cytoplasmic male-sterile lines developed and their maintainers and restorers identified (K B Saxena)

Development of stable cytoplasmic male-sterile lines will lead to an economically viable hybrid seed production system of pigeonpea. Selected 'A' x 'B' lines were grown in progeny rows, and 6 promising populations were grown in isolation along with their 'B' lines. Plants were identified for male-sterility and selections were made on the basis of segregation within progenies. The promising selections were multiplied by crossing 'A' lines with their respective 'B' lines. To study the effect of environment on CMS trait, observations were made on the photoperiod – temperature sensitive selections. Small quantity of seeds of CMS lines were distributed to scientists at 10 locations in India. In 1998, six populations were selected for multiplication in isolation (Table 4.2.3). The male-sterility in these populations ranged between 86-100 %. Of these two (85010 and 88034 crosses) were selected for advance. In 1999, in 85010 CMS 565 out of 593 plants grown (95%) were male-sterile. While in 88034 CMS, 1011 out of 1029 plants grown (98%) exhibited male sterility. Some plants also exhibited partial sterility and these were rejected. In 85010 CMS line, some plants with photoperiod sensitive reaction were found. These were harvested separately. Among the progenies sown in field only 30 progenies were selected for further evaluation. One determinate (85010 CMS) and one non-determinate (88034 CMS)

line have shown great promise with respect to plant type and male-sterility. These were selected for seed multiplication. In the photoperiod-temperature sensitive CMS selections it was observed that many sterile plants turned fertile in the month of November-December and produced pods and viable seeds. The progeny of such selection produced all sterile plants. In a glasshouse study some selections showed a remarkable shift in their pollen sterility.

Table 4.2.3. Segregation for male-sterility in the most promising CMS lines in 1998

Isolation	Total plants	Sterile plants	% Steriles
RCE 24*(85010)	585	569	97
BP 1	150	150	100
RCE-3	494	494	100
RP-17	541	465	86
RM-8	152	151	99
Glass house(88034)*	*466*	*404*	*87*

** selected for seed multiplication in 1999*

In the progenies derived through mutagenesis the results were disappointing with CMS expression dropping down significantly. Reasons for such a drastic change are not known. Efforts have been made to reconstitute the promising progenies by making plant-to-plant crosses.

Identification of fertility restorers of CMS lines is necessary to develop heterotic hybrid combinations. The promising CMS lines grown during 1998 were crossed with over 100 diverse germplasm. The F_1s were grown in 1999 season and observations were made for fertile pollen production and pod set. Among the 38 F_1s grown in 1998, ICP 13092, and MN 1 looked very promising for maintaining the male-sterility. In the remaining F_1s, the fertility ranged between 50-100%. ICP 6308, ICP 8744, PI 396279, PI 396574, 2 Tanzania, 7 Tanzania, HPL 24, ICPL 86012, and ICPL 88039 were found promising for restoring fertility. In 1999, 22 F_1s were grown and the superiority of ICP 13092 and MN 1 in maintaining CMS and HPL 24, BDN-1, 2 Tanzania in fertility restoration was confirmed. In some cross combinations the plant population was low. Crosses will be repeated to confirm these observations. Also parents showing 70-80% fertility will be purified for fertility restorer gene. In addition, about 100 new parents were included for screening fertility restorers.

Hybrid seed production procedure using CMS established and documented (K B Saxena)

Information on large-scale seed production technology is essential for the commercialization of the hybrid pigeonpea technology. Preliminary seed production trials, including one promising determinate and one non-determinate line, were grown in 1999 rainy season. Four rows of 'A' line and one row of 'B' line were grown alternatively in isolation for seed production through natural out-crossing. In the determinate CMS line, plant population was affected by wilt disease. It was also observed that in comparison to 'B' lines, germination of 'A' lines was delayed by 8-10 days. Delayed sowing of 'B' line matched with the flowering of 'A' line. In order to discard photo-thermal CMS segregants the material was grown under insect-proof cage. The cage will be removed in the month of December and observation on natural pod set will be made. Selections were made for quick germinability among CMS plants to overcome the problem of hard seed coat. The results of pod set through natural out-crossing are awaited. We propose to carryout detailed seed production studies in the next season.

Objective 4.3: Develop cultivars to meet regional needs

Sorghum

High yielding bold grain sorghum A/B lines development (Belum V S Reddy)

Trait-based breeding resulted in male-sterile lines that are less susceptible to various yield-limiting factors. They, however, lacked in high grain yield and boldness. Farmers and private sector scientists demand bold grain lines. There are four types of materials developed:

Materials generated by crossing the high yielding B-lines from different trait-based breeding programs among themselves: Selection in this group for high grain yield and boldness resulted in 707 F_4s in 1997 postrainy season, which were further selected in 1998 rainy season. The resulting 605 F_5s produced 225 F_6s. These F_6s were evaluated in 1999 rainy season. This material is called hereafter as *trait-based source bold grain lines.*

Materials developed for shoot fly resistance program particularly that belonged to the three-way crosses of i) (F_3 x 296B)-F_1s by shoot fly resistant lines and ii) (F_3s x 296B)-F_1s by 296B: In sub-group i) 380 F_4s were obtained from 918 F_3 progenies evaluated during 1998 rainy season. These 380 F_4 progenies yielded 95 F_5s which were evaluated during 1999 rainy season. This group is called hereafter as shoot fly source bold grain lines. In sub-group ii), 313 maintainer lines in backcross (BC_1) stage were obtained from selection in 126 F_4/F_5 progenies during 1998 rainy season. These were further selected and backcrossed for conversion to male-sterility in 1998 postrainy season. This resulted in 92 maintainer lines with respective A-lines in BC_2 stage. This material is called hereafter as *296B backcross bold grain lines.* The selections from 1998 postrainy season were evaluated during 1999 rainy season. Selection and backcrossing for conversion to male-sterility was taken up in 296B backcross bold grain lines.

High yielding bold grain direct selections in 296B: Twenty seven individual plant selections were made in 296B in 1998 rainy season. These maintainer lines along with respective A-lines in BC_3 stage were evaluated in 1998 postrainy season which resulted in 16 maintainer lines with their A-lines in BC_4. These were further evaluated and backcrossed during 1999 rainy season. This material is called hereafter as 296B direct selections.

Advanced generation lines derived from bold grain sources received from Russia: Bold grain lines received from Russia were crossed earlier with several bold grain B- and R-lines, and selected further. The resulting families in advanced generation were further evaluated during 1999 rainy season and selected upon for high grain yield and boldness. This material is called hereafter as Russian lines derivatives.

Pearl Millet

Improved pearl millet populations available for use in West Africa (K Anand Kumar)

Novel source populations that combine agronomically desirable traits with local adaptation are an essential component in the creation of broad-based populations and end products. West

Africa is the center of diversity for pearl millet and hence landraces exhibit a range of desirable trait combinations. Populations that combine unusual trait combinations are of value not only within the region but also in other pearl millet growing areas of the world. Progeny tests were conducted to identify better performing entries for recombination and preliminary variety development. First random mating of Sosank was undertaken in isolation. A first set of S_1s of ICMV IS 89305 (S_1s were developed in Patancheru) was evaluated for differences in threshing percentage. GGP, derived from early accessions of *Iniadi* landraces from Togo is characterized by earliness, (47 days to 50% flowering), bold grains (mean 16 g 1000 seeds^{-1}), rapid grain filling rate, low total dry matter (6.2 t ha^{-1}) and high harvest index (30%). S_1 progenies were tested (196) and 14 entries that recorded 23% more grain yield than mean of the trial (1.4 t ha^{-1}) and showed an average of 50% of plants possessing bold grain were selected to derive two experimental varieties. GGT derived from a photoperiod germplasm accession from Benin (IP 10437) is late (60 to 65 days), tall (260 cm) and has a mean 1000 grain weight of 18 g. It exhibits the stay-green trait and produces more total dry matter (8 t ha^{-1}) with a harvest index of 25%. Following testing of S_1 progenies (330) 15 progenies were selected that showed a 45% increase in yield over the mean of the trial (1.5 t ha^{-1}). In collaboration with the physiologist, an S_1 progeny test of variety ICMV IS 89305 was conducted at Sadore. Rainfall was normal (570 mm) with no intervening drought periods. Though 50 progenies recorded threshing percentage similar to ICMV IS 89305 (68%) only 29 of these recorded grain yield similar to ICMV IS 89305. Sosank is an intervarietal population derived from crossing Ankoutess (from Niger has a short stubby earhead with a large circumference) with an ICRISAT-IER co-developed variety, SOSAT-C88, to improve grain filling and grain quality of Ankoutess. Following evaluation of F_3 progenies, selected entries were random-mated. Plants in this intervarietal population have retained the characteristic earhead circumference (15 cm), show increases in tiller number plant^{-1} (2-3), increased grain mass (8.6 g vs. 11.0 g 1000 grains^{-1}) and distinct grain quality of SOSAT-C88. Through these populations novel traits and trait combinations will become available to millet breeders.

Improved pearl millet populations available for use in West Africa (K Anand Kumar)

Source populations that combine desirable traits with local adaptation are an essential component to create broad-based populations and end products. Our evaluations have shown that ICRISAT-Nigeria developed Medium maturity composite (MMC) and progenies selected from the intervarietal-cross GRP1 x GB 8735 that exhibits white grain color have potential to contribute to diversification. Selection for local adaptation and increased grain size (Faringuero) will increase the utility of these two populations in millet improvement. Half-sibs were obtained during the Summer 1999 and these were tested in the rainy season. Progenies were identified for deriving S_1s. Primary selection criteria were stand establishment in MMC and grain size in Faringuero. For MMC 79 entries of 140 tested were retained to derive S_1 progenies. Mean time to bloom was 52 days, plant height 250 cm, earhead length 40 cm and a grain yield of 1.5 t ha^{-1}. For Faringuero 200 entries were retained to derive S_1 progenies based on grain yield, head length (> 40 cm) and compactness. Visual assessments for grain size and compactness were also taken into consideration. Selected progenies will be sown in rainy season 2000 to derive S_1s for testing in 2001.

Improved pearl millet populations available for use in West Africa (K Anand Kumar and S Fernandez, ILRI)

Stover quality is an important attribute in the millet-based agro-sylvo pastoral systems of the Sahel. Our preliminary collaborative investigations with ILRI have shown that the single recessive gene for brown-midrib (bmr) reduces lignin content in leaf and stem by 30%, increases digestibility but reduces dry matter by 20% and grain yield by 30%. Of the 35 near-isogenic bmr populations developed, two (having background of CIVT) were selected. These are being evaluated in collaboration with ILRI to determine if reduced dry matter and grain yield levels are offset by improved digestibility. During the postrainy season of 1998 seed of two bmr populations (derived from crosses involving bmr source from Kansas State University x CIVT) and control CIVT was produced to sow 0.3 ha of each genotype at 33000 plants ha^{-1} during rainy season 1999. Enough dry stover was harvested before flowering and at maturity from both bmr and normal sources and is being used in experiments on intake and digestibility in sheep by the ILRI nutritionist. Results of intake and digestibility will be available in the first quarter of next year. The bmr populations flowered later (70 vs. 60 days for normal), they were shorter (217 vs. 261 cm), possessed earheads that were shorter (42 vs. 60 cm), but showed higher number of tillers (2.4 vs. 1.8 plant). Threshing percentage of bmr was 20% lower than normal (60%), and grain yield was 50% lower (normal 81 g $plant^{-1}$). In addition, the dry matter $plant^{-1}$ was just over 50% of the normal (190 g $plant^{-1}$). We have observed that re-growth of the bmr plants that were harvested at flowering was very limited in comparison to the normal. In case the pre-flowering stover has better digestibility it will be important to design agronomic experiments that will allow the harvest of leaf and stem dry matter for feeding animals before harvest of the main crop. If the intake and digestibility experiments indicate superior stover quality of bmr populations, one of these (133-52) that has a large variation for yield components should be subjected to recurrent selection to improve grain yield while maintaining superior stover quality.

Improved pearl millet populations available for use in West Africa (K Anand Kumar, Jada Gonda and Jika Naino, INRAN)

In Niger, landrace varieties of pearl millet are heavily contaminated with Shibras (weedy, mimetic forms; up to 30%). At the request of the Department of Agriculture in 1995-96, selection for elimination of the intermediate forms in the landrace Ankoutess was initiated. This landrace, grown in the Damergou and Dakoro regions, possesses a characteristic short earhead head with a large circumference (15 cm). S_1 selection was used, retaining and recombining progenies that showed complete absence of Shibras, and possessed characteristic large earhead circumference. Variety description (*Fiche technique*) was developed based on observations recorded in a replicated on-station trial. The Improved Ankoutess variety was multiplied in isolation recorded a complete absence of Shibras and exhibits varietal characteristics of the original landrace. A standard variety description was developed following on–station evaluations. Flowering in 55 to 65 days, Improved Ankoutess attains a plant height of 225 cm and a earhead length of 25 cm. Circumference of the earhead is 15 cm. On station yield recorded was between 1.5 to 2.0 t ha^{-1}. The grains are obovate with a yellowish brown color. Breeders seed of this variety was provided to Project Mayahi, INRAN-CERRA- Kollo, and Department d'Agriculture. The improved version now provides a clean uncontaminated landrace for farmer use. Three kilograms seed of this improved version is deposited in the long-term seed store at Sadoré for future multiplication and or distribution. This improved version was also used in the development of an intervarietal population, Sosank.

Improved pearl millet populations available for use in West Africa (K Anand Kumar)

Seed increase of inbreds carrying distinct grain colors for use as inbreds in inbred x variety hybrids. For topcross hybrids that use fertile inbreds as female parents it is important that such inbreds are dwarf (to permit development of dwarf hybrids), resistant to downy mildew and possess a grain color trait that would help in the identification of selfed seed. The latter is important as the inbred x variety hybrid are based on the use of the protogynous nature of flowering in pearl millet. Several inbred lines were derived by crossing d_2 sources with lines possessing different grain colors. Individual plants identified in segregating generations were selfed and are being inbred for the last four to five generations. During 1999 rainy season lines that were uniform for grain color were retained for use. Four distinct grain colors were retained for future use. In addition, an accession from Chad (TCD 125) was further inbred. This landrace is medium tall (>1.8 m), exhibits high tillering, and has small seed with a bright yellow pericarp. The four inbreds and their selections are now available for use in inbred x variety development. Based on their combining ability one or two entries could be retained to attempt conversion to male-steriles.

Improved pearl millet populations available for use in WCA (S C Gupta)

For quick utilization of germplasm/breeding lines available with Lake Chad Research Institute (LCRI), Nigeria and introduced material from SADC, India, Mali, and Niger, diverse composite populations were developed jointly by ICRISAT and LCRI. These populations can be improved following recurrent selection, and the superior varieties can be developed by recombining few the best progenies in each or alternate cycles of selection. Fourth random mating was completed in four composite populations in 1997 main season. These composites are: early maturing (147 entries of less than 55 days to flower), medium maturing (201 entries of 55 to 70 days to flower), late maturing (71 entries of 70 to 90 days to flower) and dwarf (16 entries of 1.7 to 2.0 m plant height). During 1998 main season, each composite was sown by one farmer in each of the two villages for farmers' participatory selection. The plot size was 0.2 ha. Gridded mass selection was practiced. To form photoperiod-sensitive genepool, 262 entries were selected. These entries were sown for the first random mating in 1996/97 off-season. Third random mating was completed in 1998 main season at Bagauda. Farmers' participatory selection was practiced in four composite populations in 1998. Farmers selected about 10% plants of their choice following gridded mass selection (under supervision of technician). One panicle from all the selected plants was harvested, selected panicles bulked, and threshed to form next cycle bulk. Early maturing and dwarf composites were preferred by farmers because of earliness, higher tillering, bigger grain, and brighter grain color than their locals. The selection criteria varied slightly in each village. Farmers preferred long panicles of medium maturing composite. Late maturing composite was rejected by farmers in Gargai village due to poor seed setting. However, this composite was selected in another village. Farmers were quite happy to be involved in the selection of the material from variable populations. The seed of four composite populations (early, medium, late and dwarf) was supplied to LCRI (Nigerian NARS), ICRISAT-Niamey and ROCAFREMI Coordinator for use in WCA.

Downy mildew resistant pearl millet seed parents, topcross pollinators and first set of hybrids in A_4 cytoplasm for SEA and WCA available (S C Gupta)

Nigeria is the best location in WCA to breed male-sterile lines because of high downy mildew disease pressure, a major disease in pearl millet. Generally any line resistant to downy mildew in Nigeria is resistant in most of the locations including India. Nigerian national program is very interested in this activity and collaborating with ICRISAT. To initiate this activity, we introduced A and B populations derived from Nigerian Composite d_2 (NC d_2 BC_3 in A_4 cytoplasm) from ICRISAT - Patancheru in 1996. These A and B populations were sown at Dadin-Kowa during 1997 off-season and 86 plant-to-plant crosses were made. These NC d_2 BC_4 pairs were evaluated at Bagauda during 1997 main season for male-sterility and downy mildew resistance. The male-sterility was confirmed in all the pairs. Fifty-one downy mildew resistant A/B pairs were selected and 129 A/B plant-to-plant crosses were produced. These BC_5 progenies were sown at Kadawa and Dadin-Kowa during 1998 off-season. Seventy-five A-lines were crossed with corresponding B-lines. These 75 A/B pairs (BC_6 progenies) were sown at Bagauda and Maiduguri during 1998 main season for seventh back crossing among selected A/B pairs. Based on uniformity between A/B lines within pairs and downy mildew incidence, only 30 pairs were retained for further evaluation. During 1999 off-season, 30 A-lines were crossed onto three topcross pollinators (SOSAT-C88, ZATIB, LCRI-IC 9702) to produce 90 hybrids. Ninety single cross hybrids were evaluated at three locations (Bagauda, Samaru, and Maiduguri) in a replicated yield trial during 1999 main season. Pollinators (inbreds) were developed jointly by LCRI and ICRISAT by selecting DM resistant plants in open-pollinated varieties and advancing them by selfing. During grain filling stage, 15 farmers were invited to select the hybrids of their choice. Farmers were randomly divided into three groups, to make selections in all the replications, one group one replication. In hybrid trial, seven hybrids were selected by different groups of farmers in all the three replications. Hybrids are highly resistant to downy mildew as they are based on DM resistant inbred lines. Data analysis is in progress. Nine male-sterile lines will be used extensively in producing new hybrids. About 25 hybrids from both hybrid trials will be selected for retesting in 2000. SOSAT-C 88 will be converted into male-sterile line to produce topcross hybrids between SOSAT-C88 and landrace varieties. Earlier, we have observed that SOSAT-C88 is a good general combiner when crossed with local landraces. SOSAT-C88 has been recommended for release in Nigeria as LCIC-MV1.

Downy mildew resistant pearl millet seed parents, topcross pollinators and first set of hybrids in A_4 cytoplasm for SEA and WCA available (K Anand Kumar)

It is only recently that the development and testing of hybrids has been accepted by millet breeders in this region as a complementary approach towards development of improved cultivars. The first anticipated utilization of male-steriles will be in the development of topcross hybrids (A x landrace pollinators) that will provide an opportunity to combine local adaptation in a modern productive form. A replicated trial was conducted to characterize male-sterile lines. Data were used to develop standard *fiche techniques*. In Summer 1999, 28 topcross hybrids developed using 12 Niger landraces were evaluated in a replicated trial. Maintenance reaction of A_4 cytoplasm was assessed. Data recorded on the male-sterile evaluation nursery were used to identify eight A/B pairs for use in further development and testing of topcross hybrids. Their seed was increased during Summer 1999. *Fiche techniques* were developed for these male-steriles. Mean time for flowering for topcross hybrids was 54 days (57 parents), they had 27% more tillering (62 000 earheads ha^{-1} for hybrids) and head yield was 2.01 t ha^{-1} (17% more

than parents, highest was 3.2 t ha $^{-1}$ or 86% more over mean of parents). Better performing male-sterile line was ICMA 1 which gave topcross hybrids that were slightly later than parents (60 d, desirable to avoid insect infestations) and produced 36% more head yield (2.75t ha $^{-1}$) than mean hybrid yield. Based on recorded data and visual observations, landraces Ankoutess, Boudouma, Moro, Guerguera, Zongo and Bazagome gave better hybrids. Initial evaluation of testcrosses developed using A_4 cytoplasm with six open-pollinated varieties showed that a large proportion of them were sterile. This indicates that almost all the varieties used as pollinators are maintainers (SOSAT-C88 was observed to be an excellent maintainer) thus providing access to a much wider range of genetic diversity for the development of new seed parents. Information on the use of the male-sterile lines will be provided to breeders to increase their use. Ten topcross hybrids were identified for seed increase and enlarged testing at 3-4 locations within Niger.

Screening of breeding materials for pearl millet downy mildew (D E Hess)

Pearl millet downy mildew is the most widespread fungal disease in West and Central Africa. Host plant resistance is the most economical approach to disease management. Adapted, high-yielding, disease- and pest-resistant varieties and hybrids are needed for significant production breakthroughs. Pearl millet downy mildew work is centered at ICRISAT-Niger and is conducted in close collaboration with the breeding team there. Four trials were conducted in the 1998 off-season downy mildew nursery at Niamey. All four consisted of A:B pairs, namely: a) advanced male-sterile (18 pairs); b) BC5 (57 pairs); c) ICM90 (20 pairs); and d) Nebraska (4 pairs). Among the advanced male steriles, three were free of mildew at 65 DAS. The susceptible check (7042) showed 93 % downy mildew incidence. Among the BC5s, five pairs: 650x606; 607x608, 611x612, 677x678, and 795x796 were free of disease at 65 DAS. The susceptible check in the trial manifested 82 % downy mildew incidence. Among the ICMA entries, four A-B pairs: 585-88x589-90 P2 H1; 585-88x589-90 P5 H1; 585-88x589-90 P6 H1&H2 were free of disease at 65 DAS. The susceptible check in the trial manifested 88 % downy mildew incidence. Among the Nebraska entries three entries were disease free but their corresponding A or B pair was diseased (18-57 % DM incidence). 7042 manifested 100 % DM incidence.

Entries from three trials are being screened in the off-season downy mildew nursery at Sadoré, Niger during 1999. These are: 6th back cross male-sterile entries consisting of 43 pairs in single rows (4.8 m long) without replication; ICMA ICMB-90 Entries consisting of 17 pairs in double rows without replication; and the University of Nebraska (Lincoln) entries consisting of 3 pairs in double rows without replication. Infestor rows were sown in the downy mildew nursery on 5 August. Test entries were sown on 3 September.

Groundnut

Diversified and enhanced groundnut advanced lines for yield potential, nutritional quality, multiple disease resistance and adaptation to Asia and WCA available (S N Nigam)

Many NARS in Asia and Africa obtain finished or near finished breeding products from international centers to serve their farmers with new cultivars to sustain and enhance groundnut production in their respective countries. After evaluating advanced breeding lines in three-tier system of trials at ICRISAT center, a mixed basket of genotypes with differing performance is selected for inclusion in international trials. Inclusion of genotypes with differing levels of

performance in these trials provides an opportunity to NARS to select genotypes adapted to their local conditions. In June 1999, we concluded the 7th series of international trials, which ran for two years. During 1998, 43 sets of 5 international trials were supplied to our collaborators in 12 countries in Asia and 2 countries in Africa. In the early part of the 1999, we supplied 19 sets of 5 trials to our collaborators in 3 countries in Asia, 2 countries in Africa, and one country in South America. From the 1999 rainy season we have started the 8th series of international trials. Each trial consists of 15 new genotypes with provision for a local control. In 1998/98, we supplied 754 advanced breeding lines and 792 segregating populations with various traits to our collaborators for *in situ* selection in 15 countries. Fifteen F_2 populations, specifically developed for WCA, were advanced to the next generation following single seed descent method. The breeding methodologies and material developed at ICRISAT serve the NARS effectively as is evidenced by the release of several groundnut cultivars in Asia.

Diversified and enhanced groundnut advanced lines for yield potential, nutritional quality, multiple resistance to diseases and adaptation to WCA (B R Ntare)

Elite advanced breeding lines with high yield potential and other important attributes such as earliness, fresh seed dormancy, resistance to rosette and foliar disease will meet regional needs for the various production systems in WCA. Elite pre-release lines (early, medium and late) with high yield potential (> 2 t ha^{-1} of pod and 3-5 t ha^{-1} of haulms) and resistant to rosette were identified from advanced trials conducted at three contrasting locations in Nigeria from 1997 to 1998. The most promising early maturing (< 100 days) and rosette resistant lines are: ICGV IS 96900, 96889, 96859, 96901, ICIAR19BT, ICIAR18BT, ICIAR&B an ICIAR10B. Among the medium-duration (101-115 days) lines, ICGV IS 96826, 96801, 96848, 96808, 96804, 96805, 96845,96827 are most promising. These lines are in national multilocation trials in Nigeria and some are n regional trials in Burkina Faso, Mali, Benin, Cameroon, Tchad and Togo. In 1999, 127 advanced breeding lines (F_7 to F_9) mainly of early-and medium-maturity and resistant to rosette were evaluated in replicated trials for yield performance in Nigeria. In 1998, 264 advanced short duration breeding lines introduced from ICRISAT-Patancheru, were evaluated in an observation nursery for reaction to early leaf spot at Samanko. Thirteen lines showed resistance to early leafspot (score of 5 on 1-9 scale). In 1999,113 early maturing lines were evaluated for yield potential in a replicated trials at Samanko. The yield of ten highest yielding line ranged from 3.38-4.0t ha^{-1} compared to 2.8 t ha^{-1} for the local check (47-10. Twenty three early maturing advanced lines with limited fresh seed dormancy were evaluated at Samanko in 1999. Harvesting was delayed for 20 days after maturity and then assessed for field sprouting. ICGVs 93463, 93460, 93461, 93468, 93470, 93473, 95332, and 95333 had less than 5% field sprouting compared to the non-dormant checks with more than 50% sprouting. Eighty-nine drought tolerant advanced breeding lines were evaluated for yield potential at Samanko. The yield of ten highest yielding lines ranged from 3.08-3.78 t ha^{-1} compared to the local check with a yield d of 2.95 t ha^{-1}. The breeding populations and advanced lines with important attributes such as earliness, fresh seed dormancy, resistant to Aflatoxin and drought will meet the regional needs for the various production systems in West Africa.

Diversified and enhanced groundnut advanced lines for yield potential, nutritional quality, multiple disease resistance and adaptation to SEA available (P J van der Merwe)

During earlier phases of ICRISAT projects populations with resistance to rosette, early leaf spot and rust and late leaf spot were developed. During the present phase of the ICRISAT-Lilongwe

Project, populations with rosette resistance were crossed with populations showing resistance to other constraints such as aphids or early leaf spot, rust and late leaf spot diseases to produce varieties with multiple resistance. Rosette resistance (GRV) populations were crossed with sources of aphid resistance. In 1998/99 the populations were in F_0-generation (two combinations), F_1-generation (one combination), F_4- generation, (90 breeding lines) and F_5-generation, (27 breeding lines). Populations were sown at Chitedze under high rosette disease pressure. Breeding lines (27) were screened for field resistance to rosette disease in the F_5-generation. The same lines were evaluated for aphid (*Aphis craccivora*) resistance under greenhouse conditions. Rosette resistant varieties were crossed with rust and late leaf spot resistant varieties. During 1998/99, one hundred and eighty lines in the F_5 generation with rosette resistance were evaluated for resistance to rust. Crosses were made to combine rosette resistance with early leaf spot resistance. ICG 12991 was the most resistant variety to aphids compared to EC 36892, JL 24 and CG7. Seven out of 27 breeding lines in the F_5 generation showed varying degrees of resistance to aphids and GRV. Out of 180 lines evaluated for rust, 28 lines in the F_5 generation have possibly being identified with both GRV and rust resistance. Rosette x early leaf spot resistance: The F_2 generation will be evaluated for rosette resistance during the next cropping season. The project is in the initial stages, but lines with a possible combination of resistance genes will be evaluated to verify the multiple resistance in the following cropping season.

Chickpea

Improved chickpea lines with drought tolerance and fusarium wilt resistance developed in cooperation with NARS in Asia, Africa and Central and South America (N P Saxena and F T Bantilan)

Area expansion under a crop has a large impact on increasing production. New potential areas, similar in soil and climate characteristics (iso-or homo-climes) to regions where chickpea is well adapted and produces high yield, can be identified using GIS. This would help in conducting more targeted multilocation trials for introduction of chickpea in new niches at relatively very low costs. Published soil, crop, and climate databases were retrieved from Global data bases and information was obtained from NARS partners. The soil and climate of present important chickpea growing areas in Eritrea (Hammasein and Seraye) were characterized. Areas similar in characteristics to these two provinces were also identified using GIS and models. Because of unstable political situation in Eritrea, the meeting to plan experiments could not be held in 1999. It is an important activity and need to be pursued in 2000. NARS partners are interested to participate.

Project proposal for special funding for SEA developed (Jagdish Kumar)

Chickpea is an important crop in SEA, especially Ethiopia, Tanzania, Kenya, Zambia, Malawi and Uganda. ICRISAT is helping these NARS to develop suitable varieties to increase yield and stability. Large quantities of fusarium-wilt resistant and short-duration desi and kabuli varieties and lines developed at ICRISAT were made available for on-farm testing. Preliminary reports indicate that super-early lines ICCV 96029 and 96030 have the greatest promise. ICCV 2, ICCV10 and ICCC 37 and ICCV 95423, (a large seeded kabuli) hold promise and have been recommended for further multiplication in Tanzania. The proposal and visit were postponed and

may be made after the ICRISAT-Kenya and the executing Non-government agency in Tanzania finalize their proposals. It appears that the chickpea growing season in areas of test is too short as the superearly ICCV 96029 appears to be the best. Larger quantities of seed of promising varieties (100 kg each) have been requested by Tanzania. Local breeding and seed multiplication efforts will need strengthening through ICRISAT help technically and in proposal development.

Evaluation of chickpea and pigeonpea breeding material for diseases (S D Singh)

In chickpea, major emphasis was put on wilt followed by root rots. Screening was done in artificially developed sick pots using race 1and V2 in greenhouse and in wilt sick-plot in field. For pigeonpea, screening was done for phytophthora blight and wilt in sick plots and for sterility mosaic (SM), a leaf stappling technique was used. Excellent nurseries were set up for all the diseases. Two hundred seventy three pigeonpea entries, including ICRISAT material and 43 entries from Indian program, were evaluated for phytophthora blight and sterility mosaic (SM). Six entries - ICP 10986, ICP 12290, ICPL 342, ICP 10979, ICPL 88023 and ICP 10996 remained phytophthora blight free. Final results for SM will be taken after 15 days. A total of 1073 entries including breeding material, pathology material, and material from Indian program were screened for wilt and SM. A large number of entries are free from both the diseases, but final data has yet to be taken. A total of 1258 chickpea entries including pathology material, breeding material, and material from Indian program were screened in wilt sick-plot and multiple disease sick-plot. A large number of entries remained wilt free. In greenhouse, 11 advanced breeding lines, and two RILs (168 entries) were evaluated for resistance to race 1 in pots. About 50% of the entries were either free or had less than 10% wilt. Two sets of RILs with 100 entries each were evaluated for resistance to race V2. About 10% entries showed high resistance (<10% wilt).

Pigeonpea

Advanced breeding lines available to NARS for evaluation (K B Saxena)

ICRISAT has comparative advantage in supplying diverse of genetic materials which could be adapted in different environments. The supply of elite breeding lines/germplams will enhance the capabilities of NARS to select appropriate materials. During 1998 and 1999, a total of 868 seed samples were supplied to 20 countries (Table 4.3.1). The materials include released varieties (371 samples), advanced lines (213 samples), hybrids (9 samples), and male-sterile lines (69 samples). Evaluation of pigeonpea lines in non-pigeonpea growing countries has provided very useful information about their adaptation and ability to control soil erosion. For example, in Yemen, short-duration pigeonpea have produced over 1 t ha^{-1} yield. Similarly in China, ICRISAT's breeding materials are successfully being used for fodder and soil conservation. Interest in pigeonpea in non-traditional growing areas is on increase due to its drought tolerance and ability to fit in different cropping systems.

Table 4.3.1. Pigeonpea breeding materials exchange at ICRISAT Center during 1998 and 1999

Countries	Released varieties	Advanced lines	Hybrid lines	Ms-hybrids lines	Germ-plasm	Total
Cape Verde	2	3	0	0	0	5
Ethiopia	9	4	0	0	0	13
India	269	133	7	69	206	684
Japan	0	0	1	0	0	1
Malaysia	5	3	0	0	0	8
Myanmar	2	12	0	0	0	14
Nicaragua	7	0	0	0	0	7
South Africa	17	2	0	0	0	19
Philippines	5	6	0	0	0	11
Yemen	13	16	0	0	0	29
USA	3	4	0	0	0	7
Belgium	2	0	0	0	0	2
China	12	15	1	0	0	28
Colombia	8	2	0	0	0	10
Ghana	2	1	0	0	0	3
Guyana	3	1	0	0	0	4
Mexico	2	1	0	0	0	3
Panama	1	5	0	0	0	6
Puerto Rico	1		0	0	0	1
Zambia	8	5	0	0	0	13
Total	371	213	9	69	206	868

Screening for resistance to fusarium wilt in pigeonpea (S D Singh)

Diseases of pigeonpea are increasing in eastern and southern Africa as we intensify the cultivation of the crop. Surveys carried in the region show that fusarium wilt (*Fusarium udum* Butler) is the most serious disease. Since it is soil borne, the most effective way is through plant resistance. ICRISAT – Patancheru has developed an effective field screening technique for resistance to fusarium wilt and a number of resistant varieties have been identified. However, varieties identified often are brown and small seeded and are not preferred in the region. In addition, there is variability in pathotypes, such that some of varieties identified as resistant in Patancheru often show susceptibility in the region. A wilt sick plot was, therefore, established at Kiboko in 1992/93 using the protocol developed by ICRISAT - Patancheru. Since then, we have been screening both medium- and long-duration accessions to determine their reaction to fusarium wilt before sending to our collaborators. A number of advanced breeding lines were evaluated for their reaction to wilt during the 1997/98 and 1998/99 cropping seasons. Some of the accessions were evaluated for the first time. In both seasons, ICEAP 00040 showed a high degree or resistance to wilt at Kiboko and it has been found to be resistant in Malawi. Newer lines that have shown high degree of resistance are ICEAP 926, ICEAP 00576-2, ICEAP 00795, ICEAP 00576 and ICEAP 00053, the last variety has been found to be susceptible in Malawi. ICP 9145 which has been released in Malawi as resistant to wilt was extremely susceptible at Kiboko, indicating variability in pathotypes.

Objective 4.4: Develop and evaluate strategies for farmer participatory breeding and verify performance of improved varieties in partnership with NARS and farmers.

Sorghum

Farmers' participatory development of sorghum varieties/hybrids (S C Gupta)

Hybrids are not grown in Nigeria due to unavailability of seed and there is a problem of seed production in hybrids due to non-nicking of parental lines. There is a need to develop high yielding mid-late maturing varieties and hybrids suitable for Sudanian and northern Guinea zones. During 1997 off-season at Kadawa, six crosses were produced between three late maturing varieties (SK 5912, Blanc de Karimama, and KSV 8) and two early maturing varieties (ICSV 400, and ICSV 903 NG). These crosses were advanced to F_2s at Bagauda during 1997 main season. Six F_2 populations were planted at Bagauda in June 1998 with 400 plants per population. Five farmers were invited to select plants of their choice. Two hundred sixteen self plants were selected and advanced to F_3 in the 1999 off-season at Kadawa. Three hundred eighty one F_4 progenies were sown at Samaru (IAR), Bagauda, and Minjibir in single replicated plots during 1999 main season for selection. Ten F_2 populations derived from crosses between selected varieties (CS 54, CS 95, ICSV 111, ICSV 400, Gaya Early, and BES) and *Striga* resistant lines (SRN 39, and IS 9830) were sown in *Striga* sick plot at Bagauda during 1997 main season to identify *Striga* free plants and advance them by selfing. Three hundred and sixty F_3 progenies were sown in *Striga* sick plot at Bagauda during 1998 main season. One hundred plants from 62 progenies were selected. One hundred F_4 progenies were sown at Bagauda, and Minjibir in single replicated plots during 1999 main season. The data was recorded on *Striga* count and farmers were involved in selection. The male-sterile line, ICSA 902 NG, and ICSB 902 NG were planted in 1999 main season at Minjibir for seed increase. Based on visual observations, 63 F_4 progenies were selected; 17 for early maturing group at Minjibir, 22 of medium maturing group at Bagauda, and 24 late maturing group at Samaru. Most of these progenies have combined good traits of both parental lines. These progenies will be evaluated in three preliminary variety trials in year 2000 jointly with Institute for Agricultural Research (IAR), Samaru. During 1999 main season, six farmers were invited to select the lines of their choice, and they selected 25 F_4 progenies based on visual observations. Some of these selections had high incidence of *Striga*. We will select self heads from about 25 lines considering farmers choice, our visual scores, and *Striga* count. During F_2 evaluation, the number of selections per F_2 population varied from 12 (ICSV 400 x IS 9830) to 59 (ICSV 400 x SRN 39). About 50% more plants were selected from the crosses involving SRN 39 as donor parent for *Striga* resistance than the crosses involving IS 9830. During F_3 evaluation, the majority of the plants (58 out of 100) selected were from a cross, ICSV 111 x SRN 39. The initial results suggest that SRN 39 is a better donor parent than IS 9830 for *Striga* resistance. Thirty kg seed of ICSA 902 NG, and 50 kg seed of ICSB 902 NG were harvested.

Goals and breeding objectives for West Africa redefined through participatory research (H F W Rattunde and E Weltzein)

Sorghum farmers in WCA have highly detailed knowledge of sorghum varietal characteristics and highly developed strategies for managing sorghum genetic diversity to achieve their goals. Breeding programs in the region may be able to benefit from partnerships with these farmers to establish goals and objectives that best meet famers' needs. On-farm variety trials were conducted in 1998 and 1999 to facilitate discussion with farmers about varietal characteristics and their preferences and requirements in southern Mali (12.0 to 13.4 °N). The trials were collaboratively conducted with the Institut d'Economie Rural of Mali and the following development organizations: in 1998 with Sasakawa Global 2000 (in the districts of Kolokani, Kati, and Baroueli), CMDT (Kimparana, Konobougou, Koutiala, Kita, and Klela), and Plan International (Kangaba); in 1999 with Sasakawa Global 2000 (Segou), CMDT (Kolondieba, Molobala, Koutiala, Yorosso, Bla Yangasso, Dioila, Massigui), Adaf Galle (Bancoumana), and Aprofem (Bamako). All trials were conducted with 2 to 10 farmers per village in each of two villages per district. The 1998 trials were single variety comparisons of mostly researcher bred varieties (ICSV 901, CIRAD 406, ICSV 1079, ICSH 89002, CGM19/9-1-1 and CSM 63E) with farmers' local varieties whereas. The 1999 trials offered farmers larger sets of varieties within a specific maturity class (11 early, 10 intermediate, or 4 late-maturing varieties) to provide exposure to a wider range of varietal characteristics. Mid-season and end-of-season discussions were held with farmers in the field using semi-structured interview techniques. Farmers from Katibougou (1998, 1999), Gonsolo (1999), Nianganabougou (1999) and Kolokani (1999) participated in on-station varietal selection exercises. The farmers were extremely keen to test new varieties. They expressed interest in a wide range of materials (Table 4.4.1). Increased grain productivity was universally the primary concern, but coupled with acceptable grain storage quality and culinary characteristics. Plant height was not an important consideration. The concept of an ideal panicle type with many panicle branches of intermediate length carrying large numbers of grains, and the panicle rachis with short internode distance was widely expressed. Undesirable panicle characteristics include erect panicles, long panicle branches (with increased grain shattering), and glumes not opening wide at maturity. Interest in sorghum varieties responsive to intensified production conditions is strongest in the cotton production regions of Bla, Koutiala, and Sikasso (11 to 13°N and 5 to 6°W). Striga was of widespread importance. *Caudatum* varieties were rejected outright or were appreciated for their stover quality and their adaptation to later sowing dates. Farmer's variety preferences have at times changed dramatically after harvest, and thus the awaited 1999 post-harvest results and discussions will be crucial for assessing these preferences. These results are proving invaluable for effectively defining the objectives of sorghum breeding in West Africa.

Table 4.4.1. Farmer's variety selections from on-station demonstration, Mali 1998

Gender	Number of varieties per farmer	Maturity Groups* Chosen (% of Farmers)		
		Single Maturity Group	Two Maturity Groups	All Maturity Groups
Male (16)	4.1	0	36	64
Female (11)	4.1	0	36	64

* Maturity Groups = Early, Medium and Late

Estimates of genetic variability within farmer-selected seed lots (H F W Rattunde and E Weltzein)

An iso-enzyme study has shown that intra-varietal diversity accounts for 29% of the total diversity in West African Sorghums. Estimation of the extent of genetic variation for key agronomic traits within farmer-selected seed lots will indicate the possibility of successful varietal improvement through selection within farmers' adapted varieties. Farmers selected 100 panicles appropriate for seed within their sorghum fields in the village of Katibougou. Two farmers provided the variety Folomba and two the variety Sakoyka. Each panicle progeny set (Folomba-1, Folomba-2, Sakoyka-1, Sakoyka-2) was tested in a separate yield trial in 1999, using a 10x10 triple lattice design with single-row 5m plots. There was highly significant genetic variation for days to flower, plant height and panicle yield within all four of the populations tested. The broad sense heritiabilities were acceptable for days to flower (90%), plant height and panicle yield (50%). Individual progenies within populations exhibited panicle yields differing by two tons ha^{-1}, and days to flower that differed by 10 to 14 days. These initial results suggest that significant genetic gains could be made for key agronomic traits through selection within farmers' seed stocks.

Farmer-participatory Varietal Selection for postrainy season sorghum in India (Belum V S Reddy)

Semi-arid regions of south-western India encompassing about 6 m ha area is under *rabi* (postrainy season) sorghum. Several varieties bred at research stations are not popular with farmers. As a result, M 35-1, a selection from a landrace made in 1930s is still dominating the *rabi* tract. A need is therefore felt to involve the farmers in varietal selection and breeding for postrainy season. DFID funded research is being carried out by National Research Centre for Sorghum (NRCS), from July 1999. ICRISAT is assisting the scientists in India. M 35-1, the popular *rabi* variety is susceptible to rust, and it is pigmented. We used IS 2300, IS 3443C-40, IS 7023 and ICSV 75 (all rust resistant and tan pigmented varieties), and E 36-1 (a variety resistant to charcoal rot) as donors. We introgressed rust and charcoal rot resistance and tan plant colour into M 35-1 using M 35-1 as a recurrent parent in a backcross program. The resulting materials after two generations of selection (for resistance to rust and charcoal rot, and tan plant color), were grouped into five bulks. Two bulks (M 35-1 bulk 3 and 5)were supplied to National Research Center for Sorghum (NRCS) for on-farm testing and selection by farmers in Zaheerabad area, Andhra Pradesh, India, during 1998 postrainy season. The testing was arranged by NRCS through voluntary organization (Deccan Development Society). ICRISAT sorghum breeder participated in the work plan meetings held at Sholapur, India and Bangor, UK during August, 1999. NRCS could not follow up with the on-farm testing in Zaheerabad and no report was submitted on the performance of the M 35-1 backcross bulks during 1998 postrainy season. There were differences among various partners and donors on the need to test M 35-1 bulks for the DFID funded project. However, the differences were ironed out as DFID officials emphasized the need to test these bulks on-farm. Work plans were developed for the next two years for the project during Bangor Meeting. DFID offered funding support if ICRISAT agrees to work on the development of rapid generation technique for *rabi* sorghum breeding. A concept note was developed and submitted. Project calls for collaboration among various groups of scientists and voluntary organizations. ICRISAT's role is to facilitate the seed production of various varieties that are under participatory varietal selection.

Pearl Millet

Strategy for research on participatory plant breeding for pearl millet in WCA developed (K Anand Kumar, A Batiano, (IFDC) and B Ouendeba)

Assessment of farmers preferred-traits and cultivar types would help in selection and targeting end products, and in increased adoption. Farmers' trait and end-product preferences were ascertained using a questionnaire during the field day organized at Sadoré and also in the demonstration plots laid out at Dalwey (a village 12 km South of Sadoré). In the 1998 rainy season, 20 farmers assisted in the identification of preferred traits and varieties for on-farm tests and seed multiplication in large on-station demonstration plots. Sixty percent of the farmers have previously grown improved varieties co-developed by NARS-ICRISAT. Good productive tillering, well-filled compact earheads, long earheads (>60 cm), earliness (90-100 days), and ease of threshing were the traits most often cited. Hybrids were consistently identified as early and characterized by very high uniform tillering. In the open-day field tour organized in September 1999 exclusively for farmers and extension agents, a strong preferences for varieties was noted. HKP-GMS was the most preferred variety (51% of the respondents), followed by ¾ HK-B78 (31%), Mil Aristée (23%), CIVT-GMS, ICMV IS 94206, and ICMV IS 89305 (all 17%). All these varieties possess the preferred varietal traits: early (90-100 days maturity), productive tillering, well-filled compact long earheads and have a good threshing percentage (70%). The dwarf variety ¾ HK-B78 was chosen by several farmers because it is relatively easy to scare birds away. In an on-farm trial in Dalwey, farmers indicated that the two hybrids in the demonstration plots were early and consistently high tillering compared to the varieties. They indicated that their preference is for hybrids that are later (60-65 days to flower). Performance of two improved varieties was evaluated in two on-farm trials over two years under improved agronomy (traditional control, fertilizer, FYM and ridging combinations). Traditional control yielded 0.45 t ha^{-1}. Yield increases up to 3.6 to 5.7 times were obtained (2.5 t ha^{-1} for a treatment that included 30 kg $^{-1}$ NPK and 5 t ha^{-1} of FYM and ridge planting). On-farm tests with late-maturing topcross hybrids should be given priority. Farmers have identified preferred varieties. Farmers appreciate the fact that improved varieties and better agronomic management will significantly increase grain and stover yields. However, credit and access to inputs and markets for the produce are essential to promote adoption of improved technologies.

Groundnut

On-farm evaluation of selected breeding lines in Vietnam, Indonesia, Myanmar, and Thailand (S N Nigam and S L Dwivedi)

To attain the purpose of serving the small farmers, it is necessary that the improved genetic material developed by international programs is evaluated in NARS system and on-farm in partnership with national scientists and farmers. Resources permitting, ICRISAT scientists visit these trials. In on-farm/on-station evaluations, ICGVs 91135, 91341, 92302, 93328, and 94434 for *A. flavus* resistance and ICGV 93382 for short-duration in China; ICGVs 92113, 92118, 93232, and 93277 for drought resistance, ICGVs 92054, 92064, and 92071 for medium-duration (virginia bunch), and ICGVs 92088, 93187, 92151, 93009, 93023, 92187, and 91117 for confectionery traits in Indonesia; ICGVs 93261 and 93277 for drought resistance, ICGVs 93382, 91155, and 99218, among others, for short-duration, ICGVs 92001, 92004, and 92022, among

others, for medium-duration (spanish bunch), ICGVs 90173, 90212, 90320, and 91140 for confectionery traits in India; ICGV 89235 for confectionery traits in Korea; ICGVs 90261 and 91167 for confectionery traits in Myanmar; ICGVs 88421, 89204, and93104 for confectionery traits in Nepal; ICGVs 89211, 88482, 88480,89215, 88406, 89397, and 89325 for confectionery traits in the Philippines; ICGVs 92222, 93382, and 92229 for short-duration, ICGVs 93040, 93135, 92033, and 93134 for medium-duration (spanish bunch), and OPIs 36, 44, 45, and 46 (selected from ICRISAT breeding populations) for confectionery traits in Vietnam were found promising. In South Africa, ICGVS 92116, 92121, 93261, 93233, 92109, and 92126 in drought resistance trial and ICGVs 93420, 93392, 92217, and 92218 in short-duration trial were selected for multilocation trials across Mpumalanga province. During 1998/99, ICGV 86021 (as Jerapah), ICG 1703 (as Panter), and ICG 1697 (as Singa) in Indonesia; ICGV 93382 (as Sinpadetha 7) in Myanmar; VD 5 (selected from Ly x (ICGV 88398 x USA 54) population supplied from ICRISAT) in Vietnam; ICGV 93437 in Zimbabwe, and JL 24 (as Lucna) in Zambia were released. JL 24, ICGS(E) 34, and M 13 were recommended for release in Mali. For many national programs support from ICRISAT is vital to their research activities. Seed technology is easily transferable with potential for large immediate impact, provided it is supported with good quality, regular seed production program.

Farmers participatory selection of early maturing rosette resistant groundnut varieties (S C Gupta)

The sustainability of groundnut production in Nigeria is threatened by a number of factors including drought and susceptibility to rosette in early maturing varieties. High yielding and early maturing rosette resistant varieties have been developed and have undergone some tests in Nigeria. At present all released early maturing varieties are susceptible to rosette. Kano state extension department is very keen in identifying high yielding early maturing rosette resistant varieties. Based on request from Kano state extension, we jointly developed a farmers' participatory trial for selecting farmers' preferred varieties. During 1999 cropping season, 16 early maturing rosette resistant groundnut varieties were tested on-farm in collaboration with Kano state Agricultural and Rural Development Authority (KNARDA) and farmers. Forty-eight experienced groundnut growers drawn from different agro-ecological zones of Kano state participated in this trial. The 16 varieties were divided into four sets; each set comprising four new varieties plus one control. Twelve farmers grew a set. Varieties were grouped based on days to maturity. Plot size was 5 rows of 20 m long per variety. Each farmer was given a total of six kg of seed per variety. Data was obtained on eight important traits namely maturity, plant population, pod weight, haulm weight, shelling percentage, rosette score, farmer's preference and oil content. Each farmer evaluated the over all performance of the varieties with a view to identify varieties that meet their specific needs. Each farmer graded varieties by scoring first, second and third. The most preferred trait by farmers are pod yield (big podded varieties preferred) and hulm weight. The income realised from sale of haulms is almost equal to pod. Eight out of 12 farmers selected ICGV-SM 93535 and ICGV-IS 96841 as their first and second choice in set 2. Seven out of 10 farmers selected ICGV-SM 89754 and ICGV-SM 89764 as their first and second choice in set 4. All these selections were resistant to rosette. The extension and farmers have been exposed to promising groundnut varieties. The selected varieties will be included in the Nationally Coordinated Trial of Nigeria, and KNARDA may continue to evaluate them in on-farm trials.

Chickpea

Impact studies of ICRISAT chickpea varieties released by Asian NARS (Jagdish Kumar)

Impact studies are required to determine the progress towards increased productivity and poverty alleviation. Major breakthroughs have occurred in chickpea productivity in tropical India, Barind area in Bangladesh and in Myanmar. The research and developmental programs in these countries have sent us reports and the statistics from the NARS show that much of this progress is because of the use of ICRISAT varieties and from collaborative experiments. Demand for breeder seed of ICCV 2 in India and Myanmar is tremendous. Part of the eight-fold increase in chickpea production in Andhra Pradesh, India, in the last decade is attributed to the release of ICCV 2 (Swetha) and ICCC 37 (Kranthi) in 1989 and ICCV 10 (Bharati) in 1993. The popularity of extra-early kabuli ICCV 2 appears to be because of two reasons; its kabuli seed fetches relatively higher price (up to three times more than desi type) and its earliness (it matures about two weeks earlier than Annigeri). It is also fusarium-wilt resistant.

Impact of chickpea varieties released by African NARS using ICRISAT-supplied material assessed (N P Saxena)

In Bichena province of Ethiopia a chickpea variety, Mariye, selected from the elite breeding material supplied by ICRISAT has completely saturated the area. Understanding the mechanism of the spread of this variety will help in implementing similar project activities in other areas and in other countries. NARS partners, including socio-economists, were interested in this activity. Plans were made for a systematic documentation of information on the spread of Mariye variety from 40 kg seed supplied to the whole area of Bichena. Discussions were held with Ethiopian Agricultural Organization (EARO), in June 1999 to initiate the planned study. There has been no response from NARS partners to our inquiries about the progress of the activity. Follow up is being continued.

Objective 4.5: Provide support for and participate in networks and bilateral research activities.

Sorghum

Provide improved breeding lines and breeder seed to NARS in ECARSAM countries (A B Obilana)

Demand for improved cultivars and basic seed for bulking is very high in East Africa because of drought and security problems. ICRISAT's coordinated response to the series of requests from NGOs, NARS and donors, would enhance collaborative sorghum and millets seed improvement and production projects in the semi-arid and Laze Zones of the region. A breeding nursery of 31 B-lines, 85 segregating lines in F_3-F_6, 75 new A/B lines, 22 R lines, Karimtama 1 and Hegari were established at Kiboko. Also planted and evaluated are six sorghum replicated trials and seed multiplication, three pearl millet varieties and 38 new sorghum selections. The plastic bag method was used in the crossing blocks. At Alupe, a screening nursery of 354 grain mold lines

and 100 S_1 midge lines, five disease and headpest populations, 213 selections from 15 best materials, and A/B lines from Bulawayo were evaluated for use in the Lake Zone. Three sorghum varieties IS8193, IESV93042SH and Seredo were evaluated in on-farm trials with pigeonpea at Busia, Bondo and Siaya Districts with two NGOs (SCODP and UCDRC). All seeds requested and dispatched were accompanied with signed MTAs. A total of 759 sorghum and five pearl millet samples weighing 206 kg and 50 kg respectively, were provided to four NARS, FAO, four NGOs and Universities in Kenya, Uganda, Burundi, Eritrea and Sudan. Sorghum samples totaling 119 were also received from Bulawayo (111) and Patancheru (8). In response to requirements of collaborative on-farm trials and basic seed for bulking and distribution by partners, 1054 kg of six best sorghum varieties (IESV 93036 SH IS8193, Seredo, IS 21055, IESV 93036 SH and Wagita) and 153 kg of three best pearl millet varieties SDMV 93020, SDMV 92040 and Kent PM-1) were produced and made available to NGOs and NARS Extension. Seed increases of three finger millet varieties P224 (78 kg) Gulu E (22 kg) and U15 (8 kg) were also harvested.

Ten B lines, 15 varieties and eight R lines introduced from ICRISAT Bulawayo were selected for new hybrid and variety development. Target crosses initiated with Kari mtama 1, IS8193, Seredo, IS 21055 and Wagita, and B/R lines, were completed. During the season, the Kenya national sorghum and millet coordinator made selections in ICRISAT nurseries for malting (15 sorghum lines), seed quality (9 lines), and for on-farm testing in Kenya (4 sorghum and 1 pearl millet lines). Nine improved varieties (yield range of 3.38 - 4.26 t ha^{-1}) and six new hybrids were selected from advance trials. Selected F_6 lines (12 #) were named IESV 99000LT/DL series for evaluation in new line trials. We need to have two more regional locations, in addition to Kiboko (semi-arid) and Alupe (Lake Zone) for more efficient testing in Kenya. Two 4th year students from Egerton University were on 2-month attachment (May-July 1999) at Kiboko. During their stay they learnt and participated in sorghum field and crop experimental designs and layouts, crop management, pollination and selection techniques in breeding nursery, harvesting, data collection and analysis. Two groups of farmers from Makueni and Machakos visited trials and seed multiplication fields.

Provision of improved breeding, lines and breeder seed to NARS including private sector; generate and test new male-sterile lines and varieties for commercialisation (A B Obilana and E S Monyo)

Activities of the SMIP Intermediate Results (IR) 1.1 and 1.2 involve conservation and dissemination of SADC and ICRISAT germplasm, and generation of improved genotypes suitable for commercialisation. Our backstopping activities including viability testing, rejuvenation of sorghum and pearl millet germplasm, identification of value traits for incorporation into new cultivars and cultivar testing are all geared to achieving the specified benchmarks of SMIP. A breeding nursery of 1830 genetic materials containing 1344 SADC indigenous germplasm, 59F_2s, 214F_3 and 2 F_4, 22 released varieties, 70 promising new lines, 110 hybrids and parents and 9 restorer lines, were established at Aisleby for germplasm rejuvenation, generation advance and breeder seed increase. The SADC germplasm grow out were also evaluated jointly with INTSORMIL for leaf blight and downy mildew. Six trials were established at 4-7 locations in the region in collaboration with SEED Co. Ltd. of Zimbabwe. Viability testing of germplasm stored at Bulawayo gene bank and working collection in Kiboko were done. From the breeding nursery, total of 156F_2, 636F_3 and only 4F_4 individual plants were selected for head-to-row planting in F_3-F_5. Parent combinations of Pirira 2 x Sima, Macia x

MRS94, Larsvyt 46-85 x Macia and Larsvyt 46-85 x Sima were mostly selected. During the rejuvenation exercise, 100-1900 g of pure seed were harvested from 40% of the germplasm planted, pollination bags finished in the middle of the season. The remaining 60% unselfed accessions and those that have <65% germination would be rejuvenated in 1999/2000. Only 1.3% of the germplasm stored in Bulawayo gene bank for last 15 years showed >80% germination. Six accessions (SDS13, SDS54, SDS1607, SDS2770 and SDS3217) still maintained 100% germination after 15 years of medium term storage. From the joint evaluation of SADC germplasm with INTSORMIL, 26% are leaf blight free, 35% showed no downy mildew (DM), but 49% were extremely susceptible to DM from Lesotho collections. Collaborative trials evaluation of 146 varieties and hybrids showed six varieties from two seed companies and 10 cultivars from ICRISAT-SMIP being outstanding (yielding 2.75 4.91 t ha^{-1} across the 4-7 locations; SE $\pm$ ranging from 0.137-0.329). They will be further selected for productivity and commercial use. Breeder seed of specific varieties hybrids and parents for trials, milling and brewing tests, and production in commercial production were produced (from 5-10 kg upwards to 2-3 tons).

Pearl Millet

Assistance to WCA NARS in multiplication of breeder seed (S C Gupta)

To meet the needs of NARS, breeder seed is multiplied every year of the selected varieties. This helps in popularizing ICRISAT-bred varieties to farmers through NARS or in collaboration with NARS. During 1999 main season, the seed of two sorghum lines (ICSV 111, and ICSA/B 902 NG) and two pearl millet varieties (LCIC 9702 and LCIC 9703) was multiplied at Minjibir in isolation plots. ICSV 400 and SOSAT-C88 were multiplied at Bagauda in isolation plots. In addition to the above, LCRI scientists have been trained in breeder seed production. Jointly with LCRI, we encouraged on-farm seed production during 1999. The breeder seed was supplied either by ICRISAT or LCRI to farmers. Pearl millet seed was produced by 125 farmers through on-farm seed production. Sorghum seed was produced by 66 farmers. We provided on-the job training to farmers wherever possible, and LCRI, Maiduguri is capable now of producing good quality of seed of pearl millet and sorghum. They are actually marketing seed to farmers and NGOs. We also involved two NGOs [(SG 2000, and Sokoto Agricultural Community Development Project (SACDP/IFAD)] in on-farm seed production in Nigeria.

Assistance to WCA NARS in multiplication of breeder seed (K Anand Kumar)

In West Africa, the drought of 1997 wiped out pearl millet seed stocks in several Sahelian countries. In response, the West and Central African Millet Research Network (WCAMRN) and ICRISAT, with financial assistance from USAID, provided emergency seed aid to help farmers plant their fields during the 1998 rainy season. The non-availability of breeder seed of improved varieties is a well recognized constraint to their spread and adoption. Therefore, one of the project activities planned for postrainy season 1998-99 was to multiply breeders seed of improved varieties for provision to NARS and NGOs for further production. Seed of varieties co-developed by ICRISAT-NARS were multiplied in the postrainy season of 1998 or in Summer plantings of January 1999. Seed requests were received during field days organized in September 1998 and during the annual meetings of WCAMRN. Seed was dispatched in early May to Bénin, Burkina Faso, Cameroon, Chad. Ghana, Mauritania, Niger, and Sénegal. Nearly

900 kg of seed of seven improved varieties that have been either released, or recommended for cultivation was produced and was provided to NARS, NGOs and private seed producers in eight Sahelian countries (Table 4.5.1). Estimates show that this quantity is sufficient to plant at least 75-90 ha to produce approximately 5-6 tons of foundation seed. It is important that by 2002 efforts should be made to obtain feedback from recipients of seed on how it was used in further multiplication and to get an indication of the areas of adoption.

Table 4.5.1. Summary of seed produced and distributed improved pearl millet varieties to eight countries in West Africa, June 1999

Variety designation	No. of Countries	Quantity produced (kg)	Quantity supplied (kg)
HKP-GMS	2	135	102
CIVT-GMS	3	75	92[1]
GB 8735	4	90	135[1]
SOSAT-C88	4	219[2]	50
ZATIB	5	126[2]	45
ICMV IS 89305	3	147	117
ICMV IS 92222	1	100	88
Total	-	892	629

1. Part of the seed provided was produced in postrainy season 1997-98. 2. More was produced because of very low seed stock and to ensure adequate supplies are available for future requests.

There is very limited information available in the region on the procedures for seed production and multiplication of open pollinated varieties of pearl millet. ICRISAT has produced training and information bulletins on seed production of pearl millet. The objective is to adapt these to West Africa (including varietal descriptions, agronomic practices, disease, insect pests, seasons). Relevant parts training and information bulletins were edited and varietal descriptions developed for all ICRISAT-NARS co-developed varieties. Additional photographs, related to off-types and within variety panicle variation are needed. This bulletin will be completed in French in the later half of 2000, in collaboration with WCAMRN. This will be made available to pearl millet seed producers.

Completion of multilocational testing in Niger of improved versions of CIVT and HKP (K Anand Kumar, D E Hess, B Ouendeba, J Gonda and J Naino (INRAN

Two well-known improved open-pollinated varieties of pearl millet developed by INRAN, Niger were found to be losing their original identity and contained a high frequency of Shibras (up to 30%). This has resulted because of lack of rigorous seed multiplication procedures, and non-availability of isolations. Seed of CIVT and HKP was obtained from INRAN Stations in Maradi and Kollo. Improvement for uniformity in time to bloom, plant stature, head types, seed set, seed size, and absence of Shibras was initiated in 1996 using Gridded Mass Selection (GMS). GMS was conducted for three generations in isolations, using 2500 plants. Observations on 'GMS-version' of these varieties show a clear and significant improvement for uniformity in flowering, head types, seed set, and a complete absence of Shibras. On-station trials were used to develop varietal descriptions (*Fiche techniques*). Eighty nine kg seed of HKP-GMS and 85 kg CIVT-GMS was distributed to INRAN stations in Maradi and Kollo, NGOs, and private seed producers. These improved versions were also contributed to a provenance trial coordinated by

INRAN. In the open-day organized for farmers of Western Niger 27% of the variety preferences were for HKP-GMS and 10% for CIVT-GMS. Our observations indicate significant improvements for uniformity in several characters including flowering, plant height, earhead length and shape, and grain filling. To quantify the changes a trial to compare bulks of different cycles will be conducted. To preserve the improvement made, further multiplication should be undertaken in areas where Shibras are absent or in isolation from other millet. Five kilograms seed of the improved versions is conserved at the seed storage facility at Sadoré for future use and multiplication.

Host plant resistance is the most economical approach to management of pearl millet downy mildew. CIVT and HKP, the two popular varieties in Niger, whose productivity could be significantly improved by enhancing earhead uniformity, reducing the proportion of Shibras (wild-types), and selecting for improved resistance to downy mildew. Entries from two trials are being screened in the off-season downy mildew nursery at Sadoré, Niger. These are: CIVT and HKP GMS 1 and 2. The first trial consists of four entries in plots of 4 rows (4.8m long) per entry with 4 replications. The second trial is made up of 12 entries in 4-row plots and 5 replications. Infestor rows were sown in the downy mildew nursery on 5 August. Test entries were sown on 3 September.

First set of coordinated regional pearl millet hybrid trial and on-farm tests of hybrids with INRAN in Niger available (K Anand Kumar and D E Hess)

Regional Pearl Millet Hybrid Trial (RPMHT) is a cooperative testing system in partnership with the West and Central African Millet Research Network. It is designed to evaluate topcross hybrids for grain yield, and disease resistance in a range of environments to identify better performing test entries for large scale on-farm tests. RPMHT contained ten hybrids, eight open-pollinated improved varieties (pollinator), and two control varieties. This trial was sent to 12 locations in seven countries. Across locations and entries, hybrids were six days earlier than the farmers local varieties and by three days compared to improved check. Hybrids exhibited slightly shorter plant stature and earhead length. Mean yield of all hybrids was 1.42 t ha^{-1} and of pollinator varieties 1.25 t ha^{-1}. Mean yield of the top yielding hybrid across the ten locations was 1.80 t ha^{-1} and of improved variety check and farmers variety was 1.20 t ha^{-1}. Across locations grain yield of the best hybrid as percent of the improved and or farmers variety check ranged from 3% to 150%. Only two locations reported downy mildew (DM) incidence of over 10%. At both locations, mean DM incidence on hybrids was 13%, with a range of 4% to 35% at Kano and 0% to 49% at Maiduguri. Mean on pollinators was 19% at Kano and 7% at Maiduguri. Improved check and farmers check recorded similar levels of DM. Results also indicate that it is important that topcross hybrids should not show major departures in crop maturity from the locally grown landraces because earliness tends to attract pest and disease problems previously avoided. The development of topcross hybrids involving landraces provides an opportunity to utilize local adaptation with grain yield potential. Though the spread in flowering will help in availability of pollen and optimum grain filling, it is important that variety pollinators should restore fertility in the hybrids to avoid epidemics of ergot and smut. Better performing entries from Niger and Nigeria will be included in RPMHT-2000.

Host plant resistance is the most economical approach to downy mildew management in pearl millet. Entries from the RPMHT are being screened in the off-season downy mildew nursery at Sadoré, Niger. Nine hybrids (ICMH9801 and ICMH9803-ICMH9809) are being evaluated against

six varieties (CIVT, SOSAT-C88, ICMV IS 90311, ICMV IS 92326, ICMV IS92305, and ICMV IS 90309). Infestor rows were sown in the downy mildew nursery on 5 August. Test entries were sown on 3 September.

Groundnut

Seed of groundnut pre-breeding materials, international and regional nurseries produced and made available to NARS in Asia, WCA and SEA (S N Nigam and S L Dwivedi)

Seed of international and regional nurseries is produced under assured growing conditions. Requested seed to NARS is supplied following proper seed dispatch protocol of ICRISAT. Seed of entries of the 7th series of international trials was multiplied in the 1998 rainy and 1998/99 postrainy seasons for supply to interested collaborators on request. In the 1998/99 postrainy season entries were selected for inclusion in the 8th series of international trials. Seed was also multiplied of advanced breeding lines doing well in national trials, particularly in India.

Seed of groundnut pre-breeding material, international and regional nurseries made available to NARS in WCA (B R Ntare)

Availability of adequate quantities of planting material is basic to improvement of groundnut productivity and production. Seed availability is a serious constraint for farmers researchers and development agencies. Seed multiplication and distribution seed of elite breeding lines was produced and seed made available to farmers and scientists. Thirty-three elite breeding and released lines were multiplied to obtain at least 10 kg of breeder seed for sharing with NARS, farmers and NGOs. Seed distribution in Mali was as follows: 8 varieties to CMDT, 3 varieties to IFAD project and 9 varieties to Winrock International. One hundred and thirty lines were distributed to eleven countries in West and central Africa in form of regional trials. They were grouped according to attributes such resistance to rosette, aflatoxin, drought leafspot (early and late) and rust as well as and edible groundnut.

Seed of groundnut pre-breeding materials and nurseries produced and made available to NARS in SEA (P J van der Merwe)

The phase IV of SADC/ICRISAT Groundnut Project is to make available improved groundnut varieties and management to small-scale farmers in important groundnut-growing areas of southern Africa. The project contributed to the distribution of 1218 germplasm lines to SADC countries. The project supported the production of over 25 tons of breeder seed of improved varieties to NARS and NGOs in four countries. This seed is being used to strengthen national seed production efforts in various SADC countries, and for subsequent research and technology exchange projects. On-farm study in Malawi examined the causes of yield gaps between farmers' fields and research stations. On-farm diagnostic trials were conducted in three countries and results were discussed in numerous field days in Malawi, Zambia and Mozambique. Multilocational, multi-year analysis of data from Malawi and Mozambique has provided valuable information on yield stability of new varieties. A series of groundnut production manuals has been developed for use in the major producing countries. These manuals are important in technology exchange and are used for training courses and extension. Two manuals,

for Malawi and Zimbabwe, have been published while a third, for Zambia, is in press and will soon be available. Significant progress has been made towards the project purpose of making available improved groundnut production technologies. After 2 years of on-farm diagnostic trials in Malawi and Zimbabwe, conclusive results are available, and will benefit smallholder farmers across the SADC Region. The trials have demonstrated the substantial benefits to smallholders by using improved cultural practices. During the cropping seasons 1997/989 and 1998/99 350 an-farm trials were conducted and 217 lines were evaluated. Over 2000 on-farm variety demonstrations and on-farm demonstration of improved cultural practices were conducted. The SADC/ICRISAT Groundnut Project collaborated to the release 12 improved varieties in the region. An adoption study was conducted in Lilongwe and Kasungu, Malawi, focusing on farmers who had earlier hosted on-farm variety trials or demonstrations. The study aimed to examine adoption and acceptability of three improved groundnut varieties (CG 7, ICGV-SM 90704, JL 24) and improved crop management practices, study the patterns of seed diffusion and assess the effects on household cash income and food security. The results indicate that farmers valued the new varieties sufficiently to invest their own resources to expand groundnut production. The majority of farmers continued growing the improved varieties after the trials had ended. About 90% of farmers cited positive impacts - increased food supply - from growing the improved varieties. The study also indicated good adoption potential for improved crop management practices, especially early sowing and weed control.

Chickpea

Breeding material and nurseries and breeders seed made available to NARS in Asia and Africa (Jagdish Kumar)

Dissemination of relevant breeding populations, nurseries and advanced lines with a wider genetic base and exchange of information are the key technology for progress towards stability and high yield in chickpea. We assembled sets of desi and kabuli breeding populations and elite lines as nurseries and circulated the lists to various NARS. Based on their requests the relevant materials and information was supplied. Large scale breeders' seed multiplication was continued for Indian NARS upon their request and also for Tanzania. One thousand nine hundred and eight samples of early generation breeding populations and 66 sets of short- and medium-duration nurseries were made available to various NARS (Table 4.5.2). From the material supplied earlier, Sudan released four kabuli (Wad Hamid, Hawata, Atmor, Burgeig), India five [KAK 2 (kabuli), JG 11, CO 4, JAKI 9218, and L 551(kabuli)], and Bangladesh two (Barichhola 7 (kabuli) and 8). These included a short-duration FW resistant large seeded (45 g/100 seed) kabuli type KAK 2 (ICCV 92311). Myanmar has two on the release list and Brazil is awaiting seed multiplication for the release of ICCV 3. At least eight new elite lines from ICRISAT were entered by the cooperators in the All India Coordinated Chickpea trials and a few identified as sources of resistance. About 25 tons of breeder seed of ICCV 2, 10 and ICCC 37 was produced on request and payment from the Indian NARS. Two variety registration notes and nine PMIC registrations were submitted.

Table 4.5.2. Number of samples of chickpea seed supplied during 1997/98 and 1998/99.

Country	F2 populations	Advanced lines	Other seg. Material	International nurseries (sets)	International nurseries (lines)	Total
Australia	46	89	9	6	244	388
Bangladesh	38	86	-	1	42	166
Canada	13	182	-	5	202	397
China	42	29	-	-	-	71
India	892	1694	553	39	1542	4681
Iran	14	20	8	-	-	42
Israel	6	3	-	-	-	9
Kenya	-	79	-	-	-	79
Mexico	27	-	-	2	68	95
Myanmar	30	42	-	4	152	224
Nepal	17	65	6	7	310	398
Pakistan	168	230	-	-	-	398
Peru	-	20	-	-	-	20
Portugal	62	96	-	-	-	158
Rep.of Yemen	-	6	-	-	-	6
Spain	-	127	-	-	-	127
Sri Lanka	-	8	14	-	-	22
Sudan	-	20	-	-	-	20
Tanzania	-	30	-	-	-	30
Tunisia	5	-	-	2	68	73
UAE	5	14	-	-	-	19
USA	-	263	-	-	-	263
Total	1365	3103	590	66	2628	7686

International nurseries made available to NARS in Africa (N P Saxena)

Enhanced NARS partners capability to conduct genetic enhancement of drought tolerance and develop material specifically adapted to their target agro-eco region is important in SAT. Drought tolerant and susceptible genotypes, detailed plans of the experiment, and some simple equipments and software (model) were provided for estimating soil moisture conditions. This activity was linked to an FAO/IAEA activity (AFRA III-18) on "Selection for drought tolerance (Chickpea, Ethiopia)". A 5-day training course was conducted at Debre-zeit Agricultural Research Center in which 14 NARS scientists participated. Training was imparted on theory and practical aspects of planning experiments on improvement of drought tolerance, conduct of experiments, recording data, analysis of results and preparing reports. There was no follow up from NARS partners to request seed of drought tolerant breeding lines developed at ICRISAT, despite reminders they did not send MTA to send them the drought tolerant germplasm and elite breeding material.

Pigeonpea

Breeder seed of ICRISAT developed varieties supplied (K B Saxena)

Supply of ICRISAT's breeding materials will help strengthening the capabilities of NARS. During 1998, open pollinated seed of 62 lines was produced. The total quantity harvested was 158 kg. In isolation we produced 20 kg of seed of ICPL 88039 and 50 kg seed of ICPL 98015. In addition, to support IFAD Project seed needs and that of our own, seed of ICPL 85063 (377 kg), ICP 8863 (675 kg), ICPL 87119 (460 kg), ICPL 87 (4 kg), ICPL 151 (5 kg), and ICPL 332 (10 kg) was produced. In 1999, 110 breeding lines were multiplied. In addition varieties ICPL 85063, ICP 8863, ICPL 87119, ICPL 87, ICPL 151 and UPAS 120 were multiplied on the request of National Seed Corporation. With limited resources a considerable number of breeding lines and varieties were multiplied.

SPECIAL PROJECTS

Objective 4.6: Special projects

Activity 4.6a: Sorghum and Millet Improvement Project (SMIP)

Generate improved genotypes suited for use by the commercial food and feed industry (A B Obilana and E S Monyo)

During earlier years, farmers were not involved in selecting plant and grain traits of the new varieties - choices were made by SMIP and national program breeders. However, greater input by farmers and the commercial sector in setting priorities for the next generation of improved varieties is now seen as vital to the continued success of the program. During Phase IV of the SMIP, the thrust is to go beyond food security. Food security must include enhanced capacity and economic access to both available food and other essentials. To achieve this, a project was set up to target selection of new high yielding varieties suitable for both food and industrial use. The success of this initiative will depend on the participation and decision making involvement of the clientele (the farmer and/or industry). An inventory of the grain quality database of all released varieties was conducted and missing gaps identified. Twenty-seven sorghum and 18 pearl millet varieties were involved in the analysis. The five best hybrids or varieties from each of the advanced trials were selected for further multilocational evaluation in the SADC region to form part of Sorghum and Millet Improvement Network's (SMINET) regional variety testing program. Farmer feedback on performance and acceptability of improved varieties was obtained from two sites in Zimbabwe and one in Mozambique. Sorghum varieties Macia and SDSL 89420 have been very well received. Local Mozambican varieties have excellent food quality properties and are highly resistant to storage pests and environmental deterioration. These issues are yet to be adequately addressed in the new improved varieties. For pearl millet, Okashana 1, Okashana 2, and PMV 3 were particularly liked for their drought tolerance. SDMV 89004, PMV 3 and WC-C-75 have the highest fat content; 8.20%, 9.45%, and 10.76% respectively and could be useful in the animal feed industry. The best sorghum cultivars for the brewing industry were identified as NS 5511, AMM 635 and DC 75 due to their high enzyme activity. Regional trials have helped identify potentially high-performing varieties and hybrids for promotion into national testing programs.

Technical assistance with breeder seed production (A B Obilana and E S Monyo)

In all, 45 sorghum and pearl millet varieties have been released in the SADC region. Many NARS face major difficulties in purity maintenance of these varieties. Every season SMIP receives (often unexpected) requests from NARS to supply them with nucleus seed of a variety that has lost purity. SMIP cannot afford to continue to supply large quantities of breeder seed on a regular basis. The regional program was mainly focusing on three target countries (Mozambique, Tanzania and Zimbabwe) where SMIP assisted NARS with breeder seed production on a cost-recovery basis. Simultaneously, SMIP developed regional workplans to develop systems that will ensure the availability of adequate breeder seed every year in all SADC countries. To lay the countries foundation for national seed multiplication efforts, large quantities of breeder and foundation seed of released varieties and promising varieties for testing were produced on specific request for private firms and national programs. A notable progress towards sustainability of breeder seed provision regionally was the success in the establishment

of a revolving fund account in Zimbabwe. The Zimbabwe's success story will serve as a model for the other SADC countries. Over 3 tons of seed were produced in isolation blocks of 0.2 ha each, to help alleviate seed constraints for varieties in Advanced National Trials. An additional 4.5 tons of 13 released varieties [Tanzania -- Pato (sorghum), Okoa and Shibe (pearl millet); Zimbabwe - SV 2, SV 3, SV 4 and Macia (sorghum), PMV 1, PMV 2, PMV 3 (pearl millet); and Mozambique - Macia and Chokwe (sorghum); SDMV 90031 (pearl millet)] were produced at the Matopos and Aisleby farms, for further multiplication by NARS.

SMIP's target for 1999/2000 is to have available sufficient breeder and foundation seed to produce certified seed totaling 150 tons of sorghum and 27 tons of pearl millet in the three target countries (Tanzania, Zimbabwe, and Mozambique). Good production in 1998/99, together with previous stocks, has ensured that we are on target to meet impact indicators relating to seed availability. For Tanzania, foundation seed stocks of 10 t of Pato and 2 t of Okoa are available. These are sufficient to meet seed requirements even assuming modest harvests during multiplication. For Mozambique and Zimbabwe, stocks now total more than 1 t of foundation seed of each released variety (Macia, SV 2, SV 3, SV 4, PMV 2, PMV 3). In all three countries, impact-indicator target (seeds) for the coming planting season have been met or exceeded. Future efforts should target the establishment of revolving fund accounts for Mozambique and Tanzania to emulate the success attained in Zimbabwe for the sustainability of this activity.

Promote improvements in alternative seed delivery systems (E S Monyo and D D Rohrbach)

Inadequate seed production and distribution systems are a key constraint to wider adoption of improved varieties in most participating countries. Unless the problem is tackled systematically, it will continue to slow the adoption of released varieties. There are several models in the region for addressing the problem, each with its advantages and disadvantages. It is very important now to identify the most appropriate model(s) in each case, and find partners and methods to address the issue of improving seed systems. This project will test four models. 1) Commercial sale of small-pack seed, 2) Seed delivery through NGO to develop local seed entrepreneurs in the village, 3) Public dissemination of new varieties and encouragement of multiplication and distribution within the village and 4) Seed distribution through drought relief programs. While these case studies are being compared; a workshop will be held to discuss the alternative models late in the year 2000. In Zimbabwe, the small pack seed program offered approximately 3 tons of seed of four crops (sorghum 1.4t, pearl millet 0.08t, groundnuts 0.6t and sunflower 0.99t) for sale (model 1). Virtually all the groundnut seed was sold, and farmers complained that stocks ran out quickly. Three-quarters of the sorghum seed was sold whereas only 27% of the pearl millet was sold due to late delivery. The small packs pilot program has not, in itself, contributed significantly to the improvement of adoption rates for sorghum and pearl millet varieties. However, if the scheme ultimately proves successful, an important breakthrough will have been achieved. This will be the first example of the fully commercialized delivery of sorghum and pearl millet OPVs known in southern Africa. In Tanzania the Msimba seed farm was able to meet national foundation seed requirements for sorghum and pearl millet for the first time in many years (model 3). In the 1998/99 season, the seed farm produced 10 tons Pato and 2 tons Okoa. From the 2 tons of Pato breeder seed supplied by SMIP, CCT (an NGO) produced 59 tons Pato and 1.6 tons Okoa seed through farmer seed associations in Dodoma and at the Hombolo farm (model 2). The Diocese of Central Tanganyika produced 100 tons Pato through farmers'

groups (model 2), and TanSeed produced another 50 tons (model 1). In total, 219 tons of sorghum and 3 6 tons of pearl millet were produced, versus a target of 103 tons and 5 tons of sorghum and pearl millet respectively. In Mozambique, the mandated report outlining the structure and conduct of local seed systems was completed. This led to the organization and implementation of a national workshop on seed system development. This workshop resulted in the drafting of an Action Plan for seed systems development and the formation of an ad hoc national seeds committee responsible for the implementation of this plan.

Market systems linking grain producers and individual consumers: Pilot testing of processing quality of new and traditional cultivars (D D Rohrbach and A B Obilana)

This project aimed to test the commercial interest in and economic feasibility of the milling of different sorghum varieties for the production of a composite sorghum-wheat composite flour. This included the pursuit of contract production of 10 t of five varieties of sorghum. The grain was then to be milled and combined with wheat flour for the production of alternative baked products. The main target was composite bread, but the baker is also being encouraged to use sorghum-wheat flour in the production of biscuits. Finally, the project involves test marketing of the various sorghum-wheat flour products. This activity is cross-linked with SEPP project. One hundred kg seed of five improved sorghum cultivars were provided to 21 small scale farmers in the Tsholotsho District, northwest of Bulawayo. This successfully led to the production of the mandated 10 tons of grain. Unfortunately, however, not enough seed was distributed of one of the five varieties to produce enough grain for significant milling and baking tests. Ultimately, 9.9 t of sorghum grain of four different varieties (Macia, Larsvyt 46-85, SV 2 and SDSL 89420) were obtained for the trials. The next problem to be solved was the milling of the sorghum into flour. The roller mills at Induna Foods proved incapable of milling a fine enough flour. However, with the intervention of SMIP, and linkages with collaborators at University of Pretoria, Food Science Department, industrial screens for sieving sorghum meal into flour became available. These were procured from South Africa and installed in the roller mills at the factory. The screens are of size <212 micro mesh, appropriate for required flour fractions for baking bread. The extraction rates are still not optimum, but we confirmed the fineness and acceptability of the flour produced by Induna Foods factory, at SMIP, Matopos. The roller mill produces up to 98% fine flour of sorghum. The first stage production of 50 kgs flour was provided by Induna Foods to the Lambas Bakery, Bulawayo, for compositing with wheat flour for test baking of bread. The composite bread (90% wheat: 10% sorghum flour) was baked using two varieties Macia and SV2 (108 loaves per variety), tested by panel of tasters and test marketed. The composite breads were generally acceptable as rated by 45 taste panelists: 53% good to very good for Macia and 51% for SV2, compared with control wheat bread (71%) produced in the commercial bakery. All loaves produced were sold within 24 hours, and no feedback complaints were received from consumers.

IPM options evaluated by farmers for management of armoured bush cricket in Namibia and Zambia (E M Minja)

Armoured bush crickets are sporadic but can become economically important pests on cereals and other crops in outbreak seasons. Yield losses averaging 30-60% have been reported in Namibia and Zambia in outbreak seasons with some farmers loosing all their crops of pearl millet and sorghum. The objective of the work was to test and verify IPM components for the

first time in on-farm trials for sustainable management of armoured bush crickets on pearl millet and sorghum in Namibia and Zambia. In Namibia the trials were farmer managed with researchers providing assistance when the need arose. In Zambia the trials were farmer-researcher managed where researchers assisted in providing seed of improved sorghum variety and some control technologies and farmers decided on crop management. The options included farmer-developed cultural practices (hand picking, early harvesting and stoking, uprooting crop stumps after harvest, field border trenches) and researcher developed technologies (improved early maturing varieties, egg search and collection, early sowing, clean weeding, field border insecticide baiting) (Tables 4.6.1). The improved pearl millet variety Okashana 1 was used in Namibia and sorghum variety Kuyuma in southern Zambia. Most of the practices tested by farmers in both countries reduce cricket damage although they are labour intensive. The local sorghum landrace Longo planted by farmers in Zambia failed completely in that season due to terminal drought. Very few farmers who have fields along water-ways were able to harvest some grain. The use of improved short-duration varieties, that escape terminal drought and mature before cricket population reach its peak, resulted in high grain yields for pearl millet and sorghum. These varieties were developed by SMIP/ICRISAT in partnerships with NARS and farmers in Namibia and Zambia. The use of *kraal* manure greatly improves soil fertility and moisture retention that maintains plant vigor during short dry spells enabling the plants to mature in time. Clean weeding throughout the season discourages crickets from immigrating to the fields particularly if a wide clean band is maintained around the fields. The small populations within the fields are then reduced by hand picking at weeding and bird scaring periods. While estimates of yield losses ranging from 5-15% and 10-40% respectively, were recorded for Namibia and Zambia, on-farm participating farmers in both countries suffered yield losses of less than 5%. The control methods used in the above on-farm trials were found effective. However, there is need to verify the strategies on a wider scale to enable more farmers participate and make decisions on the suitable strategies for their locations. In addition, more strategies (e.g. judicious use of pesticides, biopesticide testing, use of pheromones and other regulatory factors, study of enviromental effects, etc.) should be developed and tested in partnerships with farmers.

Table 4.6.1. IPM components tested for control of armoured bush cricket on sorghum in Zambia, 1997/98

IPM component combinations	Crickets/5m^2 at harvest	% damage on panicles	Grain yield t ha^{-1}
1. Sole crop short-duration sorghum variety Kuyuma, early planting*, clean weeding, leaf stripping, hand picking**	2.2	5.4	0.7
2. Sole crop short-duration sorghum variety Kuyuma, clean weeding, trench around field, hand picking**	2.1	4.5	0.8
3. Sole crop short-duration sorghum variety Kuyuma, clean weeding, hand picking**	3.1	5.3	0.5
4. Sole crop short-duration sorghum variety Kuyuma, one weeding within field at four weeks after germination	9.3	33.2	0.3
5. Local cultivar Longo mixed with cowpea, melon, and mung beans; clean weeding	4.3	No panicles matured	No yield
Mean	4.2	9.7	0.5
SE	± 1.1	± 2.9	± 0.2

*Early planting was practiced by all participating farmers

** Practice imported from Namibia and accepted by some farmers in Zambia

Objective 4.6b: Develop and improved acid soil tolerant sorghum hybrids and strengthen NARS capacity for research and development

Latin American Acid Soil Tolerant Sorghum and Pearl millet Project (Belum V S Reddy)

Large areas of grass lands in Latin America have Al^{+3} toxicity and therefore crop production is limited. ICRISAT in cooperation with CIAT and the national programs (Colombia, Brazil, Honduras, and Venezuela) in the region developed a research program to identify acid soil tolerant high yielding sorghum and pearl millet cultivars for adoption by farmers in these zones. A large number of grain sorghum seed parents, restorer lines and forage sorghum lines, and pearl millet A/B-lines and populations were introduced into CIAT, Cali in 1996. These were evaluated at Quilichao, Lalibertad, Matazul and Carimagua in Colombia during 1997 and 1998, while the seed increase was taken up at CIAT farm near Cali, Colombia. During Jan-June 1998, network trials (A/B-lines, R-lines and forage lines of sorghum and pearl millet) were distributed to various collaborators in the region and these were evaluated at Matazul, Meta, Colombia, besides at other locations by the network collaborators. During 1999 first season (Jan-June), off-season nursery was taken up at CIAT farm near Cali in Colombia involving the materials selected from the nurseries conducted at Matazul, during the second season of 1998 (July-Dec). Further at ICRISAT, Patancheru, India, 49 F_3s obtained from crosses of acid soil tolerant lines introduced from Colombia and high yielding B-lines were evaluated in 1999 rainy season.

Evaluation at Matazul during July-Dec 1998 season resulted in identification of promising sorghum material; these are eight B-lines and four R-lines for grain purpose and two sorghum lines (IS 31496 and IS 13868) for forage purpose. Four advanced sorghum hybrids were also selected for testing in multi-location trials. Preliminary hybrids (47), several F_3s and S_3s for grain purpose and forage purpose (high tillering) were advanced. It was noted that two forage sorghum lines (IS 31496 and IS 13868) and two pearl millet bulks from the selected populations may be considered for developing release proposals for Colombia. The activities at CIAT farm, near Cali during first semester of 1999 included seed increase of the selected A/B and R-lines, hybrids and populations, and several F_4 and S_4 selections. Evaluation for high yield potential in F_3 progenies at ICRISAT, Patancheru produced 44 F_4 selections. A workshop to review the research held at Villavicencio, Colomiba was attended by 25 scientists from Colombia, Brazil, Venezuela and Honduras. Fifteen papers were presented. Excellent discussion took place on the Network Trials. Several recommendations on conducting the network trials, and on future research program for the region were developed. A draft on "A Research and Network Strategy for Sustainable Sorghum and Pearl Millet Production Systems for Latin America - 3rd Phase Research Proposal" was prepared in addition to a concept note on the same subject. These drafts are now being circulated to CIAT and the national programs in the region.

Objective 4.6c: Improve pigeonpea production and productivity in SEA through better adapted varieties, seed supply systems and increased farm level consumption

Evaluation of F_4 progenies derived from Indian x African crosses (K B Saxena)

Broadening of genetic base by introgressing African and Indian pigeonpea germplasm will provide high yielding widely adapted materials. During 1998, F_4 progenies derived from eight crosses involving Indian and African germplasm were grown at Patancheru. Since the crop was severely damaged by phytophthora blight only single plants were selected. In 1999, a total of 66 short-duration and 42 medium-duration progenies were grown along with controls for evaluation. In 1998, a short-duration line (KAT 60/8) of African origin was crossed to an extra-early maturing line (MN 1). A set of germplasm from different origin was planted in 1999 to generate new populations. Among 108 progenies evaluated in 1999, 116 short-duration single plants having white and bold seeds were selected. After harvesting their open pollinated seeds the plants were selfed to produce pure seed for evaluation in the next season. In the medium-duration progenies selection will be done in the month of December. Some progenies appear very promising for pod and seed traits. To develop new materials, the F_1 of cross (KAT 60/8 x MN1) is grown in field. Plants have been selfed to produce pure F_2 seed. Plans have also been made to cross ICP 12176 (from Malawi), ICP 13561 (from Ethiopia), and 60/8 (from Kenya) with the germplasm of various other countries. At Patancheru most of the African germplasm has shown high level of susceptibility to water-logging and phytophthora blight. Since a significant proportion of the population is lost, this material may have limited genetic variability.

Develop thermo-insensitive early maturing advanced breeding lines with farmer and market acceptable grain characteristics (S N Silim)

Experience has shown that all pigeonpea lines (irrespective of maturity durations) are extremely sensitive to temperature. Cool temperatures (< 18 ^{o}C) delayed flowering and maturity in short-duration and accelerated in long-duration pigeonpea. This meant that the cropping sequence involving short-duration pigeonpea would be interfered when grown in cool environments. In the cool environment where long-duration pigeonpea are intercropped with maize, crops such as maize tend to be late while pigeonpea tend to be early and intercropping would often result in competition because the two crops would mature at about the same time.. In 1994/95 cropping season, we started a breeding program with two objectives i) maintain traits found in short-duration varieties like relative insensitivity to photoperiod, early flowering and maturity, and ii) incorporating ability to grow and mature early at low temperature, and resistance to fusarium wilt from long-duration varieties. For long-duration varieties being developed, the objective was to incorporate delay in maturity at low temperatures.

The short-duration variety ICPL 87091 was crossed with long-duration varieties ICP 13076, ICEAP 00020, and ICEAP 00040. The F_5 progenies in different duration groups were sown in November 1998 at Kiboko (warm, 980m altitude) and Kabete (cool, 1825 m altitude) in Kenya. The crosses are slightly later in maturity than ICPL 87091. The results, however, show that ability to mature early in cool environment of Kabete has been incorporated in at least seven of the test crosses (IAPX 95001-KIB-21-13-8-F5B, IAPX 95001-KIB-21-12-11-F5B, IAPX 95001-

KIB-10-KAB-1-F5B, IAPX 95001-KIB-4-11-6-F5B, IAPX 95001-KIB-5-3-1-F5B, IAPX 95001-KIBB-4-4-6-F5B, IAPX 95001-KIB-6-4-13-F5B). We have also increased seed mass. In the long duration trials, yields from F_5 were substantially higher than parents and seed mass was not reduced. Eleven of the crosses were later in maturity than the long-duration check, indicating that we have incorporated delay for maturity under cool conditions. The study shows that it is possible to select for areas where temperatures are cool and opens the way to growing pigeonpea in non-traditional areas.

Evaluation of non-determinate short-duration varieties (S N Silim)

Results from previous seasons had indicated that non-determinate short-duration pigeonpeas give higher yields than determinate types in those places where *Maruca* is a serious pest. However, the non-determinate short-duration varieties currently available are small podded with very small grains that are not acceptable to farmers in the region. In the non-determinate medium-duration varieties, ICP 6927 and ICEAP 00068, which are in on-farm trials in Kenya, we had variability for time to maturity. We therefore started work to select for earliness in this variety in 1993, and to date we have accessions which mature earlier than the original ICP 6927. A Short-duration Yield Trial, consisting of early maturing single plant selections from ICP 6927 and ICEAP 00068 and other early maturing varieties from different parts of the world was constituted and sent to NARS Kenya, Malawi, Mozambique, Tanzania, Uganda and Zimbabwe and, one set was planted in November 1998 at Kiboko and Kampi ya Mawe in Kenya. The trial consisted of 14 entries and checks were ICPL 87091, NPP 670 and KAT 60/8. Time to maturity at both locations in Kenya for the new varieties was almost similar. The crop was grown under irrigation in Kiboko and rainfed in Kampi ya Mawe. During the growing season, Kampi ya Mawe received less than 200 mm of rain and this is reflected in lower grain yield. The results show that some of the new varieties with ICEAP numbers are as high yielding as ICPL 87091 and their indeterminate growth habit would make them less susceptible to pests. A few have performed well in Uganda, Malawi and Kenya and need now to be evaluated on-farm. We have now identified non-determinate short-duration pigeonpea with large bold seeds. They need now to be evaluated in the on-farm trial. Since the varieties are later than the traditional indeterminate varieties, we need to start making crosses to shorten their duration.

Medium-duration multi-location trial (S N Silim)

When ICRISAT initiated research on improvement of pigeonpea in eastern and southern Africa, emphasis was on development of short-and to a lesser extent on long-duration varieties. Short-duration varieties would fit into areas with favorable moisture regime and where two crops can be grown a year or for monocropping in the dry areas where the length of the growing season is short. In eastern and southern Africa, the traditional farming systems involves the growing of long-duration and to a lesser extent medium-duration pigeonpea landrace varieties intercropped or mixed cropped with a number of other crops. The project had to develop a strategy that would balance the opportunity to introduce short-duration types and farmer requirement of medium-duration varieties for intercropping. We assembled a large number of germplasm and varieties of medium-duration lines and evaluated them in three locations in Kenya for grain yield, white bold seeds and ability to give good ratoon yield. Ability to give good ratoon yield would meet requirements of growing two crops a year and the crop can be intercropped. From these accessions, the best yielding lines with acceptable agronomic traits and good ratoonability was constituted into Medium-Duration Multilocation Yield Trial. The trial consisted of 15 entries

(some with resistance to wilt) and was sent, upon request, to collaborators in the region and we evaluated one set Kampi ya Mawe. The checks in the trials are ICP 6927 and ICEAP 00068. In the 1998/99 cropping season October –January rainfall was extremely low and the duration short, and the April-June rainfall about average. Compared to the 1997/98 cropping season, time to flower and maturity was early in 1998/99, mainly because of drought. The study showed that in areas with erratic rainfall ratoonability contributes to yield security. Varieties such as ICEAP 0068, ICP 6927 ICEAP 00553, ICEAP 00911, ICEAP 00540, ICEAP 00557 and ICEAP 00550 gave ratoon yields greater than 1 t ha^{-1}. The newer varieties such as ICEAP 00553, ICEAP 00911, ICEAP 00540, ICEAP 00557 and ICEAP 00550 are resistant to wilt and some have given very high yields in Kenya, Malawi, Mozambique and Tanzania. Extensive on-farm trials and seed multiplication now need to be undertaken for ICEAP 0068, ICP 6927 in Kenya and Mozambique where the varieties have performed well; ICP 12734 and ICPL 87051 in Uganda. We need to conduct further evaluation of other promising wilt resistant varieties.

Long-duration multi-locational trial (S N Silim)

In eastern and southern Africa, farmers traditionally grow long-duration and, to a lesser extent, medium-duration landraces that are intercropped or mixed cropped. Although productivity of pigeonpea in the system is low, it has many advantages. The crop matures and produces pods at the time when temperatures are low and as a result pest damage is low. In this system, yields are considered as bonus because the companion crop is considered as the main crop; the crop matures when there is nothing else in the field. Since 1993 we have assembled a large number of long-duration pigeonpea varieties and evaluated them at three locations in Kenya to select high yielding, white bold seeded varieties with resistance to wilt. From the accessions, the best yielding lines with acceptable agronomic traits and adaptation were constituted into Long-Duration Multilocation Yield Trial, were sent, upon request, to collaborators in the region, and we evaluated one set each at Kiboko, Kampi ya Mawe and Kabete in Kenya. The trial consisted of 15 entries replicated and checks were ICEAP 00020, ICEAP 00040, ICEAP 00053 and ICP 9145, which are in the on-farm trials. Results showed that in general, yields were high among the test entries. The study also showed that, except for ICP 9145, check varieties are still among the highest yielders. ICEAP 00040, which has shown high yield in Kenya, Tanzania, Malawi and Mozambique gave high and stable yield across locations, even at Kampi ya Mawe where total seasonal rainfall was less than 350 mm. The results of the trials indicate that high yielding varieties with white and large grains are available. ICEAP 00040 and ICP 9145 are resistant to fusarium wilt. Results showed that ICEAP O0040 is the preferred variety across the region. Seeds of ICEAP 00040, ICEAP 00020 and ICP 9145 are being multiplied in Kenya, Tanzania, Malawi and Mozambique. We expect the ICEAP 00040 to be released soon. Although ICEAP 00053 has given very high grain yield in the on-farm trials in Tanzania, farmers reported that the variety is relatively more susceptible to pests and is less resistant to fusarium wilt than ICEAP 00040. ICEAP 00053 need to be crossed with ICEAP 00040 to incorporate resistance to wilt and tolerance to pests.

Promising farmer and market acceptable pigeonpea lines identified (R B Jones)

Pigeonpea is grown both for food and as a cash crop. A good understanding of end-user requirements is needed for targeting of improved germplasm, and to guide germplasm improvement. Grain samples of improved short-, medium- and long-duration varieties were sent to end-users in India (whole grain), Malawi (whole grain), Tanzania (whole grain), and the

United Kingdom (whole grain and fresh pigeonpeas). Processing characteristics were determined using a Tangential Abrasive De-hulling Device (TADD), at the request of Malawi based processors. Farmer managed trials were carried out to determine the farmer acceptability of improved pigeonpea varieties in Malawi (medium-, and long-duration), Tanzania (short- and long-duration) and Kenya (short-, medium- and long-duration). Quantitative and qualitative information was collected through farmer visits and group assessments.

End-users in India expressed preference for ICPL 87091 because of its early maturity, grain size, grain color and taste. End-users in Europe expressed satisfaction with the same variety for green pigeonpeas because of uniform size, color and storability, but preferred grain from the improved long-duration variety ICEAP 00040 for whole grain because of its grain size and grain color. Processors in Malawi selected ICEAP 00040 for ease of dehulling, grain size and grain color. Farmer preferences in the long-duration group were for ICEAP 00040 because of its fusarium wilt resistance, earlier maturity, large grain size and cream grain color compared to local landraces. Short-, and medium-duration varieties were popular in bimodal rainfall areas because they provided farmers with the flexibility to plant twice in one year. Varietal preference within duration group varied across locations. The major complaint of farmers was susceptibility to insect pests, especially in the short- and medium-duration groups.

The portfolio of improved pigeonpea varieties that are presently available meet the full range of end-user needs so far identified. Further research is needed to develop resistance to pod borers and pod suckers as this is a major constraint to adoption by resource constrained farmers.

Sustainable seed supply systems designed, developed and implemented Rationale (R B Jones)

The lack of commercial interest in seed multiplication and distribution for open and self pollinated varieties is a major impediment to achieving impact from crop improvement efforts. The implementation of alternative seed systems is essential if the full benefit from ICRISAT's germplasm improvement work is to be realized. An adoption study of an improved medium-duration pigeonpea variety was carried out using a formal questionnaire administered to 180 farmers in Karaba location, Kenya. Small seed packs (1 kg) were marketed through 32 rural stockists in three districts of Eastern Province, Kenya to determine if there is an effective demand for a range of dryland crops including sorghum, pearl millet, and pigeonpea.

In Karaba, approximately 80% of farmers had sown the improved medium-duration pigeonpea at one time over a period of 13 years, and 60% of farmers were still growing the variety. About 75% of farmers learnt about the variety from seeing it while 25% first heard about it. Most farmers started growing the variety in the next season after first seeing it. First and second time seed acquisition was mainly through purchases from other farmers. All farmers growing the variety controlled field pests using insecticides. The crop is sold mainly for cash as its fetches a premium price before the local long-duration varieties are harvested. Twenty Eight out of 33 stockists purchased seed on a cash basis, and majority of stockists requested more seed to sell for the subsequent cropping season indicating that there was an effective demand for seed. Seed sales of improved pigeonpea varieties were highest in areas where on-farm demonstrations had been carried out. Seed was subsidized from 5-20% with seed collection and distribution costs being the biggest component.

Informal seed supply systems are effective for disseminating improved varieties. There is need to support informal seed systems during times of crop failure when traditional coping mechanisms fail. Sale of small seed packs is a cost effective way of disseminating improved varieties but needs to be linked to an effective program of information dissemination.

Improved pigeonpea processing and utilization technologies developed, verified and disseminated (R B Jones)

To stimulate production of pigeonpea in both traditional and non-traditional growing areas, there is need to develop, verify and disseminate a range of improved processing technologies. A simple process has been developed to manufacture *chakkis* (grinding stone) which are used in the preparation of *dhal*. The *chakkis* are manufactured from cement instead of stone due to the unavailability of high-quality stone and the lack of stone masonry skills. Local artisans in Kenya, Tanzania, Mozambique, Malawi and Zimbabwe have been involved in the development and verification of the technology. Rural women from Kenya, Tanzania, Mozambique, Malawi and Zimbabwe have been trained in processing and utilization of fresh, whole dry, and split pigeonpeas.

An extension manual has been developed on the manufacture of cement *chakkis*, and the technology is now being implemented by local artisans trained by the project. The consumption of fresh green pigeonpeas is favored over whole dry pigeopneas. Processing of whole dry pigeonpeas into dhal reduces the cooking time, improves storage and is preferred by consumers.

Objective 4.6d: Support to Eritrea

Establishment of an effective pearl millet breeding program in the Division of Agricultural Research and Human Resource Development , Ministry of Agriculture, Eritrea (F R Bidinger)

The Eritrean Ministry of Agriculture's development plan calls for the establishment of breeding programs for all major national crops, to develop and disseminate appropriate new cultivars for Eritrean farmers. DANIDA is providing long term financial assistance for this effort, including funding to ICRISAT to provide technical backup for sorghum and pearl millet breeding. For pearl millet, ICRISAT is providing assistance in seed production of the variety ICMV 221, assistance in establishing a research site for pearl millet breeding, and seed of new genetic materials and direct assistance in using these to establish a millet breeding program in Eritrea. During 1998-1999 ICRISAT has provided fresh stocks of both breeder and foundation seed of ICMV 221, identified in national trials in Eritrea, and provided advice on producing seed for distribution to farmers. We are also producing a poster to help promote the variety. We have also contracted with ICRISAT to fabricate a small plot planter for Eritrea, purchased bird netting to protect off-season nurseries and breeder seed multiplication plots, and identified small thresher for breeding work. A location has been identified, with ICRISAT help, near Karan in the main millet-producing zone for establishing a pearl millet breeding research station. Plans have been formulated for initiating a breeding program by introgressing parental materials from ICRISAT into selected Eritrean landrace populations to improve their disease resistance and yield

potential. A set of potential parental materials was evaluated in Eritrea in 1999 and fresh seed of selected lines is being sent to initiate crossing with landrace materials in early 2000. (The breeding work was to have begun in 1999, but was delayed by the border conflict between Eritrea and Ethiopia). Plans for 2000 call for creating and evaluating a large number of progenies from both selected Eritrean landraces and crosses of these and introduced materials, to provide a base for creating a number of experimental varieties for testing in 2001. ICRISAT (with DANIDA funding) has also supported MSc thesis research by the new Eritrean millet breeder at Patancheru.

Exotic germplasm in the form of improved varieties and breeding lines of sorghum and pearl millet continue to be introduced. These were jointly evaluated and selected by researchers (Eritrea and ICRISAT) and farmers in observation nurseries, preliminary, advanced on-station and on-farm trials at Shambuko (Western lowlands location), Halhale (highlands location) and Shieb (Eastern Wadi Lowlands). Seeds of farmer selected varieties were multiplied in both Eritrea and at Kiboko, Kenya, for distribution to the farmers. Two-year adaptive testing with on-farm testing and verification by farmers resulted in the selection of two sorghum varieties (89 MW 5003 and 89 MW 5053) for the Eastern Lowland Wadis and two sorghum varieties (ICSV 210 and PP 290) for Western Low-lands. Three hundred kilograms each of the two Wadi varieties have been produced and about 1.0 ton of each of the two western lowland ones are expected. We have advised the formal release of these four sorghum varieties. One pearl millet variety ICMV 221 was selected as preferred by farmers. Its seed is being produced.

Sorghum germplasm collected in 1997 were partially evaluated at Shambuko; two landrace varieties, Wadi Aker (Wadi Arba) and Koden, were selected for genetic improvement with adapted exotics for grain quality and maturity, respectively. From the Bizanay landrace-derived crosses with adapted sorghum cultivars made at Kiboko, Kenya, 110 F_3 selections were made for advancement in F_4 at Halhale and Shieb, Eritrea, in year 2000. A breeding strategy was presented to the DARHRD and DANIDA/IFAD for more detailed discussion and funding in next phase of the project (2000 2004).

Objective 4.6e: Enhanced partnership between ICAR and ICRISAT scientists to address research for development issues in India

ICAR-ICRISAT Partnership Research Projects (C L L Gowda in collaboration with concerned ICRISAT and Indian NARS scientists)

Being the host country, scientists from Indian national program and ICRISAT have had a long history for collaborative research. In the early years, this was informal and adhoc, but was formalized to ensure responsibility, accountability and relevance of research to both partners. The Joint ICAR-ICRISAT Policy Advisory Committee (JIIPAC) reviews the past joint research and provides broad guidelines for formulation and conduct of future partnership projects. Scientists from NARS (ICAR institutes and state agricultural universities) and ICRISAT discuss and formulate the partnership projects at joint meetings. Each project document provides information on the need for research, objectives, activities, work plan, milestones, budgets, and

responsibilities. The projects are then approved by designated authorities from ICAR (usually by Deputy Director General – Crop Sciences) and ICRISAT (Program Director).

Progress and achievements in 1998-99: The XVI JIIPAC held on 19 April 1998 recommended that future projects be more upstream utilizing the comparative advantages of both partners. Subsequently meetings were held among DDG and ADGs of ICAR and Program Director at ICRISAT to outline the broad areas of joint research. The joint meeting of ICAR and ICRISAT scientists was held 7-8 Jan 1999 to formulate the projects. Draft projects were exchanged during April to July 1999 for finalizing the proposals. The partnership projects were signed on 23 Sep 1999 by Dr R S Paroda, Director General, ICAR and Dr L D Swindale, Interim Director General, ICRISAT. Detailed list of sub-projects within each thematic area are given in Table 4.6.2.

Table 4.6.2. List of approved ICAR-ICRISAT partnership research projects, 1999-2002

Theme 1: Genetic resources: Collection, conservation, evaluation and exchange

- Maintenance and strengthening of quarantine facilities of NBPGR Regional Station, Hyderabad.
- Restoration of germplasm of ICRISAT mandate crops to NBPGR
- Modeling geneflow to assess the risk to biodiversity in traditional cropping systems: A case study with pigeonpea.
- Studies on sources of resistance to viruses and nematodes in *Arachis* gene pool

Theme 2: Diversification of male-sterility systems

- Diversification of hybrid parents for commercially exploitable cytoplasmic male-sterility systems in pearl millet.
- Development of cytoplasmic-nuclear male-sterility systems in pigeonpea.
- Diversification of A_1 and A_2 cytoplasmic male-sterile lines and their restorers for stem borer and grain mold resistance for rainy season sorghums, and for shoot fly resistance in postrainy season sorghums.

Theme 3: Development and application of molecular markers in diversity studies and marker-assisted selection

- Genetic enhancement of sorghum and pearl millet stover yield and feed quality by conventional and marker-assisted selection
- Marker-assisted transfer of pearl millet downy mildew resistance and terminal drought tolerance

Theme 4: Improving abiotic stress tolerance and adaptation

- Strategic research on selection for water use efficiency and partitioning efficiency to improve drought resistance in groundnut.

Theme 5: Improving biotic stress tolerance and adaptation

- Evaluation of effects of plant diseases on yield and nutritive value of crop residues used for peri-urban dairy production in the Deccan Plateau of India
- Safe to eat Peanut: A step towards minimizing aflatoxin contamination
- Mechanisms and inheritance of resistance to grain molds in rainy season sorghums and marker development for shoot fly and charcoal rot resistance in postrainy season sorghums.
- Characterization of pathogen diversity in pearl millet downy mildew
- Characterization of variability in chickpea fusarium wilt races and identification of multi-race resistance

Theme 6: Collaborative genetic enhancement

- Diversification, improvement and utilization of landrace-based pearl millet populations for marginal areas of N W India
- Develop groundnut gene pool populations with good seed quality and multiple resistance to abiotic and biotic stresses

Develop groundnut gene pool populations with good seed quality and multiple resistance to abiotic and biotic stresses (S N Nigam and S L Dwivedi)

India is one of the largest groundnut producing countries in the world. But groundnut productivity in the country is below the world's average. The main groundnut crop, which is

grown in the rainy season, suffers from several biotic and abiotic constraints. To bring in any significant change in world's groundnut scenario, it is important that groundnut productivity improves considerably. The main objective is to provide diversified, improved genetic material to national program scientists for selection for local adaptation and subsequent evaluation in the AICORP network. From the material supplied by ICRISAT, our collaborators in India have identified several promising lines for desirable traits. These include ICGVs 90208,90201, and 90173 for high oil; ICGVs 90312 and 90308 for high protein and sugar; ICGS 44 for acid soil tolerance; ICGVs 92206, 94357, and 92242 for high yield and short-duration; ICGVs 89359, 91058, and 91206 for high yield and medium-duration; ICGVs 88256 and 89402 for high yield and resistance to rust and late leaf spot; ICGVs 91167 and 90261 for resistance to insect pests; and, ICGVs 90325, 91089, 90212, 90173, and 90208 for high yield and large seed mass. Four confectionery varieties, ICGVs 90173, 90212, 90320, and 91104, were identified for inclusion in the Advanced Varietal Trial of AICORP. In the North East Hill region of India, ICGVs 88336, 88342, 88376, 92224, and 92229 performed well.

Diversification and improvement of landrace-based pearl millet breeding populations, and the development of improved open-pollinated cultivars and topcross hybrids for the arid zone of NW India (F R Bidinger)

Although approximately 45% of the total pearl millet area in India is in Rajasthan, this state has the lowest rate of adoption of new varieties or hybrids and the lowest average yields. The very marginal conditions of the arid zone of the central and western part of Rajasthan limit both yields and the use of higher yielding genetic materials bred elsewhere in India, which are not sufficiently adapted to this zone. This activity supports the All India Coordinated Pearl Millet Improvement Project in developing appropriate germplasm for this region through: (1) diversifying the genetic base of adapted landrace materials, (2) developing pollinators based on landrace materials to produce better adapted hybrids, and (3) evaluating the gains from combining adaptation and higher productivity in the form of landrace-based topcross hybrids. During 1998 and 1999, the activity has made crosses of Rajasthan landrace and elite ICRISAT breeding materials to create new, diversified populations for breeding of open-pollinated varieties. We initiated the development of topcross pollinators from an older landrace-based recommended variety (RCB 2) and two elite landrace composites (Barmer and Jakharana populations), through a process of composite progeny selection, followed by test cross evaluation. A test cross trial of other landrace derived varieties from the ICRISAT - Central Arid Zone Research Institute (CAZRI) - Rajasthan Agricultural University program was conducted to identity sources of future topcross pollinators. Initiated a multi-environment test cross trial to identify the best male-sterile lines to use in topcross hybrid development for the arid zone. A long-term trial was established to compare landrace-based varieties, their topcross hybrids, and standard single cross hybrids in a range of management and natural environments, to define the crossover point between conventional and landrace-based materials and the degree of heterosis possible in landrace hybrids. An extensive, long term trial was initiated to evaluate the importance of the traditional landrace plant type in adaptation of both open-pollinated varieties and topcross hybrids in the arid zone. The collaborating plant breeder from CAZRI was asked to diversify his landrace-based breeding materials, through providing parental lines and dry-season breeding facilities at Patancheru. As all of these activities are multi-year in nature, results will be available only from 2000 onwards.

Diversification of CMS lines and inheritance to grain mold and stem borer (Belum V S Reddy)

We have been collaborating with various centers in India who entered the entries derived or selected from ICRISAT materials into the All India Coordinated Sorghum Improvement Program (AICSIP) testing. Some of these outstanding entries are: SPV 1141 (a variety contributed by Parbhani Center) - 2nd rank in the advanced varietal trial (AVT) - *rabi*, SPV 1293 - a rainy season variety (contributed by Palem center) recommended for developing the release proposal, SPV 1333 - another rainy season variety (contributed by Parbhani center) recommended for developing the release proposal, SPH 840 (both parents from ICRISAT; contributed by Akola Center) - a rainy season hybrid recommended for developing the release proposal; and SPH 975 (PAC 538) (both parents base from ICRISAT; contributed by Advanta Seed Company - a rainy season private sector variety recommended for developing the release proposal. Further, JKSH 22, a private sector hybrid developed based on ICRISAT parents was notified by the Government of India for general cultivation in India. PSV 16 - a variety developed by Acharya N G Ranga Agricultural University based on ICRISAT pure lines is in advanced stage of testing on farmers fields in Andhra Pradesh. Excellent discussions between ICRISAT and NRCS scientists took place on partnership projects development. The candidate parental lines for RILs development was contributed by all the concerned scientists from Indian Program and the work was initiated at ICRISAT.

Table 4.6.3. Number of sorghum seed samples supplied to various sectors in India during 1999 (up to 30 Oct)

Sector	Male steriles	Maintainers	Restorers	Varieties	Pest resistant lines	Forage sorghums	Populations	Others	Total
Farmers	0	0	0	114	0	0	0	0	114
ICRISAT staff	0	0	0	10	0	0	0	0	10
Private seed agencies	383	387	73	19	0	32	37	1	932
Public sector : Central	134	134	11	21	0	33	0	1	334
Public sector : State	108	108	34	6	0	193	0	0	449
Public sector: state – nurseries	0	0	0	0	3711	0	0	0	3711
Others	14	14	0	13	0	0	0	0	41
Grand total	639	643	118	183	3711	258	37	2	5591

Objective 4.6f: Enhance productivity and sustainability of groundnut production through increases availability of germplasm held by ICRISAT and NARS in the region and produce and distribute foundation seed for multiplication by NARS

Conservation, evaluation and dissemination of groundnut germplasm, and foundation seed production and distribution for the West African Region (P J Bramel-Cox, B R Ntare, F Waliyar, A Mayeux and DaSilva)

Germplasm assembly, maintenance and conservation

The main thrust of the project has been establishment of a regional genebank and setting up appropriate infrastructure and facilities to conserve assembled germplasm. 5510 accessions have been assembled and are being conserved at the Niamey Gene bank under medium- term conditions. A large part of this material consists of duplicate accessions from the genebank at ICRISAT-Patancheru. The collection contains accessions from 73 countries of origin. The most common countries of origin are India (14%), Zimbabwe (12%), USA (6%), Tanzania (6%), Nigeria (5%)Brazil (5%), Argentina (4%). All the five botanical types are represented. Germplasm collection needs have been assessed in Senegal, Mali, Burkina Faso and Nigeria. These national programs have been assisted in identifying unique germplasm material for characterisation and conservation. The genebank at Niamey has short-and medium-term stores. These facilities have been improved to international standards. For regular monitoring, a genebank management system is being developed to allow continuous access to the status of the collection and ensure security. A series of database files for inventory, regeneration, processing and distribution were established and are operational. A total of 4570 germplasm accessions were rejuvenated to produce enough seed for conservation in medium-term storage conditions and/or further multiplication.

The project initiated a 3-year study in 1998 on alternative method to cold storage. This involves conserving seed under modified atmosphere(i.e. air in the storage sacks is sucked out and replaced with an inert gas such as nitrogen). This destroys most of the storage pests of groundnut, particularly bruchids (*Caryedon serratus*). It is a collaborative activity between ISRA and CIRAD. Other NARS that will conduct the experiment are IAR, Nigeria and INERA, Burkina Faso. Preliminary results indicate that there was no decline in germination rate after 12 months of storage. This observation was equally applicable whether under confined air or partially replaced by an inert gas (nitrogen). Under both conditions, the germination rate was around 92%. These results are in agreement with previous observations, which indicated that the germination rate remained high at least for 18 months. If the alternative to cold storage being tested turns out to be effective for large scale storage of foundation seed, it would be much cheaper than cold storage which relies on electrical energy.

Characterisation and multi-location evaluation of germplasm: Greater availability of key documentation and information on germplasm accessions will help breeders make more effective use of the material. Most of the duplicated germplasm has been characterised at ICRISAT-

Patancheru. All the rejuvenated accessions (4570) have been re-characterised and evaluated for agronomic characteristics at Bengou in Niger. This enabled identification of wrongly described accessions. Maturity ranged from 90 to 125 days (sowing to harvest). Both pod, haulm yield was measured, and the accessions were characterised for post harvest characteristics using a simplified groundnut descriptor. National collections in Senegal, Burkina Faso and Mali were re-evaluated based on criteria described in the simplified groundnut descriptor. The passport, characterisation and evaluation data assembled have been compiled into the first and second volumes of groundnut catalogues to be distributed to NARS in the region. A simplified groundnut descriptor is essential for ease of characterisation and evaluation of germplasm. The current descriptors were reviewed and more user-friendly descriptors have been compiled in a handbook for distribution to NARS in the region.

Identification of desirable traits

Groundnut in West and Central Africa is limited by a number of biotic and abiotic constraints. Sources of resistance to these stresses need to be tested for stability at different sites where the stress is available. This approach will save resources and enable dissemination of information generated to NARS without further verification in subsequent seasons or years. This could also generate seed to users in the crop improvement programs. One hundred germplasm lines were selected from the genebank at Niamey to screen them for foliar diseases (early and late leafspot and rust) by NARS partners. A set of lines resistant to foliar diseases and aflatoxin were distributed in form of regional trials and were sent to Guinea, Benin, Mali and Senegal. A rosette resistant regional trial was initiated and conducted in Mali, Nigeria, Ghana and Burkina Faso.

Groundnut Rosette Virus: Work on groundnut rosette virus is conducted by the Institute of Agricultural Research (IAR), Samaru Nigeria. One hundred and sixty-six lines were screened in the Rosette Disease Nursery (RDN). The lines were artificially inoculated with viruliferous aphids. Rosette incidence ranged from 0 to 100%. In early generations (F_3) more than 50 % of the populations showed rosette symptoms, while in the advance lines, only 10 % if the lines showed rosette symptoms. A number of trials involving advanced rosette resistant lines of various maturity groups were also conducted in Nigeria. Among 25 short-duration lines, ICGV-IS 96855 had the highest pod yield (1.6 t ha^{-1}) and shelling percentage (70%) across three locations. A multilocation trial to evaluate the performance of advanced breeding lines in different agro-ecological zones in Nigeria was conducted at 13 locations. Among the 16 extra-early maturing lines ICGV IS 96894, ICGV-IS 96891 and ICIAR 19BT were the best based on pod yield and shelling percentage. Rosette incidence in these lines was less than 3%. A regional trial consisting of 16 entries mainly of medium maturity group (115 days) and of Virginia botanical group, was conducted in Burkina Faso, Ghana, Mali and Nigeria. At Samaru in Nigeria, pod yield ranged from 1.2 to 2.2 t ha^{-1} with a shelling percentage ranging from 50 to 83 %. Based on pod yield (> 1.3 t ha^{-1}) and high shelling percentage (>70 %), 249-85, ICGV-SM 89764 and ICGV-IS 96846 were superior. The incidence of rosette on these lines was 0 %. At Niangoloko in Burkina Faso, the lines were compared with local check RMP 12. Despite the presence of aphids, none of the lines showed rosette symptoms. A group of 7 lines including the check (e.g. 249-85, ICGV-IS96894, M343-81A, MDR 8-15, UGA 2, M 517-801, M516-791 and RMP12) recorded pod yield ranging from 2.5 to 2.9 t ha^{-1}. Like in Nigeria 249-85 was the highest yielding with pod yield of 2.9 t ha^{-1} and shelling out turn of 78 %. Haulm yield of the best lines averaged 3.1 t ha^{-1}.

Early leafspot (ELS): Forty nine germplasm lines were screened for resistance to early leafspot at ICRISAT-Samanko in Mali. Lines ICG 6248, ICG 7878, ICG 6284, ICG 8339 and #2-94 had a score of 3 or 4 on a scale of 1 to 9 and a pod yield between 1.0 and 1.5 t ha^{-1}. In another trial consisting of 25 entries conducted at Samanko in 1998, ICG 7878, ICG 8298, ICG 6284 and ICG 8339 had a score of 4.0 compared to the susceptible check with a score of 9.0. Pod yields of these lines ranged from 1.83 t ha^{-1} for ICG 7878 to 2.67 t ha^{-1} for ICG 6284 and ICG 8298.

Late leafspot (LLS): Observations were made on the 1226 germplasm lines under rejuvenation for reaction to LLS, the most prevalent disease at Bengou, Niger. Only one line had a score of 3.0, 23 lines had a score of 4.0 and 65 lines had a score of 5.0, on a scale of 1 to 9. Forty early maturing germplasm lines supplied from the Niamey genebank were evaluated at Niangoloko, Burkina Faso for reaction to late leafspot. Lines having high pod yield ($\geq$ 2.0 t ha^{-1}) and resistant to Cercospora (< 4.0 score) were ICG 331, ICG 190, ICG 390, ICG 5313, ICG 13413. A regional trial consisting of 25 lines was conducted in Benin, Burkina Faso, Ghana and Mali (Samanko). In Benin, early and late leafspot were equally present. Among the best lines with a score of 5, ICG 7881 and ICG 1710 are of short duration (100 days) and ICGV 87779 is medium-maturity (117 days). In Burkina Faso the incidence of LLS was not very high. A group of nine lines had a score between 2.8 and 4.0. Among these lines, ICGV 87815, RM 12 and ICGV 87779 yielded more that 3 t ha^{-1} of pods. In Ghana the incidence of LLS was high with a trial mean of 6.0 on a scale of 1-9. Only two lines (ICG 7756 and ICGV 87836) had a score of 5 and are thus considered resistant. Another trial consisting of 49 entries was conducted at Bengou in Niger. Late leafspot incidence was high at Bengou The highest yielding line was ICGV 88274 with a pod yield of 2.08 t ha^{-1} and haulm yield of 4.47 t ha^{-1}. Most of the resistant lines had pod yields of less than 1.5 t ha^{-1} but with high haulm yields (>3.0 t ha^{-1}). Forty-nine lines were evaluated for resistance to rust at Niangoloko in Burkina Faso. Observations showed high susceptibility to late leafspot which masked the effects of rust. In Benin the incidence of rust was low but observations were made on lines tested for cercospora leafspot. ICG 10951, ICG 7878, ICG (FDRS) 10 and ICG 10075 showed slight rust symptoms.

Drought tolerance: Breeding for drought resistance is conducted at ISRA in Senegal by a CIRAD breeder and focuses on screening of new lines, on-station variety trials and on-farm variety trials. The screening involved lines derived from a recurrent selection program aimed at combining high yield with resistance to drought. Twenty lines were screened and selections were made based on physiological adaptation to drought. Agronomic traits were evaluated during the dry season under irrigation. From this trial, four lines (11908-13, 10915-12, 10915 (1)-7 and 12005-15) looked promising. The on-station variety trial consisted of two sets of 10 F_7 lines derived from the second population of the recurrent selection program. The on-farm trial was conducted at five locations prone to drought. The trial included three new lines with three checks: GC 8-35 for earliness, Fleur 11 for productivity and 55-437 for resistance to drought. With a total rainfall ranging from 140 to 335 mm, but well distributed during the vegetative cycle, pod yields of around 700 kg ha^{-1} were obtained. No significant differences in yield were observed among the varieties tested.

Tolerance to *Aspergillus flavus* invasion and aflatoxin contamination: This work is jointly conducted by ICRISAT and ISRA and focuses on evaluation of breeding and germplasm lines for resistance to seed colonization by *Aspergillus flavus* and aflatoxin contamination. A trial consisting of forty nine lines was conducted at Kita in Mali and Sadore in Niger. From the Kita trial, the level of *Aspergillus* colonization on seed ranged from 3 % for ICGV 91278 to 31 % for

73-73. Thirty lines showed a colonization rate of less than 10 %. Some of the high yielding lines such as JL 24 had more than 10 % seed colonization. Samples from the trial at Sadore have not yet been screened. Due to lack of chemical and vita ELISA kit, aflatoxin concentration has not been determined. A trial was conducted at Samanko in Mali (16 lines) and Bambey in Senegal (20 lines). This trial consisted mainly of breeding lines from ICRISAT-Patancheru. In Mali, percentage of *A. flavus* colonization ranked from 1.9 to 21.6%. Lines with less than 5% are : ICGV 89063, 47-10, ICGV 87815, ICGV 87084 and ICGV 91283. Aflatoxin concentration has not yet been determined. In Senegal, ICGV 89065, 55-437 (resistant check), ICGV 87084, 73-33 (local variety adapted in Nioro in Senegal), J11 (resistant check) GC 8-35 (new variety resistant to drought) showed tolerance to *A. flavus*.

Confectionery groundnut: A trial consisting of 25 lines from ICRISAT-Patancheru and ISRA was conducted in Senegal to evaluate agronomic performance under irrigation. Fifteen (15) were of Virginia type while the remaining 10 were Spanish. A variety from Senegal, 73-27 was the highest yielding with 2.1 t ha^{-1} of HPS (hand picked seed), 75 g/100 seeds and matured in 114 days after planting. NC7 from USA produced the largest grade seed with 1.75 t ha^{-1} of grains HPS, 95 g/100 seeds and matured in 112 days. The earliest maturing line was ICGV 88434 with 1.9 t ha^{-1} of HPS, 74g/100seeds and maturing in 102 days. The three lines were harvested when about 73 to 74% of the pods were mature.

Evaluations made so far have resulted in the identification of useful germplasm resistant to important constraints. These materials have been distributed to several NARS. Two NARS, the IAR, Nigeria and INERA, Burkina Faso have a regional research responsibility in groundnut rosette virus and foliar diseases, respectively. The project is backstopping efforts to strengthen collaboration among NARS and linking them into research networks to solve common problems and exchange results.

Distribution and exchange of germplasm

A regional network variety trials was initiated in the 1999/2000 crop season in Benin, Burkina-Faso Cameroon, Ghana, Guinea, Mali, Nigeria, Tchad, Togo and Senegal. Germplasm accessions obtained from Sierra Leone were repatriated after they had lost their germplasm as a result of civil strife. NGOs in Niger have been supplied with breeder seed of improved lines for use in their projects. International norms of germplasm distribution and exchange are being implemented to ensure the right of countries to their germplasm. A manual on technical aspects of germplasm transfer, exchange and quarantine has been prepared. All seed requests from NARS and other institutions were fulfilled.

Foundation seed multiplication

Foundation seed multiplication is conducted at the research station of ISRA, at Bambey, Senegal where the necessary infrastructure has been rehabilitated by the project. The seed multiplication program involves traditionally grown varieties in West Africa and other selected varieties with desirable traits such as resistance to rosette, rust, cercospora leaf spots, drought and aflatoxin contamination as well as edible groundnut. Eighty nine varieties were multiplied during the crop season 1998 and fifty during the post-rainy season. The post-rainy season targeted those varieties with limited quantities of seed.

Training

Twenty-five staff from the Ministry of agriculture, Niger, responsible for seed production had a one-day workshop at Sadore to familiarise with operations of the genebank. They were introduced to groundnut genetic resources and conservation, production and data base management. They also visited fields and glasshouse. Useful information was exchanged. Three staff from the Department of Agriculture, Niger completed a two-week training in aspects of seed handling, quality and conservation. Three other staff in the same ministry have been trained in field techniques for rejuvenation and characterisation of germplasm during the 1999 crop season.

Dissemination of information

The essential databases were established and include passport information of all accessions conserved in the genebank at Niamey, characterization of database, rejuvenation, processing and distribution. A genebank management manual, technical aspects of safe germplasm exchange , quarantine procedures and the first volume of groundnut catalogue (passport information) were completed. Issue No 3 of the GGP Newsletter was published in January,1999 and was widely distributed. Characterization and evaluation data available for the accessions held at the genebank at ICRISAT-Niamey was updated according to available data sets. The compiled data will be published as vol. 2 catalogue. The project backstopped a regional survey on national groundnut seed multiplication system funded by FAO. Survey started in August 1999 and was completed by a regional workshop organised at the end of November in Senegal. The project contributed to the organisation of the Sixth Regional Groundnut Workshop held 5-9 Oct. 1998 at Bamako, Mali. This workshop brought together representatives from 13 countries in the region. It provided an opportunity to set up a special GGP session that discussed the following topics: Intermediate results of the project, function of the seed production unit in Senegal, the international code of conduct for the collection and transfer of germplasm, regional study on groundnut seed systems and regional trials

Objective 4.6g: Support technology exchange involving mandate crops and appropriate cropping systems to increase cereal and legumes production in Asia

Cereals and Legumes Asia Network

Exchange of germplasm and breeding material (C L L Gowda in collaboration with ICRISAT and NARS scientists)

One of the main objectives of the Cereals of Legumes Asia Network (CLAN) is to strengthen the crop improvement programs in member countries to enable them to develop, test, and provide improved crop varieties of mandate crops to farmers. The requirement for specific germplasm and breeding material in each national program varies according to the need and capacity for crop improvement research. Countries that do not have many qualified plant breeders want near-finished or finished products that can be evaluated at multilocations for 2-3 years, before testing

the elite lines in farmers' fields prior to recommending the lines for release. Other countries are able to receive early generation breeding material or enhanced germplasm and use them in the breeding programs to develop high yielding cultivars. The material sent included: germplasm lines, trials and nurseries, segregating populations, hybrid parents (A/B/R lines), parental lines, and breeder seed (Table 4.6.4). The testing was done by NARS scientists in each of the countries.

Segregating generations were advanced without selection (as unselected bulks) or single plants selected and advanced as progenies. Selected progenies were tested on-station, and promising lines promoted to multilocation replicated yield trials. Results of the trials and nurseries were reported at national review and planning meetings, and in the half-yearly reports for the Asian Development Bank. Many NARS cooperators have been able to select lines that have given 20-80% more seed yield, 50-100% more fodder yield, and also resistance to major diseases and tolerance to pests. Informal discussions with NARS scientists have indicated that nearly 30 to 80% of the breeding material available in national programs is from ICRISAT-supplied material. All NARS have acknowledged the usefulness of the germplasm and breeding material. During 1998-99, the following varieties were released in India; Chickpea - JAKI 9218, JG 11, COG-4, L 551, KAK 2; Sorghum - JKSH 22; Pearl Millet AIMP 92901; Groundnut - ALR 3. In Indonesia, three groundnut varieties - Singa, Panter, Jerapah - were released. In Myanmar, groundnut variety - Simpadetha 7 - was released. In Pakistan three Chickpea varieties were released - Parbat, Dasht, Hamsafar. In Nepal, two Chickpea varieties were released - Tara and Chandra.

Table 4.6.4. Germplasm and breeding material supplied to Asian countries during 1998-99.

Crop	Germplasm	Breeding material					
		Trials & Nurseries	Breeders' seed	Segregating populations	Advanced lines	Released varieties	Others
Sorghum	4974	3	162	0	19930	108	3727
Pearl millet	1283	64	120	0	6375	0	0
Chickpea	2558	49	6	876	759	115	45
Pigeonpea	1265	0	23	28	192	336	212
Groundnut	1860	62	7	674	987	115	30
Total	11940	178	318	1578	28243	674	4014

Training of Asian NARS scientists and technicians to improve research capacity (C L L Gowda in collaboration with ICRISAT and NARS scientists)

Improving the research capabilities of scientists and technicians is essential to ensure that NARS are in a position to conduct quality research, develop and transfer technologies to farmers. The need for training of scientist and technician is identified mostly by the NARS according to the national programs' needs and priorities. In some cases, CLAN and ICRISAT scientists help and assist NARS to articulate the needs for training. Based on these needs and requirements of bilateral or multilateral research programs, CLAN organized the training programs with assistance from ICRISAT and national program scientists. Many were individual, tailor-made training programs. However, a few regional training courses and in-country programs were organized as per requirements of NARS. During the two years, 256 Asian NARS scientists participated in various training programs organized either at ICRISAT or in-country. This included 92 visiting scholars, 28 research scholars, 42 in-service participants, 86 apprentices and 8 summer trainees from 12 countries.

The following regional and in-country training programs were organized:

(a) Regional training courses (at ICRISAT-Patancheru):
- Identification of races of mite vector of pigeonpea sterility mosaic (24 Aug - 2 Sep 1998).
- Sorghum seed parents and hybrid development (14-23 Sep 1998).
- Advances in sorghum anthracnose research (23-25 Sep 1998).
- Immuno-chemical methods for aflatoxin estimation in groundnut (11-23 Dec 1998).

(b) In-country training programs:
- Sorghum seed parents and hybrid seed production (Myanmar, 29 Dec-8 Jan 1998).
- Genetic transformation using particle-inflow gun (India, 16-21 Jun 1998).
- Improvement of grain legumes (Myanmar, 26-31 Oct 1998).
- Experimental design and data analysis (Pakistan, 26 Oct-7 Nov 1998).

Working Groups for research collaboration in CLAN member countries (C L L Gowda in collaboration with ICRISAT and NARS scientists)

A 'Working group' consists of scientists who have indicated interest and commitment to come together to share research agenda towards finding solutions and/or technologies to alleviate production constraints. Working group members commit time and resources towards the common goal. A Technical Coordinator provides guidance, facilitates, and harmonizes research. Research activities are shared among members depending on their research capability and comparative advantages of the institutes. Research results are then shared (either through correspondence or at joint meetings) to collate information to arrive at possible solutions or technologies to tackle the problems.

The following working groups are currently operating in CLAN (with names of Technical Coordinators in parenthesis).
- Bacterial wilt of groundnut (Liao Boshou, China)
- Botrytis gray mold (BGM) of chickpea (M A Bakr, Bangladesh)
- Aflatoxin management in groundnut (Phan Lieu, Vietnam)
- Nitrogen fixation in legumes (O P Rupela, ICRISAT)
- Groundnut viruses in Asia-Pacific (D V R Reddy, ICRISAT)

The technical coordination of three working groups (as indicated above) was devolved to NARS, as recommended by the CLAN Steering Meeting held during 24-28 Nov 1997, in Indonesia. A group meeting of scientists working on BGM of chickpea was held in Feb 1998 in Bangladesh to formulate workplan for integrated management of the disease. Scientists working on bacterial wilt of groundnut in China, Vietnam and ICRISAT met in Hanoi, Vietnam (May 1998) to review past research and plan future research. Two issues of the NIFLA News (Vol.6 Nos. 1&2), and first issues of newsshcets for BGM in chickpea, bacterial wilt in groundnut, and Aflatoxin management in groundnut were published to share research information among members.

Objective 4.6h: Improve the production, productivity and utilization of sorghum to improve and contribute to general food security and economical well being in sorghum producing countries of WCA.

West and Central Africa Sorghum Research Network (WCASRN)

Enhancement of stakeholders participation in breeding activities and identification of novel traits for collaborative breeding (I Akintayo)

Previous breeding activities did not take into consideration end-users' s views. Because of this, generated technologies are not adopted. Thus, the objectives of this activity was; a) better understand end-users preferences and needs for grain and stover characteristics; b) identify opportunities for end-users direct participation in activities of varietal development and testing; and c) enhance communication skills of researchers and development agents through knowledge of the methods of effective end-users participation. Fifteen NARS scientists including breeders, were trained on concepts and methods for participatory breeding.

Identification of partners for seed production and distribution (I Akintayo)

One of the week link in the sorghum research and development continuum is the lack of effective production and distribution of new sorghum varieties/hybrids. Thus the objective of this activity was: a) To better understand farmers seed production and distribution systems and b) To develop new partnerships with farmers, NGOs and development agencies for effective and sustainable seed production and distribution of new sorghum varieties/hybrids. Participatory seed production projects were initiated in six Countries. The only currently available results are from Mali and Burkina Faso. In Mali 16 ha of land are sown with three improved sorghum varieties in collaboration with farmers including one women farmers' association. All involved farmers were exposed to advanced seed production methods. A total of 20tons of seeds are expected. In Burkina Faso, four tons of seeds of five improved varieties (CEF 322/53-1 -1, Sariaso 9, ICSV1049, CEF322/35-1-2, IRAT 204) have been produced in collaboration with 12 farmers in 10 localities. All involved farmers have been trained.

Evaluation of promising varieties on-farm across the sub-region (I Akintayo)

In recent years, many improved sorghum varieties have been developed by ICRISAT and NARS. There is a need to evaluate the new technologies on-farm so that they can be transferred to end-users. During the period under review this activity has been implemented in seven countries (Mali, Burkina Faso, Togo, Nigeria, Chad, Cameroun and Gambia). In each participating country, the test is conducted in at least two sites per agroecological zone with at least six volunteer cooperating farmers per site. Tests varieties are grown on large plots ($400m^2$) along with farmer's variety following the farmer's own cultural practices. Achievement: 36 improved varieties are tested on-farm with 120 farmers participating. The reports from NARS will indicate how many of the tested varieties have been selected by farmers.

Enhancement of market- driven opportunities (I Akintayo)

The limited sorghum utilization is resulting in poor market development. A number of constraints emanating from the inefficiency of sorghum processing equipment and the lack of suitable varieties for end-uses need to be addressed. Thus the objectives of this activity were; a) to transfer sorghum based products and processing technologies to end-users and b) generate new sorghum-based products. Seven projects on sorghum utilization were funded in seven countries across the WCA sub region. One pilot project on sorghum use is operational in Mali. Adopted sorghum based products are available on market in Mali.

Training (I Akintayo)

WCASRN relies on national research program for its activities. The majority of these do not have sufficient human and financial resources which could enable them to face the constraints to sorghum production. In this context, one of the objectives of the Network is to strengthen the NARS capabilities while benefiting from their comparative advantages. Two training courses on "Experimental design and data analysis" and "Making the most of on-farm test", have been organized and 35 scientists from 15 NARS trained.

Technical Workshop (I Akintayo)

A technical workshop entitled "Towards a sustainable sorghum production, utilization and marketing in WCA" has been organized. Proceedings of the workshop is in progress.

Monitoring Tour (I Akintayo)

The network activities have been monitored in five countries by the steering committee and the network coordinator and a report produced.

Objective 4.6i: Improve the production, productivity and utilization of millet to improve and contribute to general food security and economical wellbeing of millet producing countries in WCA

Réseau ouest et centre africian de recherche sur le mil - West and Central Africa Millet Research Network (ROCAFREMI-WCAMRN)

Improvement of millet-based cropping systems (B Ouendeba)

Held April 6-9 in Ouagadougou, Burkina Faso, the P4 annual meeting was attended by researchers from Burkina Faso, Côte d'Ivoire, Chad, Mali, and Niger. The representative from Senegal was not able to attend. Other organizations present were the Semi-Arid Food Grain Development (SAFGRAD), the International Sorghum and Millet Collaborative Research

Support Program (INTSORMIL), Vulgarisation Agricole (Burkina Faso), Hunger Project, and Sasakawa Global 2000.

Burkina Faso: Researchers from Burkina Faso found that organic fertilizers affect millet yield both in pure culture and in association with other crops.

Côte d'Ivoire: Three activities were initiated but not completed. They are (i) a study of monthly millet price changes, (ii) a study of the level of new technology adoption, and (iii) the publication of posters and leaflets for dissemination of technologies. However, the funds allocated to these activities are still available.

Mali: New fertilizer combinations have been developed (a combination of 4 t ha^{-1} organic fertilizer and 50 kg ha^{-1} urea, and 4 t ha^{-1} simple organic fertilizer), two types of millet/legume associations were established (1 row groundnut/1 row millet or 3 rows groundnut/1 row millet), and 45 farmers and 4 extension agents were trained on compost fabrication.

Niger: On-station trials showed that the groundnut variety JL 24 performs better in millet-based cropping systems than three other varieties. On-farm trials showed that the addition of 10 t ha^{-1} manure could improve yields in millet/cowpea cropping systems.

Chad: Experiments on cropping systems showed that the twin-lines system in millet/cowpea and millet/groundnut associations are preferred by farmers. A total of 21 farmers and 6 technicians were trained on the conduct of on-farm experiments and on seed multiplication techniques.

Regional studies: Two regional studies were conducted. The first studied the themes of rotation, fertilization and residue management, soil preparation, and varieties. Its results showed that:

- Crop rotation produces a sustainable increase in productivity;
- The response to residue management depends on soil conditions, fertilization and rainfall;
- Medium to heavy textured soil benefit more from soil preparation; and
- Improved varieties perform better and produce more during years with high rainfall.

The second regional study looked at the influence of fertilization, varieties, arrangements and planting dates in two types of crop associations: millet/legume (cowpea or groundnut) and millet/maize. The results showed that:

- In general, the use of fertilizers is essential;
- Organic and mineral fertilizers have the same performance, but a combination of organic and mineral fertilizers is preferable; and
- Fertilizers do not always affect the yield of legumes.

Millet promotion through improved processing (B Ouendeba)

Held March 22-25 in Dakar, Senegal, the annual P5 meeting was attended by researchers from Burkina Faso, Ghana, Niger, Nigeria, Mali, and Senegal, as well as representatives from Winrock International, URPATA-Sahel, the non-governmental organization (NGO) Weybi from Niger, and five private millet processing companies from Senegal.

Burkina Faso: Flour conservation studies used tamarind, hibiscus, lemon and vinegar to induce acidification. Of the two flour fabrication methods evaluated, - traditional method, and CTRAPA method- women preferred the traditional one. After several meetings in October and in February 1998, the following five areas of research focus were identified: quality of the raw material, suitability of flour rolling and drying equipment, distribution outlets, diversification of millet-based products, and standardization of flour analysis and characterization methods.

Ghana: Humidity, ash, protein, and fatty acids contents of five millet varieties (three developed by ICRISAT, and two local varieties) were determined during flour characterization experiments. Mineral content, physical characteristics and pasting properties of millet flours were also determined. Researchers did not attempt to find the preferred variety of consumers, but rather felt it was more important to provide all the characteristics of the different flours to the consumer so he can make a choice. Packaging and storage studies showed the superiority of polypropylene over polyethylene, but unfortunately it costs more than the product it should contain. During a partners' forum, fruitful exchanges between researchers, processors, tool fabricators and business owners took place.

Mali: Tangible results were obtained in terms of consumer's preferences, characteristics of various millet varieties and product shelf life. Storage tests must continue for another six months before they can yield any significant results. During a forum with partners, workplan for the next cropping season was established, and discussions on millet culture and consumption in Mali took place. The results of all surveys carried out since 1997 were evaluated. Participants to the forum estimated that the 4 millions CFA budget allocated to Mali was insufficient.

Niger: Chemical and physical characteristics of five millet varieties were determined. Sensory tests were also conducted. A correlation matrix for the various parameters was established. Nigérien researchers also organized a forum on millet (FORUMIL) attended by producers, NGOs, extension service agents, and researchers in February 1999.

Nigeria: Physical characteristics of six millet varieties were determined (variation of the humidity during dehulling, breaking rate, dehulling rate, and particle size analysis). A comparison of the traditional *fura* with one obtained by extrusion cooking showed that traditional *fura* is preferred. However, studies on improving the nutritional quality and shelf-life of *fura* through supplementation with grain legumes and extrusion cooking showed that an acceptable ready-to-serve dry *fura* pack with good sensory properties and nutritional quality could be produced. The feasibility of modifying some multipurpose threshers for pearl millet was demonstrated and a very satisfactory result obtained. The partners' forum planned for the 1998 season was postponed to the 1999 season.

Senegal: The prototype of a destoner was developed and is currently undergoing further tests at URPATA-Sahel. Preliminary results show it has a cleaning efficiency of 97%. A dehuller with locally fabricated aluminum disks and a grain-processing rate of 4 kg per minute is being tested at the private food processing unit "La Vivrière". Additional tests will be conducted to determine the presence of aluminum particles in the grains processed by the machine. Finally, the Senegal team held five meetings during which the partners' priorities and constraints were identified.

Integrated management of millet pests (B Ouendeba)

The annual meeting for P6 project was held March 8-11 1999 in Lomé, Togo. All P6 member countries (Benin, Burkina Faso, Gambia, Mali, Nigeria, Senegal and Togo) attended the meeting, as well as other organizations such as the local extension service (Vulgarisation Agricole), the International Fund for Agricultural Development (IFAD), farmers organizations, and a representative of ICRISAT.

Benin: The R3 activities indicated that the addition of mineral fertilizers to organic fertilizers and the treatment of plants with neem tree oil improve yields. They also indicated that the addition of manure reduces damage by the head miner. In addition, researchers noted that planting density affects millet yields.

Gambia: Data on the millet producing areas and detailed description of millet production constraints in these zones were updated. Experiments showed that botanical extracts (neem oil and tobacco "al jaato") have no effect on *Psalydolytta fusca* whereas the removal of senescence leaves reduced infestation. Several meetings with farmers were held, and on-farm visits gave researchers the opportunity to sensitize 25 to 30 farmers on the advantages of the IPM technique.

Mali: A survey of the farming system showed that water, fertilization, insects, diseases and *Striga* were the main constraints to production. Data on the bioecology of four insects was collected. Three main diseases were identified. A new formulation of pesticide combining henna with neem tree oil was found to be more effective against diseases than pure neem tree oil. Trials were conducted to determine whether the combination of seed treatment with Apron Plus and the use of resistant varieties had any effect. A farmers' survey revealed that 31% of respondents find the farmers' method difficult, 79% find the IPM approach difficult, 12% find the IPM to be of low cost, 90% find that IPM has no negative effect on the environment, but only 21% would choose the IPM method if they had the choice.

Nigeria: Soil fertility profiles of the trials sites were determined. The severity of infestation and the incidence of the stem borer were determined. Farmers accepted to incorporate improved varieties and seed treatment in the IPM package, but rejected residue management because they are used as fencing material and animal feed. On-farm experiments conducted with farmers led to the determination of the incidence of the stem borer, and of the incidence and severity of downy mildew on several millet varieties.

Senegal: The team conducted several surveys and agronomic trials with farmers' participation, which help to detail the permanent diagnostic and to update the constraints to production in millet producing areas. In addition, two new villages were included in an outreach program where information is provided to villagers. A basic technological package was identified and an IPM manual written.

Togo: The diagnostic survey showed that in all fields, 15% to 20% of the plants are attacked by Striga, and 15% to 45% by mildew. One major constraint was the lack of agricultural credit. Soils in the millet producing areas are very eroded and very poor.

Variety selection and seed multiplication with farmers' participation (B Ouendeba)

Held March 15-18 in Lomé, Togo, the P7 annual meeting was attended by researchers from Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Mauritania, Niger, and Nigeria. The host country (Togo) was present as an observer. Representatives of ICRISAT, the Institut français de recherche scientifique pour le développement en coopération (ORSTOM), and the West and Central African Sorghum Research Network (WCASRN) were also present.

Burkina Faso: Farmers' variety selection criteria – thickness and length of panicles, lack of insects and diseases, large grains, and variety earliness among others – were determined. Through surveys, researchers realized that farmers knew that characteristics of various crops and grains are hereditary. They also perceive a relationship between these characteristics and the environment. The research team also collected eight ecotypes, made 125 crosses, evaluated 10 hybrids, multiplied five varieties and trained 36 farmers and 20 extension agents.

Cameroon: Tests conducted on 11 hybrids and nine varieties led to the identification of the four best hybrids. Several varieties were multiplied on-station and on-farm, but quantities produced remain insufficient. Farmers conducted all the trials and received training on proper seed production techniques. A local agricultural extension project (Projet national de vulgarisation agricole) collaborated with IRAD, which is Cameroon's national agricultural research system (NARS), to establish a monthly workshop where improved technologies were discussed (Atelier mensuel de revue de technologie). Partnership agreements were established between IRAD and local NGOs.

Côte d'Ivoire: Five varieties were multiplied on station.

Niger: Surveys were conducted in the sahelian and the sudanian zones to identify the following farmers' varietal selection criteria for each production zone: crop cycle, length and diameter of the panicle, and panicle compactness. Nineteen farmers were chosen to conduct the on-farm experiments. World Vision International, Projet Agro-Sylvo-Pastoral (PASP), Peace Corps, and the national agricultural extension services are the partners. A memorandum of understanding was written with input from the different partners. The following activities also took place: collection of 15 samples from farmers fields, evaluation of 15 topcross hybrids and of 10 experimental hybrids from ICRISAT, selection of 130 lines among the varieties evaluated, multiplication of eight varieties and training of 11 technicians and 28 farmers.

Nigeria: Farmers' variety selection criteria were determined to be: earliness, yield, panicle compactness and length. More than eight t of millet seed were produced on-station and on-farm. Potential partners contacted are National Seed Service (NSS), Sasakawa Global 2000 (SG 2000), and Premier Seed Company. Other activities include the development of 30 male sterile lines, 12 showing great potential, the development of on-farm and on-station seed multiplication techniques, and the training of six farmers and 10 extension agents.

Mauritania: Yields of several varieties of millet were compared during on-farm trials conducted on three sites and entirely managed by farmers. The results of three regional trials conducted showed promising varieties and hybrids. Seed multiplication was conducted on 7 sites with the participation of 64 farmers. More than two t of seeds from three different varieties were

produced. Foundation seed of four varieties was produced under irrigation and on station. Seed transport and maintenance material were bought and distributed to the farmers before harvest. Forty-four farmers and two technicians were trained on seed production techniques (training was held in national languages), and posters for seed production and for the conduct and implementation of on-farm trials were published.

Chad: Five meetings with the four identified partners took place. Foundation seeds were multiplied on three sites, but unfortunately, all production was destroyed by blister beetles. A total of 200 kg seed was produced with the participation of development partners. Twenty-five farmers and ten technicians received seed multiplication training.

External review of ROCAFREMI completed (K Anand Kumar)

The West and Central African Millet Research Network (WCAMRN) is the principal vehicle through which several of our varieties and hybrid parents are being transferred to NARS. ICRISAT is the principal institute generating strategic research information and basic breeding materials and end products through our global research projects and provide extensive technical back-up. ICRISAT facilitated and participated in the External Review organized by the principal donor – Swiss development Cooperation (SDC). Major visits and meetings were in September / October 1999. We interacted with the panel members and provided background information and documents on ICRISAT's contributions to the evolution and delivery of outputs by the network. ICRISAT also participated in the restitution meeting held in Cotonou, Bénin. Only outcomes directly relevant to ICRISAT are highlighted.

The external evaluation panel considered ROCAFREMI activities to be generally satisfactory and recommended to the SDC that funding be continued for a transitory phase (May 2000 through April 2001) and SDC continue to support the network from May 2001 with co-financing from a new donor. The panel recommended that CORAF (the regional forum of NARS) should be informed of the financial needs of the network and solicit support from new donors. The review team acknowledged the excellent relationship that exists between ICRISAT and the network and the support that ICRISAT provides for the realization of network activities. The implementation of some projects activities has been found to be inadequate, especially the methodologies were questionable. ICRISAT was asked to provide guidance to define the terms of reference for an independent scientific council. The panel recommend that the IPM project be combined with the Production Systems project under an 'Integrated production systems' project. To ensure quality science, scientists have to be trained in participatory research methodologies. It was noted that other than several early varieties, no other technologies have been diffused in the member countries. Even varietal adoption is limited. Availability of seed of improved varieties is limited and there appears to be no clear strategy for multiplication and diffusion of varieties other than through public sector projects which often do not function effectively. The panel recommended constraint analysis for impact and initiation of a seed certification system with the Institut du Sahel. The panel recommended that a duplicate pearl millet germplasm collection should be made available at ICRISAT-Niger.

Objective 4.6j: Studies on sorghum ergot disease

Sorghum ergot collaborative research (R Bandyopadhyay)

Sorghum ergot disease, initially restricted to Asia and Africa, was recently found in the Americas and Australia. Three sorghum ergot species have been reported: *Claviceps sorghi* in India, *C. sorghicola* only in Japan and *C. africana* in all ergot-positive countries. The objective of our research was to evaluate the relatedness of ergot strains from the Americas, Australia, and India. RAPD banding patterns of 22 ergot strains from North and South America, India and Australia were evaluated with nearly 100 primers. Nucleotide sequences of ITS1 and part of 5.8S rDNA regions of representative American, Indian and Australian strains were compared with *C. sorghicola* and *C. sorghi*. All ergot strains evaluated from the United States, Mexico, Puerto Rico, Bolivia, Australia and India were *Claviceps africana*, demonstrating that *C. africana* is present in India. We suggest that *C. africana* now predominates over the previously endemic *C. sorghi* in India. *Claviceps africana*, *C. sorghi* and *C. sorghicola* are confirmed as different species by virtue of variations in nucleotide sequences of ITS1, 5.8S rDNA and ITS2 regions. RAPD banding pattern demonstrated that strains from the Americas belonged to one group (West) whereas those from Australia and India belonged to another group (East). We suggest that *C. africana* strains in North and South America and Australia possibly originated from different clones; the Australian one from India and the American one from Africa. However, more research is required to prove this hypothesis. This research was conducted in collaboration with the Institute of Microbiology of the Czech Academy of Sciences and Texas A&M University.

Microcyclic sporulation in *Claviceps africana* (R Bandyopadhyay)

The ergot fungus produces honeydew in which macroconidia of the fungus is released. Under humid conditions, macroconidia in the honeydew matrix germinate to produce secondary conidia outside the honeydew surface. It was believed that macroconidia and secondary conidia, once disseminated from honeydew, have to deposit on stigma to infect flowers. However, it has been observed that panicles bagged prior to flowering during selfing and crossing operations are often infected by the ergot pathogen although the stigmas were not exposed to the inoculum before covering the panicle with the bag. The objective of this study was to determine if macroconidia deposited on leaf surface could produce secondary conidia that in turn can infect uninoculated panicles. In the first experiment, formation of secondary conidia on leaf and glume surfaces was studied in the greenhouse by spraying these surfaces with a suspension of macroconidia. Secondary conidia formation on the sprayed surfaces was monitored under a microscope daily for 5 days. In the second experiment, panicles were covered with paper bags when they began to emerge from the boot. Leaves of these plants were sprayed with a suspension of macroconidia and the plants incubated in a humid chamber. Panicles were uncovered 24 h after spraying and the stigma were observed under a microscope 4 days later for the presence of secondary conidia. Panicles were maintained under ergot favorable conditions. We found that under humid and wet conditions, macroconidia can germinate to produce secondary conidia on leaf and glume surfaces as well. These secondary conidia can germinate and produce tertiary conidia within 24 hours if they do not encounter any stigma. At least four such cycles of repetitive sporulation have been observed. Conidia from any of these repetitive cycles can cause infection. In the second experiment, we found germinated secondary conidia penetrating stigma of flowers of plants

sprayed with macroconidia suspension only on the foliage. Nearly 5% flowers of such plants were infected. Similarly, flowers with unexposed stigma at the time of inoculation were also infected by secondary conidia. These observations suggest that the sorghum ergot pathogen has great versatility to repetitively produce wind dessiminable spores to offset the handicap posed to it by the short window of infection (stigma emergence to fertilization). This also partially explains the reasons for the recent ergot epidemic and spread in the Americas. The results also implies that in an ergot favorable environment, a thorough spray coverage with a fungicide is necessary to kill ergot spores on plant surfaces for obtaining good control of the disease. This research was conducted in collaboration with Texas A&M University.

Improved ergot resistance screening technique and sources of resistance to ergot (R Bandyopadhyay)

In the past, qualitative and quantitative ergot evaluation methods and artificial inoculation techniques have been used to screen germplasm for resistance to ergot in both the field and the greenhouse. However, quantitative assessment requires counting the number of infected spikelets, and visual ratings have been traditionally based on an estimate of the percent infected spikelets. Quantitative assessment is costly and time consuming, while the percent visual rating can be misleading. The objectives of the study were to improve the ergot screening technique and identify sources of resistance. Panicles of nearly 50 accessions were spray-inoculated with a honeydew suspension at 25% flowering stage. Ergot incidence and severity was recorded at hard dough stage. Sources of resistance to ergot were tested in Puerto Rico. These accessions were from ICRISAT and elsewhere and had been previously tested in the highlands of eastern Africa. A dual ranking system was developed that takes into account both percent incidence and a disease severity rating of each accession. This resistance evaluation is rapid, simple and efficient for routine screening of large numbers of breeding lines and germplasm over several locations and years in replicated trials. The accession IS 8525 (E62) from Uganda showed the greatest potential for use in a host-plant resistance strategy to manage the disease. It had low ergot, and when crossed to A_3 cytoplasm source, it showed low level of ergot in a sterile background. This line is being widely distributed for use in several public and private breeding programs. This research was conducted in collaboration with Texas A&M University and the United States Department of Agriculture.

Differences in ergot susceptibility among commonly used sorghum seed parental lines (R Bandyopadhyay)

The biggest threat of sorghum ergot disease is to male sterile A-lines used for hybrid seed production. Detecting the differences in ergot susceptibility between lines and understanding the reasons for these differences will allow the development of more ergot tolerant sorghum germplasm for the future. The objective of this research was to characterize the relative ergot susceptibility of a set of publicly available elite A/B lines, and R-lines. We evaluated 12 commonly used A/B line pairs and 12 popular R-lines for ergot reaction at three locations in Texas (College Station, Corpus Christi and Lubbock) and in Puerto Rico in several sowing dates. In addition, several sources of resistance reported in the literature were also evaluated. None of the A/B and R-lines was free from ergot though various degrees of susceptibility were observed. In general, A-lines were most susceptible, as expected, and R-lines were more susceptible than the B-lines with respect to ergot incidence and severity. Within A-lines, ATx 631 was most susceptible to ergot, whereas ATx 2752 and AOK 11 were less susceptible. The newer releases

of A/B-lines, such as A/B Tx631, A/B Tx635, and A/B Tx626 were significantly more susceptible than older releases such as A/B Tx2752 and A/B Tx378. R-lines varied considerably in their vulnerability to ergot. In general, R-lines with good pollen shed and seed set tended to be less susceptible to ergot. This was, however, not the case for RTx 2737, one of the more popular R-lines currently used in the sorghum industry. RTx 2737 is an excellent pollen-shedder, but is almost as susceptible as the A-lines. Further observations showed that stigma emerge from flowers of RTx2737 at least 2-3 days before anthesis, thus providing a three-day period in which the ergot pathogen may have an advantage of infection. Differences in ergot susceptibility among commonly used sorghum seed parental lines can be exploited for further use. This research was conducted in collaboration with Texas A&M University.

Vulnerability of commonly used sorghum seed parents to ergot (R Bandyopadhyay)

Vulnerability of commonly used sorghum hybrids and seed parents to ergot in the U.S. is not known since ergot is a new disease in North America and South America. There is a need to quantify the precise level of ergot susceptibility in hybrids in order to deploy them effectively. The objective of this research was to determine if differences in ergot susceptibility exist between hybrids. Commercial sorghum hybrids (20 to 116, depending upon location) were planted in 1997 and 1998 in Puerto Rico, Guanajuato, Mexico and three locations in Texas, and were evaluated for reaction to ergot, caused by *Claviceps africana*. At some locations, flowering panicles were inoculated with a spore suspension of the pathogen, while at other locations, plants were not inoculated. In the fall 1997 test in Weslaco, TX, which was not inoculated, there were distinct differences in the reaction of hybrids to ergot. The amount of infection of heads among hybrids ranged from 11% to 75%. The high level of disease was correlated with periods of temperatures below 12 C that occurred 2-3 weeks before flowering of the hybrids. Severe ergot occurred in Weslaco during the fall of 1997. In contrast, the same hybrids had little (1-5 florets infected head^{-1}) or no ergot in non-inoculated trials planted in the spring of 1998 in Weslaco and Corpus Christi, TX, and fall of 1998 in Isabela, PR, and in an inoculated, spring, 1998 trial in College Station, TX. In the latter trials, there were high temperatures at the time of flowering, or no rain. Nevertheless, there were also a few commercial hybrids that were susceptible even at less ergot-favorable weather conditions at College Station. Ergot among hybrids in an inoculated trial in Celaya, Guanajuato, Mexico ranged from 11 to >125 infected flowers per head. The severe ergot was correlated with cool temperatures prior to and during flowering. In an inoculated trial in Weslaco during the fall of 1998, ergot severity among hybrids ranged from 1-5 infected florets/head, to 76-100% of the head infected. The severe ergot during this trial was correlated with frequent rains during the flowering period of the hybrids. There were a few hybrids that had a low severity of ergot over several locations where ergot pressure was high. Differences among hybrids indicate the need to evaluate a hybrid in as many environments as possible to identify environment in which ergot may be a problem on hybrids and to identify hybrids that are more susceptible to ergot. This study shows that ergot can be a problem in some hybrids planted in several locations that can experience weather that is favorable to ergot development. This research was conducted in collaboration with Texas A&M University.

Objective 4.6k: Cytoplasmic male-sterility in pearl millet

Analysis of needs and opportunities for CMS diversification (K N Rai and D J Andrews)

Since the first review of Anand Kumar and D J Adrews in 1984, a large body of information has been generated on this subject both at ICRISAT and at the University of Nebraska, Lincoln (UNL). The objective of this review was to put this information together. The research information for this review was to come from published and unpublished documents as well as from the undocumented sources. Almost all of the field results published in the scientific literature and those available in informal documents produced at ICRISAT were put together. It appeared that most of the field results from UNL were undocumented and the nature of research conducted there during sabbatical leave of KN Rai left little time for him and the UNL staff to undertake any documentation of the data. Also, the priority focus was on conducting and writing the results of specific experiments, rather than getting involved in the time-consuming review exercise. In 1999 this review was kept on hold due to other commitments. This will be taken up later and completed by 2001

Grain yield and thermo-sensitivity of fertility restoration of pearl millet hybrids based on A_1 and A_4 CMS systems (K N Rai and D J Andrews)

Observations in mid-west of the United States showed that when temperatures fell below 50°F during flowering, there was substantial decline in fertility restoration of hybrids based on A_1 CMS system. Thus, while considering A_4 CMS system as an alternative option, interest arose to examine CMS effect on thermo-sensitivity of fertility restoration and grain yield of their hybrids. Three hybrids made from crosses of $16R_1R_4$ on $413A_1$, $413A_4$ and 413B were evaluated for fertility restoration at four temperature regimes: 65/50,75/50, 85/50 and 95/80°F with 12 h day/12 h night exposure in growth chambers. Twenty-seven hybrids, representing nine genotypes x three cytoplasms (A_1, A_4 and fertile) were yield-tested at Lincoln, USA; and 18 hybrids, representing nine genotypes x two cytoplasms (A_1 and A_4) at Patancheru, India. Both temperature and cytoplasm effects on selfed seedset (SSS) and pollen viability were highly significant. Highest proportion of viable pollen grains (95%) and SSS (71-74%) were observed at 85/50 and 75/50 °F temperature regimes, and lowest pollen viability (47%) and SSS(5%) at 65/50 °F regime. The hybrids made on $413A_4$ and 413B (fertile) cytoplasm had similar pollen viability (87-92%) and SSS (54-63%), but the hybrid on $413A_1$ cytoplasm had significantly less viable pollen grains (67%) and reduced SSS (34%). Cytoplasmic effect on grain yield was significant only at Patancheru, although the mean grain yield of hybrids on A_1 was only 4% greater than that of the A_4-hybrids. Genotype x cytoplasm interaction was significant both at Lincoln and Patancheru. It was also observed that higher-yielding genotype x cytoplasm combinations often had lower SSS and vice-versa. Therefore, it is important in such studies to use hybrids of those common restorers that give comparable SSS in all cytoplasmic backgrounds. CMS effect on thermo-sensitivity of fertility restoration and grain yield of hybrids needs to be further investigated by using common restorers that have comparable fertility in all the CMS sources under study. Such dual restorers of A_1 and A_4 have now been identified at ICRISAT-Patancheru.

Inheritance of A_4 CMS system in pearl millet (K N Rai/D J Andrews)

Most of the A_1-system restorers, accumulated in all breeding programs and selected for agronomic eliteness, good combining ability, and high DM resistance, will become obsolete on A_4-system A-lines. Thus, grain hybrid breeding on A_4-system A-lines would require conversion of these lines into A_4-restorers. A knowledge of genetics of this CMS system will have a direct bearing on the planning and efficiency of backcross breeding to achieve this objective. Two F_2 and two backcross populations derived from a cross between a restorer line $16R_1R_4$ and seed parents $413A_4/413B$ were scored for plants that shed pollen (F) and those that did not shed pollen (S). Segregation for F and S plants in both F_2 populations gave a good χ^2 fit to a 3F:1S ratio ($p>0.25$), suggesting that a single dominant gene from $16R_1R_4$ is responsible for male fertility restoration and its recessive allele for male sterility. A good χ^2 fit to a 1F:1S ratio ($p>0.25$) in both BC_1 populations confirmed the above hypothesis. Whether the F_1 based on A-line or B-line was involved as a pollen parent in producing the F_2 and the BC_1 population, it did not make, as expected, any difference to the segregation ratios. Results of this study confirm an earlier finding of single gene control of male fertility restoration of the A_4 CMS system (Rai et al., ISMN 1996:37:76-77). It is interesting that in both studies S 10B was involved in the parentage of restorer lines. The A_4 fertility restoration ability of S 10B under a single dominant gene control, hence this line can be used as an excellent donor of A_4 restorer gene for backcross breeding of diverse restorer lines.

Objective 4.6i: SADC/ICRISAT Groundnut Project

Develop and evaluate improved groundnut cultivars and agronomic management to improve production in southern Africa (Pala Subrahmanyam)

Rosette is the most destructive disease of groundnut in the southern and eastern Africa region. Yield losses due to rosette approach 100% whenever the disease strikes in epidemic proportions. ICRISAT-Lilongwe places major emphasis on the development of high-yielding cultivars, especially short-duration spanish types with resistance to rosette disease. Four short-duration rosette-resistant spanish types (ICGV-SM 93535, ICGV-SM 93561, ICG 12988, and ICG 12991) were evaluated at 23 locations in 1997/98 and at 32 locations in 1998/99 with JL 24 as susceptible control. All trials were managed by the participating farmers. The genotypes were sown in a randomized complete block design with four replications. Each plot consisted of four 6-m long rows spaced 60 cm apart. The two middle rows were used for far data collection and yield assessment. The incidence of groundnut rosette was negligible at all locations during the 1997/98 and 1998/99 crop seasons and was not possible to separate genotypic differences in terms of reaction to the disease. However, this provided an excellent opportunity to assess their yield potential in the absence of the disease. The overall yield performance of the genotypes across sites was good. In almost all trials, ICGs 12991 and 12988 outyielded other genotypes. ICGs 12988 and 12991 are the land races from Madhya Pradesh, India, and are high-yielding, short-duration rosette-resistant lines and have excellent potential for release. Farmer participatory on-farm evaluation of these lines will continue at more locations in Malawi.

Incidence and damage due to arthropod pests on groundnut varieties in on-farm trials in Malawi, Zambia, and Zimbabwe (E M Minja)

Arthropod pests are one of the major biotic constraints to groundnut production in southern and eastern Africa. Several improved high yielding groundnut varieties have already been released by national programs for cultivation by farmers in the region. Additional medium- and short-duration genotypes that are resistant to diseases (rosette, leaf spots) are at various stages of on-farm evaluation. The improved genotypes have not been evaluated for their susceptibility to arthropod infestation. The present studies were initiated to provide information on the susceptibility of improved genotypes to pest infestations compared to local genotypes. Farmers were advised by research and extension personnel to prepare their fields. Seed of groundnut varieties for on-farm testing was supplied to farmers by the project through the respective national program coordinator. Arthropod pests were monitored regularly during 1997/98 and 1998/99 crop seasons.

The distribution of pests on groundnut in Malawi, Zambia, and Zimbabwe was mainly influenced by rainfall and soil types. Central Malawi, eastern Zambia, and Zone II in Zimbabwe (mean annual rainfall 700-900 mm) had lower pest incidence and crop damage compared to southern Zambia and Zone III in Zimbabwe (mean annual rainfall 400-600 mm). Heavy soils were not preferred by some pests including the groundnut hopper, *Hilda patruelis*. This pest was only found in well drained light soils.

The key arthropod pests were aphids (vector for rosette viruses), termites, groundnut hopper, foliage sucking bugs, thrips, white grubs, wireworms, false wire-worms, and millipedes. Soil pests appeared to be a major constraint to groundnut production, causing 3-10% plant loss (*Hilda*, termites) and 5-25% pod loss (termites, *Hilda*, grubs, worms, milllipedes) depending on location and season. There were no consistent trends in damage levels on groundnut genotypes grown at different locations in each country. Each national program is evaluating different groundnut genotypes based on demand by farmers and performance in previous seasons. Several pest groups were confirmed common and widespread in the region. Information on pest species, their biology, ecology, natural enemies, and control strategies on groundnut is scantly available in the region. There is need to fill the information gap on groundnut pests and their control. Pest and natural enemy species confirmation, and selection for host plant resistance for such pests as aphids, termites and *Hilda* should be considered of high priority in the immediate future.

Objective 4.6m: Provide seed and crop management technologies to farmers through participatory on-farm research to increase groundnut production

ICRISAT-PLAN International Partnership Project on Groundnut in Malawi (Pala Subrahmanyam)

Training of field technicians and empowering the farmers with improved technologies and access to seed of improved varieties are vital to stable and sustainable groundnut production in Malawi. ICRISAT in partnership with PLAN International organized a three-day training course on groundnut production technologies at Kasungu, Malawi. The course was designed to address the

problem-solving issues related to increased groundnut production in Malawi. Some 1,000 households were provided with seed (5 kg) of an improved groundnut variety CG 7 under an agreement that they will return 10 kg after harvesting the crop. This seed will then be distributed to two more farmers (5 kg each) in the following season. Farmers were also provided with information on cultural practices for maximizing the returns from improved variety. In 1998/99, ICRISAT-PLAN organized a total of 30 field days. A total of 2,329 farmers including 1,417 women farmers participated in these field days. Over 60 participants including 20 women attended the training course. These participants are based in the communities and are expected to disseminate the skills, which they have learnt during the training course, to farmers in the community. About 99.8% of the farmers who received the seed have planted the crop. A majority of them harvested very good yields. They are expected to pay back the loan to the project, save some of the produce for planting in the following season in larger areas, use a portion of it as food, and sell the remaining to other farmers in the community preferably as seed. The 1998/99 crop season activities in Lilongwe and Kasungu units will continue in 1999/2000 and 2000/01 crop seasons.

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About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.

About CGIAR

The mission of the Consultative Group on International Agricultural Research (CGIAR) is to contribute to food security and poverty eradication in developing countries through research, partnership, capacity building, and policy support. The CGIAR promotes sustainable agricultural development based on the environmentally sound management of natural resources.

The CGIAR, established in 1971, is an informal association of fifty-eight public and private sector members that supports a network of sixteen international agricultural research centers. The CGIAR's budget for 1998 was fully funded at US $ 340 million.

The World Bank, the Food and Agricultural Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP) are cosponsors of the CGIAR.

Sorghum

Finger millet

Pearl millet

Groundnut

Pigeonpea

Chickpea

ICRISAT

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CGIAR

Consultative Group on International Agricultural Research

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