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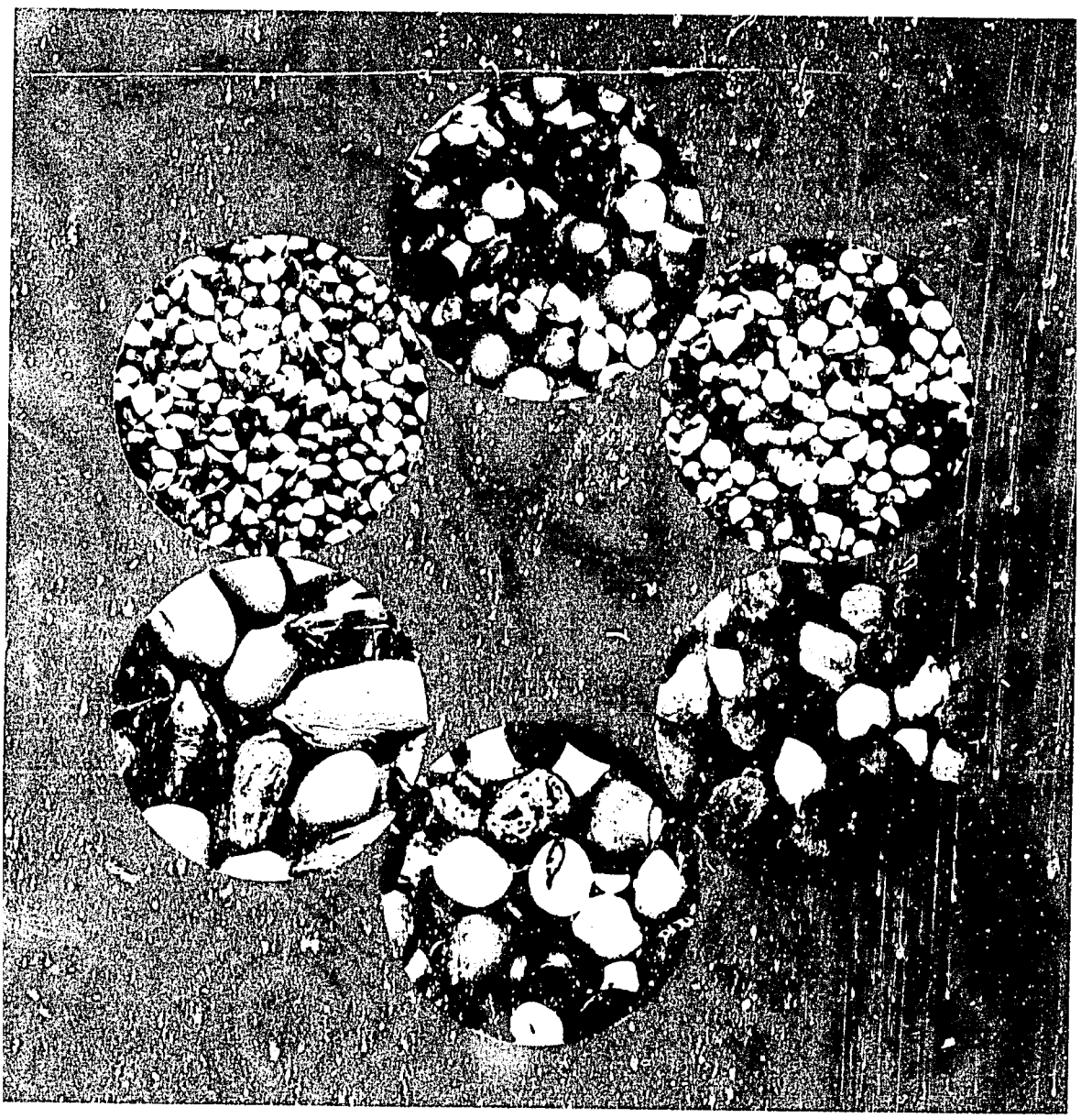
Collaboration on Genetic Resources

International Crops Research Institute for the Semi-Arid Tropics



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Cover: The crops on which ICRISAT and NBPGR (ICAR) work together: clockwise (from top): sorghum, pearl millet, chickpea, pigeonpea, groundnut, and minor millets.

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Collaboration on Genetic Resources

Summary Proceedings of a Workshop on Germplasm Exploration and Evaluation in India, 14-15 November 1988, ICRISAT Center, India

Cosponsored by

ICAR	National Bureau of Plant Genetic Resources (NBPGR) of the Indian Council of Agricultural Research (ICAR)
	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India

1989

Purpose and Objectives of the Workshop

India is rich in plant genetic resources. It is the primary center of origin for pigeonpea and a secondary or tertiary center of diversity for all other ICRISAT mandate crops. The Genetic Resources Unit (GRU) of ICRISAT and the National Bureau of Plant Genetic Resources (NBPGR) of ICAR are collaborating successfully in collection in priority areas and in multilocational evaluation of germplasm. These concerted efforts ensure the conservation of the invaluable diversity of our germplasm for present and future utilization in crop improvement. So far, 11 expeditions have been launched which helped us acquire 2202 samples of ICRISAT crops. Several thousand accessions were also evaluated jointly. The collection program has helped increase the number and diversity of germplasm in the world collections maintained at ICRISAT. By bringing together scientists who have actively participated in germplasm collection, evaluation, and utilization, this workshop aims to:

- review the progress made so far,
- promote further collaboration,
- determine the use and impact of germplasm in national crop improvement programs, and
- study and recommend future activities.

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Session I: Inauguration

Welcome Address

M. Goon

Acting Director General, ICRISAT, Patancheru, Andhra Pradesh

It is my rare pleasure to welcome all of you to ICRISAT Center as well as to the ICRISAT/NBPGR (ICAR) workshop on Collaborative Germplasm Exploration and Evaluation in India. I am particularly pleased to see Dr R.S. Paroda, Deputy Director General, Crop Sciences, ICAR who will be offering the keynote address at the Workshop. As former director of the National Bureau of Plant Genetic Resources (NBPGR) and as the present Deputy Director General of Crop Sciences, he is certainly the right choice to offer the keynote address. I am equally happy to see several distinguished scientists and collaborators.

As I glance through the program, I see that it covers all the major activities of genetic resources and I sincerely hope that you will be able to achieve the stated objectives. With such a genuine collaborative effort, it should not be too difficult to achieve your goals.

As you all know. ICRISAT places much importance on the collection, conservation, evaluation, and utilization of the germplasm of its mandate crops. That is why the Governing Board of ICRISAT has recognized the role of ICRISAT as a "world repository for the genetic resources of these crops". These activities are carried out in close collaboration with the IBPGR and national programs like NBPGR. It is therefore appropriate to express our heartfelt appreciation to these and several other international, regional, and national organizations that cooperate and assist us to achieve our present and future goals.

The 10-year Plan of ICRISAT states that the international centers are in a unique position not only to enrich their own programs but also to make invaluable genetic material available to scientists all over the world. To meet this objective, ICRISAT established the Genetic Resources Program in January 1979. The Unit has made remarkable progress in the collection, evaluation, documentation, and conservation of the vanishing germplasm of ICRISAT mandate crops. The ultimate purpose of such activities is to improve the quantity and quality of crops that farmers grow in SAT. That is where your united and dedicated efforts should continue. In this regard, the support and cooperation of NBPGR and other organizations and universities in India is highly appreciated. Therefore, not only do I wish to welcome you to this workshop, I also wish you a comfortable, successful, and fruitful stay here at ICRISAT Center.

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Inaugural Address

J.M.J. de Wet

Program Director, Cereals, ICRISAT, Patancheru, Andhra Pradesh

It is indeed a pleasure for me to inaugurate this workshop on "Collaborative Germplasm Exploration and Evaluation in India".

I am pleased to note the stated objectives: first, to review the progress made; second, to promote collaboration between ICRISAT and NBPGR (ICAR); third, to determine the use and impact of germplasm in national programs, and I would like to add 'the use of Indian germplasm in the crop improvement programs of ICRISAT'; and fourth, to recommend a plan of action for future exploration and evaluation.

Indian germplasm is of great significance not only to India but to plant breeding efforts across the world. The various kinds of genetic resources are:

1. current open-pollinated cultivars,
2. parents of current hybrid cultivars,
3. obsolete breeding lines,
4. landraces,
5. genetic stocks,
6. wild and weedy taxa of domestic species, and
7. related wild species and genera with possible future value.

During the 10-15 millennia since the origin of agriculture, man across the agricultural regions of the world domesticated and chan, ed numerous plant and animal species to fit his needs. This has created a wealth of genetic diversity that forms the basis of modern crop improvement programs.

Variation in landraces is created through natural hybridization or mutation and selection for adaptation to a range of agro-ecosystems. Landraces are in genetic balance with their environment. This balanced genetic structure is disrupted by modern plant breeding practices. Intensive plant breeding leads to a narrowing of the genetic base of a cultivar, and that of the domesticated species, since the established landrace is replaced by narrowly adapted, but more productive cultivars. It is probable that complex genetic systems determine adaptation and productivity, and that these two components of survival operate in the same system.

The Indian subcontinent is possibly the most diverse region in the world in respect to agro-ecosystems, species of plants cultivated, and possibly, the diversity of pests and diseases that attack these crops. Several crops were domesticated from indigenous species, and India therefore constitutes a major center of diversity for these crops. Agriculture has been practiced in India for at least 5 millennia providing ample time for genetic diversification and domestication of plant species. Introduced crops such as sorghum and millet have been grown in India for several thousand years, allowing

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for the development of local landraces genetically distinct from those in their native Africa.

Introduced crops such as maize and groundnut, which entered India during the 16th century, preserve genetic variation in local landraces that have become largely lost in their native New World.

The major cereals and legumes grown under rainfed agriculture in India–sorghum, pearl millet, pigeonpea, chickpea, and groundnut–are the crops that ICRISAT has a mandate to improve for cultivation across the semi-arid tropics of the world. In addition, our Genetic Resources Unit is responsible for the collection and conservation of six minor millets, all of which are important crops in India.

The value of genetic resources, and the need for their conservation is well recognized by scientists as well as politicians. Factors not always fully understood are:

- what needs to be collected,
- what is available in existing collections,
- where to collect material needed to complete gaps in existing collections, and
- how available genetic resources can best be utilized in crop improvement programs.

Use of available genetic resources in crop improvement is the most neglected part of germplasm conservation. Germplasm resources are not going to be used if the information needed by breeders cannot be supplied by germplasm banks. Germplasm collections need to be classified and useful traits identified, to facilitate their use in crop improvement programs. Collections need to be studied, and this demands cooperation of germplasm botanists with pathologists, entomologists, physiologists, breeders, and molecular biologists. Genetic resources banks cannot function as isolated research units. If divorced from crop improvement programs, genetic resources become a dead asset.

I am pleased to note that there is continuing interaction and cooperation between germplasm scientists and crop improvement scientists in ICRISAT in the areas of germplasm evaluation and screening. However, more collaborative effort is needed in the classification, identification, and promotion of useful traits for use in crop improvement.

I suggest that your discussions address strategic issues of conservation, use, and cooperation.

It is a pleasure for me to inaugurate this workshop. I wish you successful and fruitful deliberations.

Keynote Address: Collaborative Efforts on Plant Genetic Resources by ICRISAT and ICAR

R.S. Paroda

Deputy Director General (Crop Sciences), ICAR, Krishi Bhavan, New Delhi

Success in plant breeding depends largely on the extent of genetic variability available to a breeder. Therefore collection, evaluation, utilization, and conservation of genetic resources assume considerable significance, especially in view of the rapid environmental degradation and exploitation of the available genetic wealth all over the world. Considerable efforts are being made worldwide to conserve the genetic resources of important crop plants. The role played by the CGIAR system in this regard is indeed commendable. Enormous genetic wealth has been collected and preserved in the gene banks of International Agricultural Research Centers (IARC) and is available today for use in the national programs. The success of these efforts is largely dependent on the effectiveness of linkages between IARCs and the national programs.

India is one of the eight important gene centres of the world. Considerable variability exists for a large number of crops including the five mandate crops of ICRISAT i.e., sorghum, pearl millet, chickpea, pigeonpea, and groundnut. More than 96 000 accessions of these crops have been collected and conserved by ICRISAT, most of which are evaluated but yet to be utilized for crop improvement programs all over India. Also, gaps for collecting additional variability must be identified and explored. A systematic effort for joint collection, evaluation, and utilization of the germplasm was therefore considered necessary by both ICRISAT and NBPGR/ICAR. With this in view, the first joint NBPGR(ICAR)/ICRISAT committee meeting on genetic resources was held during 19/20 Dec 1985 under the chairmanship of Dr J.S. Kanwar, Director of Research, ICRISAT. It was considered desirable to accelerate joint efforts in germplasm collection, evaluation, and cataloguing of genetic resources and to exchange information and material for mutual benefit. Accordingly, a 5-year collaborative program on joint exploration, collection, and evaluation activities was finalized. Priority areas for exploration were identified and modalities for operating/planning survey programs worked out.

A strategy was evolved for systematic multilocational evaluation at some selected locations representing different agroclimatic conditions involving the regional stations of both NBPGR and ICRISAT. Training needs of scientists and technicians were identified and areas of cooperation relating to quarantine activities were defined. The philosophy behind this effort was to evolve a system of effective linkages and to

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build a partnership to share expertise as well as genetic wealth to achieve national and international benefits.

A brief account of some of the achievements made in this direction since 1986 is given here. Suggestions have also been made to strengthen this collaboration.

Exploration, Introduction, and Evaluation Activities

Thirteen explorations during 1986-88 resulted in 2000 accessions of sorghum, pearl millet, chickpea, pigeonpea, groundnut, and minor millets with emphasis on native variability and wild species from tribal pockets and agroclimatic zones in the northeast peninsular region, northwestern and northern plains, and the northwestern Himalayas. In addition, through exchange activities, over 3000 accessions have been introduced: 1130 accessions of pearl millet from Cameroon, Mali, Sudan, UK, USSR, Venezuela; 1246 accessions of sorghum including wild species from Australia, Italy, Kenya, Nigeria, Philippines, Somalia, Sri Lanka, Sudan, Tanzania, Turkey, Uganda, USA, USSR, Zimbabwe; 382 accessions of groundnut from Cameroon, Kenya, Malawi, Mali, Republic of Korea, Tanzania, USA; 210 accessions of chickpea from Australia, Iran, Morocco, Pakistan, Syria, Tanzania, USSR; and 112 accessions of pigeonpea, mainly from Kenya, Malawi, Tanzania, USA, and Zambia. Apart from these, a considerable amount of material was introduced in the case of minor millets: foxtail millet from Korea and USSR, finger millet and related species (*E. indica, E. kigazensis*) from Tanzania, UK, and USSR.

Joint evaluations were carried out at different NBPGR Regional Stations and Agricultural Universities. The photoperiod-sensitive sorghum germplasm (2000 accessions) from ICRISAT were tested at two locations - Hisar (HAU) and NBPGR Regional Station, Trichur. In forage sorghum, 1500 collections were evaluated at four locations Issapur (NBPGR), Hisar (HAU), Jhansi (IGFRI), and Akola (NBPGR) in 1986 and selected accessions again grown in 1987. A number of disease-resistant lines have been identified. During 1987, 4460 germplasm accessions comprising 4105 of Indian origin, 178 from Yemen Arab Republic, and 187 dual-purpose types were grown at Issapur. Promising forage types have been identified.

Similarly, 2000 pearl millet accessions were evaluated at Pune (AICPMIP) and Jodhpur (NBPGR). Promising genotypes have been identified for fodder and grain types. Of the 1996 accessions grown at Issapur during 1987, a number of fodder, grain, and early maturity types have been identified. In pigeonpea, extra-early and early types (479) were evaluated at Issapur, and medium- and late-maturity compact and spreading types (353) at Akola in 1986. Some selected material was grown during 1987 and early types have been identified. Besides, 200 perennial pigeonpea types were grown at Jorhat. In chickpea, 1200 accessions were evaluated at Akola and Issapur. Promising early maturing and bold-seeded types have been identified. In groundnut, 2000 accessions were grown at Jodhpur in 1986. Another 1500 were grown in 1987 at Akola and Jodhpur, comprising 723 erect bunch types, 391 spreading bunch types, and 386 runner bunch types. Promising high-yielding early types have been identified. Selected materials have been grown in multilocational trials at 3 or 4 locations and the data is being compiled.

Conservation in the National Gene Bank

Though more than 25 000 accessions of several millets and legumes are stored in the NBPGR gene bank, about 8000 accessions are ICRISAT mandate crops. These include sorghum (412), pearl millet (125), pigeonpea (2054), chickpea (3101), and groundnut (3000).

I need not emphasize the necessity to continue efforts to achieve our common objectives. The Bureau has been given the global/regional responsibility by IBPGR to hold the base collections of a large number of crops including pigeonpea and other Asiatic pulse crops. The gene bank facilities are being expanded, with more cold-storage modules being made operative soon. Shortly NBPGR will have the capacity to store more than 200 000 seed samples. Further, under the USAID Project on genetic resources, the infrastructural facilities for research and conservation are likely to be strengthened tremendously. Obviously therefore, the scope of our collaborative activities will increase.

Quarantine Activities

As per the memorandum of understanding between ICAR and ICRISAT, the NBPGR (then the Division of Plant Introduction of IARI) has the responsibility for plant quarantine. As NBPGR did not have a station at Hyderabad, this responsibility was initially discharged by the Central Plant Protection Training Institute (CPPTI). The Plant Quarantine Regional Station at Hyderabad became operational in 1986 and started processing germplasm material being exchanged by ICRISAT for quarantine clearance. During 1986 and 1987, this station processed a total of 98 181 germplasm samples which include 72 327 meant for export and 25 854 accessions imported by ICRISAT from various countries.

The imported material of all the mandate crops after laboratory examination and treatment is grown in the post-entry quarantine isolation area (PEQIA) and jointly inspected by the staff of NBPGR and ICRISAT. Groundnut material is grown in insect-proof nethouses for detection of seed-borne viruses and only healthy seedlings are planted in PEQIA. ELISA facilities of the Virology Laboratory of ICRISAT are being used for the detection of seed-borne groundnut viruses. A joint survey by ICRISAT and NBPGR scientists has resulted in the detection of the peanut stripe virus disease in groundnut in India and efforts are being made to eradicate/check this serious disease.

Training Needs

With the cooperation of the Genetic Resources Unit (GRU), ICRISAT, the Bureau has considerably benefitted by having its technical staff trained in the operational handling of gene bank equipment/instruments. Moreover, senior scientists have visited the GRU and further enriched their experience. This aspect, however, needs to be accelerated for information and data management, documentation, reprographic, computerisation, cataloguing facilities, etc.

Future Collaboration

It is evident from the description given above that collaborative efforts between ICRISAT and ICAR/NBPGR will help to strengthen the genetic resources of the five mandate crops. Joint evaluation will enable the national programs to utilize desirable genetic variability for crop improvement programs. Conservation and possible storage of useful genetic variability in the national gene bank would also be useful for immediate gains as well as for posterity. What is required now is to bring out catalogs based on joint evaluation at different locations and to disseminate this information to concerned scientists in the national system. Joint explorations should be planned to explore untapped areas not only within India but also in other countries having rich variability for the five ICRISAT mandate crops. Both ICRISAT and NBPGR could, in collaboration with IBPGR, play a leading role in imparting training in genetic resources to scientists in the developing world. This could be designed as a regular feature. Joint research publications based on collaborative efforts between the two organizations would be desirable. It will also be necessary to establish crop advisory committees for genetic resources to give proper direction to such efforts from time to time. Involvement of the All India Coordinated network for crop improvement for multilocational evaluation and utilization will be another important area worth exploring.

Efforts made so far in joint collection, evaluation, and conservation of genetic resources by ICRISAT and NBPGR are indeed quite encouraging and could serve as a model for strengthening these activities involving a larger network of different countries, making use of the genetic wealth as well as expertise available at ICRISAT. Obviously, to achieve this objective, we expect ICRISAT to play the role of catalyst.

Session II: World Germplasm Collections: Status Reports and Potentials

Status of the World Collection of Sorghum Germplasm at ICRISAT

K.E. Prasada Rao and V. Gopal Reddy

Senior Botanist, and Research Associate, Genetic Resources Unit, ICRISAT, Patancheru, Andhra Pradesh

Of the 16 138 sorghum accessions assembled by the Rockefeller Foundation in the Indian Agricultural Research Institute in the 1960s, only 8961 could be transferred to ICRISAT in 1974 by the All India Coordinated Sorghum Improvement Project (AICSIP), Rajendranagar, India. By that time the remaining 7177 had lost their viability due to lack of proper storage. Special efforts were made by ICRISAT to fill the gaps by obtaining duplicate sets from Purdue University, USA, the National Seed Storage Laboratory (NSSL), Fort Collins, USA, and from Mayaguez, Puerto Rico. This yielded about 3000 of the missing accessions but left a permanent gap of about 4000 accessions in the world collection presently conserved in the ICRISAT gene bank.

At present, ICRISAT is the major repository for the world sorghum germplasm with a total collection of 31 030 accessions. The major donors are AICSIP and Indian Agricultural Universities (4645), Ethiopia (4464), Sudan (2385), Cameroon (2241), Nigeria (1436), and the NSSL, Fort Collins, Colorado, USA (1882). IS numbers were assigned to 15 835 new accessions and the information has been computerized. Printouts are available on request for supply to sorghum scientists.

Geographic and Taxonomic Diversity

The major diversity centers of sorghum are now relatively well represented in the world collection assembled at ICRISAT. Despite the relatively good progress made so far in filling geographic and taxonomic gaps, there are some countries which were not adequately represented in the world collection, such as Algeria, Angola, Burma, Central African Republic, Congo, Guinea, hilly areas of India, Ivory Coast, Libya, Morocco, Mozambique, Nepal, Pakistan, People's Republic of China, northern Syria, Tunisia, Turkey, and Yemen (PDR).

Taxonomically, the collection is weak in some specific cultivated subraces, i.e., conspicuum, rigidum, kaoliang, membranaceum, decrue, and in transplanted types. Although we have assembled 345 accessions of 23 taxa of wild relatives so far, they form only 1.2% of our total collection. Special collection missions for wild sorghums need to be organized before they become extinct.

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Distribution of Germplasm

Germplasm is distributed mainly for utilization in crop improvement. If the world collection is to serve a useful purpose, it should be readily available to all sorghum scientists. The supply of seed material to scientists worldwide is one of ICRISAT's major responsibilities. Seed material for export from ICRISAT must pass through the National Bureau of Plant Genetic Resources (NBPGR) and this passage is facilitated by the Export Certification Quarantine Laboratory established at ICRISAT Center. However, seed supplies to Indian scientists are carried out directly and readily. This is a clear advantage for Indian sorghum scientists.

Over the years a large number of seed samples were distributed to various programs within ICRISAT, and institutions in India and abroad (Table 1). A major portion of our efforts and resources are spent on this important activity.

Germplasm Diversity Available for Utilization

The range of genetic diversity available among the cultivated sorghums and their wild relatives assembled at ICRISAT Center is truly amazing. The principal justification for maintaining this enormous natural variability lies in its utilization in broadening the genetic base for present and future sorghum improvement. As a prerequisite to efficient germplasm use, it has been evaluated using standard descriptors. Listed in Table 2 are some of the useful materials in the world collection of sorghum germplasm identified at ICRISAT Center for use by sorghum scientists.

Germplasm Enhancement

Conversion program. A major portion of the world collection consists of tall, photoperiod-sensitive landraces that are of limited value in present crop improvement programs. In order to augment the use of tropical sorghum germplasm in breeding programs, and to broaden the genetic base, we began a tropical conversion program using the long-day rainy season and the short-day postrainy season at ICRISAT Center. Over the past few years, eight Zerazera landraces from Ethiopia and Sudan were converted into photoperiod-insensitive lines. It took 6 years to convert the Zerazeras to photoperiod-insensitivity and the final converted lines are in 2 maturity and 3 plant-height backgrounds. All these lines are being assigned ICRISAT Sorghum Conversion (ICSc) numbers. Many of them have already been supplied to sorghum breeders in India and abroad.

Table 1. Recipients of sorghum germplasm seed samples from ICRISAT Center.

Recipients	No. of seed samples
ICRISAT Center programs	211 827
Institutions within India	74 032
Institutions abroad	105 900
Total	391 759

Table 2. Sources of useful traits identified from the sorghum germplasm maintained at ICRISAT Center.

Trait	No. of accessions
Named cultivar collection	237
US temperate conversion lines	176
ICRISAT tropical conversion lines	249
Rainy season basic collection	1405
Postrainy season basic collection	1002
Promising lines for pest resistance	
Shoot fly (*Atherigona soccata*)	60
Stem borer (*Chilo partellus*)	70
Midge (*Contarinia sorghicola*)	14
Head bug (*Calocoris angustatus*)	6
Promising lines for disease resistance	
Grain mold	156
Anthracnose (*Colletotrichum graminicola*)	15
Rust (*Puccinia purpurea*)	31
Downy mildew (*Peronosclerospora sorghi*)	155
Striga low-stimulant lines (laboratory screening)	645
Striga resistant lines (field screening)	24
Special purpose sorghums	
Glossy	501
Pop sorghum	36
Sweet-stalk sorghum	76
Scented sorghum	17
Twin-seeded	131
Large-glume	71
Bloomless sorghum	207
Broomcorn sorghum	52
Cytoplasmic male-steriles and maintainers	240

Introgression. At ICRISAT Center, the available wild relatives of sorghum have been screened for resistance to sorghum shoot fly and sorghum downy mildew. Sources of resistance have been identified and are awaiting imaginative use by breeders.

Since appreciable levels of resistance to shoot fly are not available in any cultivated sorghums, it has already become necessary to search for resistance in wild species. Crosses were made between resistant wild parasorghum species and adapted cultivars by hand emasculation as well as by using genetic male sterility. The F_3 progenies of the crosses are being studied for their resistance to shoot fly under artificially inoculated conditions.

Status of the World Collection of Minor Millets Germplasm at ICRISAT

K.E. Prasada Rao and V. Gopal Reddy

Senior Botanist, and Research Associate, Genetic Resources Unit, ICRISAT, Patancheru, Andhra Pradesh

Minor millets (small millets) are important crops in the Semi-Arid Tropics. Presently the total number of minor millets accessions assembled and conserved at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is 6610 (Table 1).

Assembly and Conservation

A mission to Ethiopia, to collect *Eleusine* germplasm, was organized in collaboration with the Indian Council of Agricultural Research (ICAR). A scientist from ICAR was deputed for the purpose. Two hundred and seventeen samples of *Eleusine* were collected which are yet to be received from Ethiopia.

Most of the minor millets germplasm was obtained by correspondence. Some accessions were collected during missions launched primarily for other mandate crops.

In 1986, a collaborative project between ICRISAT and NBPGR/ICAR was initiated. We received 466 new accessions of six crop species from NBPGR Regional Station, Akola, Maharashtra, India, which was a good addition to our present collection. We have transferred one complete set of minor millets germplasm from ICRISAT to NBPGR for evaluation at Akola.

All the minor millets germplasm are conserved under medium-term storage conditions at 4°C and 20% RH.

In accordance with the recommendation of the IBPGR Advisory Committee on Sorghum and Millets, ICRISAT has started assigning accession numbers to minor millets (Table 1).

Maintenance

All minor millets germplasm accessions are planted for seed increase normally in the rainy season to meet seed requests from institutions in India and abroad. Since all the six minor millet crop species are reported to be mostly self pollinated, they are maintained without any poilination control.

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Table 1. Minor (small) millets germplasm assembled and conserved at ICRISAT Center.

Crop	Suggested accession number	No. of countries	No. of accessions assembled	No. of accessions evaluated	No. of descriptors
Finger millet (*Eleusine coracana*)	IE	18	2848	1948	32
Foxtail millet (*Setaria italica*)	ISe	22	1404	1260	34
Proso millet (*Panicum miliaceum*)	IPm	26	831	753	37
Little millet (*Panicum sumatrense*)	IPmr	1	401	291	33
Barnyard millet (*Echinochloa* spp)	IEc	8	582	517	39
Kodo millet (*Paspalum scrobiculatum*)	IPs	2	544	308	38

Evaluation

IBPGR has assigned a special responsibility to ICRISAT by providing funds to characterize the available germplasm at ICRISAT. Accordingly, several accessions have been characterized for important morphoagronomic descriptors (Table 1). As part of the evaluation exercise, the six minor millets species have been classified (Table 2) in collaboration with the Crop Evolution Laboratory, University of Illinois, Urbana, USA.

Table 2. Classification of minor millets.

Crop	Number of			
	Species	Subspecies	Races	Subraces
Finger millet	1	2	6	10
Foxtail millet	2	2	3	10
Proso millet	1	1	5	-
Little millet	1	2	2	4
Barnyard millet	2	4	8	-
Kodo millet	1	-	3	-

Documentation and Computerization of Evaluation Data

All the evaluation data have been documented and the data of the following minor millets have been computerized using the IDMRS (ICRISAT Data Management and Retrieval System) program:

Finger millet: IE 1 to IE 3567
Foxtail millet: ISe 1 to ISe 1409
Little millet: IPmr 1 to IPmr 852
Proso millet: IPm 1 to IPmr 2805
Barnyard millet: IEc 1 to IEc 566

Evaluation data of Kodo millet are yet to be computerized.

Distribution of Germplasm

Since ICRISAT accepted the responsibility to be a major world repository for minor millets germplasm, seed indents have increased from institutions both within and outside India. So far, 28 831 seed samples have been distributed from the ICRISAT gene bank. The yearwise distribution to institutions in India and abroad is presented in Table 3.

Table 3. Distribution of minor millets germplasm seed samples from ICRISAT Center, 1978-88[1].

Year	Indian Institutes	Institutions abroad	Total
1978	2 721	973	3 694
1979	4 004	608	4 612
1980	1 345	1 840	3 185
1981	3 144	1 791	4 935
1982	2 080	911	2 991
1983	212	540	752
1984	-	200	200
1985	-	165	165
1986	2 138	427	2 565
1987	1 232	955	2 187
1988	567	2 978	3 545
Total	17 443	11 388	28 831

1. Up to September 1988.

Future Work Plan

The importance of minor millets is increasing in SAT countries. Since no other international center is actively involved in the conservation of the world collection of minor millets, ICRISAT will continue its genetic resources activities with these crops. At present, the regions and countries tentatively identified as priority areas for minor millets germplasm collection are: China, central Africa, eastern Africa, India, Japan, southern Africa, and West Africa. Suggestions for new areas of collection will be appreciated.

Recently NBPGR/ICAR accepted a proposal for collaborative research with GRU, ICRISAT, in collection and evaluation of minor millets germplasm. More collection missions should be organized in collaboration with NBPGR/ICAR in India and national institutions in other countries.

ICRISAT will continue to distribute minor millets germplasm to interested scientists in India and other countries through NBPGR. The Small Millets (minor millets) Steering Committee, which met in Ethiopia in October 1987 under the sponsorship of IDRC, greatly appreciated the role of ICRISAT in the collection, conservation, and exchange of small millets and proposed that ICRISAT should continue its activity as an international collaborative network involving small millets germplasm.

Status of the World Collection of Pearl Millet Germplasm at ICRISAT

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Pearl millet (*Pennisetum glaucum* (L.) R. Br.) originated in a diffuse belt from Sudan to Senegal. It is an important grain crop in Africa and Asia and a fodder crop elsewhere. Millets are grown over an estimated 39.941 million hectares in the world, producing 30.8 million metric tons of grain annually.

Assembly

Of the 3017 accessions of pearl millet germplasm assembled by the Rockefeller Foundation and ALAD, only 2141 are presently available at ICRISAT. The remaining accessions had lost their genetic identity due to contamination during maintenance and rejuvenation. Besides this, the Genetic Resources Unit (GRU) of ICRISAT, in collaboration with various national and international organizations, assembled 17 655 accessions (Table 1). The Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM) had collected 2337 accessions of pearl millet germplasm from Benin, Burkina Faso, Cameroon, Central African Republic, Guinea, Mali, Niger, Senegal, and Togo, all of which, except Guinea, were transferred to ICRISAT.

The collection missions in Africa are launched in collaboration with IBPGR, national programs of the concerned countries, and other international organizations. So far, ICRISAT has launched 10 germplasm collection missions to Botswana, Cameroon, Ghana, Malawi, Nigeria, Tanzania, Zambia, and Zimbabwe, and collected 3266 samples. While collecting other ICRISAT mandate crops, 435 samples of pearl millet germplasm were also collected from 13 countries. In India, germplasm is collected in collaboration with scientists from the National Bureau of Plant Genetic Resources (NBPGR), All India Coordinated Pearl Millet Improvement Project (AICPMIP), Agricultural Universities, and other ICAR Institutes. The materials so collected are shared by ICRISAT, AICPMIP/NBPGR, and Agricultural Universities. So far, 18 missions have been launched in 11 Indian states and 3777 samples have been collected. Of the 19 796 accessions assembled at ICRISAT so far, 2141 are from the Rockefeller Foundation and ALAD, 4888 accessions are breeding material from India, and 12 767 are collections and acquisitions from various other sources.

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Priority areas for pearl millet germplasm collection are Angola, Central African Republic, Chad, Mauritania, Nigeria, Namibia, Pakistan, Uganda, and Zaire for cultivated, and Mali, Niger, Nigeria and Senegal for wild *Pennisetum* species.

Table 1. Status of pearl millet germplasm assembled at ICRISAT Center.

	Sources[1]						
Country	1	2	3	4	5	6	Total
AFRICA							
Benin	-	-	46	-	-	-	46
Botswana	-	-	-	-	-	65	65
Burkina Faso	23	-	313	-	285	39	660
Cameroon	-	-	170	2	-	750	922
Cape Verde	-	-	-	2	-	-	2
Central African Republic	-	-	63	-	-	-	63
Chad	69	-	1	-	-	-	70
Congo	8	-	-	-	-	-	8
Ethiopia	1	-	-	-	-	-	1
Gambia	-	-	-	-	-	15	15
Ghana	4	-	-	-	-	280	284
Kenya	24	-	-	25	49	-	98
Malawi	9	-	-	-	-	289	298
Mali	51	-	729	-	-	245	1 025
Mauritania	2	-	1	-	-	-	3
Morocco	-	-	-	-	-	4	4
Mozambique	-	-	-	-	-	31	31
Niger	43	-	488	18	-	390	939
Nigeria	139	93	-	274	253	477	1 236
Republic of South Africa	21	14	-	-	89	35	159
Senegal	56	-	283	10	-	53	402
Sierra Leone	-	-	-	-	-	59	59
Somalia	-	-	-	-	-	4	4
Sudan	6	-	-	-	140	443	589
Tanzania	17	-	-	-	-	467	484
Togo	-	-	116	-	29	-	145
Uganda	36	-	-	58	18	-	112
Zambia	3	-	-	-	58	234	95
Zimbabwe	2	29	-	59	-	397	487

Continued.

Table 1. *Continued.*

Country	Sources[1] 1	2	3	4	5	6	Total
ASIA							
India	1 014	25	-	5 809[2]	-	3 833	10 681[2]
Lebanon	109	-	-	-	-	-	109
Pakistan	5	4	-	-	-	-	9
Republic of Korea	1	-	-	-	-	-	1
Turkey	-	2	-	-	-	-	2
Yemen (AR)	-	-	-	-	17	44	61
EUROPE							
Federal Republic of Germany	-	-	-	3	-	-	3
UK	-	-	-	-	31	-	31
USSR	-	-	-	13	-	-	13
THE AMERICAS							
Brazil	-	2	-	-	-	-	2
Mexico	-	-	-	10	-	-	10
USA	101	68	-	-	-	-	169
AUSTRALIA	5	-	-	2	-	-	7
Unknown Origin	392	-	-	-	-	-	392
Total	2 141	237	2 210	6 285[2]	969	7 954	19 796[2]

1. 1. Rockefeller and ALAD, 2. USA, 3. ORSTOM, 4. National Programs, 5. IBPGR, 6. ICRISAT.
2. 4888 are inbreds and breeding material.

Seed Increase and Rejuvenation

To minimize genetic drift during seed increase and rejuvenation, each accession is considered as a population and a large sample size is used at every stage. For seed increase, about 200 plants are raised for each accession and the cluster bagging method is used where 3-6 emerging spikes before stigma emergence are enclosed in a large bag to facilitate pollination among themselves. A nearly equal quantity of seed from each spike is bulked to reconstitute the population. Inbreds are maintained by selfing and male-sterile lines by hand pollinating A lines with B lines. Seed increase is done during the postrainy season as even the photoperiod sensitive types flower under short-day

conditions and rain-free days facilitate production of seed free from grain mold, and suitable for exchange and storage.

Conservation

For germplasm conservation, healthy dry seeds are stored in aluminium cans fitted with airtight screw lids. For each accession, about 400 grams of seed is kept in medium-term storage where the temperature is maintained at 4°C and 20% RH. During storage, seed viability is monitored regularly and those accessions with less than 85% viability are rejuvenated.

Evaluation

To facilitate meaningful exchange of information, internationally accepted descriptors and descriptor states were developed and published by IBPGR and ICRISAT. For evaluation, each accession is planted in 2 rows of 4-m length, 75 cm apart, and 10 cm within a row. To realize the full potential of the accession, evaluation is done under good management conditions.

All the available germplasm lines are evaluated at ICRISAT Center, Patancheru (17°27'N) during the rainy season. To compare the expression of germplasm lines under different agroclimatic conditions, two sets of 343 and 125 diverse landrace accessions were evaluated at Bobo-dioulasso and Kamboinse in Burkina Faso, Maradi in Niger, and Bhavanisagar, Jaipur, and Hisar in India. With a view to evaluate germplasm at or near the place of origin, 2000 accessions from SADCC countries were evaluated at Sebele in Botswana, Ngabu in Malawi, Hombolo in Tanzania, Kaoma in Zambia, and Gwebi, Panmure, Aisleby, and Matopos near Bulawayo in Zimbabwe. All the 878 accessions from Cameroon were evaluated at the Institut de la recherche agronomique (IRA), Maroua in Cameroon In collaboration with NBPGR, we are evaluating germplasm in batches of 2000 accessions each year at Jodhpur and Issapur, and at Pune with AICPMIP. Considerable variation was observed for all .he characters studied.

Identification of New Traits

During the course of evaluation and maintenance of germplasm, we look for new and novel traits not reported so far. Morphological variants are selfed and purified. For the first time, we identified sweet-stalked pearl millet (with 20% sugar content in the stalks), glossy genes, midribless, and a variety of chlorophyll-deficient mutants. The new dwarfing genes, cytoplasmic male-sterile lines from Ghana and Botswana germplasm, and early flowering germplasm are some of the traits useful in millet improvement. Sources of resistance to biotic and abiotic stress factors are identified by concerned specialists.

Documentation

Evaluation data on morphological characters up to IP 3017 were published in a catalog by Murty et al. in 1967 and subsequently by ALAD. Information on passport and evaluation data from IP 3018 to IP 12431 is already analyzed and is being processed for publication as a catalog. Data on IP 12432 to IP 15945 is being computerized. This information is retrieved and sent along with the seed to those who need it.

Seed Distribution

So far, we have sent 24 030 seed samples to scientists in ICRISAT, 36 026 samples within India, and 25 402 samples to scientists in 68 countries outside India.

Wild Relatives and their Exploitation

Of the 140 known species of the genus *Pennisetum*, we have assembled 371 accessions of 20 species. The species *P. schweinfurthii* is valued for its large grains and waxy coating, *P. purpureum* for forage and *P. clandestinum* as pasture, *P. setaceum* and *P. villosum* as ornamentals, and *P. hohenackeri* for thatching and rope making. *Pennisetum* is a polybasic genus with x=5,7,8, and 9. In the x=5 type, 2n=10 was observed in *P. ramosum* only. In the x=7 type, 2n=14 was observed in *P. glaucum, P. violaceum, P. mollissimum*, and *P. schweinfurthii* while 4x=28 was observed in *P. purpureum*. In the x=8 type, 2x=16, and 4x=32 were observed in *P. mezianum*. In the x=9 type, 2x=18 and 3x=27 were observed in *P. hohenackeri* and 3x=27 in *P. setaceum*. Tetraploid number 4x=36 was observed in *P. mecrorum, P. divisum, P. cenchroides, P. clandestinum, P. pedicellatum*, and *P. orientale*, while 5x=45 was observed in *P. villosum*. The species *P. squamulatum*, and *P. polystachyon* showed 6x=54 chromosomes while the highest chromosome number (68) was observed in the species *P. macrostachyum* only.

Higher meiotic chromosome associations in the diploid complement of *P. schweinfurthii* and *P. mezianum*, and the occurrence of species with x=5 in *P. ramosum*, suggests that the chromosome complement of the genus *Pennisetum* must have evolved from the basic chromosome number x=5. In *P. hohenackeri* (3x=27), 9 bivalents and 9 univalents were observed at metaphase I, so it was considered a spontaneous allotriploid.

Status of the World Collection of Chickpea Germplasm at ICRISAT

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Chickpea (*Cicer arietinum* L.) is an ancient crop, its earliest record dating back to 6250 BC, from the Middle East. The crop probably evolved in southeastern Turkey. This view is based on the fact that the three wild species of the genus *Cicer* that are most similar to cultivated chickpea occur naturally in this region. Chickpea domestication spread gradually, and it is now cultivated in over 40 countries. The recent introduction of chickpea to Australia and USA has expanded the use and potential of this crop.

The genetic resources of chickpea include primitive landraces, improved cultivars, genetic stocks, mutants of *C. arietinum*, and all other species of the genus *Cicer*. A total of 43 species are known to exist in this genus, of which only one (*C. arietinum*) is cultivated, 8 are wild annuals, and the remaining 34 are wild perennial species. The wild species are rather limited in distribution, and were noticed growing in countries around the Mediterranean Sea, Soviet Union, Ethiopia, Sudan, and in the Himalayan Mountains.

Recently the Regional Pulse Improvement Project (RPIP), India/Iran, by an extensive collection effort assembled and augmented chickpea collections that existed with various institutes. This resulted in the assembly of about 7000 chickpea accessions. When the RPIP was phased out in 1970, part of this collection was deposited with USDA, and the rest remained with several national research programs in India and Iran. In 1972, after ICRISAT came into existence and assumed responsibility as the world repository for genetic resources of chickpea, various institutes, universities, and research organizations donated most of their collections.

ICRISAT started collecting germplasm in priority areas in the early eighties. Collection in other countries, such as in Ethiopia, Afghanistan, Turkey, Nepal, Bangladesh, Morocco, and Syria has helped to narrow the apparent gaps in the world collection. In India, 17 missions have been organized jointly by ICRISAT, Agricultural Universities, and the National Bureau of Plant Genetic Resources (NBPGR). This resulted in the collection of 1400 samples (Table 1). Presently the ICRISAT gene bank holds 15 564 chickpea accessions representing 42 countries. Besides filling the geographical gaps, the above missions provided some very useful materials, e.g., tuberculated-seed types, twin-podded, and extra-large seeded desi materials from Madhya Pradesh, very-large seeded desi from Tamil Nadu, black seed coated, high-anthocyanin types from Ethiopia, extra-large seeded kabuli, desi types of Middle East origin, and twin-podded kabuli from Morocco and Syria.

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Table 1. ICRISAT collection expeditions for chickpea and wild *Cicer* species, 1975-88.

Year	Country	No. of accessions
1975	Afghanistan, India, Pakistan, Turkey	192
1976	Afghanistan, India	144
1977	Afghanistan, India (3)[1], Turkey	227
1978	India (2), Pakistan	71
1979	Bangladesh, India (2), Nepal	234
1980	Burma, India (2), Nepal	250
1982	Ethiopia, India	251
1983	India	47
1984	Ethiopia	104
1985	Bangladesh, India	206
1986	India	197
1987	India, Morocco	279
1988	India, Syria	140

1. The figures in parentheses refer to the number of expeditions, in countries where there has been more than one collection mission.

Germplasm evaluation helps us to not only characterize and document diversity of the germplasm, but also to identify and describe new and useful genetic traits. For example, we have identified, over several years of evaluation, 86 erect types, 100 twin-podded types, 43 multi-seeded types. Ultimately, the value of the diverse germplasm depends on the extent of its utilization in crop improvement programs. Currently the chickpea germplasm is evaluated for 25 morphoagronomic characters. The screening for resistance to various diseases and insect pests is done by concerned disciplines and several resistant sources have been identified (Table 2). In order to suitably document the information and distribute it to users, the passport and evaluation data of most of the accessions have been computerized and subjected to statistical analysis. The information has been summarized in the 'ICRISAT Chickpea Germplasm Catalog' which will soon be distributed to chickpea research workers. This analysis has revealed very useful information, e.g.:

- Accessions from Chile seem to be better sources for longer growth duration, higher plant height, heavy seed mass, and semi-erect growth habit.
- Accessions from Bangladesh appear to be better sources for high pod number and resistance to fusarium wilt.
- Accessions from Nepal produce a high number of basal secondary branches and seeds pod^{-1} but they produce small pods, few apical secondary branches, and exhibit shorter flowering duration.

Germplasm evaluation has now begun at several locations. In India, this work continues at ICRISAT Center, Akola, Gwalior, and New Delhi, in collaboration with NBPGR.

Table 2. Chickpea germplasm accessions with resistance to diseases and insects, evaluated at ICRISAT Center.

Disease/Insect pest	No. of accessions
Fusarium wilt	166
Dry root rot	47
Stunt disease	11
Fusarium wilt and dry root rot	18
Fusarium wilt and black root rot	18
Fusarium wilt and botrytis gray mold	1
Fusarium wilt and ascochyta blight	1
Fusarium wilt and sclerotinia stem blight	8
Botrytis gray mold and ascochyta blight	2
Botrytis gray mold and colletotrichum blight	2
Ascochyta blight and stunt	3
Fusarium wilt, dry root rot, and black root rot	2
Pod borer	22

The potential users of the chickpea germplasm are chickpea scientists throughout the world. Every year, they test/utilize a large number of accessions in their research programs. A total of 157 824 chickpea seed samples have been distributed from the Genetic Resources Unit (GRU) from 1974 to 1987. Besides their use in crop improvement programs, some elite materials have directly been used for cultivation. In the last 10 years, some 26 chickpea germplasm lines were released for commercial cultivation. Examples are chickpea cultivars Dhanush, Trishul, and Radha in Nepal; BDN 9-3 and Jyoti in India; Shendi in Sudan; and ILC 482 in Algeria, Morocco, Syria, and Turkey.

The status of chickpea germplasm is reviewed periodically. Some of the main points of future interest are the following:

- Some chickpea growing regions, viz., Burma, parts of Ethiopia and India, Malawi, Tanzania, and Turkey are not yet well represented in the world collection. Germplasm from these countries should be collected as early as possible.
- Germplasm accessions will have to be additionally screened for response to fertilizers, resistance to lodging, early seedling vigor, low-light interception, etc.
- Evaluating germplasm at more locations will have to be continued, if possible near or in their original habitat.

Status of the World Collection of Pigeonpea Germplasm at ICRISAT

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It is believed that pigeonpea (*Cajanus cajan* (L.) Millsp.) originated in India. This view is based on archaeological finds of pigeonpea seeds at Bhokardan, Maharashtra which presumably date back to the period 200 BC - 300 AD. It appears that *Atylosia cajanifolia* is the closest related species of pigeonpea followed by *A. lineata, A. scarabaeoides, A. sericea, A. albicans*, etc. The name 'pigeonpea' originated in the Americas where it reached during the 15th Century AD. As the seeds were favored by pigeons, the name 'pigeonpea' came to be used. Several botanical names have been used for pigeonpea, but the latest and most accepted is *Cajanus cajan* (L.) Millsp.

Pigeonpea belongs to the subtribe *Cajaninae* which encompasses a vast gene pool of about 300 species belonging to 13 genera. There is some similarity among these species. Of this vast gene pool, pigeonpea is the only cultivated form. This was often considered to be a monotypic genus, since all the other Asian and Australian species that were described and were similar to pigeonpea, were transferred to the genus *Atylosia* because of the presence of seed strophiole. van der Maesen suggested merging all species of *Atylosia, Rhynchosia acutifolia* F.V. Muel. ex Benth, and *Dunbaria heynei* W. & A. into *Cajanus*, thus recognizing 32 species in the genus.

Pigeonpea is cultivated on about 3 m ha all over the world. However, this appears to be an underestimation, as it probably does not include pigeonpea that is commonly grown in small stands in backyards and on field bunds. Pigeonpea is known to be cultivated in over 50 countries, the most important being Burma, India, Dominican Republic, Kenya, Malawi, Tanzania, and Uganda. Pigeonpea has been gaining popularity in Australia since its recent introduction.

In keeping with its role as the world repository of its mandate crops ICRISAT started to assemble the pigeonpea germplasm that already existed with various institutes. The initial collection consisted of the lines assembled by the former Regional Pulse Improvement Project (RPIP), a joint project of USDA, India, and Iran. When the RPIP was phased out in 1970, sets of this collection remained with various agricultural universities and institutes in India. In 1973/74, the material from these centers was donated to ICRISAT. RPIP had also stored one set of this material with USDA. At ICRISAT's request, this material was sent to Puerto Rico and then to ICRISAT. Some institutes made new efforts to collect germplasm, and these materials were also shared with ICRISAT. Simultaneously, ICRISAT, in consultation and cooperation with other institutes, started collecting germplasm from priority areas. So

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far 34 missions have been carried out in India and 19 abroad and more than 3500 germplasm samples collected (Table 1). With the addition of the new samples, the pigeonpea germplasm collection now comprises 11 034 accessions representing 52 countries. The outstanding achievements were the collections from Kenya, Malawi, and the Caribbean Islands which yielded samples with extra-tall plant height, purple stem color, large seeds, and multiseeded pods. The last two characteristics are important for vegetable-type pigeonpea.

During the germplasm collection efforts, particular attention was paid to survey and collect the *Cajaninae* species that are apparently close to pigeonpea. This has resulted in a collection of 271 accessions of 47 species belonging to 6 genera.

Systematic evaluation of the accessions is necessary to describe the material and to identify desirable lines for utilization. Pigeonpea accessions were grown in batches at ICRISAT Center and evaluated for 40 morphoagronomic traits. Several accessions with desirable characteristics have been identified (Table 2). The concerned disciplines screen germplasm for resistance to diseases and insect pests. The number of resistance sources identified are listed in Table 3.

Recently, germplasm evaluation has begun at more locations. This work is done in Kenya jointly with the National Dryland Farming Research Center. Similarly, in India, ICRISAT and NBPGR are jointly conducting germplasm evaluations at Akola, New Delhi, and Jorhat.

Table 1. Collection expeditions launched by ICRISAT for pigeonpea and its wild relatives.

Year	Area	No. of accessions
1974	India (2)[1]	134
1975	India (3)	331
1976	India (5), Kenya	426
1977	India (5)	241
1978	India (3)	195
1979	Australia, Bangladesh, India (4), Malawi, Nepal	345
1980	Burma, India (6), Nepal, Sri Lanka, Thailand, Zambia	272
1981	India (2), Mozambique, Philippines, Tanzania	399
1982	Kenya, South Africa, Zimbabwe	290
1983	India, Malawi	459
1985	Caribbean Islands, India	271
1986	Caribbean and Central American region, India	142
1987	India	52
	Total (in 53 expeditions)	3557

1. Figures in parentheses refer to the number of expeditions, in places where there was more than one mission.

Table 2. Pigeonpea germplasm accessions identified with specific agronomic characteristics, evaluated at ICRISAT Center.

Character	No. of accessions
Determinate growth habit	298
Short plant height (<1 m)	321
Short maturity duration (<120 days)	47
Heavy seed mass (100-seed mass >18 g)	48
High seed protein (>27.6%)	14
Multiseeded (>6.0 seeds pod^{-1})	15

Table 3. Pigeonpea germplasm accessions with absolute resistance to diseases, insects, and nematodes, evaluated at ICRISAT Center.

Disease/Insect/Nematodes	No. of accessions
Fusarium wilt	65
Sterility mosaic	326
Phytophthora blight	140
Two diseases	28
Three diseases	12
Three diseases and nematodes	2
Pod borer (*Heliothis armigera*)	18
Podfly (*Melanagromyza obtusa*)	15
Pod borer and podfly	4
Nematodes (complex of 8 species)	9

In order to suitably document the information, the passport and evaluation data of most of the accessions have been computerized and subjected to statistical analyses. The results are given in the ICRISAT Pigeonpea Catalog which has been prepared in two parts, and has already been distributed to users.

The main users of the germplasm are scientists at ICRISAT and at various national institutes in the semi-arid tropics. Scientists from 90 countries have drawn pigeonpea germplasm samples from the ICRISAT gene bank to utilize them in their respective research programs.

The contribution of landraces as source material for improvement has been substantial. There are also examples of germplasm lines that have directly been used for commercial production, e.g., UPAS 120, a short-duration selection from a germplasm line that was released in northern India in 1976 for cultivation. In Fiji, the germplasm accession ICP 7035, a field collection from Madhya Pradesh, India, has been released

for cultivation. Because of the high sugar content in its seeds, the line has been named 'Kamica' which means sweet in Fijian. This line combines resistance to fusarium wilt and sterility mosaic with good vegetable-type characteristics. Another accession, ICP 8863, a field collection from Uttar Pradesh, has been released in Karnataka under the popular name 'Maruti'. Recently the Government of Malawi identified ICP 9145 as suitable for cultivation. This line is in fact a landrace collected in 1976 from Kenya.

The status of the pigeonpea germplasm is reviewed periodically. Some of the main points of future interest are the following:

- Germplasm from the priority areas, i.e., Burma, India (Bihar, Orissa, and Karnataka), Indonesia, Uganda, and Thailand should be collected.
- In addition to the 40 descriptors presently used, germplasm should be evaluated for response to fertilizer, reduced flower drop, tolerance to rains during maturity, etc.
- The efforts should continue to evaluate germplasm at more locations.

Status of the World Collection of Groundnut Germplasm at ICRISAT

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Origin and Distribution

The genus *Arachis* probably originated in the area referred to as the Brazilian shield. Cultivated groundnut (*Arachis hypogaea* L.) originated in Bolivia and northwest Argentina on the eastern slopes of the Andes.

The natural occurrence of the genus *Arachis* is confined to South America – in Argentina, Bolivia, Brazil, Paraguay, and Uruguay. In this region, its distribution is restricted to the area that is bounded by the Amazon river to the north, the la Plata river to the south, the Atlantic to the east, and by the Andes to the west. However, more explorations for *Arachis* have to be made in many areas, and the distribution of the genus may eventually be found to be much wider. The geocarpic habit has largely determined the evolution and distribution of the genus. Species belonging to all sections of *Arachis* occur in Brazil, and four sections, *Ambinervosae*, *Caulorhizae*, *Extranervosae*, and *Triseminalae*, are known to occur only in Brazil. Species in sections *Arachis* and *Rhizomatosae* occur in all five countries, but species in section *Erectoides* are not known to occur in Uruguay. The cultivated groundnut gradually spread all over the world, especially during the immediate post-Columbian period. It is now cultivated in more than 80 countries.

Collection and Assembly

When ICRISAT started groundnut germplasm work in 1976, top priority was given to acquiring collections from other gene banks or research centers. Over 5066 accessions were assembled from various research centers in India, and 5297 accessions from the People's Republic of China, Indonesia, Japan, Malawi, Nigeria, Senegal, South Africa, Tanzania, UK, USA, USSR, Zambia, and Zimbabwe.

ICRISAT also carried out several collection expeditions in India and abroad in cooperation with national and international agencies, and collected 857 samples in India and 996 from outside India. During these trips, besides collection of germplasm, information on cultivation practices, and occurrence of pests and diseases was also recorded.

ICRISAT has a special interest in wild species of *Arachis* for cytogenetic and resistance breeding work. The present collection of 201 accessions represents about 35

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species, descriptions of some of which are yet to be published. Many more need to be assembled.

The groundnut germplasm collection at ICRISAT presently totals 12 160 accessions from 89 countries (Table 1). Additional germplasm is yet to be collected from the

Table 1. Groundnut germplasm collection status at ICRISAT Center, October 1988.

Origin	No. of accessions	Origin	No. of accessions
AFRICA	3 496	Swaziland	8
		Tanzania	396
Angola	7	Togo	11
Benin	15	Uganda	171
Botswana	1	Zaire	116
Burkina Faso	62	Zambia	226
Cameroon	6	Zimbabwe	558
Central African Republic	2		
Chad	15		
Comoros	1	ASIA	3 820
Congo	6		
Cote d'Ivoire	81	Burma	21
Egypt	17	India	3 050
Equatorial Guinea	13	Indonesia	139
Gambia	32	Iran	11
Ghana	53	Israel	88
Guinea	22	Japan	47
Kenya	50	Kampuchea	1
Liberia	12	Malaysia	53
Libya	1	Pakistan	1
Malagasay Republic	49	People's Republic of China	215
Malawi	148	Republic of Korea	74
Mali	187	Sri Lanka	23
Mauritius	27	Syria	1
Morocco	21	Taiwan	48
Mozambique	149	Thailand	6
Niger	25	The Philippines	29
Nigeria	343	Turkey	7
Republic of South Africa	146	Vietnam	4
Rwanda	1	Yemen (AR)	1
Senegal	262		
Sierra Leone	24	EUROPE	112
Somalia	9		
Sudan	223	Belgium	3

Continued.

Table 1. *Continued.*

Origin	No. of accessions	Origin	No. of accessions
Bulgaria	4	Mexico	21
Cyprus	7	Paraguay	184
Greece	7	Peru	317
Hungary	2	Puerto Rico	21
Portugal (Azores)	6	Trinidad and Tobago	5
Spain	4	Uruguay	40
UK	16	USA	1 828
USSR	63	Venezuela	9
THE AMERICAS	3 656		
Argentina	404		
Barbados	4	AUSTRALIA AND OCEANIA	59
Brazil	465		
Chile	12	Australia	57
Columbia	1	Fiji	2
Costa Rica	1		
Cuba	40		
Ecuador	3	Unknown	1 017
Honduras	4		
Jamaica	4		
Martinique	6	TOTAL	12 160

priority countries/areas identified in consultation with the International Board for Plant Genetic Resources (IBPGR), ICRISAT scientists, and national scientists in the germplasm resource areas.

Conservation and Maintenance

At ICRISAT, all the cultivated groundnut accessions and seed-producing wild species are maintained by growing in the field. The rhizomatous and nonseed-producing wild species are maintained in concrete cylinders. The legumes cytogenetics section at ICRISAT Center has been helping GRU maintain the rhizomatous wild species of groundnut.

Generally about 1 kg pods are stored in the medium-term cold storage (4°C and approximately 40% RH). Viability of accessions is monitored regularly and rejuvenation is carried out when the seed quantity is low or the viability falls below the

germination standard (85%). Larger quantities of seed for genetic stocks and accessions for which demand is greater are also retained in the short-term storage at 18°C. The long-term cold storage facility (20°C) is being developed.

All possible care is taken to effectively maintain and conserve healthy and good-quality seeds in the ICRISAT gene bank. Reports on peanut stripe virus (PStV) have become a major source of concern to ICRISAT because of its role in germplasm exchange. Enzyme-linked immunosorbent-assay technique (ELISA) is used to detect the presence of the virus in the seed. Virus-free seeds are then planted for seed increase and pods from such plants are conserved in our gene bank. This process will continue until all the groundnut accessions in our gene bank are checked, so that we can maintain and supply healthy seeds. Additionally, whenever germplasm is grown in the field, our pathologists examine the plants, especially for viral disease symptoms.

Evaluation

The 'Groundnut Descriptors' developed by IBPGR and ICRISAT in 1981 form the basis for evaluation and characterization at ICRISAT. Preliminary evaluation for morphoagronomic characteristics is carried out in both rainy and postrainy seasons. Further evaluation for pest and disease resistance, and physiological and biochemical characteristics is carried out in collaboration with other disciplines at ICRISAT Center.

Such evaluation exercises have resulted in the identification of a number of useful groundnut accessions which are being utilized extensively in groundnut improvement at ICRISAT and elsewhere. We presently have about 60 accessions resistant to late leaf spot, about 12 promising ones for early leaf spot, about 100 resistant sources for rust, a few with field tolerance to bud necrosis and peanut mottle virus, resistance to seed invasion by *Aspergillus flavus*, and pod rots. We have about 100 accessions resistant to thrips, jassids, aphids, and *Spodoptera* spp. We have also in our gene bank 17 drought-tolerant accessions and some with higher biological nitrogen-fixing ability. We have a few accessions with higher oil and protein content.

Multilocational evaluation of groundnut germplasm in India in collaboration with NBPGR is in progress. With the expansion of ICRISAT's own program in southern and West Africa, more such multilocational evaluations are needed to exploit the available diversity for utilization in groundnut improvement. In future, germplasm will be evaluated for more attributes such as oil quality and sources of resistance to other pests and diseases.

Documentation

'Groundnut Descriptors' consist of 40 passport descriptors and 39 preliminary evaluation descriptors. Descriptor states have also been provided for a number of descriptors for further evaluation, the data on which are being supplied to GRU by other groundnut scientists. The revision of groundnut descriptors is in progress. A separate list of descriptors for wild *Arachis* is also under preparation.

Passport data have been computerized for 12 160 ICRISAT accessions. Morpho-agronomic data are being computerized. A computer program, ICRISAT Data Management and Retrieval System (IDMRS) is being used for this purpose. The computer file forms the base live catalog. Publication of groundnut germplasm catalogs on passport data and evaluation data is planned.

Distribution

Since 1976, 96 656 samples have been distributed, including 45 704 samples to ICRISAT scientists, 26 536 to scientists in India and 24416 to scientists in 83 other countries. Generally, groundnut germplasm is supplied as pods to scientists in India and it is always supplied as seed to scientists outside India after completing all the plant quarantine requirements.

World Germplasm Collections and Their Potential in Crop Productivity

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Concerted efforts during the past 25 years by international and national organizations have resulted in the collection, evaluation, and some mobilization of world genetic resources mainly in cereals, legumes, and oilseeds, and to some extent in other food crops, with timely prevention of their elimination by fast-spreading new cultivars. IBPGR and ICRISAT, with their cooperators, have prepared standard descriptor lists and documentation procedures. There is an on-going effort to make collections in priority crops and regions in spite of difficulties in the movement of material across continents because of quarantine and other controls. The mobilization of world collections has greatly benefitted crops of the semi-arid tropics which form the staple food in several developing countries. These crops are normally grown under marginal conditions and have high local adaptation. The Sorghum Conversion Program in Puerto Rico, for example, helped sorghum production in the USA as much as in the tropics of Asia and Africa, and extended the range of adaptation of the cultivars globally.

Dwarfing Genes and Biomass Production

The utilization of genes for dwarfing and photoperiod insensitivity from local varieties, to restructure plant type in the major cereals, has enormously improved their productivity and range of adaptation, and has added stability to production, as is evident in the national coordinated crop improvement programs. The next quantum jump in cereal yield for the 21st century requires a greater diversification of the genetic base, including cytoplasmic diversity, since only a small fraction of the world collections have actually entered the parentage of present-day advanced lines.

The Dee-gee-Woogen and Norin dwarfing genes in rice and wheat and similar genes in sorghum and millet have complex functions, influencing a constellation of characters. These genes improve the partitioning of dry matter without a significant increase in the total biomass production. Hence there is an urgent need to evaluate the world collections for higher biomass to complement the superior harvest index. Transfer of alternate sources of dwarfing with rapid biomass accumulation, traits found in some winter wheats, the Assam rice collection, new dwarfing genes in millet at ICRISAT, and in the sorghums of Latin America, into improved types, is essential.

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For a planned transfer of these genes into advanced cultivars, basic studies are needed on adaptation mechanisms of genotypes to moisture, disease, soil, and climatic stresses, and on the biochemical basis of their resistance to such biotic and abiotic factors. The adaptive mechanisms of genotypes with potentially high biomass under these stress conditions need special attention.

New Tools from Frontier Sciences

Frontier sciences like biotechnology now provide the tools for the transfer of specific DNAs into new cultivars. Similarly, protoplast fusion can be utilized to reconstitute a new cytoplasmic base from the existing diverse cytoplasms, to produce more productive cytosteriles. The sequencing of the DNA of the diverse sources of dwarfing, for example, to distinguish common and contrasting features, will aid the incorporation of multiple sources of efficient physiological mechanisms. Genetic analysis at the molecular level, as is being done in soybean about the basic processes of nodulation using nonnodulating, supernodulating, and normal genotypes, can be applied to other leguminous crops. The inhibitors produced by the shoot in localizing nodulation in soybean helps us to better understand transcription and translation mechanisms in the genetics of nodulation. A similar evaluation in chickpea, pigeonpea, and groundnut is recommended.

Among the drought-tolerant landraces, stage-specific resistance (rather than resistance over the entire growth period) is common at the seedling, mid-season, or terminal stage, as in some of the upland rices in India. Since such stage-specific adaptations are due to diverse physiological mechanisms, integrating those genes into one genotype to face the random drought in SAT countries requires biotechnological expertise for specific DNA transfer.

Landraces as Genetic Components of Stability

An analysis of the parentage of the widely adapted high-yielding cultivars indicates that the pooling of the diverse gene blocks for adaptation from different landraces have contributed to their wider adaptation to various stresses. Such examples are IR 60, IR 36 and IR 42 in rice; C 306, HD 2189, Chenab 70, Sholey and Bijiga yellow in wheat; JG 62, BG 203, G 130 and K 850 in chickpea; CSH 5, CSH 9 and CS 3541 in sorghum; BK 560, WC-C 75, Pusa 23 and ICMH 423 in millet, to mention a few. There is need for an indepth study of these mechanisms of adaptation.

Cytoplasmic constituent stability is evident in protoplast fusion products and for reciprocal crosses involving only female parent. The conversion program needs to take this into consideration. The analysis of the mt DNA isozyme pattern in landraces will be necessary to characterize these genetic stocks more precisely.

The genetics of characters associated with adaptation in landraces needs to be studied in crosses between landraces and high-yielding cultivars and the information included in the documentation on the landraces. The sequencing of DNA of landraces with specific adaptation, e.g., salt and drought tolerance, will be useful.

The genetic diversity in natural populations with specific or wide adaptation can be assessed by the Markov process of estimating nucleotide substitution rates. Generally, natural mutation rates are very high under some specific ecological conditions. Such an analysis would be worthwhile in the Rajasthan and Ghana collections of pearl millet, the sorghums of Sudan and Ethiopia, and the chickpeas of Ethiopia and South Iran, which are all adapted to severe environmental stress. Simulation studies using available data on specific isozyme loci will be useful supplements in analyzing adaptation in specific world collections.

Genetic Analysis of World Collections

To understand the mechanisms of adaptation and evolution particularly in landraces, more genetic information needs to be obtained during the evaluation process. The following approaches must be considered.

- Use of RFLP as genetic markers and their polymorphism analyzed for assessment of diversity between location-specific widely adapted accessions will be of use.
- Cytoplasmic differentiation can be examined by analyzing organelle DNA with emphasis on mt DNA rather than ct DNA, and looking for unique types of mt DNA in indigenous races, as is being done in maize.
- Simple and complex probes in RFLP studies to trace the contribution of different landraces to the germplasm used in the breeding program will be useful supplements to organelle-DNA analysis.
- Work on protoplast fusion to produce cybrids from diverse cytoplasms needs to be strengthened. These cybrids can be examined for mt DNA and ct DNA recombinants. If these cytoplasmic constituents are stable, it is possible to maintain the functional diversity of the protoplast fusion products without disrupting the adaptative gene blocks in mt DNA.

Diversification of Genetic Base in Plant Breeding Programs

The diversity in present-day advanced lines in regional trials indicates that the gains already realized by the limited use of genetic resources in the released cultivars can be accelerated by a sustained effort for a wider genetic base. Although several varieties were released during the past 15 years (322 in rice, 167 in wheat, 46 in maize, 40 in sorghum, 32 in pearl millet, 68 in chickpea, and 65 in groundnut), only a few are extensively grown by farmers and all these are releases of a decade or longer. For example, Sonalika, released in 1965 is still the most popular wheat cultivar followed by HD 2285, HD 2329, HD 2189, and HD 2009 released during 1974-79. A similar situation exists in rice with IR 36, IET 1444, Mashoore, and IR 20 released during 1966-81. Ratna, the upland rice released in 1970 is yet to be replaced by a better variety. In sorghum, CSH 5 and CSH 9 released in 1974 and 1981 are the ruling hybrids. In pearl millet, BK 560 released in 1975 is still popular, followed by WC-C 75 of 1982. In maize, Ganga 5, and some others, released 10-15 years ago, are still

extensively grown. While the stability of such varieties over long periods is interesting, their adaptation mechanisms are not adequately understood. The genetic architecture of the subsequently released cultivars must be studied if they are to contribute to a diversified genetic base. Some of the recent pearl millet hybrids, e.g., Pusa 23, ICMH 451, and ICMH 423, are the results of such a planned diversification based on studies of adaptation under stress. Utilization patterns of the large collections already available, and the limited and uneven field performance of varieties released in the last decade must be carefully studied. An analysis of their pedigree and selection methodology is necessary for the introduction of new genes from other sources in the world collection, to remedy the above situation.

An examination of the parentage of the advanced lines in the regional trials during 1987-88 has indicated the genetic constraints limiting their productivity. Of 620 wheat entries, a majority are based on four varieties, HD 2009, HD 2160, HD 2281, and S-308, which are themselves of a complex parentage. It is necessary to further widen the base if the present yield barrier is to be broken. The use of more winter wheats or intermediate forms in crossing is proposed. In rice too, a similar situation appears to exist. In the case of sorghum and millet, further success will depend on the diversification of the cytoplasmic base as the present conversion of male steriles are restricted to one cytoplasmic source. The postrainy-season sorghum improvement is still to take off. The widely used material from Sudan, Ethiopia, Cameroon, Yemen, and Nigeria should be considered along with Maldandi lines and Central Indian materials. It is necessary to characterize the important genetic resource, i.e., cytoplasm, biochemically and at the molecular level by fractionating mitochondrial DNA for further manipulation of productive cytosteriles.

Even among the legumes, e.g., chickpea, where considerable hybridization has taken place over the past 15 years, the advanced lines under testing are mostly based on five varieties: G 130, C 214, BG 203, K 850, and C 235. The best lines with consistent performance over the past 3 years are only two, WBL 12 and GZ 769. The yield difference in the Central Zone between the checks (1300-1500 kg ha^{-1}) and the advanced lines (950-1665 kg ha^{-1}) is very small, much below the expectations based on a wide crossing program. An analysis of their parental lines and infusion of other genotypes from the world collection is called for.

It is interesting to compare the yield advances made in sorghum and millet where considerable effort was made to mobilize world collections with those of upland rice and rainfed wheat where large collections are also available. In the IET trial under timely sowing, of 25 entries of durum wheat, the control Meghdoot yielded 1620 kg ha^{-1} as against the mean of 1530 kg of all the other entries. In the rainfed bread wheat trial in the Eastern Zone, C 306, the check released over 30 years ago yielded 1900 kg ha^{-1} compared to 1960 kg ha^{-1}, the mean of the six entries, the difference not being significant. The rainfed regional trial revealed that NI 5439, a check, yielded 1600 kg ha^{-1} compared to 1200-1370 kg of the other best five entries. The yield performance in the upland rice program was similar to that of rainfed wheat. It would appear that a greater effort in rainfed wheat and rice can be effective only if the available genetic resources including the new collections are mobilized as is being done in sorghum and millets.

Overcoming Some Constraints in Mobilizing Genetic Resources

Greater attention by both National and International Genetic Resources organizations may be considered on the following aspects of generation of material for regional problems, testing in contrasting environments, with emphasis on feedback on the evaluation of working collections in multilocation testing.

- Evidence is accumulating that stress tolerance to biotic and abiotic factors and high yield potential are likely to be due to independent mechanisms. Simultaneous screening of world collections for biomass, yield potential and stress tolerance in specific stress environments is needed.
- Intermediate forms including natural and man-made introgression products can be treated as genetic stocks for evaluation as revealed by the utility of such forms as *Pennisetum typhoides* × *P. violaceum* in the sub-Saharan regions. These products retain their adaptation to stress and are far more useful to breeders than the products of synthetic species hybrids.
- Creation of complex hybridization products involving several landraces and intermediate forms of introgression, and their supply to regional centres for selection in local conditions will accelerate the mobilization of germplasm. Feedback on this testing can be incorporated in the documentation.
- Creation of gene pools for groups of important characters in cross-pollinated crops will permit easy management of the genetic material and availability for ready use, which is difficult for individual accessions. Diverse sources of cytoplasms (cytosteriles) can be used to create such gene pools in both self- and cross-pollinated crops. This will also promote recombination on a wider scale.
- Regular exchange of information between users and genetic resources units on regional problems needing identification of suitable genotypes, decentralization of generation of material, and testing of core collections in contrasting environments will accelerate the mobilization of the several useful stocks already identified.

While logistic difficulties exist in the evaluation of large collections over several locations, it is desirable to evaluate representative core collections in multi-environmental testing to understand the mechanisms of adaptation for a set of important variables like root activity, maturity, growth pattern, duration of flowering grain filling, disease and pest resistance, and related physiological parameters. This is necessary if one is to comprehend the totality of G × E interactions of all these variables taken together. This is possible using multivariate procedures like multidimensional scaling and principal coordinates analysis combined with regression analyses as was attempted recently in maize. Simulation studies using the existing data on character combinations in the world collections can be used to predict a plant type with higher production potential and adaptation, or to formulate a set of useful ideotypes in tropical legumes and oilseeds where the present efforts of restructuring the plant type are meeting with only limited success.

The importance of genetic resources for the future of mankind cannot be minimized, as illustrated above, particularly with the fluctuating production of food crops in several semi-arid tropical regions, and even in USA, where the recent drought attributed to the greenhouse effect has been devastating. With the identification of specific genes and genotypes after critical evaluation of the world collections, and the

utilization of modern tools, it is not difficult to transfer several useful genes into present-day cultivars to achieve the next breakthrough in the yield barrier. It must therefore be concluded that the available world collections offer genetic diversity of great potential for increased and sustainable crop productivity.

IBPGR's Objectives and Plan of Work in South and Southeast Asia

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Past Achievements

The International Board for Plant Genetic Resources (IBPGR) was formed by the Consultative Group on International Agricultural Research (CGIAR) in 1974 to focus on collecting threatened germplasm and establishing facilities and methods for long-term conservation through a coordinated international network. Some of its major past achievements are:

- The development of a global network of gene banks to conserve this germplasm. At present, the network comprises over 50 effectively operating gene banks in developing and developed countries.
- The stimulation of other institutions on national, regional, and international levels to assume the responsibility to collect, characterize, and store plant genetic resources. These gene banks now operate in over 100 countries and range from emergent national entities to highly sophisticated centers in the CGIAR.
- The establishment of priorities by species and regions for the collection of threatened germplasm. Over 400 collection missions worldwide were organized and/or supported.
- The support to train some 1300 individuals in all aspects of genetic resources conservation and utilization.
- The standardization of characterization and evaluation work through the production of descriptor lists for all major crop species.
- The publication and dissemination of scientific reports, directories, and newsletters.

IBPGR's Extended Mandate

In 1986 the CGIAR approved an extended mandate to enable IBPGR to catalyze whatever actions were needed to support and widen the already existing global genetic resources network. This mandate is:

> "To further the study, collection, preservation, documentation, evaluation, and utilization of the genetic diversity of useful plants for the benefit of people throughout the world. IBPGR shall act as a catalyst both within and

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outside the CGIAR system in stimulating the action needed to sustain a viable network of institutions for the conservation of genetic resources for these plants".

After focussing for a decade or so on collecting priority crops and establishing a network of base collections through direct technical and scientific support as well as training, IBPGR started reorganizing its program and staffing to meet the new requirements. The need for strategic and appropriate research in plant genetic resources conservation and utilization is being fully recognized and this is reflected in the establishment of a Research Program.

Basic Program Structure

The basic program components of IBPGR are, for administrative and management reasons, organized in three major thrusts: administration, field program, and research. The nine components and their major elements are listed below.

1. Administration – support for all IBPGR activities, operations, committees, etc.
2. Technical services – provision of technical support and information to all staff and the scientific community; public affairs, publications, and library.
3. Global genetic resources network – developmental activities with the centres, including fostering base and active collections, and data management and transfer.
4. Germplasm acquisition – monitoring degree of genetic erosion, collecting threatened germplasm, supplementing existing gaps in germplasm, and facilitating germplasm flow on a global scale.
5. Germplasm characterization and evaluation – standardization of procedures to process, store, and distribute characterization and evaluation data. Data acquisition, data analysis, application, and evaluation strategy are the program elements.
6. Training – the development of conceptual, technical, and managerial skills through support of manpower training. This involves postgraduate training, specialized short technical courses, individual training, and intern fellowships.
7. In vitro culture research – development of in vitro techniques for the collection, conservation, and exchange of genotypes for "recalcitrant" species, including collection and tissue culture technology, disease indexing and therapy, cryopreservation, genetic stability, and a pilot study for in vitro gene banks.
8. Genetic diversity research – to enhance our understanding of the origin, evolution, and variation patterns of crop gene pools. This includes species mapping, ecogeographic studies, development of biochemical methods of description, and research on wild relatives in priority crop gene pools.
9. Seed conservation research – to establish and implement standards for seed storage. This effort includes study of physiology of stored seeds, their genetic stability, dormancy, regeneration, and genetic integrity, as well as nondestructive disease indexing.

Work Plan of the IBPGR Office for South and Southeast Asia

To enable IBPGR to function more effectively, a series of offices around the world have been established. Two new offices were opened in Asia in 1988, one in New Delhi for South and Southeast Asia (replacing the previous office for Southeast Asia in Bangkok), and the other one in Beijing for China and East Asia. Besides facilitating and/or coordinating field activities in areas of great genetic diversity, these offices will:

- Advise, assist, and stimulate national programs on plant genetic resources in their endeavor to conserve and utilize genetic resources.
- Initiate, coordinate and/or catalyze regional activities, especially in the field of collecting and characterizing germplasm.
- Participate in scientific work to strengthen national efforts, including hands-on demonstrations, maintenance of IBPGR standards for germplasm conservation, monitoring of genetic erosion, gathering information, and periodic assessment of activities.
- Establish and update computerized databases for plant genetic resources activities in each country of the region.
- Liaise with the International Agricultural Research Centers (IARCs), FAO Commission, bilateral funded genetic resources projects, and relevant nongovernmental organizations.
- Participate in and/or coordinate regional meetings, workshops, training courses, etc., and assist in their organization.
- Provide a scientific evaluation of all field project proposals submitted from the region for IBPGR support.

The following specific activities are planned by the IBPGR Office for South and Southeast Asia for the near future:

- Assist in the establishment of national plant genetic resources programs in countries like Bhutan, Kampuchea, Laos, and Vietnam.
- Assist and advise recently established national gene banks to become fully operational (i.e., Sri Lanka, Burma, Thailand, and Philippines).
- Analyze past collection activities, define existing "gaps" and collect germplasm, especially wild species and/or landraces of priority crops accordingly (i.e. *Vigna* spp, aroids, allium, okra, eggplant, *Brassica* spp, *Mangifera* spp, *Musa* spp, *Citrus* spp, sugarcane, rice, and maize), but give also due emphasis to national/regional priorities and needs (i.e. minor crops).
- Assist and activate the development of a global crop network in the region by coordinating global collection, conservation, and utilization activities which IBPGR will help to establish. Priority will be given for the time being to banana, groundnut, okra, sweet potato, and safflower.
- Encourage and support the use of locally adapted germplasm in the national breeding programs.
- Organize regional training courses on genetic resources management aspects which lack trained personnel.
- Coordinate genetic resources activities with the IARCs in complementing rather than duplicating their efforts.

- Foster the free flow of germplasm between the member states of the region as well as with the rest of the world.
- Publish regularly (perhaps quarterly) a continental Asian Germplasm Bulletin; assist in the publication of relevant national or regional scientific findings in the field of germplasm conservation, evaluation and utilization.
- Initiate relevant applied research activities and help build up local research capabilities.
- Pursue the implementation of the activities laid down in the Memorandum of Understanding between the Government of India and IBPGR.

Session III: Germplasm Exploration, Collection, Evaluation, Documentation, Exchange, Quarantine, and Conservation

ICRISAT/NBPGR Collaborative Exploration Program

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India is extremely rich in plant genetic resources. This subcontinent is a center of diversity for the ICRISAT mandate crops, among which a great deal of variability occurs. The area is also known for its richness in wild species, particularly of pigeonpea. Considering the region's potential as a gene center, NBPGR and ICRISAT have been operating for well over a decade in different areas of the country, to collect native variability, primitive cultivars, wild species, etc., so as to enhance the existing genetic wealth. With the common objective of tapping germplasm resources, specifically of the ICRISAT mandate crops which are also of national priority, GRU-ICRISAT and NBPGR-ICAR worked out a joint strategy in 1985 for exploration and evaluation within India, and a 5-year program was framed. The effort made to collect germplasm during 1986-88 is discussed.

Priority Areas for Exploration

ICRISAT and NBPGR have jointly worked out the areas for germplasm collection keeping in view the threat of genetic erosion, distribution of native types, wild species, etc. Some of these areas are contiguous agroecological zones, others are more sporadic, ecologically diverse, exacting habitats. Major priority areas for exploration for ICRISAT mandate crops, their wild relatives, and related species are as follows.

Sorghum (*Sorghum bicolor* (L.) Moench). Eastern Uttar Pradesh, northern Bihar and adjacent West Bengal, Adilabad and adjoining areas in Andhra Pradesh and Maharashtra, the Jhabua district in Madhya Pradesh and adjoining hilly areas, northwestern sub-Himalayan region, northeastern hilly regions, and the plains of Assam.

Pearl millet (*Pennisetum glaucum* (L.) R.Br.). Western Rajasthan, Gujarat, Madhya Pradesh, northern Uttar Pradesh for cultivated, and peninsular region, northwestern sub-Himalayan region, Orissa, Bihar, West Bengal and Maharashtra for wild species.

Chickpea (*Cicer arietinum* L.). Rajasthan (around Ganganagar), northwestern Himalayas (wild types), Gujarat (Junagadh), Bihar (Sabor), and Maharashtra.

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Pigeonpea (*Cajanus cajan* (L.) Millsp.). Western Ghats, eastern/northeastern hills (wild species), north Bihar and eastern Uttar Pradesh, north Karnataka (for garden types) and eastern Maharashtra, Madhya Pradesh, and Orissa.

Groundnut (*Arachis hypogaea* L.). Haryana, Rajasthan, Madhya Pradesh, Uttar Pradesh, and Bihar (sporadic in central and southern peninsular tract).

Explorations Undertaken and Diversity Collected

So far ICRISAT and NBPGR have launched 11 expeditions in 10 different states of India and have collected 2202 samples of ICRISAT mandate crops and their wild relatives comprising sorghum (364), pearl millet (913), pigeonpea (100), chickpea (412), groundnut (200), and minor millets (213). These are detailed in Table 1 and are discussed below.

Table 1. Germplasm collection missions launched jointly by ICRISAT and NBPGR and number of samples collected, 1986-88.

		Number of samples[1]						
State(s)	Year	SG	PM	CP	PP	GN	MM	Total
Rajasthan and Haryana	1986	-	111	-	-	25	-	136
Andhra Pradesh, Bihar, Orissa and Madhya Pradesh	1986	177	32	5	16	30	88	348
Madhya Pradesh	1986	-	-	198	28(2)	-	-	228
Madhya Pradesh	1987	-	-	157	51(1)	-	-	209
Karnataka	1987	40(1)	181(5)	2	1	16	18	264
Tamil Nadu and Kerala	1987	-	4	-	-	126	2	132
Tamil Nadu	1987	18	270(8)	-	1	-	46	343
Tamil Nadu	1987	115(13)	8	-	-	-	16	152
Gujarat	1988	-	-	50	-	-	-	50
Coastal Andhra Pradesh	1988	-	93	-	-	3	43	139
Haryana	1988	-	201	-	-	-	-	201
Total		350(14)	900(13)	412	97(3)	200	213	2202

1. SG: sorghum, PM: pearl millet, CP: chickpea, PP: pigeonpea, GN: groundnut, and MM: minor millets.
2. Figures in parentheses refer to number of wild relatives.

Sorghum

The expedition to the predominantly tribal-inhabited areas of Andhra Pradesh, Bihar, Orissa, and Madhya Pradesh in November 1986 resulted in the collection of 177 samples of sorghum, a majority belonging to the races "guinea" and "roxburghii". They grow over 3 m tall without tillers and the inflorescences are large and loose with drooping branches. The clasping glumes expose the small white grain. The Bastar area appears to be a transitional zone for the races roxburghii, guinea, and durra. *Panicum sumatrense* and *Paspalum scrobiculatum* are extensively grown in the tribal areas of Orissa and Bihar. *Pennisetum pedicellatum* is found in most of the areas along the roadside and on the bunds. *P. hohenackeri* locally called "upiri" around Bastar is used to make ropes. Other collections made during this exploration included pearl millet (32), pigeonpea (16), chickpea (5), groundnut (30), and 88 samples of minor millets.

The hilly/subhilly parts of Annamalai in Tamil Nadu were surveyed in December 1987 to collect wild relatives and primitive cultivars of sorghum. Collections include 115 samples of primitive cultivars of sorghum belonging to races guinea, bicolor, and durra, and 13 samples of wild sorghum which included a rare wild type, *S. nitidum*. Eight samples of pearl millet and 16 of minor millets were also collected.

Pearl Millet

The collection mission to the dry areas of the northern and eastern districts of Karnataka during Oct-Nov 1987 yielded 264 samples of which 181 are cultivated pearl millet. It is grown mixed with pigeonpea, groundnut, or moth bean. Most of the pearl millet samples appear to be dual-purpose types grown both for grain and fodder. The incidence of downy mildew and ergot on pearl millet was sporadic. Other germplasm collected include 40 sorghum, 2 chickpea, 1 pigeonpea, 16 groundnut, and 18 minor millets samples besides wild relatives of *Pennisetum* (5) and Sorghum (1).

A pearl millet collection mission to Tamil Nadu during December 1987 yielded 270 cultivated and 8 wild samples of *Pennisetum*, 18 sorghum, 1 pigeonpea, and 46 minor millets samples.

A joint exploration to the northeast coastal areas of Andhra Pradesh during September 1988 resulted in the collection of 93 early maturing pearl millet and 43 finger millet samples. Both pearl millet and finger millet are transplanted in furrows opened by a wooden plough. Farmers believe that raising a nursery of seedlings offers better weed control, good crop stand, and reduces crop duration in the main field. The early maturing pearl millet is called "pittaganti".

Haryana, an important pearl millet growing state was jointly explored during Sep-Oct 1988. Primitive cultivars are still grown in isolated remote areas, especially on sand dunes around Loharu, Narnaul, Chiriya, and other areas. A primitive type called "bajri" grows to a height of about 125 cm, produces many very thin stems with sequential maturity of spikes. The spikes are very small, thin, seeds are loosely arranged, and the glumes almost cover the small oval grain. A dual-purpose form called "dholsari" is grown around Choudhari-ki-Nangal for grain and fodder. It grows

over 3 m tall, produces very thick stems and dark green leaves. The spikes are thick and medium sized. Further, some special forms which produce spikes more than 40 cm long were found around Narnaul, Pilani in Rajasthan, and in some isolated areas. Smut was very common, probably due to heavy rains during flowering. Since improved cultivars and local landraces are grown in adjacent fields, there is scope for exchange of genes between the two forms. Recombinants with desirable characters could be useful in millet improvement.

Chickpea

In 1986, an expedition was organized to western Madhya Pradesh during which 198 chickpea samples were collected, representing large-seeded, gulabi (suitable for parching), kabuli, tuberculated seed-surface types, and twin-podded types. Some 28 pigeonpea and 2 *Atylosia scarabaeoides* samples were also collected.

A survey of the eastern part of Madhya Pradesh in 1987 in collaboration with Jawaharlal Nehru Krishi Viswa Vidyalaya (JNKVV), Sehore, resulted in collections of 157 chickpea samples comprising tuberculated-seed (katila), typical desi, "peela chana", gulabi, twin-podded ("do ghanti"), large-seeded desi (dabbo), and kabuli types. Collar rot was observed to be an important disease of chickpea in Madhya Pradesh. Crop losses due to *Alternaria* blight and excessive vegetative growth were also seen around Jabalpur. Diverse types of pigeonpea (51 samples) and a sample of *Atylosia scarabaeoides* were also collected.

In 1987, the Zanskar valley in the Ladakh region was surveyed to collect genetic diversity in *Cicer microphyllum*. Samples from 14 different populations were collected. Collections made represented variability in seed size (medium bold/small types), seed color (deep black to brown), and pod-bearing potential.

The coastal areas in Gujarat - Junagadh, Amreli, Bhavnagar and Ahmedabad districts were explored and 50 seed samples collected during March 1988, in collaboration with the NBPGR regional station, Jodhpur and Gujarat Agricultural University, Junagadh.

Pigeonpea

Pigeonpea germplasm was collected mainly from Madhya Pradesh, during explorations undertaken to collect chickpea in 1986-87. An effort was also made in Meghalaya to locate *Atylosia elongata* during 1987-88. Recently, this was located in its natural habitat and collection of ripe pods, etc. will be made in the future.

Groundnut

A collection mission to the groundnut-growing areas of Tamil Nadu and Kerala during Nov-Dec 1987 resulted in the collection of 132 samples which included 126 groundnut, 4 sorghum and 2 finger millet.

Geographic Diversity and Adaptation

Considerable diversity was observed in the germplasm collected which might have evolved to adapt to the diverse agroclimatic conditions in India. For example, very early maturing types with profuse nodal tillering were grown on the sand dunes of Haryana and Rajasthan where soil moisture is a limiting factor. In contrast, the long-duration types of sorghum and pearl millet grown in the tribal areas of the Estern Ghats escape grain molds by maturing after the rains cease.

Future Emphasis

The untapped/underexplored and other promising areas will be surveyed for germplasm collection. An exercise to this effect has already been initiated by NBPGR and ICRISAT. The collection of wild species should be emphasized. Some areas of variability, particularly the sub-Himalayan hilly tracts in western/northeastern regions, would need thorough surveying. Another promising area for sorghum and pigeonpea germplasm would be the Indo-Burma border, in Arunachal Pradesh, Nagaland, Manipur, and Tripura. NBPGR recently opened two more centres at Ranchi and Srinagar and these stations will also undertake exploration. Thus, apart from the Headquarters Exploration Division, 11 Stations will undertake germplasm collection based on the program for the 5-year period. Joint efforts by ICRISAT and NBPGR should prove rewarding in this time-bound venture.

ICRISAT/NBPGR Joint Evaluation of Germplasm in India

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A joint ICRISAT/NBPGR program to evaluate the germplasm of ICRISAT mandate crops was started from the 1986 rainy season. The trials were conducted at NBPGR's Headquarters at New Delhi and its regional stations at Akola, Jodhpur, Trichur, and at other centers according to the plan. The details of individual crops for each year are discussed below.

Sorghum

Sorghum germplasm was evaluated for photoperiod sensitivity, forage, and for use as a dual-purpose crop.

Evaluation for Photoperiod Sensitivity

Two thousand accessions of photoperiod-sensitive sorghum were grown at Hisar (29° 10'N, 75° 44'E) and Trichur (10° 15'N, 76° 18'E) during the 1986 rainy season. At Trichur, only 964 entries survived up to the flowering stage, while 110 entries flowered within 120 days. In others, flowering ranged from 126-180 days. Nineteen characters were studied: early seedling vigor, days to 50% flowering, mean number of flowering stems (basal tillers), nodal tillering, stem thickness, number of nodes, internodal exposure, phyllotaxy, presence of stilt roots, plant height, head exsertion, head compactness and shape, head length, head width, number of leaves, plant aspect score, leaf width, grain yield per plot, and natural incidence of diseases and insect pests. The same accessions were again grown during the 1987 rainy season for evaluation of their photoperiod sensitivity. A total of 1957 collections survived, of which 156 did not flower under local conditions. They remained stunted and died before flowering. Flowering in others ranged from 49-201 days. Plant height ranged from 100-400 cm, total number of leaves varied from 7-35, inflorescence length ranged from 5.1-75.0 cm, inflorescence width from 10-35 cm, and leaf width from 1.1-13.0 cm. In general, flowering was delayed by at least 15 days as compared to ICRISAT Center, and it was decided that Hisar was not a suitable location for evaluation of photoperiod-sensitive germplasm.

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Evaluation of Forage, Grain, and Dual-Purpose Types

One thousand and five hundred accessions of forage sorghum were evaluated for fodder yield and its components at four locations i.e., Issapur (near Delhi), Hisar, Jhansi, and Akola during the 1986 rainy season (Table 1). Thirteen characters were proposed for study: early seedling vigor, days to 50% flowering, basal tillering, culm branching, culm thickness, number of leaves, leaf length, leaf width, midrib color, plant height, stalk juiciness, juice quality, and forage yield (in kg m row^{-1}). Data were recorded for almost all the characters at all the locations. Based on the data, 147 dual-purpose types were selected and were again tested at Issapur during the 1987 rainy season. Screening was also done against foliar diseases (including gray leaf spot, anthracnose and zonate leaf spot), grain mold, stem borer and shoot fly. Under natural conditions, nearly 89 lines were found to be resistant to foliar diseases, 50 lines to grain mold, 181 to stem borer, and 212 to shoot fly. It was also observed that at these locations, most of the germplasm from India and the Yemen Arab Republic were better for forage yield compared to germplasm from Africa. Hence it was decided that during the 1987 rainy season all the material of Indian origin and some more promising material from the Yemen Arab Republic should be tested for forage yield and its components at Issapur.

Accordingly, during the 1987 rainy season, 4430 germplasm accessions comprising 4105 from India, 178 from the Yemen Arab Republic, and 147 dual- purpose accessions identified from the 1986 multilocational evaluation trials were grown at Issapur. Some 320 accessions did not flower, being photoperiod sensitive. Another 300 accessions did not set seeds properly. A good amount of variability was observed for days to 50% flowering (49-175 days). IS 22092 was the earliest (49 days) to flower while IS 1556 was very late (175 days). Plant height ranged from 45 cm (IS 21960) to 333 cm (IS 4107). Stem diameter ranged from 0.30 cm (IS 3226) to 3.56 cm (IS 4593). Number of leaves per plant ranged from 7 (IS 4505, 5267) to 36 (IS 4280). Leaf length ranged from 31.33 cm (IS 5236, 1416) to 97.66 cm (IS 5236, 1416). The leaf width ranged from 2.55 cm (IS 1572) to 11.56 cm (IS 4164).

Table 1. Range of variability exhibited by 1500 forage sorghum accessions in multilocational trials, rainy season, 1986.

	Range			
Characters	Jhansi	Hisar	Akola	Issapur
Days to 50% flowering	37-191	35-90	59-1635	48-122
Plant height (cm)	11-438	69-330	47-299	60-392
No. of leaves	8.0-85	5.0-20.0	5.0-21.0	6.5-50
Leaf length (cm)	16.0-152.2	15.0-98.0	20.0-98.0	41.2-105
Leaf width (cm)	1.7-10.8	2.0-10.9	2.0-11.0	2.9-9.4
Stem thickness (cm)	0.5-9.8	-	-	1.6-4.8
Fodder yield (kg m row^{-1})	0.15-9.8	-	0.16-4.0	-

On the basis of overall scoring, 72 forage types were identified. The most promising early flowering lines were IS 4234, 4240, 5376, 5377, and 5481. In the medium-maturity range types, 13 promising accessions were identified of which 6 accessions were from India (IS 6005 to 6006). In the late-maturing types, 3 nonsenescing lines, i.e., IS 3912, 3913, and 3914 were identified as promising. Thirty five accessions were also identified as dual-purpose types. Some of the most promising accessions were IS 24329, 24330, 24331, 6327, 6328, 6329, 5528, and 1560. Five promising tillering types were also identified (IS 4231, 4232, 4276, 6275, and 6270). All the accessions except IS 1087 had nodal tillering. Based on field screening, about 50 lines for overall leaf diseases, 40 lines for grain mold, and 60 lines for stem borer and shoot fly infestation were found resistant.

A set of promising selections for forage was sent to the National Research Center for Sorghum (NRCS), Rajendranagar for testing and utilization in the breeding program.

In collaboration with the All India Coordinated Sorghum Improvement Project (AICSIP) the "Kharif Basic Collection" of germplasm has been evaluated for grain at five locations: Coimbatore (Tamil Nadu), Akola (Maharashtra), Indore (Madhya Pradesh), NRCS, Rajendranagar, and ICRISAT Center, Patancheru. The most promising lines have been selected by sorghum breeders for further testing and use in breeding programs.

Pearl Millet

During the 1986 rainy season, 2000 pearl millet germplasm accessions were grown and evaluated at Jodhpur and Pune. Fourteen characters were proposed for study: early vigor, days to 50% flowering, green fodder-yield potential, number of productive tillers, plant height, ear exsertion, spike length, spike thickness, seed set, yield potential, overall plant aspect, grain shape, grain weight, and scoring for prevalent diseases. The data from Pune were not received by NBPGR. The germination at Jodhpur was fairly good. Marked differences in vegetative growth were observed after 1 month of sowing. The plant height ranged from 78-176 cm. Based on overall tillering, leafiness, and vegetative bulk, 12 accessions were judged as the best fodder types. Most of the accessions flowered between 41 to 65 days. On an average, 4-6 productive tillers plant^{-1} were observed. The spike length varied from 16-32.2 cm with thickness ranging from 14 to 22 mm. Variation was also observed in seed shape and size. Twenty accessions with bold seeds were identified. The average seed yield plant^{-1} ranged from 2-16 g, and 80 accessions were identified as the best grain yielders. Ninety five accessions were found highly susceptible to leaf spot caused by *Curvularia penniseti*.

During the 1987 rainy season, 1960 accessions, consisting of collections from Africa, Australia, India, Latin America, Middle East, and USSR were grown at Issapur, and data gathered according to the decided descriptors. The germplasm at Jodhpur could not be sown due to lack of rain. Some 250 good fodder types, 156 good grain types, 54 very early types were identified at Issapur. Another 41 were identified as promising in terms of overall plant aspects. The material showed good range of variation for days to 50% flowering (35-114 days), plant height (50-377 cm), number of

tillers plant^{-1} (1-12), number of productive tillers plant^{-1} (1-10), spike length (8-92 cm), and spike thickness (0.5-4.5 cm).

Pigeonpea

Three sets of germplasm were evaluated. The extra-early and early accessions were evaluated at Issapur whereas the medium and medium-late type accessions were evaluated at Akola. The accessions were scored for 17 descriptors: seedling vigor, nodulation, days to 50% flowering, days to 75% maturity, base flower color, flowering pattern, growth habit, plant height, number of primary branches, number of secondary branches and racemes, number of seed pod^{-1}, seed weight, plant weight, shelling ratio, yield plant^{-1}, and plant stand.

In 1986, a set of 479 accessions (128 extra early, and 351 early were evaluated at Issapur and 18 promising lines were identified. The protein content of 25 accessions was analyzed, and found to vary from 18.4-24.8%. At Akola, the following ranges of variability were observed for 353 germplasm accessions. Days to flowering: 102-157, days to maturity: 146-209; plant height: 76.5-197 cm; number of primary branches: 3.02-20.0; number of secondary branches: 2.6-28.6; raceme number: 2.3-24.0: number of seeds pod $^{-1}$: 2.1-5.0; 100-seed weight: 6.0-18.18 g; biological yield plant $^{-1}$: 13.3-258.3 g; shelling ratio: 35.29-92.02%; and yield plant^{-1}: 2.3-94.08 g. The high-yielding lines identified were ICP 6656, 7059, 7257, 8654, 8706, 9048, 9285, 10258, 12283, and NP (WR 15).

During 1987, a set of 350 accessions comprising 126 extra-early and 244 early types were evaluated at Issapur. The germination was very good, but the crop suffered severely due to drought. However, 33 germplasm accessions performed better of which 15 were good grain types, and 4 vegetable types. At Akola, 300 medium- and medium late-maturing types were evaluated and 15 promising types were identified. Two hundred accessions of long-duration pigeonpea were also grown at Jorhat for evaluation during 1987.

Chickpea

A set of short-duration chickpea was sown at ICRISAT Center and Akola while another set of long-duration types was sown at Gwalior, Issapur, and Jodhpur. These lines were evaluated for 14 characteristics: seedling vigor, days to flowering, nodulation, plant canopy height, growth habit, biomass, score for diseases, days to maturity, branching, number of pods plant^{-1}, seeds pod^{-1}, seed size, plot yield, and plant type. Each germplasm set consisted of 1320 lines. During 1986/87, at Jodhpur and Issapur, the agronomic performance of the crop was poor due to soil factors and it was decided to evaluate the same set of germplasm during the 1987-88 postrainy season. However, when the same set of accessions was sown at Gwalior, crop performance was very good and most of the accessions could be evaluated satisfactorily. Five accessions (ICC 148,

327, 1034, 1083, and 1341) yielded over 3250 kg ha^{-1} and this score was better than any of the check cultivars included.

At Akola the following lines were found promising and high-yielding: ICC 5685, 5702, 5792, 7497, 8611, 8613, 8628, 10962, 10969, 10979, 11038, 11054, 11192, 12269, 12518, 12597, 12636, 12651, 12777, 12791, and 12797.

During the 1987/88 postrainy season at Akola, of the 1320 lines tested, the best 5 accessions were ICC 5784, 6072, 10388, 11047, and 12241. The boldest seed was observed in ICC 5769 (38.7 g 100 $seeds^{-1}$), days to flowering ranged from 42 (ICC 4934) to 106 days, plant height 20.5 (ICC 6042) to 62.7 cm (ICC 12237), and days to maturity 96 (ICC 7498) to 146 days (ICC 5760). During both crop seasons, the evaluation experiments at ICRISAT Center performed satisfactorily and meaningful data were obtained on most accessions.

Groundnut

Two thousand accessions of groundnut were grown at Jodhpur during the 1986 rainy season. Observations on 14 characters were recorded: days to emergence, days to 50% flowering, days to maturity, growth habit, stem branching pattern, plant width, leaf color, number of seeds pod^{-1}, seed color, split testa, 100-seed weight, pod yield, seed yield and plant stand. Days to 50% flowering varied from 34-47 days. Some of the high-yielding lines identified were: ICG 551, 606, 608, 609, 659, 724, 725, 817, 882, 883, 884, 891, 980, 1084, 4005, 4021, 4027, 4047, 4070, 4087, 4127, 4131, 4137, 4588, 4589, 4682, 4683, 4712, 7389, 7843, 8351, 9594, 9597, and 10751.

During the 1987 rainy season, 1500 collections including 723 erect bunch types, 391 spreading bunch types, and 386 runner bunch types were evaluated at Akola and Jodhpur. At Jodhpur, the experiment was damaged due to drought.

The groundnut evaluation at Akola was satisfactory. The following spectrum of variations were recorded: days to flowering: 23-35 days; maturity: 103-129 days, and pod yield row^{-1}: 1.5-43.5 g.

In all, 69 lines were found promising against leaf anthracnose (*Colletotrichum dematium*) and 'Tikka' disease (*Cercospora* sp), while 51 lines were found resistant to groundnut leaf miner (*Stomopteryx* sp).

Germplasm under Evaluation for 1988-89

The following germplasm has been grown for evaluation during the 1988 rainy season. Data collection is in progress.

Sorghum:

- 3000 accessions of forage and dual-purpose types at Issapur.
- 1500 grain and dual-purpose types at Akola.

- Multilocational trial of 200 promising and dual-purpose types at Issapur, Akola, Jhansi, and Hisar.

Pearl millet:

- 2000 accessions at Issapur and Jodhpur.
- Multilocational trial of 200 promising varieties at Jodhpur, Issapur, Akola, Jhansi, and Hisar.

Groundnut:

- 1500 accessions at Akola.
- Multilocational trial of 200 accessions at Akola, Jodhpur, and Gwalior.

Pigeonpea:

- 150 extra-early and early-maturing accessions at Issapur.
- 500 medium and medium-late varieties at Akola.
- 200 promising late-maturing, vegetable-type accessions at Jorhat.

Chickpea:

- 1200 long-duration accessions at Issapur.
- 1200 short-duration accessions at ICRISAT Center, and Akola.

Conservation of World Germplasm Collections of ICRISAT Mandate Crops

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In tropical and subtropical environments, under ambient conditions, seeds lose viability very quickly, necessitating their frequent rejuvenation. This is expensive and involves the danger of genetic contamination due to outcrossing, selection pressure, mechanical mixture, human error, etc. Loss of viability also leads to accumulation of genetic damage in surviving seeds, and more important, it causes genetic drifts in heterogeneous germplasm accessions due to differential survival of the constituent genotypes and selection pressure. The most important part of conservation, obviously, is that seeds maintained in a gene bank should always produce plants which show representative characteristics of each accession.

The gene bank at ICRISAT, established in 1979, serves as the major repository for the world collection of germplasm. It currently holds 96 194 samples comprising sorghum (31 030), pearl millet (19 796), pigeonpea (11 034), chickpea (15 564), groundnut (12 160), and six species of minor (small) millets (6610). Among the other gene banks that conserve these crops worldwide, the National Bureau of Plant Genetic Resources (NBPGR) of the Indian Council of Agricultural Research (ICAR) has developed excellent facilities that are already operational. The total number of accessions presently conserved by ICRISAT and NBPGR and the number of countries represented are shown in Table 1. All these crop species produce seeds which show orthodox behavior, hence they are conserved by storing the seeds.

It is established that temperature and moisture content of the seeds influence seed deterioration during storage, and longevity of orthodox seeds can be dramatically improved by controlling these factors. In order to maximize longevity and preserve genetic integrity, predried seeds are packed in moisture-proof containers and stored in chambers with controlled environment, under low temperature and low relative humidity.

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Table 1. Germplasm accessions conserved at ICRISAT Center, Patancheru and NBPGR, New Delhi.

Crop	At ICRISAT		At NBPGR
	Accessions	Countries	Accessions
Sorghum (*Sorghum bicolor*)	31 030	87	412
Pearl millet (*Pennisetum glaucum*)	19 796	42	125
Chickpea (*Cicer arietinum*)	15 564	42	3 101
Pigeonpea (*Cajanus cajan*)	11 034	52	2 054
Groundnut (*Arachis hypogaea*)	12 160	89	3 000
Finger millet (*Eleusine coracana*)	2 848	18	-
Foxtail millet (*Setaria italica*)	1 404	22	-
Proso millet (*Panicum miliaceum*)	831	26	-
Little millet (*Panicum sumatrense*)	401	1	-
Barnyard millet (*Echinochloa crusgalli*)	582	8	-
Kodo millet (*Paspalum scrobiculatum*)	544	2	-
Total	96 194		8 692

Conservation Facilities at ICRISAT

All the germplasm is conserved under medium- and long-term conditions that meet the international standards (Table 2) suggested by the International Board for Plant Genetic Resources (IBPGR) and others.

Short-term storage. This facility is maintained at a temperature of 18°C and 30% relative humidity (RH) and is used to hold seeds temporarily while they are dried slowly and prepared for subsequent transfer to medium- and long-term storage facilities. The room has a capacity of 680 m^3, has independent air conditioning and relative humidity control equipment, and its own air exhaust system for fumigation.

Medium-term storage. Four rooms with a capacity of 125 m^3 each and two rooms with a capacity of 210 m^3 enable us to store the active collections. The rooms are maintained at 4°C and 20% RH (30% RH in 210 m^3 rooms).

Long-term storage. Three rooms are under test, each with a capacity of 130 m^3, maintained at -20°C to store the base and duplicate collections of germplasm for future use.

The medium- and long-term storage chambers each have two independent refrigeration and dehumidification systems, one of which acts as a standby. The gene bank also has a standby power generator set to cope with longer periods of power failure. The medium- and long-term storage rooms are constructed on a modular principle with prefabricated panels. All storage rooms have mobile shelving systems, each capable of

Table 2. Gene bank standards of major importance.

	International standards (IBPGR and others)	Standards followed at ICRISAT
Storage Conditions		
1. Long-term		
a. Temperature	-10 to -20°C	-20°C
b. Moisture content	5%	5%
2. Medium-term		
a. Temperature	0 to 10°C	+4°C
b. Relative humidity	15%	20%
Containers	Metal cans Laminated foil packets Glass jars	Metal cans with screw caps and rubber gaskets (medium-term) Laminated foil packets (long-term) Plastic bottles for groundnut pods
Seed Drying	10 to 15°C 10 to 15% RH	15°C 15% RH
Accession Size	4000 seeds for self pollinated; 12 000 seeds for cross-pollinated crops	Sorghum 15 000 seeds Pearl millet 30 000 seeds Chickpea 2000 seeds Pigeonpea 4000 seeds Groundnut 1 kg pods Minor millets 20 000 seeds
Rejuvenation	1. 85% viability 2. If number of seeds falls below that required for 3 regenerations	1. 85% viability 2. If quantity of seeds is reduced to 1/4 of initially stored
Viability Monitoring	5 years in medium-term 10 years in long-term	5 years for cereals and pulses 3 years for groundnut
Moisture Content and Germination Testing	ISTA recommendations Initial germination tests on 400 seeds	ISTA recommendations 100-200 seeds tested for germination
Safety Precaution	Two air-conditioners, standby generators, alarm system	Two air-conditioners, standby generator alarm system
Duplicate Base Conservation	Highly recommended	Fort Collins, Ottawa, ICARDA, New Delhi, Brazil, Ethiopia, Niger, SADCC, Argentina

accommodating 30 000 or more germplasm accessions. The temperature and relative humidity inside the storage rooms are monitored regularly with thermohygrographs. Audible and visual electronic alarm systems have been installed to safeguard the seeds from any rise in temperature and relative humidity and to help maintain the desired conditions.

Conservation Facilities at NBPGR

The active collections of germplasm of the mandate crops are now being stored under medium-term conditions, at 10°C and 35% RH. Four modules procured from Watford Refrigeration Co. (UK), which run at -20°C have been commissioned recently for long-term conservation of the base collections. All rooms have mobile shelving and an effective air-lock system (anteroom), with controlled conditions (22-24°C and 35% RH).

NBPGR recently established a national facility for a plant tissue culture repository. This facility was sanctioned by the Department of Biotechnology, Ministry of Science and Technology, Government of India. This development in NBPGR offers considerable scope for national and international cooperation in emerging biotechnological techniques applicable to ICRISAT mandate crops and their wild relatives.

Plans for a National Repository have now been finalized. This extensive scientific and physical expansion will strengthen the role of NBPGR as an alternate, base conservation center for the world collection of pigeonpea and if possible, for other mandate crops of ICRISAT.

Gene Bank Operations

The seeds produced during the postrainy season are generally of high quality, hence are used for conservation. Threshing sorghum and millets is done by hand, but in chickpea and pigeonpea it is usually done by machines. Groundnuts are harvested manually and stored as pods, and studies at NBPGR have shown that removal of shell, while facilitating early germination, reduces the storage life of the seeds. At ICRISAT, the cleaned disease- and insect-free seeds/pods are brought to short-term storage (18°C and 30% RH) where they are prepared for medium and long-term conservation. Since the ambient relative humidity at the time of harvest (Feb-Apr) is generally low, the moisture content of the harvested seed will also be low, e.g., 7-8% in groundnut and 10-12% in other crops, which is sufficient for medium-term preservation. However, for long-term preservation, the moisture content should be 5±1%, and conventional techniques (sun-drying or heated air drying) do not always achieve this level without affecting viability. A satisfactory drying system at 15°C and 15% RH is employed both at ICRISAT and NBPGR to dry seeds of most crops to the desired moisture levels for long-term conservation.

The active germplasm collections under medium-term conditions at ICRISAT Center are stored in aluminium cans with screw caps that have rubber gaskets inside to

keep them moisture proof. Groundnuts are stored in plastic bottles to accommodate a sufficient quantity of pods. To minimize the frequency of rejuvenation, a relatively large quantity of seed (300-400 g in sorghum, pearl millet, chickpea, and pigeonpea, 70-80 g in minor millets, and 1 kg of pods in groundnut) is stored.

The base collections under long-term conditions at ICRISAT will be stored in sealed laminated aluminium foil packets. The recommendations on the minimum quantity of seeds by the IBPGR Advisory Committee on Seed Storage will be followed (4000 seeds in homogeneous and 12 000 seeds in heterogeneous germplasm accessions).

At NBPGR, the entire germplasm both under long- and medium-term is conserved hermitically sealed in three-layered specially-designed laminated aluminium foil pouches which match the standards specified by IBPGR.

Monitoring of Viability

The viability of the seeds is determined at the start of storage and at regular intervals during storage (3-5 years in various crops) to predict the storage life and the time of rejuvenation. Viability is monitored by conducting germination tests following recommendations of the International Seed Testing Association (ISTA) for the various crops. The seed biology laboratory at ICRISAT Center is equipped with germinators which provide optimum conditions for germination. Sorghum and pearl millet are germinated usually at 25°C or at 20-30°C on top of paper (TP), while groundnut, chickpea, and pigeonpea are germinated at 20°C or 20-30°C by the rolled towel method between papers (BP) or in sand (S). Dormancy is a problem often encountered in freshly harvested seeds of sorghum, millets, and groundnut, and their wild relatives, while hard seeds are common in chickpea, pigeonpea, and their wild species. Appropriate procedures are followed to overcome these problems during the germination tests, e.g. prechilling and storage of the seeds at 40°C before germination as in sorghum, use of alternating temperature regimes (20-30°C for 16h/8h) for germination as in sorghum and pearl millet, and after-ripening in groundnut. The results of the periodic tests on viability are stored in a microcomputer for easy retrieval and identification of the accessions that require rejuvenation. A regeneration standard of 85% is adopted for all crops and accessions which show germination below this level are rejuvenated following the appropriate methods to minimize genetic drift. Germination studies have revealed that almost all accessions are maintained at a reasonably high level of viability.

Computerized Documentation and Retrieval Systems for Genetic Resources Work at ICRISAT — Present and Future

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The ICRISAT Data Management and Retrieval System (IDMRS) has been developed primarily to meet the information-handling needs of ICRISAT germplasm scientists. The data being managed using IDMRS comprise sets of observations from different growing seasons and locations on several thousand germplasm lines of sorghum, pearl millet, chickpea, pigeonpea, and groundnut. Each set of observations consists of a set of data descriptors, or attributes, which represent qualitative, quantitative, and classification information common to each germplasm line within a crop. These form a static data base which requires the addition of new information once or twice a year and occasional updating to correct clerical errors. Deletion of records is a very uncommon requirement. Retrieval normally demands the selection of data records based on a combination of characteristics, not on a single key or attribute. The entire system has been programmed in the VAX-11 BASIC programming language under the VMS operating system on a VAX-11/780 computer system.

Dictionary and Data File Structures

The storage of data under IDMRS requires a data dictionary file containing the definitions of the data descriptors to be used, and a data file to hold the data itself. A unique data file is required for each set of data, but a dictionary file can be shared among any number of data files.

The data dictionary contains general information about the data descriptors it defines in addition to specific information about names, data type, etc., for each individual descriptor. The general information includes a one-line title, the date of dictionary creation, the name of the person responsible for managing the dictionary, and six lines of text of the data manager's choosing. The information required for each data descriptor definition consists of a name, abbreviation, description, data type, print format, and range data depending on data type.

IDMRS supports functions for creating, editing, and updating both dictionary and data files. The editing functions are initiated through the use of a two- or three-letter command and the editing functions are further directed through a dialogue with the user.

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Data Validation

There is one command and a small set of ancillary programs which operate on the IDMRS file structure to help validate the data in a data file. The CHECK command will test whether a selected subset of numerical descriptors fall within their defined minima and maxima. The alphanumeric descriptors are currently checked using a set of programs which create an indexed list of the stored states in a special file.

Data Utility Commands

There are five data utility commands in IDMRS. The APPEND command is used to add a file to an existing file. The TEXT-FILE option permits the creation of a file in text format from an IDMRS file or an IDMRS collection. The SORT command permits the reordering of data and subsequent storing of the reordered data as a new data file. The STORE command allows the user to store a collection of records as a separate data file. The PRINT command permits the option of sorting the data prior to printing.

Data Retrieval

Records may be selected from IDMRS data files based on a logical combination of conditions on descriptors stored in the file. The set of records selected can be saved in a collection file. The general form of the selection operator is

SELECT [descriptor] [IN collections] WITH logical-expression

where the bracketed words are optional. The different sections of the expression are explained below:

[descriptor]

If a descriptor abbreviation is included after the word SELECT, then its type must be A, I, or C.

[IN collections]

The search space can be restricted to a previously defined collection or logical combination of collections.

logical-expression

A "logical-expression" comprises a set of simultaneous conditions to be imposed on values of descriptors for the purpose of data selection.

Data Summary Commands

There are currently two IDMRS commands available for summarizing the data stored for descriptors within a file. The command CLASS-COUNT is used to count the frequency of numerical values within user-defined intervals. The command STATE-COUNT is used to generate a frequency distribution of the states of an alphanumeric descriptor with a finite number of states.

How IDMRS is Used by GRU

The great volume of the existing germplasm collection at ICRISAT and the associated information on various descriptors, are major factors affecting the exchange of information. Approximately 95 000 accessions of 5 mandate crops and 6 minor millets are maintained and conserved at ICRISAT. However, plant breeders or other users of this germplasm would be interested, at any given time, in only a small part of this large collection. So it is necessary to use certain computer techniques to store, sort, and select from these data to meet the information and germplasm seed needs of the users.

All the crops conserved at ICRISAT have descriptor lists developed in collaboration with crop scientists and IBPGR. Major classes of descriptors are the passport data, characterization and preliminary evaluation data, and further evaluation data. In each class there are subclasses and descriptors. This hierarchical classification of descriptors makes them dynamic and amenable to easy manipulation.

As described, IDMRS is an integrated set of procedures which can record, store, process, and retrieve information on the mainframe computer. There are two parts to its design; one is the internal process of information storage and retrieval; the other is the user interface. GRU staff are mainly concerned with the latter. Various processes that are used by GRU staff are listed below.

- Data entry and editing.
- Printing all or a few of the descriptors and/or records.
- Retrieving information on a few selected descriptors - This is one of the most important data retrieval activities. Accessions can be identified with varying combinations of descriptors. For example, we can select accessions that originate in a given country, collected at certain altitude, having red seeds together with resistance to a particular pest or disease, provided such accessions are available in the collection.
- Retrieving information on a specific set of accessions either with all the data on these accessions or with information only on a few descriptors.
- Retrieving information on the number of accessions belonging to a particular class (quantitative) or state (qualitative), e.g., the number of sorghums in the gene bank which are landraces, etc.
- Manipulation of the stored data for statistical analyses to examine patterns of variation.

Using the microcomputer, GRU has been storing and retrieving data on seed despatches using the dBase III program. This helps us keep track of the distribution of seed samples to ICRISAT scientists, scientists within and outside India, and to follow up on the utilization of germplasm thus distributed. Presently, we are in the process of improving this so as to extend the system for use by all the other disciplines in ICRISAT. We are also using dBase III to store and retrieve seed viability data in order to facilitate rapid identification of material needing rejuvenation, and to determine the time for the next germination test.

Future Plans

Since the development of IDMRS, sophisticated database management systems have

become available which facilitate data storage and retrieval, and the customization of user interfaces. There are plans to modify IDMRS to take advantage of one such database system now available at ICRISAT.

The proliferation of microcomputers, and the increased load on our central computer systems dictate that we look at ways of distributing the workload required for data storage and retrieval between microcomputers and large central computer systems. We plan to explore the possibility of using microcomputers for data entry and validation, and as a "front-end" for queries posed against a central database on a large computer.

The increased sophistication of microcomputer-based database management systems now makes it possible to consider the implementation of germplasm data management and retrieval systems on microcomputers. This, coupled with the availability of compact disc (CD) technology which can store large amounts of data, will make it possible to distribute large amounts of germplasm data economically. Such a system has already been developed by CIMMYT in Mexico.

Germplasm Exchange and Quarantine in India

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It is essential that each country has an efficient quarantine system to safeguard the possible entry of new pests and diseases while exchanging germplasm, seed, and planting material for crop improvement programs.

In India, NBPGR is the primary organization which is responsible, inter alia for the exchange of germplasm of agri-horticultural crops between India and other countries, ensuring that such exchanges are made under strict phytosanitary conditions in accordance with quarantine regulations. The Bureau maintains exchange links with about 70 countries including international institutes.

Of the 3000 cultivated taxa representing global genetic wealth, only 160 species are reported to occur in the Indian gene center. During the last 20 years, the introduction of germplasm and other plant material has enriched the variability and helped diversify the genetic base in the country. During 1976-85, 58 434 accessions of different agrihorticultural crops were introduced. During 1976-87, 838 399 samples of plant genetic resources were imported and 53 312 exported through NBPGR.

Apart from NBPGR, other institutes of the Indian Council of Agricultural Research (ICAR), coordinated projects of different crops, agricultural universities, and some state departments of agriculture also handle important collections of various crops. It is estimated that about 0.15 to 0.2 million collections are maintained by different national agencies. Besides these, ICRISAT maintains 95 886 accessions of its mandate crops, including minor millets.

Plant Quarantine in India

In India, import and export of plants and plant materials are governed by rules and regulations framed under the Destructive Insects and Pests (DIP) Act 1914. The Act has since been revised eight times by the Government of India (GOI). The main objective of this Act is to prevent the introduction into the country, and the transport from one state to another, of any insect, fungus, or other pest which is or may be destructive to crops. Originally seeds were not included in the DIP Act, but in 1984, the GOI passed the Plants, Fruits and Seeds (Regulation of Imports into India) Order,

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which came into effect in 1985. This new order stipulates the conditions of import for 17 important crops.

Authorized Quarantine Agencies

The Directorate of Plant Protection, Quarantine and Storage, an attached office of the Ministry of Agriculture, GOI, implements the plant quarantine rules framed under the DIP Act. This organization handles bulk export and import of plants and plant materials for commercial purposes through its 27 plant quarantine and fumigation stations at different seaports, airports, and land frontiers. The GOI has also approved other agencies to act as plant quarantine authorities for research. These include the NBPGR, New Delhi, for agrihorticultural and silvicultural crops; the Forest Research Institute (FRI), Dehra Dun for forestry plants; and the Botanical Survey of India (BSI), Calcutta, for other plants. In view of the mandate to introduce and exchange genetic material of agrihorticultural crops that should be pest and disease free, the quarantine procedures at NBPGR are followed rigidly. About 60 000 samples are examined each year; and during 1976-1985, about 0.6 million samples were imported through NBPGR.

Quarantine System at ICRISAT

As per the memorandum of understanding, the GOI authorized ICRISAT unrestricted movement of seeds and genetic materials of its mandate crops into and out of India as required for collaborative work in any part of the world consistent with the appropriate quarantine regulations prevailing in the country. The GOI took a number of steps to support this provision. The Central Plant Protection Training Institute (CPPTI), Hyderabad, was named the quarantine authority for clearance of ICRISAT mandate crops; ICRISAT was permitted to set up an Export Certification Quarantine Laboratory in 1978 at the ICRISAT Campus under the overall authority of CPPTI; and finally, NBPGR was authorized to act as the sole plant quarantine authority to clear ICRISAT mandate crops.

Quarantine Procedures for Import

The germplasm/seed material received at NBPGR, duly accompanied by a phytosanitary certificate from the National Plant Quarantine Services of the exporting country, is fumigated, examined, and treated before it is released to ICRISAT to be grown in the Post-Entry Quarantine Isolation Area (PEQIA) for one generation. Groundnuts are grown in a screenhouse, kept under observation, and healthy seedlings free from viruses released for planting in the QIA. Cuttings of wild *Arachis* species are subjected to intermediate quarantine in a non-groundnut growing country. Between 1973 and 1987, 157 678 samples of ICRISAT mandate crops were imported from 94 countries.

Quarantine Procedure for Export

The quarantine regulations for the export of seed material are based on the International Plant Protection Convention (1951), and are modified from time to time according to specific requirements of the importing countries. The procedure for seed inspection, fumigation, and treatment are similar as for imported material prescribed by the national plant quarantine agency. At ICRISAT, the plant quarantine rules and regulations of different countries are available and are updated from time to time.

From 1974-1987, 704 547 samples of ICRISAT mandate crops were exported to 143 countries. There has been no report of any pest or disease having been introduced through exchange of ICRISAT germplasm.

Future Perspectives and Suggestions

Germplasm Exchange

1. Various gene centers in the country hold a rich diversity of crop materials, but more specific germplasm of pulses, oilseeds, fibre crops, and minor millets are required to screen for disease and pest resistance, and quality in the crop improvement program for utilization under different agroclimatic conditions.
2. It is necessary to compile crop inventories of introduced genetic resources in addition to the ones existing at NBPGR.

Quarantine System

In order to update the quarantine system in the country, the following factors may be considered:

1. use of enzyme-linked immunosorbent assay (ELISA) technique, and different anti sera for detecting virus and bacterial pathogens;
2. exploration of tissue culture techniques wherever possible for exchange of germplasm;
3. updating the treatment schedules and procedures under different environmental conditions;
4. compilation of information on pests, diseases, and weeds of plant quarantine significance, and outbreaks at the regional or global level;
5. avoidance of bulk export and import of germplasm to facilitate thorough inspection;
6. preparation of a plant quarantine manual jointly by ICRISAT and NBPGR to guide countries involved in germplasm exchange;
7. upgradation of greenhouse facilities to allow close observation of germplasm of high quarantine risk; and
8. creation of offshore quarantine facilities for postentry studies on plantation crops like coconut, banana, pineapple, and other vegetatively propagated materials.

Biotechnology in Conservation of Plant Genetic Resources (Background Paper)

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The traditional landraces and wild relatives of crop plants which constitute a significant pool of genetic diversity are now giving way to genetically homogenous strains. This is because of the continued efforts of plant breeders to develop new, high-yielding, and adaptable strains to meet the food requirements of the increasing population. While this has contributed to an increase in productivity, it has at the same time narrowed the genetic base, making crops more vulnerable to fast-evolving pathotypes. The realization of the importance of genetic variability in crop improvement and an awareness of the consequences of genetic erosion has led to an increased initiative worldwide for conservation of germplasm and establishment of gene banks for the collection, evaluation, conservation, rejuvenation, and retrieval of germplasm.

Limitations of Conventional Germplasm Conservation Methods

Gene banks aim to collect a wide range of germplasm in the form of seeds and vegetative propagules of crop plants and their related species. Germplasm collected and stored in the conventional manner loses viability over a period of time and is vulnerable to destruction by pests and pathogens. Moreover, the periodic assessment for viability and rejuvenation of new stocks entails enormous expenditure.

Role of Tissue and Cell Culture Techniques

The capacity of plant somatic tissues and cells to regenerate into whole plants has been demonstrated in several agriculturally important plants. This demonstration has led to the assessment of feasibility of biotechnological tools, e.g., in vitro storage, for germplasm conservation. The advantages of biotechnological approaches are:

1. large numbers can be handled for storage in a limited space,
2. storage is possible in a pathogen-free state, and
3. international exchange of germplasm is greatly facilitated.

A major limitation with this approach is the likelihood of genetic instability in the process of culture. However, this problem can be overcome by a careful choice of

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explant. Shoot tips and cambial tissues, for example, yield genetically stable cultures. Elimination from the culture medium of growth regulators like 2,4-D also reduces the risk of genetic instability.

Two different approaches have been adopted to conserve germplasm through in vitro storage.

Storage by Growth Limitation

Conservation of germplasm by this approach involves storage of morphogenic in vitro cultures at low temperatures varying between 1 and 9°C. Low temperature storage affects curtailment in the rate of culture growth and extends the subculture interval from 6 months to 1 year against a normal interval of 3 weeks. Virus-free strawberries have been stored for 6 years at 4°C. Grape plants have been stored for over 15 years at 9°C by yearly transfer to a fresh medium.

Significant inhibition of the growth rate of meristem is achieved by alternating day (12°C) and night (6°C) temperatures. A high sucrose content and an increase in the culture volume significantly increased the survival frequency of *Solanum* cultures. Osmotic retardants (manitol and sorbitol), stress agents (abscisic acid), partial dehydration, maintenance of culture at low atmospheric pressure and low oxygen tension, overlayering of cultures with mineral oil, and use of chemicals like cycocel are some of the methods by which long-term storage of germplasm has been attempted. Storage by these methods requires only refrigeration equipment. The imposed stress, however, can result in degenerative processes. This risk must be assessed before the approach can be applied extensively.

Cryopreservation

The development of cryopreservation methods for storage of plant germplasm is an extension of the significant advances made in freeze preservation of animal germplasm through storage of sperm. Cryopreservation involves freezing, and maintenance in frozen state, of plant material at temperatures of liquid nitrogen (around -196°C). At this temperature, cells are in a state of metabolic inactivation. There are two major advantages with this approach. Firstly, inhibition of cell division allows storage of material with minimal risk of genetic instability. Secondly, tissues can be stored virtually indefinitely with low labor costs. However, the problem of cryoinjury limits wider application of this technique. Cryoinjury often occurs when the intracellular water freezes and forms ice crystals, which rupture the internal membranes. Cryopreservation can also lead to adverse effects if the intracellular solutes accumulate to a toxic level, or if vital solutes leak during freezing.

The use of cryoprotectants such as low molecular weight compounds (glycerol and dimethyl sulphoxide) which penetrate the cell with ease, and high molecular weight compounds (like polyvinyl pyrrolidone and dextran) which penetrate slowly, can reduce cryodamage significantly. Cryoprotection by these compounds is attributed to

their ability to protect surface membranes by reducing growth rate and size of ice crystals and by lowering the effective concentration of solutes in equilibrium with ice inside and outside the cell. Cryoprotectants also help to increase membrane permea-

Table 1. Breakdown of conservation activities and available approaches.

	Approach		
Activity	Conventional	Advanced	Molecular
Collection	seed; vegetative budwood; tubers	meristems; embryos; vegetative parts in vitro	fixed material; raw DNA
Conservation	seed; field; gene banks	in vitro cultures; slow growth; cryopreservation	raw DNA: gene libraries
Multiplication	normal sexual cycle; vegetative propagation	micropropagation; subculturing	plasmids; bacteria; viral clones
Characterization	morphology	isozymes; proteins	RELPs; gene sequencing
Evaluation	field trials; tolerance	range of in vitro possibilities	gene identification
Distribution, quarantine	culturing pathogens; indexing by grafting	ELISA	DNA probes
Medium	seed; plants; plant parts	plantlets; cultures	bacterial clones; raw DNA
Utilization	normal sexual crossing	wide hybridization (with embryo rescue)	gene transfer; agrobacterium; microinjection' cell fusion
Scope	primary gene pool	secondary and tertiary gene pool	all source of DNA
Nature of new variation	allele reassortment	allele reassortment; gene addition/ replacement; somaclonal variation.	gene addition

bility which aids removal of water from the cell and facilitates protective dehydration in the early stages of freezing.

Cultures are frozen by either the slow-cooling or the rapid-cooling method. In the slow-cooling method, the rate of freezing is between 0.5 to 4°C min^{-1} while in the rapid-cooling process the rate of freezing, before transfer to liquid nitrogen, is more than 1000°C min^{-1}. Tolerance to freezing, as judged by survival of freeze-thawed cultures, indicates that rapid cooling is more effective. Thawing of frozen material is achieved by transfer to warm water at 40°C. The optimal thawing rate is one that prevents ice formation by recrystallization in the process of warming. The recovery of freeze-thawed cultures can be improved by nursing them through an initial recovery period involving gradual dilution of cryoprotectants through several steps of washing and by keeping osmotic disruption to the minimum. Morphogenic material, like shoot apices and embryos, which regenerate without any difficulty, are ideal for long-term preservation of germplasm. Callus, cell suspension, and protoplasts are more difficult to cryopreserve.

The IBPGR has categorized the different conservation approaches as conventional, advanced, and molecular (Table 1). Conservation by conventional approaches involving collection, evaluation, storage, and retrieval of seed material has limitations in terms of space and human labor. Though advanced techniques of conservation, involving the use of tissue and cell cultures can overcome the limitations of conventional germplasm conservation methods, there are several problems that need resolution. Difficulty of reconstituting the original genotype through high-frequency morphogenesis of freeze-thawed cultures and culture-induced variability are the two major problems. An integration of time-tested conventional conservation methods and tissue and cell culture techniques seems to be the best option. The molecular approach is an emerging option, but a clearcut slot is not evident in any immediate conservation strategy.

Session IV: Use and Impact of Germplasm on Crop Improvement in India

Use of Sorghum Germplasm and its Impact on Crop Improvement in India

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The traditional sorghum cultivars and landraces grown in India over centuries have been selected primarily for their ability to survive under stress conditions rather than for high productivity. They are characterized by tall stature, late maturity, localized adaptation, and low harvest index.

Grain Yield and Agronomic Desirability

In order to achieve a breakthrough in productivity and enhance sorghum production in the country, the Indian Council of Agricultural Research (ICAR) in collaboration with the Rockefeller Foundation initiated the hybrid sorghum development program in the early 1960s. To meet the program's requirements temperate sorghum material from the USA, and tropical germplasm from India and Africa were assembled.

Since the establishment of the All India Coordinated Sorghum Improvement Project (AICSIP) in 1969, nearly 500 hybrids and 1000 varieties from various breeding programs were tested and 45 cultivars were released in India. The first sorghum hybrid released in the country in 1964, CSH 1, has clearly demonstrated the possibility of realizing average grain yields of the order of 2.5-3.0 t ha^{-1} even under rainfed conditions. More important, it introduced the concept of genotypic alteration to match the environment. Systematic breeding with selected temperate and tropical germplasm has provided material of the appropriate height and maturity for the development of hybrids and high-yielding varieties.

Since its establishment in 1972, ICRISAT has made efforts to (1) diversify the germplasm base to enhance yield levels, and (2) to identify resistance sources and use them to develop varieties and seed parents. This contributed to the release of 2 cultivars in Burma, 2 in Burkina Faso, 1 in Ethiopia, 3 in India, 12 in Latin American countries, 1 in the Sudan, 1 in Yemen, 1 in Zambia, and 2 in Zimbabwe.

The major germplasm sources utilized so far in varietal improvement include temperate lines from USA, Zerazera lines from Ethiopia and Sudan, and some lines of Indian origin. The male-sterile gene sources used were mainly CK 60, 172, 2219, 3675, 3667, and 2947. These were further diversified by using parents such as CS 3541, BT x 623, population derivatives (Bulk-Y, Indian Synthetic, FLR, Rs/B, US/B, Serere,

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Diallel, and WAE), IS 6248, IS 2225, IS 3443, IS 12611, IS 10927, IS 12645, IS 517, IS 1037, IS 19614, E 12-5, ET 2039, E 35-1, Lulu 5, M 35-1, and Safra. In the development of restorer parents and varieties, the basic germplasm sources used were IS 84, IS 3691, IS 3687, IS 3922, IS 3924, IS 3541, IS 6928, ET 2039, Safra, E 12-5, E 35-1, E 36-1, and IS 1054, IS 1055, IS 1122, IS 1082, IS 517, IS 19652, Karper 1593, IS 10927, IS 12645, IS 12622, IS 19652, IS 18961, GPR 168, and IS 1151.

Although germplasm material from different regions of the world was used to develop improved cultivars, the number of lines involved was rather small. This has led to a plateauing of yields in the rainy-season genotypes and only marginal increases in the postrainy-season genotypes. To break the plateau, efforts are being made to involve recently collected accessions from Ethiopia, Yemen (AR), Cameroon, and Nigeria.

Resistance to Biotic and Abiotic Stresses

The main strategy adopted for the control of insect pests and pathogens including *Striga* has been incorporation of resistance. In pursuit of this objective, systematic studies were initiated in 1964 to screen the germplasm material for sources of resistance against key pests and diseases. This area of study was intensified during the past decade in collaboration with ICRISAT. So far, the bulk of the germplasm and breeding material has been screened for most of the important pests and diseases. This has facilitated the identification of several sources of resistance to various pests and diseases.

Among the insect pests, the most exhaustive screening was carried out for shoot fly and stem borer. Many of the resistant sources were found to exhibit low infestation under high pest pressure. The resistant sources identified are predominantly of Indian origin, while a few are from Ethiopia, Nigeria, the Sudan, and USA. The stable resistant sources for shoot fly and stem borer are IS 1082, IS 2205, IS 5604, IS 5470, IS 5480 (India), IS 18577, IS 18554 (Nigeria), IS 2312 (the Sudan), IS 18551 (Ethiopia), IS 2122, IS 2134, and IS 2146 (USA). Some of these have been used both in the Indian and ICRISAT programs. Besides, other Indian germplasm lines like M 35-1 (IS 1054), BP 53 (IS 18432), Karad Local (IS 18417), Aispuri (IS 18425), etc. were used to impart resistances.

Extensive screening of the germplasm was also carried out for midge, and many resistant sources identified. Notable among these are DJ 6514 (IS 18700), IS 18961, S-GIRL-MR 1 (IS 18699), TAM 2566 (IS 18697), IS 3443, IS 12573C, and AF 28 (IS 18698). The lines DJ 6514 and IS 3443 were used at ICRISAT to develop an improved midge-resistant variety, ICSV 197 (SPV 694).

Spectacular success was achieved in the identification and utilization of disease-resistant sources. Highly stable resistant sources were identified for all foliar diseases. The tan-pigmented plant type was found to be associated with foliage diseases. Grain-mold resistance was found to be moderate in the white-grain background. For charcoal rot, E 36-1, QL 101, QL 102, and QL 104 have been identified as the most stable resistant types.

A notable feature of disease resistance has been the availability of multiple resistance in some lines. Based on multilocation evaluation over the years, the following lines were found to have multiple disease resistance: ICSV 1, ICSV 120, ICSV 138, IS 2058, IS 18758, and SPV 387 (anthracnose and rust); IS 3547 (grain molds, downy mildew, anthracnose and rust); IS 14332 (grain molds, downy mildew, and rust); IS 17141 (grain molds and anthracnose); IS 2333 and IS 14387 (grain molds and downy mildew); and IS 3413, IS 14390, and IS 21454 (grain molds and rust). These lines are currently being used in the breeding programs.

Resistance to *Striga* has been reported in several indigenous sources. Based on extensive laboratory and field screening, ICRISAT identified many *Striga*-resistant lines from the germplasm. However, many of these sources could not be used in the breeding programs due to their undesirable agronomic base. Some germplasm lines used in *Striga* resistance breeding are IS 18331 (N 13), IS 87441 (Framida), IS 2221, IS 4202, IS 5106, IS 7471, IS 9830, and IS 9951. Some of the breeding lines like 555, 168, SPV 221, SPV 103, etc. proved to be useful resistant sources. The *Striga*-resistant variety SAR 1 developed at ICRISAT from the cross 555 x 168 was released for cultivation in *Striga*-endemic areas. Several other promising selections derived from the mentioned resistant sources, both from ICRISAT and Indian programs, have been identified.

Nearly 1300 germplasm lines and 332 breeding lines were screened for early- and mid-season drought stresses. The most promising for various droughts are:

- Early-season and terminal drought: E 36-1, DJ 1195, DKV 17, DKV 3, DKV 4 IS 12611, IS 6928, and DKV 18.
- Mid-season stress: DKV 1, DKV 3, DKV 7, DJ 1195, ICSV 378, ICSV 572, ICSV 272, ICSV 273, and ICSV 8295.

Conversion

Tall, late and photoperiod-sensitive landraces are converted into dwarf and early types for use in breeding programs. The landraces involved are Zerazera (8 lines), Guinnense (3), Kaura (5), and Durra/Caudatum (5).

Populations for Multiple Resistances

Three populations are under development at ICRISAT. These are ICSP 1BR/MFR (resistance to grain mold, stem borer/shoot fly, and midge), ICSP 2BR/MFR (resistance to grain mold and *Striga*, and improved stand establishment) both with rainy-season adaptation, and ICSP 3BR/MFR (resistance to stem borer/shoot fly and rust, and improved grain quality) with postrainy-season adaptation. Several resistance

sources from the germplasm are transferred to these populations. Their distributions, by region and trait are as follows:

ICSP 1BR/MFR and ICSP 2BR/MFR (rainy season) populations:

- From India (8 lines), Ethiopia (3), Sudan (2), Nigeria (1), Zimbabwe (2), Egypt (1), USA (9), and Australia (2).
- Resistant to shoot fly (3), stem borer (6), midge (5), grain mold (1), leaf diseases (3), and *Striga* (1); good grain (3), stand establishment (3), and early and dwarf (13).

ICSP 3BR/MFR (postrainy season) populations:

- From India (13), Ethiopia (27), Nigeria (12), Sudan (8), Botswana (8), Cameroon (8), Yemen (12), Malawi (1), South Africa (1), Egypt (1), USA (6), Mexico (1), and Australia (3).
- Bold grain (20); with postrainy-season adaptation and resistance to terminal drought (29); photoperiod-sensitive (2), temperature-insensitive (28); resistant to shoot fly/stem borer (4) and downy mildew (1); stay-green (6); stand establishment (3), and early and dwarf (3).

High-Lysine Sorghums

The high-lysine sorghum lines, IS 11167 and IS 11758 from Ethiopia were used in the breeding program for transferring the gene to a desirable agronomic background. Some promising high-lysine derivatives with shrivelled and plump grain have been obtained.

Sweet Sorghums

Based on evaluation of the germplasm, several sweet-stalked sorghum lines were selected. Notable among these are: IS 20963, IS 15428, IS 3572, IS 2266, IS 9890, IS 9639, IS 14790, IS 21100, IS 8157, and IS 15448. These materials, which were further screened at some of the centers of the Sorghum Project, were found to be very promising.

Forage Sorghum Improvement

The forage sorghum germplasm was systematically evaluated over several years at Hisar Center for various yield and quality traits, for which a wide range of variability has been noted. The lines identified with desirable forage attributes were IS 1044, IS 12308, IS 13200, IS 18577, IS 18578, and IS 18580. In respect of quality parameters IS 1059, IS 2944, IS 3247, IS 4776 and IS 6090 were selected for low HCN, and IS 3247 and PJ 7R for low tannin content.

The need for further critical evaluation of germplasm materials and their utilization in forage sorghum improvement is keenly felt. This work is being strengthened in the Sorghum Project and the National Centre has initiated a program on forage sorghum improvement.

Use of Pearl Millet Germplasm and its Impact on Crop Improvement in India

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Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is endowed with enormous genetic variability for yield components, adaptation, and quality traits. This variability has evolved as a result of natural selection for adaptation to diverse agroecological environments coupled with human selection for local preference. Pearl millet germplasm was collected and maintained during the 1920s and 1930s at Coimbatore and Niphad, during the 1960s at New Delhi, and since 1970s has been assembled at ICRISAT Center, Patancheru. A large bulk of the variability for numerous characters is well represented in the 19 800 accessions (from 42 countries) maintained in the world collection at ICRISAT. Most of these accessions have already been evaluated at ICRISAT. They have also been extensively sampled and screened for stable sources of disease resistance and some qualitative traits.

Before the establishment of the All India Coordinated Millets Improvement Project (AICMIP) in 1965, mass selection led to the development of several varieties (CO 2, CO 3, AKP1, AKP2, RSJ, RSK, N-28-15-1) from Indian landraces and CO 1 and S 530 from African landraces. However, low grain yields and lateness prevented their commercial success. Pearl millet germplasm assembled at the Indian Agricultural Research Institute (IARI), New Delhi, during the 1960s led to the development of Improved Ghana and Pusa Moti by mass selection. Random mating of the S_2 progenies from African × African crosses produced Vijay and Visakha. Lack of seed production and extension support limited the impact of these varieties.

The commercial impact of an open-pollinated variety came with the development and release of WC-C75 in 1982. This variety was developed at ICRISAT by intercrossing seven full-sib progenies of the World Composite introduced from Nigeria. In 5 years of AICMIP trials, WC-C75 produced 98% grain yield and 119% fodder yield of the most popular and widely grown hybrid BJ 104. Its high downy mildew resistance continues to hold even after 6 years of widespread cultivation in the country. Another open-pollinated variety, ICMS 7703, was developed at ICRISAT by intercrossing seven partial inbreds derived from single-cross populations involving mostly breeding lines of Indian and African origin. In 6 years of AICPMIP trials, ICMS 7703 produced 102% grain yield and 116% fodder yield of BJ 104. This variety, released in 1985 and widely cultivated in Tamil Nadu, has also retained its high resistance to downy mildew.

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The success of WC-C75 and ICMS 7703 sparked off a chain reaction leading to the release of RCB 2 (half-sib selection from Indian landraces), PSB 8 (developed from 60 inbreds of Indian × Indian crosses), HC 4 (derived from 7 inbreds of Indian × African crosses), Mallikarjuna (derived from 12 inbreds of Indian × African origin), CO 7 and Nagarjuna (developed from Indian × African F_1's), and Balaji (developed from S_2 progenies of African × African population). None of these, however, were commercially significant. All these varieties were produced from enhanced germplasm. A commercially successful open-pollinated variety directly produced from a landrace is ICTP 8203, developed at ICRISAT by intercrossing five S_2 progenies from a landrace originating from Togo. This variety, released by the Central Variety Release Committee on 11 October 1988 for cultivation in Maharashtra and Andhra Pradesh, yields as much as MBH 110. Moreover, it is early maturing (75 days), has large seeds (12 g 1000^{-1}), tolerates drought, and has a high level of resistance to downy mildew. A host of open-pollinated varieties of diverse genetic base which have performed well in AICPMIP trials but have not been able to compete with the leading varieties to make it to the farmers' fields have greatly broadened the genetic base of all millet programs.

The greatest impact of germplasm utilization on pearl millet improvement in India has been on the hybrid front. The pearl millet hybrid era in India started in 1962 with the introduction of the male-sterile line Tift 23A from Tifton, Georgia, USA. Five hybrids based on this line were released during 1965-69. Of these, HB 3 (involving J 104 as a pollen parent), released in 1968, was the most popular and was extensively cultivated until it succumbed to downy mildew in 1974. J 104 was derived from the Indian germplasm. Three hybrids were released in 1977: two of these (BJ 104 and BK 560) were based on male-sterile line 5141A and one (CJ 104) was based on 5054 A. Both BJ 104 and CJ 104 involve J 104 as pollen parent. The pollen parent of BK 560 (K 560-230) was developed from Indian germplasm. The nuclear genome of 5141A is derived from Indian germplasm whereas that of 5054 A involves African germplasm. BJ 104 dominated in northern India, BK 560 dominated in central and southern India, and CJ 104 became popular in drier parts of Gujarat. During 1981-84, another 10 hybrids were released of which only 3 were of any significance. MBH 110 became popular in Maharashtra, and GHB 27 and GHB 32 in Gujarat. GHB 27 is based on 5141A and pollen parent J 2002 and GHB 32 is based on 5141A and pollen parent J 1188. Both pollen parents are derived from Indian germplasm. MBH 110 is based on parental lines developed from materials bred at the Serere Research station, Uganda.

Following the breakdown of 5141A and J 104 to downy mildew, four hybrids (ICMH 451, ICMH 501, MH 182, HHB 30) were released in 1986 and three others (ICMH 423, MH 169, HHB 50) were released in 1987. Of these, only ICMH 451 has been cultivated widely. The hybrids released in 1987 are still in the seed-production stages, and GHB 30 is restricted to Gujarat. The female parent of ICMH 451 (81A) is related to Tift 23 D_2A_1 and its pollen parent (ICMP 451) is a derivative of Late Composite developed at ICRISAT. GHB 30 is based on 5054A and J 2002 (derived from Indian germplasm). ICMH 423 is based on 841A (related to 5141A) and ICMP 423 (derived from Early Composite) developed at ICRISAT. MH 169 is based on 841A; its pollen parent is a downy mildew resistant selection from K 560-230. Hybrid HHB 50 is based on 81A and H 90/4-5 (an inbred derived from Indian germplasm).

Early efforts between 1961 and 1962 at Punjab Agricultural University, Ludhiana led to the development of two male-sterile lines (L 66A, L 67A) which later studies showed to be of two different cytoplasmic systems as well as different from Tift $23A_1$. The cytoplasm of L 66A (later named L $66A_2$) was derived from a genetic stock IP 189 originating from Malawi. The cytoplasm of L 67 (later named L $67A_3$) was derived from a population of a natural cross involving an African germplasm. Another male-sterile line (PT 732A) developed at Tamil Nadu Agricultural University, Coimbatore, derives its cytoplasm from a landrace material from Andhra Pradesh and is claimed to be different from Tift $23A_1$. None of these cytoplasms have yet been commercially exploited because of their unstable sterility.

Recently, several sources of cytoplasmic male-sterility (cms) have been identified in diverse germplasms. Work at Ahmadu Bello University in Nigeria has identified a cms source in Ex-Bornu. The ICRISAT Cereals Program has identified cms sources in Early Gene Pool and in a population derived from African × African cross. The ICRISAT Genetic Resources Unit has identified new cms sources in accessions from Ghana and Botswana, and ORSTOM scientists in France have identified a cms source from an accession of *P. americanum* ssp *violaceum* (Lam.) L. Rich. originating from Senegal. ORSTOM work showed this cytoplasmic system to be different from Tift 23 A_1. Studies at ICRISAT, based on the pollen fertility restoration of hybrids made on isonuclear lines (i.e., 81 B nuclear genome with Tift $23A_1$ and *violaceum* cytoplasms) showed both cytoplasmic systems to be similar. Such studies, we believe, are essential for reliable classification of the cytoplasmic systems. Nevertheless, several sources are now available which are being studied for their diversity.

Indian landraces provide excellent sources of early maturity, better tillering, and shorter height. In contrast, African sources, particularly those from the West African region, provide excellent sources of larger head volume and seed size, higher degrees of resistance to diseases, and better seed quality. West African germplasm accessions provide far more genetic variability than the Indian germplasm. Increasing use of the African germplasm at ICRISAT, and in almost all Indian National programs (mostly through the breeding materials generated at ICRISAT), has substantially contributed to the diversification of the genetic base of breeding programs. About 65% of the 694 inbred lines presently maintained in the active pollinator collection at ICRISAT were derived from crosses involving at least one parent (mostly a breeding line) originating from Africa. About the same proportion of the 344 B-lines now at the advanced stages of their evaluation or in backcrossing for A-lines development, involve African germplasm. Two large-seeded male-sterile lines (863A, ICMA 88004) with high hybrid yield potential and downy mildew resistance were developed directly from a landrace originating from Togo. Both these male-sterile lines are now being used for the development of experimental hybrids.

The world collection of germplasm at IARI, New Delhi was screened for resistance to downy mildew, smut, ergot, and rust under natural conditions. Development of effective field screening techniques at ICRISAT led to the development/identification of excellent sources of resistance in the germplasm and breeding lines originating mostly from West Africa. These are being widely utilized in several breeding programs.

Extensive efforts in search of novel traits in the germplasm collection at ICRISAT have led to the identification of genes that control dwarfism, earliness, glossiness, trichomelessness, and white seed color. Lines with up to 20% stalk-sugar content and >15% grain-protein content have also been identified in the ICRISAT germplasm collection. It is highly likely that sources will be identified for drought tolerance, lodging resistance, better seedling emergence, increased seedling vigor, high growth rates, and stay-green character, the utilization of which in breeding will help stabilize the grain yield of pearl millet at higher levels.

Use of Groundnut Germplasm and its Impact on Crop Improvement in India

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In India, vast collections of groundnut (*Arachis hypogaea*) are assembled, maintained, and utilized by Research Centers under the All India Coordinated Research Project on Oilseeds (AICORPO), various Universities, the National Research Centre for Groundnut (NRCG), and at ICRISAT Center.

AICORPO Centers

Fifteen AICORPO Centers and various Agricultural Universities located in the major groundnut-growing regions maintain need-based working collections of about 7900 accessions. The individual collections range from 250 to 2900 accessions with about 30% duplicate samples. These collections, which are being utilized in several breeding programs, have been evaluated for various agronomic traits such as earliness, fresh seed dormancy, high shelling percentage, high oil content, large seed size, synchronous flowering, compact fruiting habit, resistance/tolerance to drought, and to major insect pests and diseases. Since reports on resistance/tolerance to various stress factors are based on field observations at various locations, confirmation under epiphytotic conditions is required.

National Research Centre for Groundnut (NRCG)

It acts as a repository of active germplasm and aims to describe each accession for various morphoagronomic characteristics. The working collections belonging to virginia bunch/runner (2510), spanish (2144), and valencia (820) groups have been screened for useful agronomic characters. Both material and evaluation catalogs were shared with workers in India. Several promising accessions possessing high pod yield, oil content and peg strength, tolerance to cold and heat, and resistance to late leaf spot, rust and *Alternaria* leaf spot were identified.

Some accessions which perform better in summer under limited irrigation have also been identified. The promising material was evaluated for productivity and simultaneously utilized in the breeding program. Both segregating material and germplasm accessions were distributed to AICORPO Centers and other research institutes for in-situ selection. Among the promising selections, NRGS(E)-2 and NRGS-4 were promoted to CVT under the AICORPO system.

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ICRISAT Center

The Genetic Resources Unit has so far assembled about 11 800 accessions of *A. hypogaea* from 89 countries and over 200 accessions of wild species.

The breeding program has so far utilized 729 germplasm accessions comprising virginia bunch (266), virginia runner (148), spanish bunch (240), and valencia (75) types as donors for various stress factors and other desirable characters.

After extensive field screening of over 10 000 accessions, 78 genotypes resistant to rust, 34 resistant to late leaf spot, and 31 genotypes with combined resistances to both diseases have been identified. Recently another 50 lines were tentatively identified as rust and/or late leaf spot resistant. Breeders have successfully incorporated rust and late leaf spot resistances into high-yielding backgrounds and developed 464 elite lines using ICG 7013, ICG 1697, ICG 4747, ICG 2716, ICG 7882, and ICG 7884 as resistant donors. Some of these lines are in various stages of testing in the national program. ICG(FDRS) 4 and ICG(FDRS) 10 are in adaptive trials and ICG(FDRS) 43 is in the AICORPO 1988 rainy-season National Elite Trial (NET) in the peninsular zone.

Field screening of 3500 germplasm accessions for pod rots led to the identification of 11 genotypes which have shown significantly lower incidence of rotted pods than the popular check cultivars. Dry seed coat resistance to *A. flavus* in several genotypes (ICG 1326, ICG 7633, ICG 4750, ICG 4749, ICG 3700, and ICG 2224) has been either identified or confirmed. These sources have been extensively used in the breeding program and 365 elite breeding lines have been developed and are being tested. In addition, 500 germplasm lines have been tested for levels of aflatoxin production by *A. flavus* and two lines, ICG 4681 and ICG 7101 have been identified as low toxin producers. Field tolerance to bud necrosis disease was found in 20 accessions. Two lines, ICG 2716 and ICG 7013, did not transmit Peanut Mottle Virus (PMV) through seeds and ICG 5043 was found to be tolerant to PMV.

Screening against insect pests has resulted in identification of resistant lines: 20 for thrips (*Frankliniella schultzei*), 25 for leaf hopper (*Empoasca kerri*), 18 for leaf miner (*Aproaerema modicella*), 4 for aphids (*Aphis craccivora*), and 20 for termites (*Odontotermes* spp). A large number of single and multiple crosses have been made using ICG 5040, ICG 5042, ICG 5043, ICG 5045, ICG 6764, ICG 2271, etc., as insect-resistant donors. The advanced breeding lines are in various stages of testing.

Thirty one resistant sources were identified by ICRISAT pathologists and APAU scientists after screening more than 1500 germplasm lines for a nematode disease known as "Kalahasti Malady" caused by *Tylenchorhynchus bravilineatus*.

Drought screening of about 1000 accessions resulted in identification of 18 tolerant accessions. Five accessions, ICG 1697, ICG 3657, ICG 4728, ICG 4729, and ICG 4730 have been utilized in the breeding program and the hybrid derivatives are being evaluated.

Screening for higher biological nitrogen-fixing ability resulted in the identification of one spanish type, ICG 1561 and two virginia types, ICG 2405 and ICG 4969 with higher nitrogenase activity. Progenies of crosses involving these accessions were found to yield better. Six lines, ICG 1175, ICG 3660, ICG 2405, ICG 3080, ICG 799, and ICG 476 were found to be promising for photoperiod insensitivity. About 100 spanish/va-

lencia germplasm accessions have been screened for iron deficiency and preliminary observations suggest that 7 accessions hold promise. We have identified seven early-maturing (less than 90 days) germplasm accessions, ICG 476, ICG 4117, TG 2E, Ah 316/S, ICG 147, and ICG 3754. These lines have been extensively utilized as early maturity donors in the breeding program and we have developed and are testing about 529 elite early maturing (90-100 days) advanced lines.

Seven germplasm accessions with large seed mass, USA 47, USA 54, ICG 720, ICG 5662, ICG 7360, ICG 3043, and ICG 6150 have been extensively utilized in the confectionery breeding program. We have developed more than 75 large-seeded, high-yielding confectionery lines which are currently being tested.

We have also utilized more than 500 germplasm accessions to develop broad-based breeding lines with wider adaptability and high yield potential. From this activity, two lines, ICGS 11 and ICGS 44 have been released for general cultivation during the postrainy season in India. Another line, ICGS 37 has been recommended for adaptive trials and 5 lines, ICG 87, ICG 103, ICG 105, ICG 84, and ICG 109 are in 1988/89 postrainy-season NET. Similarly two virginia varieties, ICGS 65 and ICGS 76, and the spanish bunch cultivar ICGS 44-1 are in the rainy-season trials. Several other varieties are in initial stages of testing in various groundnut zones.

Research is in progress at ICRISAT Center to incorporate useful genes into the cultivated groundnut from the secondary gene pool comprising wild *Arachis* species. Special breeding techniques including ploidy manipulations, hormone treatment, mentor pollen, and tissue-culture techniques are being utilized to introgress genes from both compatible and incompatible *Arachis* species. Several stable tetraploid derivatives involving compatible species, *A. cardenasii*, *A. chacoense*, and *A. batizocoi* have been developed. These lines possess very high levels of resistance to rust and leaf spots and some of them are even resistant to leaf miner and bud necrosis disease. These lines are being utilized in the conventional breeding program for further improvement.

Impact on Crop Improvement

The commercial varieties in India were developed through selection within and between exotic or local adapted accessions (37), hybridization (21), and mutation (5) and only 3 were direct introductions (Kadiri 2, UF 70-103, Kuber). Performance of improved commercial varieties introduced from developed countries was not encouraging. Two secondary selections made from the introductions (Robut 33-1 and JL 24) were highly successful in replacing the low-yielding old cultivars. The area under these two cultivars has increased throughout the country and they are being extensively utilized in the national breeding programs.

Groundnut improvement programs are undertaken at AICORPO Centers, Agricultural Universities, ICAR Institutes, and at ICRISAT. Improved genotypes are entered into all-India trials under the AICORPO program. During 1981-88 as many as 356 varieties developed through introduction (2), selection (38), hybridization (297), mutation (12), and interspecific hybridization (7) were evaluated. In the development

of these new varieties as many as 36 parents were involved in hybridization but only Robut 33-1 (89 crosses), M 13 (53 crosses), JL 24 (43 crosses), and J 11 (26 crosses) were frequently utilized. While 195 germplasm accessions were utilized in hybridization, only a few were frequently utilized with specific objectives such as incorporation of earliness, disease and pest resistance. These were: ICF 476 (42 crosses), NC Ac 17090 (ICG 1697) (26 crosses), Manfredi (12 crosses), NC Ac 2821 (ICG 2405) (11 crosses), GDM (11 crosses), Asiriya mwitunde, NC Ac 2214 (ICG 5040), NC Ac 76446(292) (ICG 2716), PI 259747 (ICG 4747), NC Ac 2232 (ICG 5042), Dh 3-20, TG 18, and TG(E) 1. The other lines appear to have been used as parents with a view to improve yield.

Involvement of special-feature accessions with specific breeding objectives led to the development of varieties with rust and late leaf spot resistance (40), bud necrosis tolerance (11), extra-early varieties (32) suitable for postrainy-season cultivation, and confectionery (28) selections. Since 1985, these varieties are being tested for their yield potential and some of them may be released within the next 2-3 years. However, none of the new confectionery lines were superior to the control cultivar, M 13. At least 13 selections resistant to foliar diseases were derived from interspecific hybridization involving *A. cardenasii* as one of the parents.

For cultivation in postrainy season about 112 improved varieties developed through selection (15) and hybridization (97) were tested during 1981-88 by AICORPO Centers. Only ICGS 11, Kadiri 3, ICGS 44, UF 70-103, G 201, CGC 3, and RSHY 1 were found promising.

During 1983-88, 9 spanish varieties, GG-2, Jawan, CO 2, Dh 8, ICGS 11, SG 84, VRI 1, ALR 1, and BG 3; Girnar-1; 3 virginia bunch varieties, Kaushal, ICGS 44, and UF 70-103; and 3 virginia runner varieties, Chitra, GG-11, and M 335 were released for commercial cultivation. The area under the cultivars ICGS 11 and ICGS 44 might increase phenomenally in future as large-scale ICAR-LEGOFTEN demonstrations have clearly shown their superiority over the existing popular cultivars in six states. Girnar-1 possesses multiple resistance to foliar diseases and insects and tolerance to drought and could be successfully cultivated in both seasons. These varieties are expected to revolutionize groundnut cultivation if the seed production program is simultaneously strengthened.

Use of Minor (Small) Millets Germplasm and its Impact on Crop Improvement in India

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In many parts of India, six species of minor (small) millets are cultivated for grain and fodder. These are: finger millet (*Eleusine coracana* (L.) Gaertn.), foxtail millet (*Setaria italica* (L.) P. Beauv.), proso millet (*Panicum miliaceum* L.), kodo millet (*Paspalum scrobiculatum* L.), little millet (*Panicum sumatrense* Roth. ex Roem. and Schult.), and barnyard millet (*Echinochloa colona* (L.) Link). In India, these are grown as rainfed crops in marginal and submarginal conditions of soil fertility and moisture. On an average, approximately 6 m ha are planted under these crop species of which finger millet alone occupies around 2.5 m ha followed by kodo, little, foxtail, proso, and barnyard millet, in that order.

Systematic improvement in small millets was not attempted until recently in India. Obviously most of the cultivars are local landraces which are products of indirect human and natural selection over a period of time. Small millets are indispensable to Indian agriculture, being the main life-support species in the worst drought years. Of late there has been an appreciation of the need to improve the productivity of these crops through modern methods of breeding. Genetic improvement through conventional breeding approaches depends solely on the availability of diverse germplasm. Germplasm is the basic raw material and one has to bank upon a broad genetic base for crop improvement. Therefore, easy access to germplasm is necessary. This is especially true of small millets where only a small part of the available vast genetic resources has been explored, studied, and utilized.

Small millets have always been of local and regional importance, and as a result have attracted little attention from national and international organizations. They have always received the lowest priority in terms of funding and manpower allocation. In India, though crop improvement work on small millets has been going on for several years, these crops have received less attention compared to other major food crops. It was only after 1969 that the millets started receiving some attention, with the launching of the Coordinated Millets Improvement Project. Small Millets Improvement received a boost during 1978-79 with the establishment of five crop-specific lead research centers under IDRC assistance. The research on these crops was broadened during the Seventh Plan, with the launching of All India Coordinated Small Millets Improvement Project (AICSMIP) at Bangalore. One of the major objectives of the project is the diversification of the varietal base by evolving high-yielding, disease-resistant, and widely adaptable varieties of various small millets.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Collaboration on Genetic Resources: summary proceedings of a Joint ICRISAT-NBPGR(ICAR) Workshop on Germplasm Exploration and Evaluation in India, 14-15 Nov 1988, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

Germplasm Availability

In the past, small millets scientists worked with limited plant materials and a narrow genetic base collected locally. Coupled with difficulties in artificial hybridization, this blunted the opportunities of yield improvement through genetic manipulation. The situation was to some extent rectified in the 1960s when the Rockefeller Foundation of USA and the Indian Council of Agricultural Research (ICAR) made the first concerted effort in India to pool the collections of various small millets to make them available to scientists working in different parts of the country. One set of this world collection has been rejuvenated by ICRISAT in 1976 and was made available to the All India Coordinated Millets Improvement Project (AICMIP). The conservation and supply activities further gained momentum with NBPGR, New Delhi, playing a key role in augmenting the small millets collections. Recognizing the importance of conservation and easy access to germplasm, the AICMIP established a germplasm unit at Bangalore in 1979. The unit has been making efforts since 1980 to pool the available germplasm of small millets from various sources and to make it available to breeders.

At Bangalore, a total of 8522 accessions of various small millets have been assembled. These include 4490 finger millet, 1300 foxtail millet, 544 little millet, 577 proso millet, 646 barnyard millet, and 965 accessions of kodo millet.

Apart from the collections maintained at Bangalore, ICRISAT is assembling and maintaining one of the most comprehensive world collections of small millets. The gene bank at ICRISAT has made efforts at the global level in the last 6-8 years to assemble and conserve germplasm, and to make it available to workers all over the world. This has made possible easy access to diverse germplasm, thereby strengthening the national breeding programs.

Utilization of Germplasm

The full utilization of germplasm depends upon two factors: (1) evaluation and characterization, and (2) identification of useful gene sources.

Characterization, classification, and cataloguing of germplasm are slowly gaining momentum. While fairly large diversity has been achieved, we still have a long way to go in studying and assessing their breeding value. Germplasm evaluation has two facets: characterization of germplasm by botanists and evaluation/screening by concerned crop improvement scientists/breeders. Germplasm characterized and documented solely by a botanist may fail to depict the true worth of the material for selection and utilization in current breeding programs. Germplasm screening from the breeder's angle for agronomic, physiological, pathological, and quality characters demands a great deal of time and resources. The breeding value of the material is best judged by studying the accessions in field trials, rather than depending solely on documented data. An attempt was made in this direction by NBPGR by growing small millets germplasm from the Indian National Program and ICRISAT at Akola and inviting breeders for selection. This type of evaluation may be encouraged in future.

During the last 5 years, a large number of selected germplasm accessions were evaluated in the all-India testing network and a number of superior genotypes have been released for general cultivation in different parts of the country. Of the 28 varieties of different small millets released during the last 5 years, 22 are selections either directly or indirectly from the germplasm (Table 1). This indicates the importance of direct utilization of germplasm in small millets improvement.

In finger millet, hybridization work was started as early as 1959 in Karnataka and so far, 13 varieties have been released in Karnataka through recombination breeding. Similarly, recombination breeding in Tamil Nadu has resulted in the release of about six varieties. The most significant aspect of finger millet improvement has been the extensive use of exotic germplasm particularly from Africa, in the hybridization program. The African finger millets are characterized by thick stems, robust growth, early vigor, large ears, broad, dark green leaves, and higher grain density. These characters are rarely seen in the Indian germplasm. Indo-African crosses were first attempted in early 1970s with the identification of a few donor parents such as IE 927, IE 929, IE 980-R, IE 810, and IE 902. The crossing of these lines with the local agronomic base (Hollubele, K1, Annapurna, Purna, Cauvery, Shakti, CO 7, CO 1, and Hamsa) resulted in the generation of vast breeding material for subsequent selection and release of the Indaf and HR series of improved varieties. Some of the most popular varieties developed from Indo-African crosses are Indaf 1, Indaf 3, Indaf 5, Indaf 8, Indaf 9, and more recently HR 911. Some of these varieties - Indaf 5, Indaf 8, Indaf 9, and HR 911 - have become extremely popular in Karnataka with more than 50% coverage in area. They have an yield potential of around 6 t ha^{-1} under irrigated conditions.

In finger millet, breeding for blast resistance is one of the priority objectives. The entire finger millet germplasm has been screened for blast disease and 40 accessions with stable sources of resistance have been identified. There appear to be more sources

Table 1. Number of varieties of small millets identified through direct selection and hybridization, 1982-87.

Crop	No. of varieties identified through		
	Direct selection from germplasm	Hybridization	Total
Finger millet	4	6	10
Foxtail millet	3	-	3
Little millet	2	-	2
Proso millet	5	-	5
Barnyard millet	5	-	5
Kodo millet	3	-	3
Total	22	6	28

of blast resistance in African germplasm than in Indian germplasm. Large-scale hybridization involving blast-resistant lines and elite agronomic base has been undertaken during the last 5 years and a number of stabilized selections are undergoing large-scale yield tests in different states.

Further, many useful genetic stocks have been identified both in finger millet and foxtail millet. Accessions possessing higher protein, desirable physiological attributes with high carbon dioxide fixation and low leaf area suitable for rainfed conditions, and genotypes which can germinate with limited moisture and in hard soil crust have been identified. Long glume types with high test weight will be of special interest in the improvement of seed size in finger millet.

In foxtail millet new sources of dwarfing controlled by oligo genes have been identified. The plant type of these accessions is very similar to dwarf wheat or rice and so they form very interesting breeding material. The variability available for protein content (7.16-15.73%); and seed fat content (4.0-7.1%) in foxtail millet is enormous. Thus identified sources with high protein and seed fat are available both for direct exploitation and use in breeding.

As mentioned already, the utilization of germplasm in small millets is most important. So far, only a fraction of the vast available diversity has been utilized and that too only in finger millet. There is wide scope to utilize the diversity present in these crops through a well planned hybridization program.

Use of Chickpea and Pigeonpea Germplasm and their Impact on Crop Improvement in India

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The important pulse crops grown in India are chickpea (*Cicer arietinum* L.), pigeonpea (*Cajanus cajan* (L.) Millsp.), mung bean (*Vigna radiata* (L.) Wilczek), urd bean (*Vigna mungo* (L.) Hepper), lentil (*Lens culinaris* Medik.), fieldpea (*Pisum sativum* L.), cowpea (*Vigna unguiculata* (L.) Walp.), moth bean (*Vigna aconitifolia* (Jacq.) Marechal), horse gram (*Macrotyloma uniflorum* (Lam.) Verdc.), grass pea or khesari (*Lathyrus sativus* L.) and dry bean (*Phaseolus vulgaris* L.). Other pulses of minor importance grown in restricted areas in India are faba bean (*Vicia faba* L.), rice bean (*Vigna umbellata* (Thunb.) Ohwi and Ohashi), lablab bean (*Lablab purpureus* (L.) Sweet), and winged bean (*Psophocarpus tetragonolobus* L.). Among these, chickpea and pigeonpea are the most important.

Many of these pulses have been cultivated since time immemorial under diverse agroclimatic and management conditions which favored genetic diversity in these crops. Efforts have been made from time to time to collect, evaluate and utilize the germplasm of these pulses, particularly pigeonpea and chickpea. However, these efforts have been localized and scattered over different pulse-growing states. Germplasm collections were also made under the Rockefeller Foundation's Regional Pulse Improvement Project. All these collections were later transferred to ICRISAT. Since the establishment of the National Bureau of Plant Genetic Resources (NBPGR), joint missions involving scientists from NBPGR, Agricultural Universities, and ICRISAT have been collecting germplasm in the country.

Available Germplasm Resources

The gene bank at ICRISAT has 15 564 chickpea accessions of which 5863 lines are from India. In pigeonpea, there are 11 034 accessions of which 9084 are of Indian origin. Part of these collections are maintained under the All India Coordinated Pulses Improvement Project (AICPIP). Working collections are maintained at various centres. Among the various pulse crops, chickpea and pigeonpea are at the top of the list with respect to the number of germplasm lines.

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Germplasm Distribution

As a world repository of chickpea and pigeonpea germplasm, the ICRISAT gene bank supplies germplasm to scientists working on these crops. From 1974 to 1988, a total of 33 020 samples of chickpea and 20 502 samples of pigeonpea have been sent to different programs and scientists in India. Under AICPIP, 11 centers have been assigned the responsibility to assemble and evaluate the existing germplasm, and make it available to workers in the country.

The germplasm accessions available at ICRISAT have been evaluated for 25 characters in chickpea and for 40 characters in pigeonpea. Some of these accessions have been evaluated at different locations in India—Akola, Gwalior, Issapur, and Hisar—in collaboration with NBPGR, to characterize them in different agroecological zones.

Uses of Germplasm Lines

Chickpea and pigeonpea germplasm has been used in the country in the following manner:

- direct use as released varieties for cultivation,
- sources of resistance to biotic stresses like diseases and insect pests,
- sources of tolerance to abiotic stresses like moisture deficit/excess, high/low temperature, soil salinity, etc.,
- parental material for hybridization for improvement of agronomic traits,
- base material for polyploidy and mutation breeding,
- sources of new plant types to study physiological and agronomic adaptation,
- material for basic studies on phylogenic and cytogenetic relationships, and
- material for genetic studies on the mode of inheritance, to study the expression of a gene or group of genes under different genetic backgrounds.

Impact on Crop Improvement

Many germplasm lines have been directly released as varieties. In India, germplasm lines account for about 63% of the varieties of pulses released so far. Of the 291 varieties released in 13 pulse crops, 175 are direct selections from the germplasm. Of the remaining, 6 are pure line selections, 96 through hybridization, and 14 through mutation breeding. Recent examples include ICP 8863 of pigeonpea, released as Maruti in Karnataka; and ICC 8933 of chickpea, released as JG 315 in Madhya Pradesh.

A large number of germplasm lines have been used as sources for transferring resistance to diseases. These include pigeonpea lines resistant to fusarium wilt, sterility mosaic, phytophthora blight, and chickpea lines resistant to fusarium wilt, ascochyta blight, and stunt. Most of the lines in the AICPIP Disease Nurseries that are tested at different locations are germplasm lines. Some of these are resistant to more than one isolate strain, and also to more than one disease.

Compared to disease resistance, there are very few resistant sources for insect pests, and the level of resistance is also not high. Some lines have been identified with resistance to *Heliothis* pod borer in chickpea, and resistance to pod borer and podfly in pigeonpea. These are now being used in breeding programs.

Many lines with desirable agronomic characters such as earliness (in breeding extra-early pigeonpeas), seed size, and color (in breeding bold-seeded and kabuli chickpeas) have been used in hybridization programs to develop varieties with high yield and desirable plant type. Germplasm has contributed significantly in these programs.

The use of pigeonpea germplasm lines with the genetic male sterile gene has opened up possibilities for hybrid pigeonpeas in India. Many institutions are now using the original or converted germplasm lines in their hybrid pigeonpea programs.

Germplasm lines have been used to generate information on the inheritance of characters, and also to elucidate cytogenetic and phylogenic information.

Future Emphasis

1. The areas which have not been explored so far should be surveyed for collection of germplasm.
2. The existing germplasm available at different centers should be pooled and evaluated so as to discard duplicates and to identify desirable types.
3. Germplasm accessions should be evaluated under different agroclimatic situations and growing conditions in order to characterize them, and to test the stability of characters; the entire germplasm collection should be characterized and catalogued.
4. All the information related to germplasm should be computerized.
5. One set of germplasm should be kept at NBPGR in long-term storage, for future use.
6. Facilities to screen the germplasm against viral diseases should be strengthened and techniques for quick screening should be devised.

Highlights of Discussions

Discussions were held at the end of each session of the workshop. Presented here are the salient points arising from these discussions.

World Germplasm Collections: Status Reports and Potentials

1. The assembly and availability of world collections of germplasm of ICRISAT mandate crops and six small millets was appreciated. From the point of view of genetic resources, the overall number of germplasm accessions assembled at ICRISAT Center was considered to be relatively small compared to the world collections of other major crops such as wheat, rice, maize, and barley. Some concern was expressed on the relatively low number of germplasm accessions that have so far been utilized in breeding programs. More interaction between plant breeders and germplasm scientists during evaluation and identification of new and useful traits should enhance germplasm utilization.
2. Breeders should diversify the genetic base of their material by using more landraces including wild and intermediate forms. Particular reference was made to the limited germplasm that has been used for improvement of rabi (postrainy-season) sorghum. Fortunately, ICRISAT has recently obtained material from Cameroon and Ethiopia, which are from similar environments. More efforts should be made to collect similar material from Mali, Nigeria, Chad, and parts of India. It was also proposed to collect sorghum landraces from low-temperature and high-elevation areas of China, India, and African countries.
3. The continuing effort to combine resistance to biotic and abiotic stresses with high yield components was discussed. Although there were some cases where resistance to stresses like drought were associated with low yield, members generally agreed that there was potential for using stress-tolerant landraces in the development of new, high-yielding cultivars.
4. The need for obtaining more agroclimatic data during germplasm collection missions was stressed. It was pointed out that all germplasm collections undertaken by ICRISAT scientists include basic agroclimatic data. However, many donated germplasm accessions do not have passport and climatic data. At any rate, it was proposed that germplasm scientists should extract and document whatever information they can on the environment of existing collections, and relate that information with the landraces prevalent in different and discrete agroclimatic zones. As the main responsibility of germplasm scientists is to collect and salvage germplasm from extinction, the help of agroclimatologists should be sought to achieve this important task.
5. A question was raised on the disparity between the large number of germplasm lines with resistance to major pests and diseases and the lack of stable resistance to some of the same diseases and pests in breeding materials. An example of this is *Heliothis* in chickpea and pigeonpea which remains a major constraint to higher production

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even though several resistance sources are identified in germplasm lines. It was suggested that these sources, which have been identified after several years of intensive germplasm screening, should be more effectively utilized.

Germplasm Exploration/Collection, Evaluation, Documentation, Exchange and Quarantine, and Conservation

1. Participants recognized the success of joint exploration missions by ICRISAT and NBPGR. It was suggested that future collection programs cover unexplored and underexplored areas with more emphasis on wild species.
2. Clarifications were sought on the rationale of collecting groundnut germplasm in the northeastern hills of India and in the state of Kerala. Specific areas like the Indo-Burma border area for new types, and parts of Kerala for old landraces were suggested for further exploration.
3. The extensive NBPGR/ICRISAT joint and preliminary evaluation programs were presented and discussed in detail. To facilitate evaluation of thousands of accessions, an improved and a local check are repeated at frequent and regular intervals in an augmented block design. The program was launched to enable crop improvement scientists to evaluate the germplasm lines in their own regions and to select desirable types for further testing, and subsequent use in crop improvement programs. Questions were raised on the reliability of the data generated for pest and disease resistances. NBPGR scientists clarified that pest and disease resistance evaluation was a preliminary program done by NBPGR plant protection scientists, which could be further assessed by AICCIP scientists. It was also suggested that increased participation of AICCIP scientists would be essential in all multilocational evaluation of germplasm in India.
4. A clarification was given on the type and nature of germplasm evaluation programs that are undertaken by genetic resources scientists. It was stated that germplasm scientists deal with the characterization and preliminary evaluation of the collected material with an attempt to classify and document germplasm diversity. Subsequent evaluations of germplasm for detailed studies, screening, selection, and utilization are usually done under the responsibility of the concerned crop improvement scientists.
5. It was suggested that NBPGR serve as the alternate base conservation center for at least the world collections of pigeonpea and minor (small) millets germplasm.
6. Computer-based germplasm data documentation and exchange was discussed and considered highly desirable. The use of compact discs for data storage, processing, and exchange was demonstrated.
7. The collaborative plant quarantine procedures applied to both import and export of germplasm, and the timely, safe, and orderly methods of insuring national and international germplasm exchanges were appreciated. It was also suggested that a joint ICRISAT/NBPGR manual be prepared on plant quarantine systems and practices applicable to ICRISAT mandate crops and small millets.

8. Participants from ICAR, NBPGR, and AICCIP greatly appreciated the role of GRU, ICRISAT, in mobilizing genetic resources in the country. On their part, the ICRISAT scientists noted that they had received tremendous cooperation from NBPGR, ICAR, and other Indian national programs. Participants from ICRISAT and others particularly noted Dr Paroda's efforts to enhance this collaboration.

Use and Impact of Germplasm on Crop Improvement in India

1. Differences were observed on the extent of use and impact of germplasm among ICRISAT mandate crops.
2. Landraces are generally known to possess local adaptation and stability, while improved cultivars with broad genetic base are more likely to have wider adaptation for productivity. Judicious selection and utilization of germplasm have had a visible impact on crop production, as shown by AICCIP for sorghum, pearl millet, pigeonpea, and small millets.
3. The criteria used to identify the usefulness of germplasm and its utilization need to be re-examined. Those lines which did not produce the required end product or cultivar should not be rejected.
4. Some landraces of chickpea (ICC 8933), pigeonpea (ICP 8863), and several small millets were reported to have been released as high-yielding cultivars. Other landraces like the Togo material in pearl millet, Zerazera in sorghum, ICC 12237 from India in chickpea, multiple disease-resistant material in pigeonpea, and Peruvian accessions in groundnut have been extensively used in breeding programs and have made substantial contributions towards the development of high-yielding varieties or hybrids.
5. It was considered desirable to assess the relative yield performance of small millets and pearl millet under high temperatures and dry conditions.
6. The constitution of gene pools for specific characters was regarded as a priority task for all crops. This task is to be undertaken by GRU, ICRISAT, in close collaboration with plant breeders.
7. Training for specific requirements and the development of human resources were recognized as vital for sustainable crop production.
8. To increase the impact of germplasm on crop production, suggestions were made to:
   - Evaluate the entire germplasm in batches in collaboration with crop improvement scientists, wherever possible in "hot spots", to identify new sources of resistance to biotic and abiotic stresses;
   - Produce classified and simple germplasm catalogs on characters of major economic importance; and
   - Utilize new biotechnology methods for hybridization involving cultivated or wild relatives, and their intermediate forms, and also to create new sources of variability through various in vitro techniques.

Recommendations

Several recommendations were made by the technical working group of the workshop which was composed of 20 members representing different organizations, crops, and disciplines. The following are the major recommendations.

1. A single, more comprehensive, and effective collaborative program should be envisaged for germplasm exploration, evaluation, and subsequent utilization in crop improvement. The collaborative program should:
   - Involve NBPGR (ICAR), National Agricultural Research Organizations like the All India Coordinated Crop Improvement Projects and Agricultural Universities, GRU and other crop improvement scientists in ICRISAT, and IBPGR.
   - Be time bound with regular and annual meetings.
   - Recognize and give due credit to all collaborating individuals and centers.
2. Wherever possible, depending on availability of funds, crop improvement scientists should participate in some specific areas of germplasm collection in order to observe and obtain more comprehensive data on biotic and abiotic stresses under which the landraces have evolved and are being cultivated.
3. It was stressed that the nutritional value of minor (small) millets should be kept in mind while breeding for higher yield. It was suggested that grain quality of improved cultivars of small millets be assessed at ICRISAT Center.
4. Participants felt that further efforts must be made by ICRISAT, NBPGR, and IBPGR to train scientists in various genetic resources activities.
5. The collective name of the six minor millets should be changed to small millets, a term that has been adopted by the International Small Millets Steering Committee.
6. The following were identified as priority areas of collection for the various crops.

   Sorghum. Bihar (early grain and fodder types); Madhya Pradesh (Malwa plateau and Hoshangabad area); Assam, Madhya Pradesh, and Orissa (Koraput area) for fodder types; South Gujarat; Uttar Pradesh (Bundelkhand area); Northeastern hilly regions; and Maharashtra and Karnataka (for rabi sorghums).

   Pearl millet. Maharashtra (Western Ghats); Orissa (Eastern Ghats); Western Madhya Pradesh; Gujarat (Kutch); North Uttar Pradesh; Rajasthan (during drought); and Bihar, Bengal, and northeastern region for wild species.

   Chickpea. Rajasthan (Northwest, Ganganagar, Pali and Jodhpur); Madhya Pradesh; Southern Bihar; Eastern Uttar Pradesh; Eastern Maharashtra and Andhra Pradesh; and Haryana (Mahendergarh).

   Pigeonpea. Unexplored areas in the Northeast, Bihar, Orissa, and Karnataka; and Rajasthan (Alwar district).

   Groundnut. Northeastern area of Andhra Pradesh; Haryana; Northwestern parts of Rajasthan; Uttar Pradesh; and Bihar.

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Minor millets. Western Ghats of Maharashtra; South and North Bihar; Hilly areas in Uttar Pradesh; Northeast hill areas; Madhya Pradesh; and Tamil Nadu.

7. A collaborative multilocational germplasm evaluation in India was recommended for implementation starting the next growing season. The collaborating agencies will be NBPGR (ICAR), all-India crop improvement scientists of ICAR, Agricultural Universities, GRU, and crop improvement scientists of ICRISAT. The crops, number of samples, and areas of evaluation that are listed below will be reviewed annually. The seed samples required for the evaluation program will be supplied by GRU, ICRISAT. The field data will be compiled by NBPGR and forwarded to GRU, ICRISAT, for documentation and analysis with the help of the computer. The data will be used to expand the germplasm database of the world collections, for utilization in crop improvement programs, and to prepare and publish joint NBPGR/GRU germplasm catalogs.

Sorghum. Forage: Every year about 1000 accessions at Jhansi, Issapur, and Rajendranagar (NRCS).
Grain: Every year about 1000 accessions at Akola, Coimbatore, and Rajendranagar (NRCS).
Rabi (postrainy-season) sorghums: Every year about 500 accessions at Rahuri, Bijapur, and ICRISAT Center, Patancheru.

Pearl millet. Every year about 2000 accessions at Jodhpur, Coimbatore, and Pune.

Chickpea. Long duration: Every year about 1000 accessions at Kanpur, Hisar, and Gwalior.
Short duration: Every year about 1000 accessions at Akola and ICRISAT Center, Patancheru.

Pigeonpea. Long duration: Every year about 1000 accessions at Kanpur and Varanasi.
Medium and medium-long duration: Every year about 1000 accessions at Akola, Kanpur, and ICRISAT Center, Patancheru.
Short-duration(New germplasm): Gwalior.

Groundnut. Kharif (rainy season): Every year 1000 accessions at ICRISAT Center, Patancheru, Junagadh, and Akola.
Rabi (postrainy-season): Every year 500 accessions at Junagadh and ICRISAT Center, Patancheru.

Minor millets (small millets). Every year around 1000 or available number of accessions will be evaluated for the following crops at the locations mentioned below:
Finger millet: Bhowali, Akola, Bangalore, and Coimbatore.

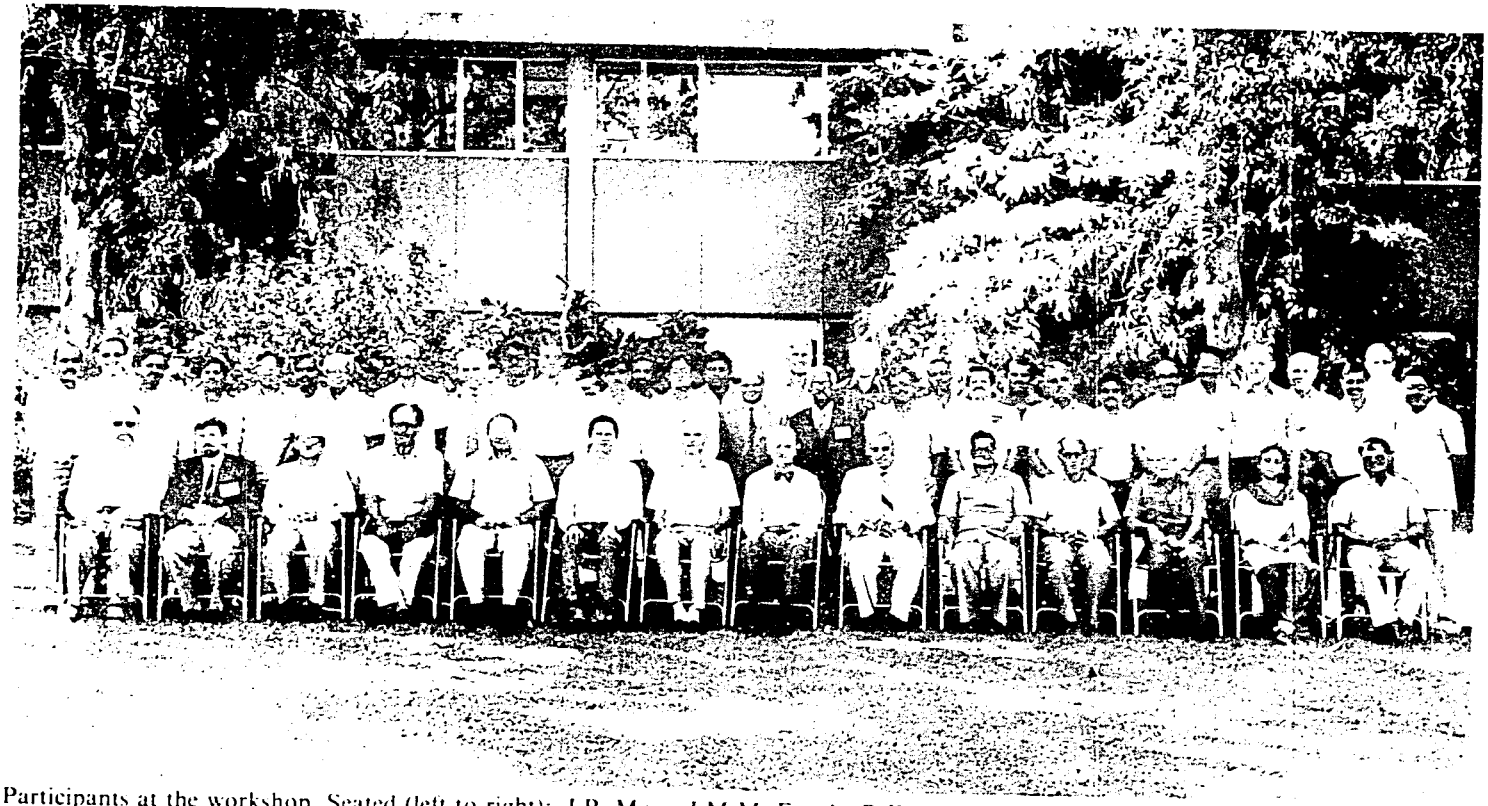
Foxtail millet: Nandyal, Bangalore, and Bhowali.
Proso millet: Akola, Ranichori, Bangalore, and Dholi (postrainy season).
Little millet: Rewa/Dindori, Ranchi, Bangalore, and Similiguda.
Barnyard millet: Almora, Coimbatore, and Bangalore.
Kodo millet: Dindori/Rewa, Coimbatore, and Bangalore.

It was recommended that agroclimatic data be collected during the period of crop growth for all locations.

Acronyms and Abbreviations

AICCIP	All India Coordinated Crop Improvement Project
AICPMIP	All India Coordinated Pearl Millet Improvement Project
AICPIP	All India Coordinated Pulses Improvement Project
AICORPO	All India Coordinated Research Project on Oilseeds
AICSIP	All India Coordinated Sorghum Improvement Project
AICSMIP	All India Coordinated Small Millets Improvement Project
AGLN	Asian Grain Legumes Network
ALAD	Arid Lands Agricultural Development (Program)
CCRN	Cooperative Cereals Research Network
CGIAR	Consultative Group on International Agricultural Research
cms	cytoplasmic male sterile
CPPTI	Central Plant Protection Training Institute, (India)
ct DNA	cytoplasmic DNA
DPR	Directorate of Pulses Research
ELISA	Enzyme-linked Immunosorbent Assay
GOI	Government of India
GRU	Genetic Resources Unit
HAU	Haryana Agricultural University (India)
IARI	Indian Agricultural Research Institute
IARC	International Agricultural Research Center
IBPGR	International Board for Plant Genetic Resources
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in Dry Areas
IDMRS	ICRISAT Data Management and Retrieval System
IGFRI	Indian Grassland and Fodder Research Institute
ISTA	International Seed Testing Association
JNKVV	Jawaharlal Nehru Krishi Vishwa Vidyalaya, (India)
mt DNA	mitochondrial DNA
NBPGR	National Board for Plant Genetic Resources (India)
NRCG	National Research Centre for Groundnut
NRCS	National Research Centre for Sorghum
NSSL	National Seed Storage Laboratory
ORSTOM	Institut français de recherche scientifique pour le développement en coopération (France)
PEQIA	Post-Entry Quarantine Isolation Area
PMV	Peanut Mottle Virus
PStV	Peanut Stripe virus
RH	Relative Humidity
RPIP	Regional Pulse Improvement Project
SADCC	Southern African Development Coordination Conference (Botswana)

Participants



Participants at the workshop. Seated (left to right): J.P. Moss, J.M.M. Engels, R.K. Arora, M.H. Mengesha, R.S. Paroda, M. Goon, J.L. Montieth, J.M.J. de Wet, B.R. Murty, G. Harinarayana, R.V. Vidyabhushanam, N.C. Joshi, U. Raman, S. Appa Rao.

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