International Crop Germplasm Exchange at ICRISAT

CL Laxmipathi Gowda* and HD Upadhyaya
ICRISAT, Patancheru, Andhra Pradesh-502324, India

Plant genetic resources are essential for sustainable development of agriculture and food security. Rapid loss of plant biodiversity and realization of its importance during twentieth century led to collection, conservation and exchange of large number of germplasm in genebanks across the planet, resulting in the conservation of more than 6.1 million accessions in over 1,300 genebanks. Eleven International Agricultural Research Centers (IARC) maintain over 6,00,000 accessions and supply seed samples freely to scientists globally. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has the global responsibility of collection, conservation, evaluation, improvement, and distribution of sorghum, pearl millet, chickpea, pigeonpea, groundnut, and six small millets (finger millet, foxtail millet, proso millet, little millet, kodo millet, barnyard millet) germplasm. ICRISAT holds in trust 1,16,799 accessions from 142 countries. To support the research of national programs ICRISAT supplied over 1.22 million seed samples in 172 countries. A total of *583* varieties were released in 76 countries from the ICRISAT supplied germplasm and breeding material. Germplasm accessions at ICRISAT were evaluated for morpho-agronomic, biotic, abiotic, and quality traits in batches as and when they were acquired. Core collections of sorghum, pearl millet, chickpea, pigeonpea, groundnut, and finger millet and mini core collection of chickpea, pigeonpea, and groundnut were developed to enhance the utilization of germplasm. Genetically diverse, new sources of early-maturity, large seed size, drought tolerance and chilling tolerance at germination were identified using core/mini core collection approach.

Key words: ICRISAT, Germplasm, Collection, Exchange, Utilization, Diversity, Core collection, Mini core collection

Plants have formed the basis of agriculture for more than 10,000 years and they continue to provide food security globally. Success of crop improvement depends on the availability of diverse germplasm resources. Collection and assembly of germplasm at some locations and easy access to those germplasm has facilitated crop improvement progress globally. Historically, there have been several exchanges and introductions of crop germplasm, across the globe. However, purposeful efforts to explore, collect, exchange, and conserve the germplasm resources started in the 1920s. Over the years, gene banks have been established in a number of countries and the number of accessions conserved in genebanks now exceeds six million (FAO, 1998).

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has world mandate for the germplasm collection, characterization, conservation, and distribution of sorghum, pearl millet, chickpea, pigeonpea and groundnut, and the genetic enhancements of these crops. In addition, it also has mandate for collection, characterization, conservation, and exchange of germplasm of six small millets, namely, finger millet, foxtail millet, kodo millet, little millet, proso millet, and barnyard millet. This has necessitated exchange of the germplasm among the number of countries and ICRISAT.

* *E-mail: icrisat@cgiar.org*

Germplasm Assembly in the ICRISAT Genebank

Soon after the establishment of ICRISAT in 1972, efforts were initiated to assemble and collect the germplasm. The Rockfeller Foundation working with the Indian national program during 1960s, had assembled over 16,000 sorghum germplasm accessions from major sorghum areas, and ICRISAT acquired 11,961 accessions of this collection in 1974 that existed in India and USA. Initially, ICRISAT also acquired over 2,000 pearl millet germplasm accessions assembled by the Rockfeller Foundation in India, and another 2,000 accessions collected by the Institut Francais de Recherché Scientifique pour le Development en Cooperation (ORSTOM) in Francophone, West Africa.

The chickpea and pigeonpea germplasm initially acquired by ICRISAT consisted of the material originally collected and assembled by the former Regional Pulse Improvement Project (RPIP), a joint project of the Indian Agricultural Research Institute (IARI), the United States Department of Agriculture (USDA), and Karaj Agricultural University in Iran. Sets of this germplasm placed in several agricultural research institutes in India and Iran, and at the USDA were donated to ICRISAT in 1973. ICRISAT also acquired over 1,200 chickpea accessions from the Arid Lands Agricultural Development (ALAD) program in Lebanon. Similarly, much of the

groundnut germplasm was received from the Indian groundnut research programme, now the National Research Center for Groundnut (NRCG-Junagadh, India), and USDA (USA).

ICRISAT also initiated programmes to add new germplasm of the five mandate crops. Special efforts were made to collect or assemble landraces and wild relatives from areas threatened by genetic erosion. During 1974 and 1997, ICRISAT launched 212 joint collection missions in areas of diversity in 61 countries and collected 8,957 sorghum; 10,802 pearl millet; 4,228 chickpea; 3,870 pigeonpea, and 2,666 groundnut accessions. Apart from ICRISAT's own collection efforts, the donations from the national programmes of countries namely Ethiopia, Sudan, and India contributed to enrich the germplasm collections at ICRISAT. Presently, ICRISAT genebank (named as Rajendra S. Paroda Genebank in 2002) is holding 1,16,799 accessions from 142 countries (Table 1).

Table 1. Germplasm holdings in the R S Paroda Genebank, ICRISAT, Patancheru (upto July 2006)

Crop	Active collection	Base collection	In-trust
Sorghum	36,774	33,039	36,771
Pearl millet	21,594	18,870	21,563
Chickpea	19,187	16,977	17,117
Pigeonpea	13,632	11,547	13,389
Groundnut	15,419	10,709	14,803
Finger millet	5,949	4,620	5,949
Foxtail millet	1,535	1,054	1,535
Proso millet	842	576	835
Little millet	466	384	462
Kodo millet	658	630	656
Barnyard millet	743	487	743
Total	**1,16,799**	**98,893**	**1,13,823**

Germplasm Characterization and Evaluation

Agronomic and morphological characterization is necessary to facilitate the utilization of germplasm. Evaluation of germplasm accessions for traits of agronomic importance enhances its utility by the research workers. Therefore, the germplasm accessions of all the crops were sown in batches over the years and characterized for morphological and agronomic traits. Germplasm accessions were also screened against stresses in collaboration with various disciplinary scientists. Grains were tested for nutritional value such as starch, protein, oil content, cooking time, etc. Germplasm sets were evaluated over locations jointly with NARS in India, Nepal, Thailand, Indonesia, Ethiopia, Kenya, and a few countries in West Africa to enhance the value of characterization, and at the same time-share the germplasm with partners. A total of 96% accessions have been characterized for all morpho-agronomic traits upto July 2006. Following is the crop-wise progress in brief on germplasm characterization at ICRISAT.

Sorghum

Germplasm characterization was initiated in 1973 by sowing the germplasm accessions in batches over the years. During 1997, the status of characterization work was reviewed and the gaps were identified. To fill these gaps, a set of 781 new germplasm accessions was sown for characterization. In addition, data were recorded on 2,000 accessions for grain characteristics. Also characterized and classified 498 germplasm accessions received earlier from South Africa and 348 accessions of converted zera-zera sorghums. Protein content of 364 accessions analyzed during 2002 ranged between 8.3 to 17.7%. Out of 122 accessions of wild relatives of sorghum screened for shoot fly resistance, 11 accessions were identified as resistant in addition to the two accessions of cultivated sorghum (IS 2146 and IS 18551).

Pearl Millet

During 1973-96, most of the germplasm accessions of pearl millet had been characterized. Work done was reviewed in 1997 and as result 197 germplasm accessions were characterized for traits that were missing from earlier years. In subsequent seasons, 1,815 and 1,394 accessions were sown to record the data on days to flowering, plant height, spike length, and spike thickness.

Chickpea

Chickpea germplasm characterization work was almost fully achieved by 1996. However, data on some traits on part of the germplasm were missing and the additional data were recorded during 1997/98. Forty-nine accessions of wild *Cicer* were characterized in the field, and another 100 accessions received from ICARDA were sown under extended day length conditions in the glasshouse and characterized for 22 traits. Preliminary screenings of the chickpea collections of Asian origin indicated the presence of good levels of genetic resistance, particularly to collar rot and botrytis gray mold disease.

Pigeonpea

In continuing the work of germplasm characterization of pigeonpea, 388 accessions received from USA were sown during 1997 crop season for characterization and

seed increase. Information on photoperiod reaction on 11,000 pigeonpea accessions was added to the database. A very diverse set of 28 accessions of pigeonpea and 12 related wild species were tested for tolerance to damage by pod fly (*Melanagromyza obtusa* Malloch) and pod wasp (*Tanaostigmodes cajaninae* La Salle). Accessions ICPW 141, 278, and 280 (*Cajanus scarabaeoides*); ICPW 14 (*C. albicans*); ICPW 214 (*Rhynchosia bracteata*); and ICPW 202 (*Flemingia stricta*) showed resistance to both pod fly and pod wasp damage (Sharma *et al.*, 2003).

Groundnut

Almost all the germplasm accessions had been characterized by 1996 for most of the traits. However, missing data for one or more traits were recorded in 1997. Also characterized 158 accessions of wild *Arachis* species using 70 descriptors. Rosette and early leaf spot (ELS) are the most destructive diseases of groundnut in the West and Central Africa (WCA) and southern and eastern Africa (SEA) regions. Out of 4,420 groundnut germplasm accessions and 80 accessions of wild species evaluated, 20 genotypes in 1997/ 98 and 28 genotypes in 1998/ 99 showed low (<20%) disease incidence. Identified 35 additional sources of resistance to ELS. Of these, 30 are from South America (mostly from Peru and Bolivia) and are Valencia types. Eleven accessions of wild *Arachis* species (ICGs 8131, 13211, 13222, 14855, 14856, 14888, 14875, 14907, 14924, 14939, and 14946) were highly resistant and 15 others were resistant to ELS. We identified seven wild species accessions (ICG 8131, 8193, 8904, 11560, 13212, 13261 and 15875) with low *Aspergillus flavus* colonization and aflatoxin contamination. In West Africa, 500 accessions were screened over two years for tolerance to *A. flavus* invasion and aflatoxin contamination. Thirty-one lines were consistently tolerant to seed invasion and aflatoxin production. Against late leaf spot disease, 24 promising sources of resistance were identified from several wild species accessions. Out of 48 accessions of wild *Arachis* species screened against peanut bud necrosis disease (PBND), ICG 8131, ICG 8144, ICG 8944 were identified as disease free and ICG 11551 with <5% disease incidence. A number of germplasm accessions were identified for resistance. This included six accessions for resistance to jassids (*Empoasca kerri* Pruthi), 11 for thrips (*Thrips palmi* Karny.), one for aphids (*Aphis craccivora* Koch.), 10 for termites (*Odontotermes* spp.), and two for leaf miner (*Aproaerema modicella* Deventer) (Ranga Rao and Wightman, 1999).

Geographical Pattern of Diversity

Chickpea

Data on 16,820 accessions of chickpea germplasm for seven morphological and 13 agronomic traits, and reaction to fusarium wilt was analyzed to determine phenotypic variation in the accessions from different geographical regions. The means for different agronomic traits differed significantly between regions. The variances for all the traits among regions were heterogeneous. South Asia contained maximum range of variation for all the traits. Seed color and days to 50% flowering showed the highest pooled diversity index. Principal component analysis using 13 agronomic traits and clustering of the first three principal component scores delineated two regional clusters consisting Africa, South Asia, and Southeast Asia in the first cluster and Americas, Europe, West Asia, Mediterranean region, and East Asia in the second cluster (Upadhyaya, 2003) (Fig. 1).

Groundnut

The data on groundnut germplasm (13,342 accessions) for 16 morphological and 10 agronomic traits in two seasons were analyzed to study geographical patterns of variation. Phenotypic variation was found for most traits in all the regions, and means for different agronomic traits differed significantly among regions. The variances for all the traits among regions were heterogeneous. Principal component analysis using 36 traits and clustering on first seven principal component scores delineated three regional clusters, consisting of North America, Middle East, and East Asia in the first cluster; South America in the second cluster; and West Africa, Europe, Central Africa, South

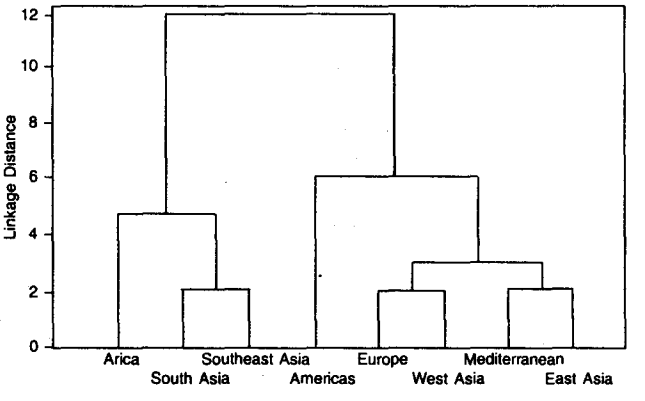

Fig. 1: *Dendogram of eight regions in the entire chickpea germplasm based on first three principal components*

Asia, Oceania, South Africa, East Africa, Southeast Asia, Central Asia and the Caribbean Islands in the third cluster (Upadhyaya *et al.*, 2002a) (Fig. 2). Similarly, geographic regions differed significantly for morpho-agronomic traits in pigeonpea (Upadhyaya *et al.*, 2005).

Forming Subsets of Germplasm to Enhance its Utilization

With increased emphasis on germplasm assembly and explorations during the last four decades, most genebanks have now huge collections. However, the germplasm accessions could not be characterized effectively and the documentation was not achieved as desired. This resulted in under utilization of the germplasm resources. One of the means to enhance utilization is developing a subset of core collection (Frankel, 1984). A core collection contains a subset of accessions (about 10%) from entire collection that captures most of the available genetic diversity of species (Brown, 1989). The core subset can be evaluated extensively and the information derived will provide a targeted entry point for more efficient utilization of the entire collection. At ICRISAT, we have accomplished this by making subsets at three levels: (i) Global core-, (ii) Mini core- and (iii) Regional core collections.

Global Core Collection

Using the sampling theory of selectively neutral alleles, Brown (1989) argued that the entries in a core subset should be about 10% of total collection, with a ceiling of 3,000 per species. This level of sampling is effective in retaining 70% alleles of the entire collection. At ICRISAT, we have developed core collections for all the five mandate crops and finger millet. The core collections provide an effective mechanism for the proper exploitation of germplasm resources for the genetic improvement and simplifies the genebank management.

Mini Core Collection

In many crops, the number of accessions in genebanks are several thousands, and a core subset consisting of 10% of entire accessions would again be large and unwieldy to identify useful parents for traits of economic importance. Thus, there is a need to reduce the size of the subset further without losing species diversity. Upadhyaya and Ortiz (2001) suggested the strategy for sampling the entire and core collections for developing a 'mini-core' collection, which contains about 1% of the entire collection but captures most of the useful variation of the crop. ICRISAT scientists have already developed mini-core collections of chickpea (Upadhyaya and Ortiz, 2001), groundnut (Upadhyaya *et al.*, 2002b) and pegeonpea with 211, 184 and 146 accessions, respectively.

Regional Core Collection

To enhance the utilization of crop genetic resources in a particular region, regional core collection could also be developed. At ICRISAT, an Asian core collection of groundnut consisting of 504 (10.6% of entire collection) accessions was developed (Upadhyaya *et al.*, 2001a).

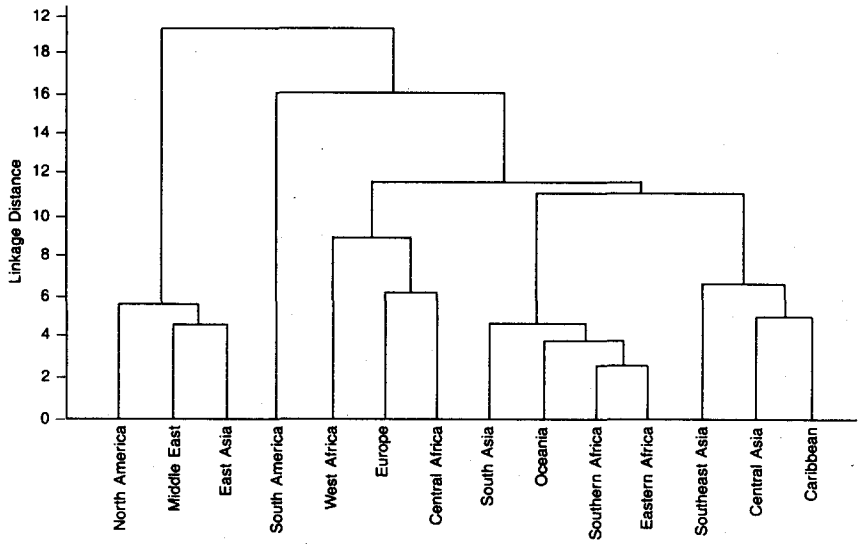

***Fig. 2:** Dendogram of 14 regions in entire groundnut germplasm based on scores of first seven principal components (Upadhyaya et al. 2003)*

Uses of Core Collections in Crop Improvement

In most groundnut breeding programs globally, Chico has been predominantly used (Gangapuri and JL 24 also) as a source of earliness. This has resulted in the narrow genetic base of short-duration cultivars. We used groundnut core collection consisting of 1,704 accessions (Upadhyaya *et al.*, 2003) to identify new sources of early maturity. We selected 21 early maturing landraces (similar to Chico in maturity) and evaluated them at 1240° Cd [(equivalent to 75 days after sowing (DAS)] and 1470° Cd (equivalent to 90 DAS) in rainy season at Patancheru, India along with Chico. ICGs 4558, 4729 and 9930 (1.97-2.15 t ha^{-1}) produced 25-36% more pod yield than the early maturing Indian cultivar JL 24 at 1240° Cd in the 2001/02 post rainy season. Diversity studies indicated that the new germplasm lines are diverse from widely used source of early maturity, Chico and Gangapuri.

We have been able to select promising accessions for low temperature tolerance using core collection of groundnut. The set of 1,704 core accessions was screened for low temperature tolerance at germination under laboratory conditions, and 343 accessions were found promising. Of this, 164 landraces were further characterized for yield and related traits and 24 accessions were found most promising (Upadhyaya *et al.*, 2001b).

In USA, the peanut core collection of 831 accessions (Holbrook *et al.*, 1993) was tested against various stresses and a number of resistant sources were identified. They included 36 core accessions resistant to root knot nematode (Holbrook *et al.*, 1997), 14 tolerant to pre-harvest aflatoxin contamination (Holbrook *et al.*, 1998), and six with high level of resistance to *Rhizoctonia* limb rot (Frankel *et al.*, 1999).

The 184 mini-core accessions of groundnut (Upadhyaya *et al.*, 2002) were evaluated for traits related to drought tolerance, specific leaf area (SLA) and soil plant analysis development (SPAD) chlorophyll meter reading (SCMR), and 18 accessions were identified with high water use efficiency (WUE) at ICRISAT-Patancheru (Upadhyaya, 2005). The chickpea mini-core developed at ICRISAT (211 accessions) was evaluated at IIPR, Kanpur during 2003-04 season and 12 accessions were selected for use in the crop improvement program. Five accessions, namely ICCs 14199, 12034, 14194, 14196, and EC381882 have already been involved in hybridization to develop large seeded kabuli types. This will help to broaden the genetic base of the cultivars.

Germplasm Distribution from ICRISAT

Supply of Breeding Material and the Basic Germplasm

Supply of healthy, viable, and genetically representative seeds of germplasm accessions to the research workers is one of the major objectives of the ICRISAT Genebank. During 1973 to 1996, 5,93,388 seed samples were supplied to users in 134 countries. During the recent years (1997 to 2006), we have distributed 85,869 samples to the users (Table 2). Additionally, we provided 1,22,338 seed samples within ICRISAT for utilization in research and screening against various stresses. The number of samples exchanged from ICRISAT, including supply from the genebank as well as the breeding materials or nurseries sent by the crop improvement scientists is over 1.22 million samples exported and 0.16 million samples imported (Tables 3 and 4).

Insight into the Germplasm Supplied to Users

One of the main areas of research is to assess the patterns of demand for germplasm accessions to guide future

Table 2. ICRISAT germplasm distributed during 1997-July 2006

Crop	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total
Sorghum	3,900	4,022	1,144	1,523	3,857	1,783	778	822	327	599	18,755
Pearimillet	915	1,330	366	1,080	394	2,063	621	284	339	1,194	8,586
Chickpea	1,414	1,632	2,833	848	3,715	1,344	1,233	2,139	1,511	56	16,725
Pigeonpea	837	856	693	1,297	2,147	2,470	845	591	98	1,001	10,835
Groundnut	4,657	2,039	3,011	3,002	1,350	546	1,358	1,631	339	1,035	18,968
Finger millet	394	71	342	41	5,115	293	167	193	1,609	1,010	9,235
Foxtail millet	38	21	16	3	1,233	134	10	47	40	1,542	
Proso millet	–	21	29	3	19	121	6	45	–	–	244
Little millet	–	6	11	5	463	104	2	45	10	–	646
Kodo millet	30	1	15	1	–	–	2	14	–	–	63
Barnyard millet	–	1	39	–	9	105	52	44	20	–	270
Total	**12,185**	**10,000**	**8,499**	**7,803**	**18,302**	**8,963**	**5,074**	**5,855**	**4,293**	**4,895**	**85,869**

Table 3. Import of germplasm (no. of samples) to ICRISAT during 1974-2006

Continent/ Region	No. of countries	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Small millets	Total
ASIA								
East	11	6,632	1,098	102	267	1,443	3,426	12,968
South	4	115	241	585	333	53	824	2,151
West	7	14,172	3,723	21,966	0	0	926	40,787
AFRICA								
North	3	1,332	975	131	0	46	0	2,484
East	7	7,004	629	436	805	495	298	9,667
West & Central	16	5,572	10,215	113	217	1,925	26	18,068
South	8	5,382	3,855	40	436	2,305	2,969	14,987
AMERICAS								
North	2	22,203	2,689	3,596	1,906	7,299	449	38,142
Central	4	1,344	12	173	38	0	151	1,718
Caribbean Is.	11	2,060	0	0	2,464	15	0	4,539
South	7	781	2	156	127	478	0	1,544
Europe	14	4,716	2,222	978	113	6,076	1,649	15,754
Oceania	2	1,086	4	623	813	98	0	2,624
Total	**96**	**72,399**	**25,665**	**28,899**	**7,519**	**20,233**	**10,718**	**1,65,433**

Table 4. Export of germplasm (no.of samples) from ICRISAT during 1974-2006

Continent/ Region	No. of countries	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut	Minor millets	Total
ASIA								
East	17	57,003	2,981	28,403	14,260	41,511	1,824	1,45,982
West	17	20,715	3,404	70,645	2,430	1,854	90	99,138
South	6	21,988	10,785	89,280	14,750	7,048	2,261	1,46,112
AFRICA								
North	5	8,773	756	14,607	148	521		24,805
East	9	84,875	8,030	28,920	15,708	3,930	6,429	1,47,892
West & Central	26	1,50,832	1,14,050	5,946	7,988	16,709	702	2,96,227
South	12	68,610	20,284	3,966	8,911	30,982	3,155	1,35,908
AMERICAS								
North	3	25,213	4,354	18,433	4,294	2,991	776	56,061
Central	8	32,310	1,952	12,802	2,571	998	283	50,916
Caribbean Is.	16	1,817	79	168	4,144	829		7,037
South	12	22,491	4,933	13,241	4,844	1,673	937	48,119
Europe	30	12,521	12,134	13,450	1,863	5,340	3,168	48,476
Oceania	11	4,249	1,114	6,889	3,741	1,371	129	17,493
Total	**172**	**5,11,397**	**1,84,856**	**3,06,750**	**85,652**	**1,15,757**	**19,754**	**12,24,166**

strategies for germplasm regeneration and management. The germplasm distribution data of sorghum, pearl millet, chickpea, groundnut, and pigeonpea till 1998 were analyzed, and the following patterns emerged.

***Sorghum*:** Of the 36,727 germplasm accessions held in the genebank, 30,570 (83.2%) accessions were distributed at least once. Of this, about 83% were landraces, 16% breeding material and 1% wild sorghums. Twelve accessions, including three zera-zera accessions were dispatched more than 99 times.

***Pearl Millet*:** Of the 21,392 accessions, 15,366 (71.8%) accessions were distributed at least once during 1973 to 1998. The diversity in the distributed material was almost same as in the entire collection. A total of 1,769 accessions were distributed more than 10 times. IP 4021, an earliest flowering accession from Gujarat, India was distributed 94 times.

***Chickpea*:** 16,311 accessions of chickpea accessions were supplied to scientists in 81 countries. A maximum of 302 requests were received for ICC 4973 (L 550), a kabuli cultivar from India. Shannon-Weaver diversity index (H') of the accessions distributed was similar to the accessions contained in the global collection, indicating that the diversity available in the entire collection has been distributed.

***Groundnut*:** All assembled accessions except 794 (5.3% of the entire collection), have been distributed. Countries in Africa have received the maximum number of

accessions (92.3%) followed by countries in Asia (76.6%), Europe (5.6%), Americas (5.3%), and Oceania (2.2%). ICG 799 (Kadiri 3), *A. hypogaea* cultivar from India, was supplied to 292 requestors globally.

Pigeonpea: The summary of germplasm distributed from 1974 to 2003 revealed that 65,749 germplasm seed samples were supplied to users. These samples represented only 10,648 unique accessions, indicating that only 78.1% of the accessions held in the genebank have been distributed. The scientists from India were the major recipients of the seeds (68.7% of the total). The pigeonpea accessions requested most frequently were: ICP 7035 (DSLR-55), a germplasm collection from Madhya Pradesh (distributed 305 times), ICP 26 (T 21, distributed 267 times), and ICP 7182 (BDN 1, distributed 253 times).

Restoration of the Basic Germplasm to National Programmes

The global collections held at ICRISAT serve an important purpose in restoration of germplasm to the source countries when national collections were lost due to lack of adequate storage facilities, natural calamities, civil unrest, etc. For example, we supplied 362 sorghum accessions to Botswana; 1,827 sorghum and 922 pearl millet to Cameroon; 1,723 sorghum and 931 chickpea to Ethiopia; 838 sorghum and 332 pigeonpea to Kenya; 1,436 and 445 sorghum accessions respectively to Nigeria and Somalia, and 71 pigeonpea accessions to Sri Lanka as part of restoring the lost germplasm that originated from these countries. The germplasm collections maintained in the Rajendra S Paroda Genebank include 44, 822 accessions received from or jointly collected with the Indian National Programs. The National Bureau of Plant Genetic Resources (NBPGR), India requested ICRISAT for restoration of this entire germplasm in 1998. As part of ICAR-ICRISAT Partnership Projects, the ICRISAT genebank has already repatriated the entire set of accessions by July 2004. This included sorghum (14,637), pearl millet (7,189), chickpea (7,488), pigeonpea (5, 988), groundnut (6,060), and six small millets (3,460) accessions.

Impact Realized by the NARS

From the materials supplied by ICRISAT, 583 varieties and hybrids (sorghum: 200; chickpea: 100; pearl millet: 129; groundnut: 105; and pigeonpea: 49) have been released in 76 countries spread over all the five continents (Fig. 3). This includes some of the basic germplasm accessions supplied from the ICRISAT genebank. Sixty-six varieties selected directly from the germplasm have been released in 44 countries, world over (Fig. 4).

Gaps in Germplasm Collections

In the initial years, we concentrated on assembling the germplasm from various R & D institutes across the world.

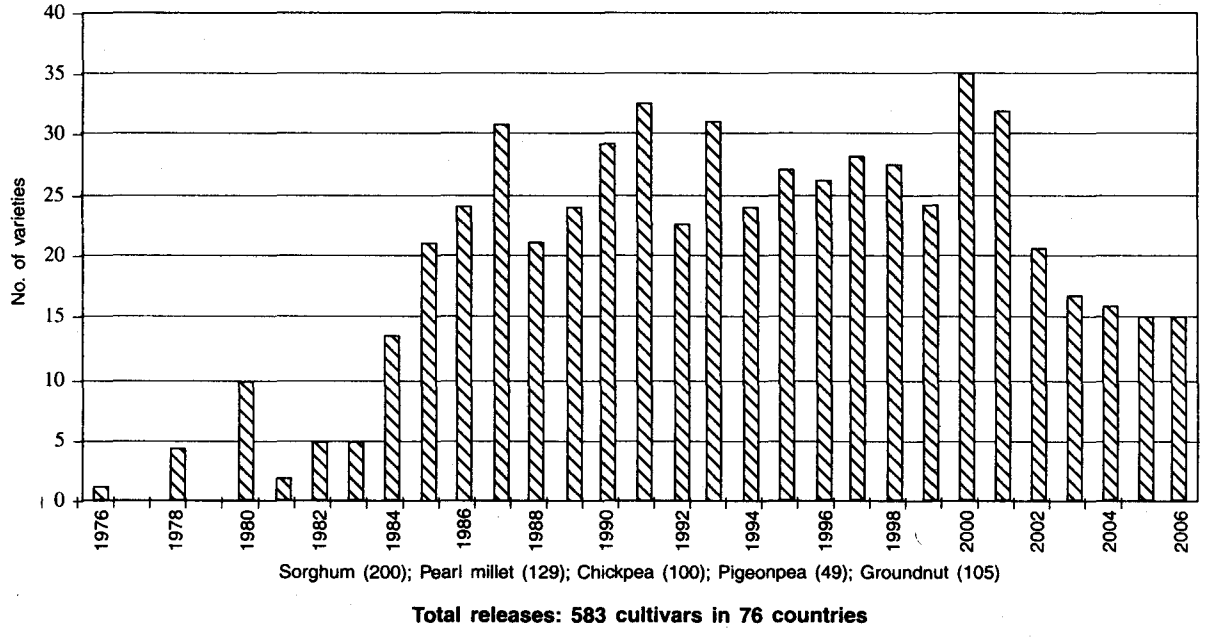

Fig. 3: Number of cultivars released worldwide from the ICRISAT supplied germplasm materials, 1975-2006

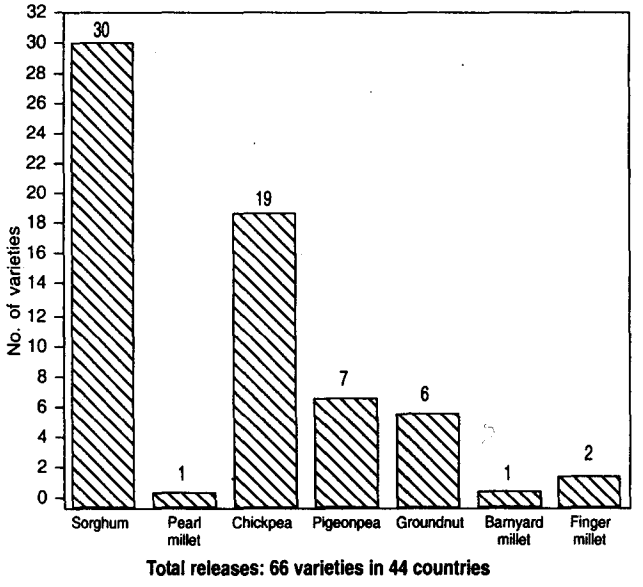

Fig. 4: Number of cultivars released worldwide from the basic germplasm supplied from ICRISAT genebank 1976-2003

Subsequently, germplasm collecting missions were launched in areas that were poorly represented. With availability of passport and characterization data and their summarization, we have arrived at specific germplasm types that are not adequately represented in the genebank (genetic gaps) and also the regions hitherto less represented. Such gaps for germplasm are listed in Table 5, and need attention for future collections.

Protocol for Germplasm Exchange

Starting in 1999, germplasm is supplied under the 'Material Transfer Agreement' (MTA) whereby the recipient agrees not to claim ownership over the material, nor to seek Intellectual Property Rights (IPRs) over that material, or its genetic parts or components, in the form received. The recipient also agrees not to seek IPRs over related information received, and to ensure that any subsequent person or institution to whom he/she may make samples of the material available, is bound by the same provisions and undertakes to pass on the same obligations to future recipients of the material.

Acquisition of the Germplasm from outside India

Import of crop germplasm from out side India needs approval from the National Bureau of Plant Genetic Resources (NBPGR) through issuing for Germplasm Import Permit (IP). This IP is sent to the institute from where germplasm material is to be imported. The sender prepares the germplasm under the guidelines given in the IP and sends the consignment along with IP and Phytosanitary Certificate to the NBPGR. After the germplasm consignment is found pest-free by the NBPGR scientists, the material is planted in the Post Entry Quarantine Isolation Area (PEQIA) at ICRISAT research farm at Patancheru under the joint supervision of NBPGR and ICRISAT researchers. The PEQIA is situated in one corner of the farm, surrounded by 45 ha uncultivated land (mostly covered with thick population of trees and shrubs) and it is more than 200 m away from any cultivated field.

The NBPGR and ICRISAT researchers jointly inspect the germplasm raised in PEQIA, regularly throughout the growing period until harvest. Any unhealthy or diseased plants are promptly rouged and burnt as and when detected. Every effort is made to grow disease and insect-pest free plants in the PEQIA, and seeds only from healthy plants are harvested. These seeds are then released to ICRISAT for subsequent use in research and or for conservation in the genebank.

Germplasm Supply outside ICRISAT

ICRISAT is committed to the strict plant quarantine guidelines for export of seeds to other countries. The crop areas from which seeds are collected for export are inspected regularly by the scientists to monitor incidence of any peculiar disease or insect-pests and suggest the control measures. This helps us to meet the plant quarantine requirements, if any, of the germplasm importing country.

Table 5. Need for further procuring germplasm of ICRISAT mandate crops

Crop	Genetic gap	Geographic gap
Sorghum		Algeria, Angola, Congo, Cota de Ivory, Guinea, Libya, Morocco, Syria and Tunisia
Pearl millet	Sources for yellow endosperm, white seeds	Botswana, Central Africa Republic, Ghana, Kenya, Malawi, Sierra Leone, Tchad, Togo, Uganda
Chickpea	Kabuli type	Ethiopia, Mediterranean countries
Pigeonpea		Eastern and Western Ghats (India)
Groundnut	Bot. Var. *hirsuta* and *aequotoriana*	Angola, China, Ecuador Laos, Namibia, Paraguay, Peru, South Africa, and Urugay

The export of germplasm from ICRISAT started in 1974. The requirements as laid down by the FAO/ Plant Protection Convention 1951 for the issue of a Phytosanitary Certificate for export of seeds are strictly followed. The Government of India has established an export certification laboratory at ICRISAT-Patancheru, which is supervised by the NBPGR scientists. ICRISAT provides the laboratory facilities and support staff to carry out the initial operations for preparing the seeds for export. The following inspection and testing procedures are followed while processing the seed consignment for export:

X-ray and other Examination: Seed samples for export are X-rayed for detection of latent infestation by insect-pests. Apparently healthy looking seeds showing internal infestation are detained and destroyed and only the healthy seed samples are cleared for further processing.

***Plating*:** Each seed sample is plated according to the international standards for seed testing for observation on seed-borne diseases. After seven days, seeds are examined for germination percentage and seen under the microscope for the presence of pathogens. Seeds samples showing poor germination or infection by the pathogen of quarantine importance to the concerned country are not exported.

***ELISA Test*:** ICRISAT has facility to detect peanut mottle virus (PMV) reported in India, which can be transmitted by seeds (0.1 - 3.5%). Enzyme-linked Immunosorbent Assay (ELISA) tests are carried out to ensure freedom from PMV before export.

***Treatment*:** The seeds ready for export (after all the tests) are finally inspected by the NBPGR scientists, and only after their approval, the seeds are treated with insecticide or fungicide or fumigated as mentioned in the import permit of the indenting country. Seeds intended for specific research and requested not to dress them with any chemical, are exported without treatment.

***Additional Declaration*:** Special care is exercised to meet any additional declaration or requirement of the importing country while processing the seed material for export.

Issue of Phytosanitary Certificate (PSC): The certificate is signed and issued by the authorized official of the NBPGR in the form prescribed by the FAO International Plant Quarantine Convention, 1951, which is also called the "Rome Certificate." It contains details of seed health and all treatments given to the seeds, and mention of additional declaration, if any. The original PSC is put in an envelope affixed to the seed consignment.

Issues for Future

- Endangered germplasm from threatened areas of diversity to be salvaged and conserved for future use.
- Morphological and molecular characterization of germplasm to enhance their utilization in crop improvement.
- Multi location evaluation of core and mini core subsets to identify useful parents.
- Safety duplication of germplasm at other locations.
- Development of quick and reliable nucleic acid based detection and identification techniques for pathogens, particularly bacteria and viruses for quarantine purposes.
- Information generation on Pest Risk Analyses (PRA) of important pests of quarantine importance in ICRISAT-mandate crops.
- Conserve germplasm and provide samples to bonafide users.

References

Brown AHD (1989) Core collections: a practical approach to genetic resources management. *Genome* **31:** 818-824.

FAO (1998) The state of ex-situ conservation. P. 90. In *The state of the world's plant genetic resources for food and agriculture.* FAO, Rome.

Frankel OH (1984) Genetic perspectives of germplasm conservation In: W. Arber *et al.* (eds) *Genetic Manipulations: Impact of Man and Society*. Cambridge Univ. Press, Cambridge, England, pp 161-170.

Frankel MD, TB Brenneman and CC Holbrook (1999) Identification of resistance to *Rhizoctonia* limb rot in a core collection of peanut germplasm. *Plant Dis.* **83:** 944-948.

Holbrook CC, WF Anderson and RN Pittman (1993) Selection of a core collection from the U.S. germplasm collection of peanut. *Crop Science* **33:** 859-861.

Holbrook CC, MG Stephenson and AW Johnson (1997) Level and geographical distribution of resistance to *Meloidogyne arenaria* in the germplasm collection of peanut. *Agron. Abstr.* 157.

Holbrook CC, DW Wilson and ME Matheron (1998) Sources of resistance to preharvest aflatoxin contamination in peanut. *Proc. Am. Peanut Res. & Educ. Soc.* **30:** 21.

Ranga Rao GV and JA Wightman (1999) Status of the integrated management of groundnut pests in India. In: Upadhyaya RK, KG Mukerji and RL Rajak (eds.) *IPM System in Agriculture.* Aditya Books Pvt. Ltd., New Delhi, pp 435-459.

Sharma HC, G Pampapathy and LJ Reddy (2003) Wild relatives of pigeonpea as source of resistance to pod fly (*Melanagromyza*

obtusa Malloch) and pod wasp (*Tanaostigmodes cajaniae* La Salle). *Genetic Resources and Crop Evolution* **50**: 817-824.

Upadhyaya HD (2003) Geographical patterns of variation for morphological and agronomic characteristics in the chickpea germplasm collection. *Euphytica* **132**: 343-352.

Upadhyaya HD (2005) Variability for drought resistance related traits in mini core collection of peanut. *Crop Science* **45:** 1432-1440.

Upadhyaya HD, PJ Bramel, R. Ortiz and Sube Singh (2002a) Geographical patterns of diversity for morphological and agronomic traits in the groundnut germplasm collection. *Euphytica* **128:** 191-204.

Upadhyaya HD, PJ Bramel, R Ortiz and Sube Singh (2002b) Developing a mini core of peanut for utilization of genetic resources. *Crop Science* **42**: 2150-2156.

Upadhyaya HD, SN Nigam and Sube Singh (2001b) Evaluation of groundnut core collection to identify sources of tolerance to low temperature at germination. *Indian J. Plant Genet. Resour.* **14:** 165-167.

Upadhyaya HD and R Ortiz (2001) A mini core subset for capturing diversity and promoting utilization of chickpea genetic resources. *Theoretical and Applied Genetics* **102:** 1292-1298.

Upadhyaya HD, R Ortiz, PJ Bramel and Sube Singh (2001a.) Development of core collection for Asia region.In: Kharkwal, M.C., and R.B. Mehra (eds.). *Hundred years of post-Mendelian genetics and plant breeding - Retrospect and prospect.* Diamond Jubilee Symposium of Indian Society of Genetics and Plant Breeding IARI, New Delhi, India, pp 43.

Upadhyaya HD, R Ortiz, PJ Bramel and Sube Singh (2003) Development of a groundnut core collection using taxonomical, geographical, and morphological descriptors. *Genetic Resources and Crop Evolution* **50:** 139-148.

Upadhyaya HD, RPS Pundir, CLL Gowda, KN Reddy and Sube Singh (2005) Geographical patterns of diversity for qualitative traits in the pigeonpea germplasm collection. *Plant Genetic Resources* **3(3):** 331-352.