Diversity and Utilization of Pearl Millet Germplasm

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Abstract

The extent of variability in genetic resource collections of staple food crops, and the effectiveness of its exploitation determines the potential and adaptation of future varieties. The availability of genetic resources has changed dramatically in the last 15 years with the establishment of the International Board for Plant Genetic Resources (IBPGR). Genetic resources conservation is now an internationally coordinated effort. ICRISAT has the responsibility for the collection, maintenance, conservation, documentation, and distribution of pearl millet genetic resources.

The greatest number of cultivated, wild, and weedy forms of pearl millet occur in tropical Africa where the crop was domesticated. The ICRISAT collection is over 17 000 accessions, of which over 10 000 are authentic landrace accessions from 42 countries.

With better screening methods available to identify desirable traits from such a large germplasm collection, use of genetic resources should expand and contribute to broadening the genetic base of the crop. Pearl millet geographic variability occurs for all characters of interest to breeders. Preliminary studies have helped to identify regions of maximum diversity, and to provide guidelines to group accessions for their effective utilization.

Intercrossing, selfing, and pooling are techniques to maintain accessions and increase seed. The merits of each are discussed and formation of trait-specific gene pools is advocated as a convenient system. Conditions for seed storage are described. General guidelines for the choice and use of accessions for breeding are outlined, and key examples are included.

Résumé

Diversité du matériel génétique du mil et son exploitation : *Le potentiel et l'adaptation des nouvelles variétés sont déterminés par la variabilité des ressources génétiques collectées ainsi que l'efficacité de l'exploitation de cette variabilité. L'établissement du Conseil international de ressources phytogénétiques (IBPGR) a augmenté sensiblement, au cours de ces 15 dernières années, le matériel génétique mis à la disposition de la recherche. Sa conservation fait l'objet d'un travail coordonné au niveau international. L'ICRISAT tient la responsabilité de prospecter, conserver, documenter et distribuer les ressources génétiques du mil.*

L'Afrique tropicale, lieu de domestication du mil, présente le plus grand nombre de formes cultivées, sauvages et adventices de mil. La collection de l'ICRISAT comporte 17 000 accessions dont 10 000 sont des races non améliorées locales provenant de 42 pays.

L'amélioration des méthodes de criblage visant à identifier les caractères intéressants à l'intérieur d'une aussi grande collection permettra de mieux exploiter les ressources génétiques et d'élargir la base génétique de cette culture.

Il existe une variabilité géographique pour tous les caractères utiles aux sélectionneurs. Les études préliminaires ont permis de déterminer les régions présentant la plus grande diversité tout en faisant ressortir un système pour classer les accessions en vue de leur exploitation.

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Les avantages de l'entrecroisement, de l'autofécondation et de la mise au point des pools géniques, en tant que techniques de conservation des accessions et de multiplication des semences, sont examinés. Il convient de constituer des pools géniques en fonction des différents caractères. Les conditions d'emmagasinage des semences sont décrites. Le choix et l'utilisation des accessions sont expliqués avec des exemples utiles.

Introduction

Most of the staple crops grown today were domesticated and brought under cultivation thousands of years ago. With natural and human selection processes, they have diversified into innumerable varieties, each showing adaptation to the local environment. This invaluable genetic resource, or pool of genetic variation, forms the base for the plant breeder's ability to genetically change the crop in response to changing needs and situations (Lawrence 1975). These traditional landraces and their wild and weedy relatives possess characters such as resistance to physical and biotic stresses, which need to be incorporated into breeding material to increase both production and stability. The importance of a broad genetic base was recently demonstrated by the vulnerability of hybrids to downy mildew (Safeeulla 1977).

The necessity of searching available varieties for a particular character was recognized by early plant breeders. For example, Welsh and Johnson (1951) stated that to breed for rust resistance in oats "genes governing rust resistance cannot be created at will but must be searched for on the assumption that they exist somewhere in nature." In earlier years, no systematic efforts were made to collect and preserve genetic resources so there was little desired variation available to breeders. In recent times, the need for a diverse genetic base has been recognized.

Fortunately, the availability of genetic resources has improved very rapidly in the last 15 years with the establishment of the International Board for Plant Genetic Resources (IBPGR). Genetic resource conservation has been transformed from individual efforts into an internationally coordinated network. One of the first and significant tasks undertaken by the IBPGR, in collaboration with the French organization for scientific research overseas, Institut Français de Recherche Développment en Coopération (ORSTOM), was the collection and conservation of pearl millet and sorghum in West Africa when the Sahelian drought of 1969-1974 threatened these two crops. The responsibility to collect, maintain, conserve, document, and distribute pearl millet genetic resources was entrusted to ICRISAT, and is being done in accordance with the recommendations made by the Advisory Committee on Sorghum and Millets Germplasm, jointly sponsored by the IBPGR and ICRISAT (IBPGR 1976).

Domestication of the Crop

Pearl millet (*Pennisetum americanum*) almost certainly originated and was domesticated in tropical Africa. The greatest number of cultivated and related wild and weedy forms are found there (Pernès et al. 1984). Archaeological evidence suggests that this crop was domesticated before 1000 BC (Davies 1968). Harlan (1973) suggested that there is no apparent center of domestication, and th diffused and important belt occurs from the S in the east to Senegal in the west. Porteres (1976) attributed racial variation patterns in pearl millet to independent domestications and migrational events. He recognized four distinct, diverse areas: extreme West Africa, central West Africa, eastern Nile-Sudan, and eastern Africa and Angola. Once domestication occurred, it was introduced throughout the drought-prone areas of the Sahel and other semi-arid regions of Africa. In southern Africa, although several *Pennisetum* species are found, none of them cross easily with the cultivated form, leading to the conclusion that pearl millet is an introduced crop there (Appa Rao et al. 1985a). The shattering types found in a few isolated areas were attributed to the contamination by shibras of the original introductions and their perpetuation through survival of the seed shed in the soil. The crop was also introduced through early human migration into India, which is a secondary center of diversity (Purseglove 1976).

Progenitors of Pearl Millet

Bilquez and Le Conte (1969) proposed that *Pennisetum violaceum* (= *P. americanum* ssp. *monodii*) should be considered a very primitive form of pearl millet, both of which have evolved from a common ancestor. Harlan (1975) observed that the evolution of pearl millet heads from the numerous small heads of *P. violaceum* is nothing short of spectacular. Cultivated forms have broad tipped, persistent spikelets

with protruding grains, but in the wild species the spikelets are narrower, pointed, readily shatter, and have small grains. Human selection has been for large grain, and spikelets that do not shatter.

Pennisetum Gene Pool

Brunken (1977, 1979) and Brunken et al. (1977) grouped all the annual diploid species of penicillaria section, including cultivated pearl millet and its relatives, into the single species *P. americanum* because there are no genetic barriers to hybridization. This species was further subdivided into three subspecies: *americanum*, the cultivated form; *monodii*, the wild form; and *stenostachyum*, the intermediate and weedy types. The last of these subspecies mimics various pearl millet races morphologically, is generally characterized by nonpersistent involucres, and represents the hybrid swarms in all areas of contact between pearl millet and *monodii*. These three subspecies of *americanum* form the primary gene pool. The subspecies *americanum* was further subdivided into four races: *typhoides*, *nigritarum*, *globosum*, and *leonis*, based on the shape of the caryopses.

Existing Collections

The first attempt to assemble a world collection of pearl millet was launched by the Rockefeller Foundation and the Indian Agricultural Research Institute during 1959-62. This led to the assembly by field collections in India and by correspondence from Africa and the USA, of 2716 accessions. However, these IP (Indian *Pennisetum*) accessions were so badly contaminated and modified that a new start had to be made (Rachie and Majumdar 1980, Harlan 1973).

ICRISAT, in collaboration with the IBPGR and national programs, has launched several expeditions to important millet-growing areas of Africa (15 countries, 22 expeditions, 1654 accessions) and India (14 expeditions, 2690 accessions) (Table 1). In addition, several researchers have made contributions to the collection held at ICRISAT. At present ICRISAT is the major repository for the world pearl millet germplasm with over 17000 accessions, of which 10803 are authentic landrace accessions, 6278 are inbreds from breeding programs, and 633 are weedy types. These authentic landraces were assigned IP numbers (International *Pennisetum*) and originate from 42 countries (Table 2). Burkina Faso, Cameroon, Ghana, India, Malawi, Mali, Niger, Nigeria, Senegal, and Sudan are relatively well represented in this collection, and have contributed more than half of the present collection. ICRISAT and the IBPGR have identified Chad, Egypt, Ghana, Mauritania, Ethiopia, Pakistan, and parts of India as priority areas for collection. It is hoped that in the future this world collection will include more accessions from these countries.

Besides the germplasm held at ICRISAT, which represents the largest collection of *Pennisetum* species, a collection of over 2700 accessions representing cultivated, weedy, and wild relatives is maintained by Services Scientifiques Centraux of ORSTOM at Bondy, France. These accessions are from 10 West African countries and represent collections made between 1975-82 by ORSTOM in collaboration with the IBPGR (Hamon, personal communication; Clement 1985a).

Most breeding programs in countries where pearl millet is an important crop generally hold small collections of local and immediate interest. These collections often include advanced or segregating breeding lines. An example is the accessions held at the Institut Senegalaise de Recherches Agricoles (ISRA) at Bambey, Senegal. This collection has over 2400 accessions and includes 1120 landraces and improved varieties from West Africa, and over 1300 introduced, or program-generated, advanced breeding lines (NDoye, personal communication).

The need to maintain national germplasm collections associated with germplasm conservation will soon be reduced because of the plans for holding a germplasm collection at the ICRISAT Sahelian Center (ISC), Niamey, Niger, in addition to the world collection at ICRISAT Center in India. At the ISC, major emphasis will be on collection, medium-term conservation, and evaluation of accessions in collaboration with national programs.

Geographic Variability

The immense geographic variability of pearl millet (Bono 1973) in the three bioclimatic zones of West Africa is a result of human selection for maturity period, head size and shape, large grains, and nonshattering habit.

This variability cannot be grouped in a very systematic way, and so far, classification attempts have been on the basis of photoperiod response or maturity cycle. Both in the Sahelian (300-600 mm annual rainfall) and Sudanian Zones (600-900 mm), rainfall

Table 1. Pearl millet germplasm collected from 1980-85.

Country	Year	No. of samples	Participating national program
Africa			
Botswana	1980	47	Dept. of Agric. Res., Gaborone
Burundi	1982	2	Min. of Agric., Bujumbura
Cameroon	1983	20	Inst. of Agron. Res., Maroua
	1985	330[1]	Inst. of Agron. Res., Maroua
Gambia	1980	17	Dept. of Agric., Banjul
Ghana	1981	135	CRI, Kumasi & GTZ, Tamale
Malawi	1979	277	Min. of Agric. & Nat. Res., Ngabu
Mozambique	1981	15	INIA, Maputo
Nigeria	1981	15	Inst. of Agric. Res., Samaru
	1983	390	Inst. of Agric. Res., Samaru
Sierra Leone	1983	59	Min. Agric., Free Town
Somalia	1979	3	Min. of Agric. Mogadishu
South Africa	1982	30	Res. Inst. for Grain Crops, Potchefstroom & Bot. Res. Inst., Pretoria
Sudan	1979	19	Gezira Agric. Res. Stn., Wad Medani
	1983	7	Gezira Agric. Res. Stn., Wad Medani
Tanzania	1978	63	Univ. of Dar es Salaam, ARI (Ilonga)
	1979	102	Min. of Agric., Dar es Salaam
	1981	13	Min. of Agric., Dar es Salaam
	1985	12	TARO, Dar es Salaam
Yemen Arab Rep.	1984	10	Min. of Agric. & Agric. Res. Auth., Taiz
Zambia	1980	25	Min. of Agric. & Water Devpt., Lusaka
	1982	63	Res. & Spe. Ser., Harare
	1985	340	Res. & Spe. Ser., Harare

1. Material yet to be released

is erratic, and selection by farmers has been towards two broad groups, early and late, as an attempt to provide stable production. Earliness and lateness are relative depending on the region. There is a north-south gradient for earliness, but early millets are not only confined to northern parts of the Sahel, but are also intercropped in wetter regions of the Sudanian Zone. In West Africa, approximately 80% of millet production is from early varieties. Information on geographic diversity of pearl millet has recently been summarized for nine West African countries (Clement 1985a), Botswana (Rao and Mengesha 1980), Ghana (Appa Rao et al. 1985b), Malawi (Appa Rao 1979b), Mauritania (Clement 1985b), Nigeria (Appa Rao et al. In press), Tanzania (Appa Rao and Mengesha 1980), Zambia (Appa Rao 1980a), Zimbabwe (Appa Rao and Mengesha 1982), and, following collection missions, for millets from Gujarat, Maharashtra, Rajasthan, and Uttar Pradesh in India (Appa Rao 1978, 1979a; Appa Rao and Reddy 1980).

In West Africa, farmers traditionally cultivate a particular landrace in any given region, but the variability within individual landraces is low. Landraces are called by different names depending on the ethnic group and region. For example, Haini Kirei, the predominant landrace of western Niger, is also called Foulania, Aderankobi, Henele, and Tiouma (Clement 1985a). Excluding the millets of the oasis, the early group matures in 70-90 d, the interme group in 90-120 d, and the late group in 120- (Table 3).

The oasis millets of West Africa and North Africa and the desert types from Rajasthan and Gujarat (India) have a short cycle of 60 d and represent day-neutral millets. The landraces Djanet of Hoggar province of Algeria, and Faya and Ligui of Chad are oasis millets (Gast and Adrian 1965). The Chadi type from Rajasthan and Bhilodi of Gujarat represent desert types, and the Pittaganti type, grown by the hill tribes of the Eastern Ghats, represents an early type in India.

Table 2. Pearl millet accessions assembled at ICRISAT Center (as of December 1985).

Country	No. of accessions assembled by: Rockefeller Foundation	ICRISAT/ IBPGR/ ORSTOM	Plant Introduction (USA)	National Programs	Total
Africa					
Benin	0	40	0	0	40
Botswana	0	45	0	0	45
Burkina Faso	22	365	0	0	387
Cameroon	0	191	0	0	191
Cape Verde	0	1	0	0	1
Cent. Afr. Rep.	0	58	0	0	58
Chad	62	0	0	0	62
Congo	3	0	0	0	3
Ethiopia	1	0	0	0	1
Gambia	0	13	0	0	13
Ghana	1	245	0	0	246
Kenya	2	67	0	0	69
Malawi	2	243	0	0	245
Mali	39	1003	0	0	1042
Mauritania	1	0	0	0	1
[illegible]ambique	0	28	0	0	28
[illegible]bcco	0	3	0	0	3
Niger	36	997	0	0	1033
Nigeria	282	777	86	0	1145
Senegal	27	334	0	0	361
Sierra Leone	0	55	0	0	55
Somalia	0	3	0	0	3
South Africa	10	87	12	6	115
Sudan	2	557	0	0	559
Tanzania	0	138	0	0	138
Togo	0	75	0	0	75
Uganda	48	0	0	0	48
Zambia	0	81	0	0	81
Zimbabwe	2	97	26	50	175
Source unknown	11	0	0	0	11
Subtotal	551	5503	124	56	6234
Asia					
India	793	2720	24	7600	11137
Korea	1	0	0	0	1
Lebanon	71	0	0	0	71
Pakistan	5	0	3	0	8
Turkey	0	0	1	0	1
USSR	0	14	0	0	14
Yemen Arab Rep.	0	17	0	0	17
[illegible]otal	870	2751	28	7600	11249
Europe					
UK	0	27	0	0	27
West Germany	0	1	0	0	1
Subtotal	0	28	0	0	28
The Americas					
Brazil	0	0	1	0	1
Mexico	0	7	0	0	7
USA	48	0	42	8	98
Subtotal	48	7	43	8	106
Australia	0	0	0	0	4
Total	1469	8293	195	7664	17621

671 accessions from 5 countries are awaiting release from plant quarantine authorities. In addition 330 accessions from Cameroon were collected recently.

Table 3. Maturity period variation of West African millets in different geographic regions.[1]

Country	Maturity group (d)		
	Early (70-90)	Intermediate (90-120)	Late (120-180)
Benin	Ignati Nara	-	Amala
Burkina Faso	Iniadi	Haini Gouri	Kazouya Ouine
Cameroon	-	Mouri	-
Ghana	Nara	-	-
Guinea	-	-	Moutiri
Mali	Souna	Tiotioni	Sanio
Niger	Boudouma Ba Angoure	Haini Kirei	Soumno
Nigeria	Gero	-	Maiwa
Senegal	Souna	-	Sanio
Togo	Ignati	-	Amala

1. Based on Clement 1985a.

Variability exists for all other agronomic characters of interest to breeders:

- tillering ability (Moro of Cameroun, Boudouma of Niger, and all Indian millets),
- head length (from 4 cm in oasis millets to 2 m in Zongo of Niger),
- head shapes differ greatly, and form a basis for classification after maturity. They range from lanceolate, cylindrical, conical, club, fusiform, to globular types,
- head girth (Ankoutess of Niger),
- peduncle length (Iniari millets as a class),
- grain size (up to 19 g 1000^{-1} in accessions from Ghana and Togo), and
- grain shape (hexagonal, obovate, elliptical, globular).

Bristle length and number also vary. The range observed for all of the qualitative characters scored in the world collection is as large as the range described in the IBPGR-ICRISAT descriptor list (1981).

Genetic Diversity

Studies on genetic diversity using statistical techniques such as principal component analysis help to identify regions of maximum diversity, and to group accessions for effective utilization and maintenance (Pernès et al. 1984).

One of the first attempts to analyze genetic diversity in pearl millet was by Murty et al. (1967) using the first IP collection. They studied eight characters and found that major variability occurs in Africa, and that accessions from India showed low but distinct diversity.

Bilquez and Sequier (cited by Marchais 1975) analyzed genetic diversity in a West African collection and found that millets from Niger and Senegal are not distinct and were characterized by early maturity and long to medium-long heads (30-150 cm). Accessions from Burkina Faso formed a single group characterized by a long maturity cycle and heads (20-40 cm). Iniadi, the early millet fro southern region and the long-cycle Ouine from Nouna region formed distinct groups. The Malian collection was split into two groups: the Niafunke-Timbouctou region and the Dogoun plateau. Oasis millets such as Massue of Mauritania, and Faya and Ligui of Chad, were grouped together.

Bono (cited by Marchais 1975) analyzed 11 characters of pearl millet from six West African countries. Millets from Senegal and Niger were grouped together, and the second group contained those from Mali, the Ivory Coast, Mauritania, and Burkina Faso. There seemed to be a transition from long to short heads on the east-west axis and thin to thick heads with large girth on the south-north axis. Accessions from Senegal and Ivory Coast were characterized by compact heads and small grains, and those from Niger and Burkina Faso by semicompact heads and large grains. Within Niger, Ankoutess formed a distinct cluster, and types Zongo, Haini Kirei, and Matam Hatchi were g together. As expected, both the long cycled Maiwa and Soumno types formed one group. Maximum diversity was found in Niger characterized by semicompact heads and large grains. Those from Senegal were characterized by intermediate head length (30-60 cm) and compact heads with small grains, while those from Mali had short heads with intermediate head girth. Accessions from Burkina Faso possessed thin, semicompact heads with large grains, and those from the Ivory Coast had compact heads with small grains.

Marchais (1982) found that Malian and Senega-

lese millets constitute two distinct groups. In Mali, there is a strong regionalization on a north-south axis, and accessions are relatively more diverse. Surprisingly, this study found that the millets of western Mali do not constitute an intermediate group, but are distinct and unrelated to the Senegalese millets.

There is a need for more systematic research on diversity, particularly to include new collections that have recently been added.

Maintenance of Accessions

The principal objective of genetic resources maintenance is to obtain from the first grow-out, a cross-pollinated and representative sample of the original accession, and seed in sufficient quantities for subsequent evaluation, distribution, and storage. The subsequent maintenance determines the extent of genetic variability that will be conserved within an accession.

Recently Burton (1979, 1985) suggested three ways to increase and maintain accessions of cross-pollinated crops: intercrossing, selfing, and pooling.

Intercrossing. Increase by intercrossing 100 or more plants in isolation, would maintain an accession close to the original form in which it was collected. Unfortunately, because the number of isolations is limited, hand intercrossing has to be used. This should involve maximizing the intercross between 100 or more plants, and minimizing outcrossing with other accessions. Pollinating one receptive head on each plant with a mixture of pollen from the rest of the plants is an effective method of intermating. At ICRISAT, to avoid hand pollination, a cluster-bagging method was used to allow cross pollination. In this method, 10 equally spaced plants were planted in a cluster, and 20 clusters were grown for each accession. At flowering, one head from each plant within a cluster was enclosed in a paper bag, and at harvest an equal quantity of seed of each of the heads under the bag was bulked to constitute an accession (Appa Rao 1980b). In later years, this method was discontinued and was replaced by sowing the plants in rows and bagging heads from adjacent plants. Enclosing heads of several plants under one bag will intermate only those that flower at the same time. They will be isolated from others, with which they would have intermated in an isolated field, with a resultant undetermined amount of selfing (Burton 1983).

Selfing. Burton (1983) suggests that selfing, particularly of those plants that are used to describe an accession, is the best way to obtain large amounts of seed of a new accession. Selfing to produce S_1 seed offers a number of advantages: it requires less labor and time, is less likely to produce outcrosses, retains genes responsible for classification, uncovers recessive genes better than other seed increase methods, and can be used to screen for both dominant and recessive genes. Compared with intercrossing, plants grown from seed produced by selfing may have altered seed set and size, and plant vigor.

Pooling. The third method to increase and maintain accessions, is to form gene pools which are constituted by mixing together seed from a number of similar accessions (in pearl millet, as in many crops, accessions collected from any one region tend to be alike). The mixture is planted in an isolated field to intermate and seed is harvested from a part or all of the plants. Burton (1979) states that germplasm pools that are increased each year and contain many accessions offers an easy way to handle germplasm. It breaks linkages, increases gene interchange, and may improve adaptation. However, Burton (1976) found that advancing five germplasm pools for three generations has narrowed the phenotypic variability of the original pool, lost genes, and obscured "hard to recover characteristics".

To overcome loss of phenotypic variability in gene pools, Witcombe (1984b) suggested dividing accessions into pools on the basis of morphological characters and region of origin. The first step is to evaluate the accession and use the results to create trait-specific gene pools (TSGs) based on characteristics such as head length, seed size, and height. The TSGs are formed from accessions of a country or region, since they tend to be similar, thus insuring that only accessions of similar daylength sensitivity are pooled. As mentioned previously, multivariate analysis would provide the best basis of forming TSGs. Each TSG consists of a number of selected accessions which are mixed in equal proportions and maintained as a bulk by growing them as a single isolated population with natural crossing. For genetic resources purposes TSGs are best maintained by subjecting them to minimum selection pressures. By allowing natural selection to operate, adaptation to local conditions is improved. Using this approach, a TSG for large grain size has been formed at ICRISAT.

Choosing a method. The choice of the method to maintain accessions depends on the objective, number

of accessions to be increased, and resources available. Selfing appears to be better for individual accessions, but forming gene pools is recommended for accessions that are similar and originate within a narrow geographic region. Regardless of the method of increase employed, enough seed should be produced to facilitate evaluation, utilization, exchange, and storage.

Storage Conditions

Seed storage in a favorable environment is the most efficient method to preserve accessions. Often lack of appropriate storage conditions has led to the loss of collections in some West African countries (ISC 1985). In a gene bank, it is necessary that seed be stored under optimum conditions to maximize longevity. Two factors influence viability of seed in storage: seed moisture content and storage temperature. Burton (1979) has been able to dry seed for long-term storage to 5-7% moisture content in a forced air oven at 40°C without any germination loss.

Two kinds of collections are generally maintained by gene banks: a base collection and an active collection. The base collection is for long-term storage and preservation, and the active collection is for medium-term storage for distribution, evaluation, and multiplication. The IBPGR has established two standards for seed storage. The preferred standards for long-term seed storage are -18°C or less with the seed at 5±1% moisture content in airtight containers. The second acceptable standard is 5°C with the seed at 5-7% moisture content in airtight containers, or at 5°C in unsealed containers with a controlled relative humidity (RH) of 20%. According to Witcombe (1984a) this level of humidity is not expensive to maintain in a well-designed store where unintended ventilation is well controlled. The rule of thumb is that each 1% reduction in seed moisture content and each 5°C temperature reduction doubles the longevity of the seed. It may be desirable to treat seed of active collections with an appropriate seed-dressing to prevent fungal and insect damage, but it should be avoided if at all possible. In the ICRISAT gene bank, 500 g seed of each accession after treatment with insecticide and fungicide, is maintained at 4°C and 35% RH in aluminium cans with screw thread lids. Before the seed quantity of an accession falls to a critical level, the seed is rejuvenated in the post-rainy season, to permit the harvest of relatively dry, clean seed.

Other storage aspects such as sample size, periodic germination tests, RH control methods, and choice of containers are discussed by Witcombe and Erskine (1984), Chang (1985a), and Ellis et al. (1985).

Utilization

The use of genetic resources to breed crop plants has received much attention and was reviewed by Krull and Borlaug (1970), Zeven and van Harten (1979), Hawkes (1981), and Chang (1985b).

If the use of a genetic resources collection is to improve yields, desirable genetic variability from the collection must be used by breeding programs to broaden the genetic base. A narrow genetic base in a breeding program is recognized when progress is poor despite vigorous breeding efforts (Simmonds 1983), or in the event of wide-scale disease or epidemics (NAS 1972). The success of a br program lies in the initial genetic base, which determines the potential and adaptability of future varieties.

Regional and national programs often feel that accessions held by an international gene bank represent true genetic resources. On the contrary, some plant breeders regard accessions in a gene bank as primitive landraces or wild and weedy species of little immediate value. The terms germplasm or genetic resources for plant breeders do not always refer to accessions drawn from a gene bank, but include genotypes chosen to incorporate or improve a given trait in a population. Thus, until very recently, the search for important genetic traits was limited to the material with which a breeder was familiar.

Generally five sources of new genetic material are available to a breeder (Simmonds 1983):

- locally adapted varieties produced by other breeders in similar environments, but which often the drawback of being closely related;
- exotic and unadapted varieties, which are of value for specific attributes produced by backcrossing, but are usually unpromising for use as parents;
- landraces which may not contribute much potential apart from general adaptation;
- related species to provide specific attributes such as transfer of pearl millet genome into the cytoplasm of *P. violaceum* (Marchais and Pernes 1985); attempts towards interspecific gene transfer involving pearl millet, *P. orientale*, *P. squamula-*

tum, P. purpureum, (Dujardin and Hanna 1983a and b, Hanna 1983); and
specific sources, which are needed for special traits such as cytoplasmic male-sterility and dwarfing.

ieneral guidelines for choosing and using acces- ions include:

Visualizing the potential of a given trait when incorporated into adapted backgrounds.
Determining the region where this trait occurs in the local crop.
What qualities the source possesses in its own area of adaptation.
How closely the source and user regions compare climatically.
Choosing appropriate breeding and screening methods to rigorously select from good agro- : types among the progeny for the desired

This last step will determine the time required to ıake tangible gains. A practical solution to broaden ıe genetic base using unadapted material is to estab- sh backup or source populations, and build a reas- nable level of adaptation by manipulating day :ngth (e.g., off-season nurseries to permit gene xchange between late and early accessions). After :veral generations with low selection pressure and eliberate recombination, source populations may pproach the adaptation level of the local.

Systematic utilization of germplasm has been very ɔw until very recently. In many instances, needs 'ere not well defined, and there were problems btaining desirable material. The growth habit of ıe accession and climate of the source region may ave been unknown, and the necessity of an enhance- ıent step, if the source was unadapted, consumed ~~~ time and resources.

ls situation is rapidly changing. Following the stablishment of the ICRISAT gene bank, the situa- on will change and improve as plans to evaluate ccessions in regional and national programs in Vest Africa are implemented. The range of available ermplasm is vastly increased, and has been evalu- ted and documented. Although the traits that need nprovement in a breeding program usually include igh yielding ability, stress tolerance or resistances, nd grain quality characteristics, the development nd availability of screening techniques for traits ıch as *Striga* resistance (Roger and Ramaiah 1983), rowth rate (Bramel-Cox et al. 1984), seedling estab- lishment under high soil temperature and drought (ICRISAT 1985), and drought resistance (Bidinger et al. 1982), will increase the future use of genetic resources in breeding programs.

Examples of Utilization

Thanks to the efforts of participating national programs, ICRISAT, and the IBPGR, the fundamental collection step is nearly accomplished, and a reservoir of large genetic variability is now available.

Examples of the utilization of germplasm in breeding programs are given below, and their number should multiply with more reports from germplasm users.

Burton (1982) compared deriving inbreds from exotic germplasm by selfing either the introduction or by selfing the F_1 hybrid of the introduction with an elite inbred. He found that crossing exotic germplasm with elite lines before inbreeding may be expected to increase inbred seed yield up to 50%, and reduce losses due to poor seed set.

Experience at the ICRISAT Sahelian Center (ISC) has shown that sampling variability within generally heterogeneous and heterozygous accessions, by using individual plants in crosses and retaining better performing F_1s, is a very valuable approach in prebreeding. The attrition rate of crosses is very high, particularly when the weather conditions (low rainfall, sand storms, and high temperatures at the time of seedling emergence in the Sahel) are harsh. In the newly established program at the ISC, crosses between selected plants from landraces and improved varieties were made to generate variability. Over 500 F_1s were made and evaluated from crosses between single plants among 27 parents. At the F_3 generation over 840 progenies from 173 crosses were retained, while at the F_5 generation only 170 progenies from 87 of the original cross combinations involving only 12 of the parents were retained. This is a retention of only 17% of the original cross combinations. Analysis of pedigrees indicated that for retention of a cross, one of the parents had to be of local (Niger) origin.

Most of the improved varieties, particularly in West Africa, represent selections from locally adapted landraces (Lambert 1982). However, the variety CIVT (Composite Intervarietal de Tarna) of Niger represents the use of germplasm available within a country to breed an early-maturing, high-yielding variety. This variety involved four parental populations: P_3Kolo (an improved variety bred from cross-

ing two landraces, Haini Kirei and Zongo), Haini Kirei, Guerguera, and Tamangagi (INRAN 1985).

Variety ITMV 8304, released in Niger, is an example of using germplasm from within its region. This variety was selected from a gene pool constituted from Ankoutess (of Niger), Souna (Mali), and Iniadi (Burkina Faso/Togo) landraces (INRAN 1985).

The first world collection assembled in India was successfully used in Nigeria to form populations, and in Uganda it was separated into restorers and nonrestorers to form appropriate recurrent selection bulks (Peters 1967).

Two composite populations formed at the Institute for Agricultural Research (IAR) of the Ahmadu Bello University, Nigeria, represent an efficient use of germplasm (F.H. Kadr, personal communication). The Nigerian Composite, now a released variety in Nigeria, was formed from 200 S_4 progenies derived from 275 accessions from Nigeria, and 54 from other West African countries. The World Composite was constituted from 144 S_4 progenies derived from over 1000 accessions of the first world collection, and East African and Nigerian Gero collections. At ICRISAT, the World Composite was used to breed a high-yielding and downy mildew-resistant variety, WC-C75 (ICMV 1), which was released for general cultivation in India in 1982 (Andrews et al. 1985a).

Pioneering work on the transfer of the d_2 dwarfing gene into populations was carried out by Chantereau and Etasse (1976). The variety Souna II was crossed with 11 dwarf lines from India, 3 from Tifton, Georgia, USA, and a partially dwarf line, 1472. The subsequent population served as a donor of the d_2 gene for the conversion of three tall populations Souna, Haini Kirei, and Ex Bornu, into dwarf versions. These are known as 3/4 populations, (e.g., 3/4 Souna), because only 1/4 of the genes are from the donor. Recently, the d_2 dwarfing gene has been introduced into seven tall composites which have been used in the recurrent selection program at ICRISAT. Preliminary yield trials have indicated that the d_2 dwarf versions of some of these composites have the potential to yield as much as, and even outyield, their respective tall counterparts (Andrews et al. 1985b). These now make available a broad genetic base in a dwarf background for further exploitation to breed dwarf open-pollinated varieties, and dwarf hybrid parents.

The most useful germplasm to supply desirable variability to breeding programs has come from Iniadi, a prominent, productive, bold-seeded, and early-maturing landrace that is found in Benin, Burkina Faso, Ghana, and Togo. This material was used in the formation of composites of the Serere series, and the male-sterile line Serere 10LA (EAAFRO 1974). Male-sterile Serere 10LA was used in the production of the current commercial Indian hybrid MBH 110. This material also forms the basis for dwarf, large-seeded, male-sterile lines bred at Kansas State University, USA. These were supplied to ICRISAT, where further selections for downy mildew resistance were made. Two of these male-steriles, 843 A (ICMA 2) and 842 A (ICMA 3) were recommended by the All India Coordinated Millet Improvement Program (AICMIP) for general use as seed parents (ICRISAT 1985).

A further male-sterile line, 834 A (ICMA 4), was bred at ICRISAT from SIOLA. Two varieties derived from a Togo population, ICTP 8202 and ICTP 8203, were among the highest-yielding varieties across 11 locations in India in the ninth ICI coordinated International Pearl Millet Adaptation Trial (IPMAT 9). In Sudan, variety ICTP 8202 yielded 30% more than the local control Bayuuda, and has been promoted for on-farm trials (ICRISAT 1985). Serere material also formed the basis for a variety, Ugandi, released for general cultivation in Sudan. Ugandi was selected from Serere Composite-2 (Jain 1981). In India, a variety called improved Ghana (later renamed as Pusa Moti), which is now lost, was bred from Ghana/Togo material (Joshi et al. 1961). In West Africa, descendents from Togo × Souna (Mali) crosses have been used extensively as parental material for composites from which varieties have been derived. In Burkina Faso, progenies derived from the photoperiod-sensitive local Kapelga × Iniadi cross are proving to be of immense value (Lohani 1985).

At ICRISAT, in a program to utilize new sources of genetic variability by hybridization, the largest variation in the segregating generations has usually been found in crosses between Indian and African material. Indian landraces, or lines from Indian millet breeding programs, have mainly served as sources of earliness, higher tiller numbers, superior harvest index, and local adaptation, whereas African material has been a good source of high head volume, large seed size, and disease resistances. Among African material, early groups have proved more promising in crosses at ICRISAT than late, photoperiod-sensitive groups. An investigation into the pedigrees of about 1700 promising lines pedigree-selected up to the F_8 generation showed that the breeding populations and lines contributed much

more to useful genetic diversification than landraces. A general picture emerges of the great value of African material to the Indian breeding program. Moreover, African materials have been of most use when in the form of breeders' lines or populations, even though such materials have often only been selections from local landraces (Andrews et al. 1985b).

The development of effective disease resistance screening techniques for downy mildew (Williams et al. 1981), smut (Thakur et al. 1983), and ergot (Thakur et al. 1982) has permitted the identification of several resistant sources (ICRISAT 1985). Accession IP 2696 (Ligui) from Chad is used extensively to establish infector rows in downy mildew nurseries. The lack of disease screening facilities in most programs (with dependence on natural, erratic incidence) has prevented the effective utilization of resistant sources. Use was made of the smut-resis-
reening nursery and smut-resistant lines to
ie Smut Resistant Composite. ICMV 82132, derived from this composite, is currently in AICMIP trials. For rust, two sources of resistance are available (Andrews et al. 1985c, Hanna et al. 1985).

Conclusion

Geographic and genetic diversity in pearl millet is enormous and the most important task of collection is nearly accomplished. Genetic erosion in the classic sense, replacement of landraces by improved varieties, does not pose an immediate danger to landraces in West Africa. On the contrary, decreasing rainfall and consequent droughts over the last 15 years, and infestations by pests and birds are indeed leading to significantly reduced variability among traditional varieties. Examples are provided by the near extinction of the landrace Thiotande in Mauritania and Senegal, and replacement of Souna in Mali because
icks by cantharides and birds. Collection and
vation of variability should be undertaken as soon as possible in areas where genetic resources are under threat.

Accessions in the pearl millet gene bank at ICRISAT are maintained by bagging several heads and forming gemplasm pools, evaluated using the descriptors list (IBPGR-ICRISAT 1981), and are documented. Seed from this gene bank is freely available to scientists throughout the world.

A broad genetic base is important to breeding programs: it determines the potential and adaptation of future varieties. The use of genetic resources to improve pearl millet has been limited until recently. The examples cited indicate the opportunities available to broaden the genetic base and the potential to identify superior parents in collections. With the availability of appropriate screening methods, and identification of resistances to biotic and physical stresses, use of genetic resources will significantly expand and contribute to millet improvement programs. Breeders must now assign resources and time to systematically introduce new germplasm and broaden the base of their programs. What is done now will determine the potential of pearl millet as a crop in the future.

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