A World Survey of Sorghum and Millets Germplasm

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PREFACE

The International Board for Plant Genetic Resources (IBPGR) has the major task of organizing and providing a global network of genetic resources centres to safeguard and make available germplasm of all major crop species for use in present and future breeding programmes. This report surveys the existing collections of sorghum and millets in order to identify gaps and inadequacies which exist in the collections and to provide a basis for the formulation of recommendations for further collecting.

The actual or potential loss of the indigenous variability of sorghum and millets is due to numerous causes but a major one has been the widespread drought in the Sahelian zone of Africa where the greatest variability of sorghum, pearl millet, finger millet, fonio and teff is to be found. Drought conditions and the accompanying crop failures have led to the disappearance of many local cultivars. The wild and weedy relatives are also threatened with loss.

Breeders must be assured of a supply of diversity and therefore it is important that collections of sorghum and millets are properly conserved and that they should include as much representative variability as possible.

DEDICATION

To Jack R. Harlan, in recognition of his achievements in the field of sorghum and millets genetic resources.

THE BACKGROUND TO THIS REPORT

Sorghum and millets are the most important cereals of the semi-arid zones of the world; for many millions of people in Africa and Asia they are staple crops - although they do have other uses.

The urgent need to collect and conserve germplasm of sorghum and pearl millet in particular, but also of Eleusine and other millets, was recognized two decades ago because of the then threat of loss of the primitive cultivars due to replacement by high-yielding cultivars and hybrids.

The first major effort to assemble world germplasm collections of sorghum and pearl millet was initiated by the Rockefeller Foundation in association with the Indian Agricultural Research Programme, (Harlan, 1971; House, 1980; Murty et al., 1967). An assessment of the resultant collections by the Rockefeller Foundation's Committee on Sorghum and Millet Germplasm noted conspicuous gaps in the world collections (Table 1).

In 1976, following the drought in the Sahel, the Crop Ecology and Genetic Resources Unit of the Food and Agriculture Organization of the United Nations (FAO) organized the collection of sorghum and millet in the Sahelian zone of Africa by contracting to the Office de la recherche scientifique et technique outre-mer (ORSTOM) and funding was provided by the United Nations Environment Programme (UNEP).

With the establishment of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) by the Consultative Group on International Agricultural Research (CGIAR) in 1972, and the IBPGR in 1974, action emerged to systematically collect and conserve sorghum and millets. The IBPGR and ICRISAT (which has a world mandate for sorghum and millet germplasm) have been partners in carrying out the work. When the IBPGR listed its priorities for action on crops in 1976, both sorghum and Pennisetum pearl millet were considered of highest global priority; other millets were considered to merit a somewhat lower priority. The IBPGR established jointly with ICRISAT a Committee to advise on Sorghum and Millet Germplasm and the first meeting was held in October 1976 at ICRISAT in Hyderabad, India to formulate a world programme for collection and conservation of sorghum and pearl millet. Priority ratings for geographical regions for field collecting were determined (Table 2) although, in general, the geographical and species gaps identified by the Rockefeller Foundation in 1971 were still found to be valid and hence were reaffirmed (IBPGR, 1976).

Table 1. Major gaps in collection in 1971 (Rockefeller Committee)

Taxonomy	Countries/Regions
1. No species other than S. bicolor 2. Very few wild races 3. Very few shattercanes 4. Few cultivated grassy subraces 5. Very few kaoliangs 6. Short on some special subraces (rigidum, membranaceum, décrue and transplanted et al.)	1. North Africa: Algeria, Egypt, Libya, Morocco, Tunisia 2. West Africa: Central African Republic, Congo, Ivory Coast, Ghana, Guinea, Sierra Leone, Togo 3. Southwest Africa: Angola 4. East Africa: Mozambique, Somalia, Tanzania, Zambia, Zimbabwe 5. Near East: Iran, Iraq, Israel, Jordan, Lebanon, Saudia Arabia, Syria 6. Afghanistan, Pakistan 7. Hill country: India, Nepal, Sikkim 8. Southeast Asia: Burma, Indonesia, Kampuchea, Lao, Philippines, Viet Nam 9. China 10. Japan, Korea

PENNISETUM MILLET

The material have not been classified, but the general impression is that they should be recollected and handled differently.

ELEUSINE

The Indian collection may be adequate but the only African collection that could be close to adequate is the Ugandan one. East Africa and South Africa should be collected. Eleusine africana should be collected as well as E. coracana.

SETARIA

The most obvious gap is China where the crop presumably originated.

OTHER MILLETS

The collections are essentially Indian although some of them are grown in Africa, the Near East and Europe. Other sources should be obtained. The Echinochloa collection is especially weak.

Table 2. Priority countries for collection in 1976 (IBPGR/ICRISAT Committee)

SORGHUM	
First Priority:	Mali, Niger and Sudan
Second Priority:	Botswana, Central African Republic, Chad, Malawi, Mozambique, Somalia, Tanzania and Zambia
Other Priorities:	Burma, China, Indonesia, Malaysia, Philippines, Saudi Arabia, northern Syria, Thailand, Turkey, AR Yemen and PDR Yemen
PENNISETUM MILLET	
First Priority:	Central African Republic, Chad, Mali, Mauritania, Namibia, Niger, Nigeria, Senegal, Sierra Leone, Sudan, Togo and Upper Volta
Other Priorities:	Algeria, Angola, Egypt, Ghana, Guinea, India, Ivory Coast, Kenya, Lesotho, Malawi, Morocco, Mozambique, Pakistan, Saudi Arabia, South Africa, Spain, Tanzania, Tunisia, Uganda, A.R. Yemen, PDR Yemen, Zaire and Zimbabwe

By 1981 the Committee had reviewed the progress made and revised priorities as necessary (Table 3). The work initiated following the recommendations of the Committee had led not only to field work but the descriptor lists for sorghum and pearl millets, which were published jointly by IBPGR and ICRISAT in 1980 and 1981 and a directory of germplasm collections listing those centres with major collections was issued (including the types of samples held at each centre, the geographical representation of the samples, storage conditions, location of duplicates and information on evaluation and documentation).

In relation to conservation, as per the recommendation of the Committee, the IBPGR designated the following centres to host major base collections for long-term safety and to make materials available to the relevant active collections.

SORGHUM	
Cultivated and wild	ICRISAT, NSSL
MILLETS	
Cultivated and wild	NSSL
Pennisetum spp.	ICRISAT, PGR
Eleusine spp.	ICRISAT, PGRC/E
Minor Indian millets	ICAR
Eragrostis spp.	PGRC/E
Panicum miliaceum	ICRISAT
Setaria italica	ICRISAT

This report attempts to provide data on the work that has been accomplished so far on sorghum and millets. It includes the most up-to-date information on existing collections and makes suggestions for further work on collection, conservation and evaluation.

The species included in this report are: *Sorghum bicolor*, *Pennisetum americanum*, *Eleusine coracana*, *Setaria italica*, *Panicum miliaceum*, *P. sumatrense*, *Echinochloa frumentacea*, *E. crusgalli*, *E. colona*, *Paspalum scrobiculatum*, *Digitaria exilis*, *D. iburua* and *Eragrostis tef*.

Whilst identifying gaps in the collections attempts have been made to take into account the evolutionary relationships between taxa and their distribution, the importance of each taxon, the areas of greatest variability and the amount of material that has been collected from those areas.

Because there are several taxonomic systems in use and there is a great deal of synonymy in the documentation, a discussion of the taxonomy has been included where this provides clarification. Synonyms and common names are given in Appendixes I and II.

SORGHUM

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the four major food grains of the world. As a source of human nutrition it is preceded by only wheat, rice and maize. It is the staple food for millions of people in Africa and India. The estimated area under cultivation in 1981 was 47.8 million ha with 16 million ha in India and 15.3 million ha in Africa (FAO, 1981).

Domestication

Sorghum is believed to have been domesticated in the savannah zone of Africa and all the close wild relatives of sorghum are confined to Africa. The first reliable

Table 3. Priority countries and regions for collection in 1981 (IBPGR/ICRISAT Committee)

	SORGHUM
Africa:	Angola, Chad, Ghana, Madagascar, Mauritania, Mozambique, Namibia, Rwanda, Sierra Leone, Somalia, Sudan, Tanzania and Uganda
Asia:	China, uncollected areas of India, Yemen AR and PDR Yemen
	PENNISETUM
Africa:	Angola, Benin, Burundi, Chad, Egypt, Ethiopia, Cambia, Ghana, Ivory Coast, Mali, Rwanda, Sierra Leone, Uganda, Upper Volta, Zaire, Zimbabwe
Finger millet (*Eleusine coracana*)	China, Ethiopia, India, Kenya, Nepal, Somalia, Sri Lanka, Sudan, Tanzania, Uganda, Zimbabwe
Foxtail millet (*Setaria italica*)	China, India, Iran, Japan, Korea (DPR), USSR
Proso millet (*Panicum miliaceum*)	Afghanistan, China, Europe, India, Iran, Mongolia, USA, USSR
Barnyard millet (*Echinochloa* spp.)	China, India, Japan, USA
Kodo millet (*Paspalum scrobiculatum*)	India
Little millet (*Panicum sumatrense*)	China, India
Fonio (*Digitaria* spp.)	West Africa

archaeological record of sorghum is from Ahar, Rajasthan, India, dated *ca.* 1725 BC (Doggett, 1976). Since the crop was introduced into India from East Africa, sorghum domestication must have taken place well before 3000 BC.

The main area of variation lies in the Ethiopian region where diversity of both wild and cultivated sorghum is widespread. There is, however, a lack of botanical diversity in the Ethiopian cultivated forms, many of which belong to races which are highly developed (durra and durra-bicolor). Doggett (1976) proposed that the excellence of these races had resulted in their being favoured to the exclusion of other forms. Agriculture was brought to Ethiopia from the Near Eastern Centre by the Cushites, 4000 to 3000 BC. The Cushites brought with them wheat and barley which thrived in the Ethiopian highlands and they developed through domestication a range of local crops including finger millet, teff and sorghum (Doggett, 1965; Murdock, 1959).

Morphological data correlated with present day distribution patterns seem to suggest that sorghum was enobled in several independent centres in Africa from three morphologically different prototypes (de Wet and Huckabay, 1967). Although different cultivated forms are associated with different wild races, changes associated with cultivation make it impossible to determine the exact prototypes. Guinea sorghums are grown by the West African negroids; the distribution and morphological affinities suggest that the crop was enobled in tropical West Africa through selection from members of race arundinaceum. The kafir sorghums are grown primarily by the Bantus of Southern Africa. The Bantus originated from the Cameroon and Doggett (1976) proposed

that they came into contact with sorghum at the southern edge of the Congo forest and took it with them into the dry savannah country to the south. The distribution and morphology of the kafir sorghums indicate close affinities with the wild race verticilliflorum. Race caudatum is associated with the Nilotic and Nilo-Hamitic people in Uganda and western Kenya. Race durra was developed in Ethiopia and Sudan and is associated with the Hamitic people and Islamic culture (Doggett, 1976). Comparative morphological studies seem to suggest that race durra and race caudatum could have originated out of selections from race kafir (De Wet, personal communication). Bicolor sorghums are widespread in Africa but their centre of diversity is in Asia. The bicolor complex shows affinities with race aethiopicum of the Sudan region and selection for particular purposes after introduction to Asia would have given rise to the wide variability characterizing this race.

Changes associated with domestication include the development of persistent sessile spikelets on a tough rachis and a compact, highly productive head. Selection for increased seed size (often to the stage where the grains are extruded from short gaping glumes) led to seeds being easily accessible to birds and selection against this characteristic would have accompanied selection for high yield.

The ability of some sorghum cultivars to survive in disturbed habitats may indicate some degree of primitiveness but weediness could also be associated with hybridization between the crop and its wild relatives and does not necessarily indicate a prototype of the cultigen. (Harlan and Zohary, 1966; Harlan, de Wet and Price, 1973). Bicolor sorghum have weedy characteristics and selection from among these may present some very primitive relicts. Guinea sorghum have large seeds which indicate that the race has been highly selected although some primitive relicts may be preserved in West Africa because of the antiquity of the race there. Similarly, primitive types of durra may still be cultivated in parts of Asia.

Sorghum is believed to have spread from East Africa along a coastal route to India at an early date; the crop was introduced to Arabia from East Africa also at an early date and then spread through the Near East. The spread to Southeast Asia and China is thought to have been later and in China the crop is believed to have introgressed with Sorghum propinquum to produce the kaoliang and cane sorghums (Doggett, 1976). Grain sorghum was introduced to the New World in the 19th century.

The Sorghum Genepool

The genus is subdivided into subgenera or sections. The cultivated forms fall within Sect. Sorghum (Eu-Sorghum) which contains two polymorphic wild diploid complexes, S. propinquum (Kunth.) Hitchc. (Southeast Asia) and S. bicolor subsp. arundinaceum Desv. (Africa). There is also a tetraploid S. halepense (Linn.) Pers. which overlaps in distribution of the two diploid species complexes and is thought to be an autotetraploid of S. propinquum (de Wet, personal communication). The wild and cultivated grain forms of sorghum are derived from S. bicolor. Sorghum halepense is a fodder form (Johnson grass). Another species, S. almum is a tetraploid between cultivated diploids and S. halepense and arose in Argentina. The kaoliang types of sorghum of China derived from hybrids between cultivated diploids and S. propinquum.

The cultivated and wild members of the S. bicolor complex are interfertile and introgression between these have given rise to a wide array of agro-ecotypes. A taxonomic treatment of cultivated sorghums by Snowden included 31 species, 158 varieties and 523 forms making a total of 712 taxa and as such, people working on the crop found this classification unmanageable and over the years they have led to more simplified classifications (Appendix I) related to the species complexes listed above.

Applying numerical taxonomic methods, de Wet and Huckabay (1967) divided S. bicolor Moench into two sections: perennial rhizomatous species were included in subsp. halepense and annual cultivated, wild and weedy species were included in subsp. bicolor. The wild species of bicolor were partitioned into three varieties, the weedy species were recognized as "crop-weed hybrids" and the cultivated grain sorghums were included as variety bicolor. The cultivated sorghums were further subdivided into four races (bicolor, quinoa, kafir and durra).

A simplified classification for S. bicolor in which the cultivated grain sorghums and their interfertile wild and weedy relatives were all recognized as one species S. bicolor was proposed by Harlan and de Wet (1972). The cultivated grain sorghums were included in subsp. bicolor and variations among the cultivated species were sectioned into five basic races (characterized mainly by spikelet morphology) and 10 intermediate races made up of all possible combinations of the basic races. The head types were also sectioned into nine groups which correlated in certain ways with spikelet morphology (Fig. 1).

The simplified classification enabled the clearer understanding of the genepool (Fig. 2).

The primary genepool of sorghum is made up of all the cultivated grain sorghums and their interfertile wild and weedy relatives as well as S. propinquum. The secondary genepool includes the tetraploids S. halepense and the tertiary genepool is made up of members of the other sections/subgenera of Sorghum.

Pertinent information about the entities in the genepool are provided below (see also Fig. 3).

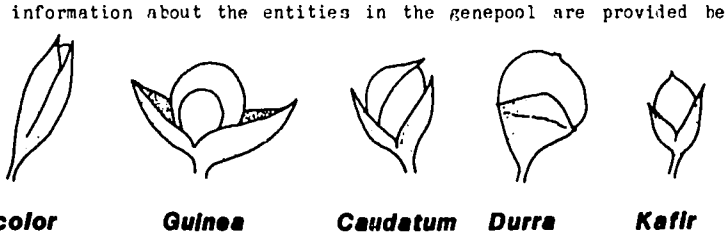


Figure 1(a). The five basic spikelet types of cultivated sorghum

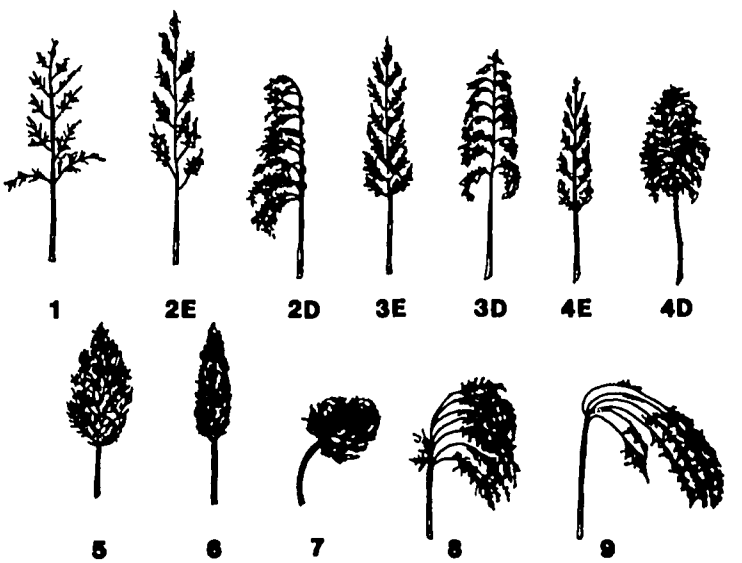


Figure 1(b). Head types of cultivated sorghum

Type 1	Wild Sorghum races
Type 2, 3 & 4	Bicolor Guinea
Type 5, 6 & 7	Kafir and Durra
Type 8	Various cultivated races
Type 9	Bicolor

Caudatum spikelets are found on various head types

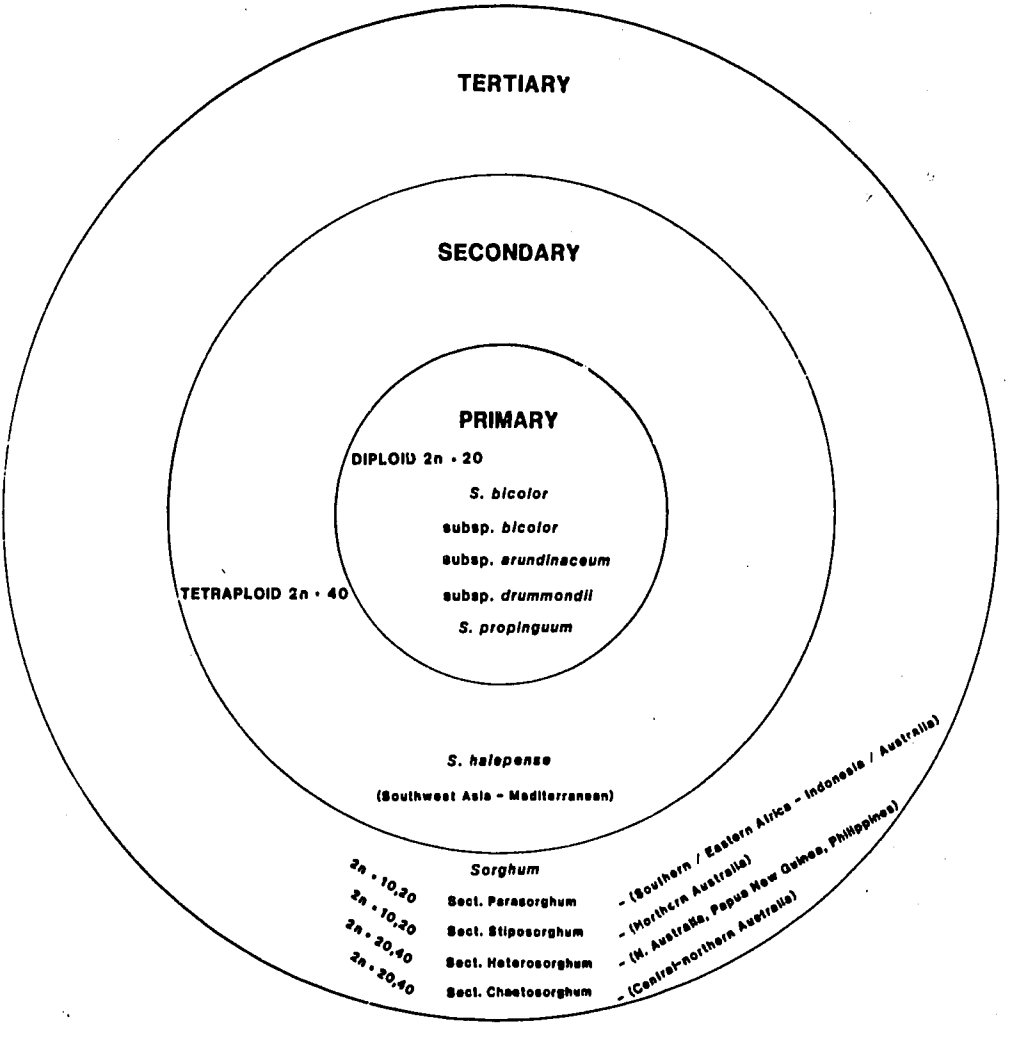

TERTIARY
SECONDARY
PRIMARY
DIPLOID 2n = 20
S. bicolor
subsp. bicolor
subsp. arundinaceum
subsp. drummondii
S. propinguum
TETRAPLOID 2n = 40
S. halepense
(Southwest Asia - Mediterranean)
Sorghum
2n = 10,20 Sect. Parasorghum - (Southern / Eastern Africa - Indonesia / Australia)
2n = 10,20 Sect. Stiposorghum - (Northern Australia)
2n = 20,40 Sect. Heterosorghum - (N. Australia, Papua New Guinea, Philippines)
2n = 20,40 Sect. Chaetosorghum - (Central-northern Australia)

Figure 3. Distribution areas of cultivated and wild races of sorghum in Africa: Subsp. bicolor and subsp. arundinaceum (modified from de Wet et al., 1976; Harlan and Stemler, 1976)

Subspecies bicolor

i) Race **bicolor** is based on subseries Bicolaria of Snowden (1936). It is characterized by open inflorescences and long clasping glumes that usually enclose an elongate seed at maturity. Bicolor sorghums although widely distributed as a whole are low yielding. It occurs in all sorghum growing areas of Africa, extending from southern Africa to eastern Asia but is never extensively cultivated. In spite of the fact that this race has more primitive characteristics than other cultivated races, many of the cultivars are highly specialized in specific characters. Some cultivars are grown for sweet stems, but others grown for their bitter grains are used to flavour sorghum beer.

Intermediate races involving race bicolor are of minor importance but durra-bicolor is grown extensively in the highlands of Ethiopia.

ii) Race **guinea** has open inflorescences and is characterized by flattened ovate or elliptic grains that are obliquely twisted between widely gaping glumes. Race guinea is basically West African with a secondary centre in Malawi. This race is adapted to high rainfall areas with as much as 3,000 mm p.a. but equally well adapted to areas with a quarter as much rain (de Wet and Shechter, 1977). Some cultivars are tolerant to flooding and are used in dérue agriculture (Harlan and Pasquereau, 1969). Important intermediate races involving guinea include guinea-caudatum which is a major race of Nigeria, Chad and Sudan and guinea-kafir (S. roxburghii) which is a major race in India and is grown to some extent in East Africa.

Sorghum race guinea damaged by stem borer

iii) Race **caudatum** is characterized by turtle-backed grains that are flat on one side and distinctly curved on the opposite side. The grains are usually exposed between the shorter glumes at maturity. The inflorescences range from compact to open; the more compact inflorescences are confined to the drier zones and those with open inflorescences in the wetter regions. The caudatum race is dominant in parts of the Sudan, Chad, Nigeria and most of Uganda (Stemler, Harlan and de Wet, 1975). It is also grown in Ethiopia and in the Cameroon. The most important intermediate race involving race caudatum is kafir-caudatum (most American hybrid grain sorghums are of this race).

iv) Race **kafir** is characterized by spikelets that are broadly elliptical with the glumes tightly clasping the usually shorter grain. The inflorescence is somewhat open and often cylindrical in shape. Race kafir is extensively grown in eastern and southern Africa. Aside from guinea-kafirs of India and kafir-caudatums of the American sorghum belt, kafir-durras have been important sources of breeding materials. The cytoplasmic male sterile system used in hybrid grain sorghum is from this race.

v) Race **durra** is characterized by compact inflorescence. It has flattened ovate spikelets with very wide glumes, the tip of which is a different texture from the base and often with a transverse crease across the middle. It is essentially the only sorghum cultivated along the southern fringe of the Sahara across arid West Africa and is the dominant race in Ethiopia. Some cultivars are adapted to flooding and are the dominant sorghums in décrue agriculture in Mali (Harlan and Pasquereau, 1969).

Subspecies arundinaceum

The wild sorghums closely related to S. bicolor are included in subspecies arundinaceum. These taxa hybridize freely whenever they are sympatric and also cross readily with the cultivated types. Harlan and de Wet (1972) treated them as races rather than varieties of subspecies arundinaceum.

It was mentioned earlier above that each major cultivated form is related to a wild annual race. These are arundinaceum, aethiopicum and verticilliflorum.

i) Race **arundinaceum** is a forest grass of West Africa adapted to the wet tropics well beyond the normal range of cultivated sorghum and should be unique for improving sorghum adaptation for humid conditions. It should also be a most likely source of resistance to striga, shoot fly, smut and other diseases and pests that thrive under high rainfall. Race arundinaceum can also carry out photosynthesis efficiently under reduced light conditions and should be a most valuable source for sorghum adaptation to more humid conditions.

ii) Race **aethiopicum** is a desert grass distributed across the Sahel from Mauritania to Sudan. This race is thought to be on the verge of extinction (Harlan, 1973) and as such, every effort should be made to collect representative samples before it is too late.

iii) Race **verticilliflorum** is widespread savannah grass over all of Africa and has been introduced into India, tropical Australia and the New World. It has large open inflorescences with spreading but not pendulous branches. The race has weedy tendencies and is often found in sorghum fields with which it crosses to produce a shattercane. It is believed to be on the decline because it occupies habitats suitable for agriculture; as more savannah is brought under cultivation, more stands of verticilliflorum will disappear. The race is morphologically highly variable by virtue of its wide distribution as it must have come into genetic equilibrium with various races of parasites and diseases and should provide useful sources of resistance.

In addition there is race virgatum which is weedy and grows on disturbed habitats along the Nile Valley in arid northeastern Africa from Khartoum to Cairo. It also occurs in other areas and is considered to have contributed to the origin of Sudan grass "S. sudanense" - a shattercane used for forage.

Subspecies drummondii

The weedy members of subsp. arundinaceum, or shattercanes, are now recognized as a subspecies of S. bicolor (de Wet, 1978) on the basis of their habitat preferences. Subspecies drummondii occur in disturbed habitats and wherever cultivated sorghums are sympatric with their close wild relatives and are considered to be hybrids between wild and cultivated sorghums. Morphologically stabilized forms often accompany grain sorghums as weeds beyond the natural range of S. bicolor. Subspecies drummondii occur widely in the Ethiopian highlands and India. They are more rare in West Africa but become progressively more abundant eastwards from Senegal and Chad. Members of this subspecies have rather contracted panicles and variable grains which usually resemble the crop from which the weed was derived.

S. propinquum

The rhizomatous S. propinquum crosses readily with members of the arundinaceum and was included as a race of arundinaceum by Harlan and de Wet (1972). It is perennial and not confined to Africa; the taxon is widely distributed in tropical South and South-eastern Asia. A more recent review by de Wet (1978) recognizes it as a separate species on account of its spatial isolation from the annual members of S. bicolor.

Sorghum collections

Table 4 shows the number of samples which have been collected from particular countries between 1975-82. The countries listed are those identified by the Committee to represent a priority for collecting (see Table 2, page 2). The holdings of the world collection at ICRISAT are listed in Table 4 and also, there are over 25,000 other samples held by other institutes (NSSL, 15,000; ORSTOM, 2,626; PGRC/E, 5,000; SRPIS, 3,620; and VIR, 9,615). Most of the ICRISAT samples are duplicated. Other collections are listed in Appendix II.

Since the numbers of samples do not mean that representative variability has been garnered, numbers of samples alone cannot form a basis for estimating gaps. The following conclusions are clear:

i) There is still, in general, extremely poor representation and collection of wild and weedy material.

ii) Two countries accorded second priority need urgent work: Central African Republic and Chad. Little immediate work is needed in other second priority countries.

iii) Probably little field work is needed immediately in Benin, Cameroon, Egypt, Ethiopia, India, Kenya, Mali, Niger, Nigeria, Senegal, South Africa, Sudan, Togo, Upper Volta, Yemen and Zimbabwe **except for wild and weedy materials.** On the basis of the primary centre of sorghum diversity, the countries for the collection of both wild and weedy species are: Ethiopia, Sudan (eastern part), Uganda, Burundi, Rwanda, Kenya and Tanzania.

iv) A large number of countries remain from which little material is available. Priorities need to be assigned on a reasoned set of criteria.

Table 4. Sorghum collections in priority areas (1975-82)

	Country	Total	Cultivated Sorghum	Wild Sorghum	Weed/ Sorghum	Not Identified	Samples From The Country Held At ICRISAT (Dec.'82)
First Priority							
	Mali	1,381	1,012	-	-	369	111
	Niger	553	553	-	-	-	408
	Sudan	469	236	22	-	211	2,256
Second Priority							
	Botswana	138	137	1	-	-	190
	Malawi	495	406	8	3	78	437
	Mozambique	25	25	-	-	-	42
	Somalia	110	-	-	-	110	125
	Tanzania	236	154	20	6	56	432
	Zambia	-	-	-	-	414	210
Second Priority (no IBPGR action 1975-82)							
	Central African Rep.	-	-	-	-	-	39
	Chad	-	-	-	-	-	138
Other Priorities							
North Africa	Algeria	35	32	-	-	3	0
	Tunisia	3	-	-	-	3	0
West Africa	Benin	1,222	528	-	-	694	4
	Cameroon	63	63	-	-	-	1,835
	Ghana	48	-	-	-	48	64
	Nigeria (North)	253	248	5	-	-	1,173
	Senegal	398	394	4	-	-	237
	Togo	375	370	5	-	-	0
	Upper Volta	390	389	1	-	-	216
East Africa	Burundi	102	98	4	-	-	-
	Ethiopia	67	-	-	-	67	4,242
Southern Africa	Zimbabwe	302	300	-	-	2	186
Southwest Asia	Yemen A.R.	352	-	-	-	-	216
Southern Asia	India	268+	265+	-	3	-	4,138
Other Priorities (no IBPGR action 1975-82)							
North Africa	Libya	-	-	-	-	-	0
	Mauritania	-	-	-	-	-	0
	Morocco	-	-	-	-	-	0
West Africa	Guinea	-	-	-	-	-	-
	Ivory Coast	-	-	-	-	-	1
	Sierra Leone	-	-	-	-	-	3

Table. 4. Sorghum collections in priority areas (1975-82) (Contd.)

		Total	Cultivated Sorghum	Wild Sorghum	Weedy Sorghum	Not Identified	Samples From The Country Held At ICRISAT (Dec.'82)
East Africa	Rwanda	-	-	-	-	-	
	Uganda	-	-	-	-	-	612
Central Africa	Angola	-	-	-	-	-	29
	Congo	-	-	-	-	-	0
Southern Africa	Madagascar	-	-	-	-	-	1
	Namibia	-	-	-	-	-	1
Southwest Asia	Iran	-	-	-	-	-	7
	Iraq	-	-	-	-	-	4
	Jordan	-	-	-	-	-	0
	Lebanon	-	-	-	-	-	360
	Saudi Arabia	-	-	-	-	-	1
	Syria (North)	-	-	-	-	-	4
	Turkey	-	-	-	-	-	51
Southern Asia	Afghanistan	-	-	-	-	-	6
	Pakistan	-	-	-	-	-	29
	Burma	-	-	-	-	-	8
	Cambodia	-	-	-	-	-	-
	Indonesia	-	-	-	-	-	32
	Laos	-	-	-	-	-	-
	Philippines	-	-	-	-	-	5
	Viet nam	-	-	-	-	-	-
Eastern Asia	China	-	-	-	-	-	68
	Japan	-	-	-	-	-	111
	Korea	-	-	-	-	-	-
Other Collections							
	Egypt	102	-	-	-	102	22
	Gambia	70	-	-	-	70	57
	Kenya	302	246	30	26	-	761
	Spain	3	3	-	-	-	3
	Sri Lanka	28	-	-	-	28	25
	South Africa	77	-	-	-	77	726

PEARL MILLET

Pearl millet [Pennisetum americanum (L.) Schum.] is widely cultivated in the semi-arid areas of Africa and India. Although it is not a major crop in terms of world production it has great potential because of its drought resistance and is grown at the extreme limits of agriculture e.g., the desert margins of Africa, India and Pakistan. In the Sahelian region, harvests of pearl millets are obtained with as little as 250 mm of annual rainfall and it can also grow on poor sandy soil.

Domestication

Pearl millet is believed to have originated in the drier regions of West Africa where the greatest number of cultivated and related wild forms occur. Like many African domesticates it has not been possible to determine exactly the antiquity of pearl millet because of the lack of prehistoric and archaeological evidence.

The earliest archaeological record concerning pearl millet noted impressions of inflorescences on sherds at Ntereso in northern Ghana dated the late second millenium BC, (Davies, 1968). Munson (1976) has reported pottery impressions of pearl millet in the Dhar Tichitt region of southwestern Mauritania dated 1100 to 1000 BC, indicating that pearl millet was almost certainly domesticated before 1000 BC.

Numerous reports indicate that the Sahara region has undergone climatic fluctuations over the past 30,000 years. According to Livingstone (1975), the climate of the Sahara was wet between 12,000 and 3,000 years ago but the region had a transitory dry phase between 5000 and 3000 BC inferring that the Sahara was dry at the period suggested for pearl millet domestication although there has been a wet and dry phase since. The present dry phase started 3,000 years ago. Many authors, however, believe that the last wet period was between 7,000 and 4,000 years ago and as such the area of the headwaters of the Niger region should have been rain forest (Munson, 1976; Brunken et al., 1977).

Pollen analysis suggests that the vegetation of the Sahara region was Mediterranean during the last wet phase and most of the semi-desert periphery was shifted 100 to 200 kms inward. The central highlands of the Sahara were mesic areas surrounded by drier lowlands (Brunken et al., 1977). Davies (1968) also pointed out that even within the present day forest areas of West Africa, especially along the coast of Ghana, Ivory Coast and Gabon, there are patches of savannah in regions where forest should exist.

The greatest diversity of pearl millet today occurs in West Africa south of the Sahara and north of the forest zone. Harlan (1971) suggested a diffused belt stretching from western Sudan to Senegal, a "non-centre" for the origin of pearl millet. Portères (1976) observed that patterns of racial variation observed within pearl millet had been attributed to independent domestications or migrational events very early in the history of the crop. He recognized four distinct centres of pearl millet diversity in Africa; (a) an extreme West African area limited on the east by the river Niger, and (b) a central West African area between the lower Niger and Lake Chad which are ancient palaeo-Nigritic regions; (c) eastern Nile-Sudan area which is a Nilotic-Cushitic region; and (d) East African and Angolan area extending from Kenya to Natal and from Tanzania to Angola which is a Bantu region.

Brunken and co-workers (1977) believed that pearl millet was domesticated along the southern margin of the central highlands of the Sahara at the beginning of the present dry phase (probably between 3000-2000 BC).

Once domestication had occurred pearl millet was introduced throughout the drought-plagued regions of the Sahara. The crop was also introduced through human migration and trade to semi-arid tropical regions beyond the Sahara. It was taken at an early date (at least 3,000 years ago) to East African and thence to India where a secondary centre of variability developed and improved cultivars were evolved (Purseglove, 1976). Archaeological remains in the form of carbonized grains indicate

that pearl millet had reached the Gujarat coast of India by 1000 BC (Rao et al., 1963, cited by Brunken et al., 1977). A single grain uncovered in the Ngade region of northern Malawi indicates that the crop had reached southern Africa by 800 or 900 AD (Rabinson, 1966). Pearl millet was introduced to the south of Spain from North Africa after the Moorish invasion in 800 AD (Colmeiro, 1885, quoted by Brunken et al., 1977).

The Pennisetum genepool

Pennisetum Rich. is a genus of annual and perennial grasses distributed throughout the tropics. The most extensive treatment of the genus was contributed by Stapf and Hubbard (1934) who divided the genus into five sections: Gymnothrix, Pennisetum (Eu-pennisetum), Penicillaria, Heterostachya and Brevivalvula. Cultivated pearl millet and its wild and weedy relatives were included in section Penicillaria which included 14 cultivated species, 6 wild species and 13 intermediate species.

In a more recent classification of West African representatives of the genus, Clayton (1972) recognized 19 species and section Penicillaria included 6 species. All forms of cultivated pearl millet were included in a single species P. americanum.

Brunken (1977) further reduced the number of species in section Penicillaria to two on morphological and cytological grounds: P. purpureum was maintained as a separate species because of its perennial life cycle and tetraploid chromosome number. All the annual diploid species of the section, including cultivated pearl millet and its relatives, were recognized by Brunken as a single species P. americanum because hybridization experiments indicated no genetic barriers. All cultivated forms crossed readily with each other as well as with their wild relatives, several of which in general, occur as weeds in the fields of pearl millet. Furthermore, numerical methods showed continuous variation except for the persistence of the involucre at maturity. P. americanum was divided into three subspecies based upon their morphology and adaptive strategies to domestication: the cultivated species as subspecies americanum, the wild forms as subspecies monodii and the intermediate and weedy types as subspecies stenostachyum. A comparison of the various classifications of the genus Pennisetum is given in Appendix II. The distribution of americanum, monodii and the wild perennial purpureum is shown in Fig. 4. Subspecies stenostachyum, including all the weedy and intermediate forms between subsp. monodii and subsp. americanum, often mimic the various races of pearl millet in their morphology. Subspecies stenostachyum occurs throughout much of the pearl millet growing areas of Africa. They are especially common in western Senegal where ex- tensive hybrid swarms between this subspecies and cultivated pearl millet occur. There is a high frequency of hybrids in all areas of contact between pearl millet and subsp. monodii.

Brunken et al. (1977) subdivided subsp. americanum into races: typhoides, nigritarum, globosum and leonis based on the shape of the caryopses.

i) Race **typhoides** is characterized by caryopses which are obvate in both frontal and profile views and are obtuse and terete in cross-section. This race is widely distributed throughout Africa and is the only race found outside Africa.

ii) Race **nigritarum** has grains that are as obvate as those of typhoides but extremely angular in cross section with 3 to 6 facets on the grain. The centre of nigritarum distribution is from western Sudan to northern Nigeria.

iii) Race **globosum** has grains that are characteristically spherical otherwise te- rete and obtuse. The race has been collected from western Sudan to Upper Volta.

iv) Race **leonis** has an acute oblanceolate terete caryopsis and is centred in Sierra Leone although it occurs infrequently as far north as southern Mauritania.

The wild progenitor of pearl millet is believed to be P. americanum subsp. monodii which occurs in disturbed habitats in the Sahel zone of Africa. The forms of P. americanum all form the primary genepool, the perennial P. purpureum, the secondary genepool and other species of Pennisetum the tertiary genepool.

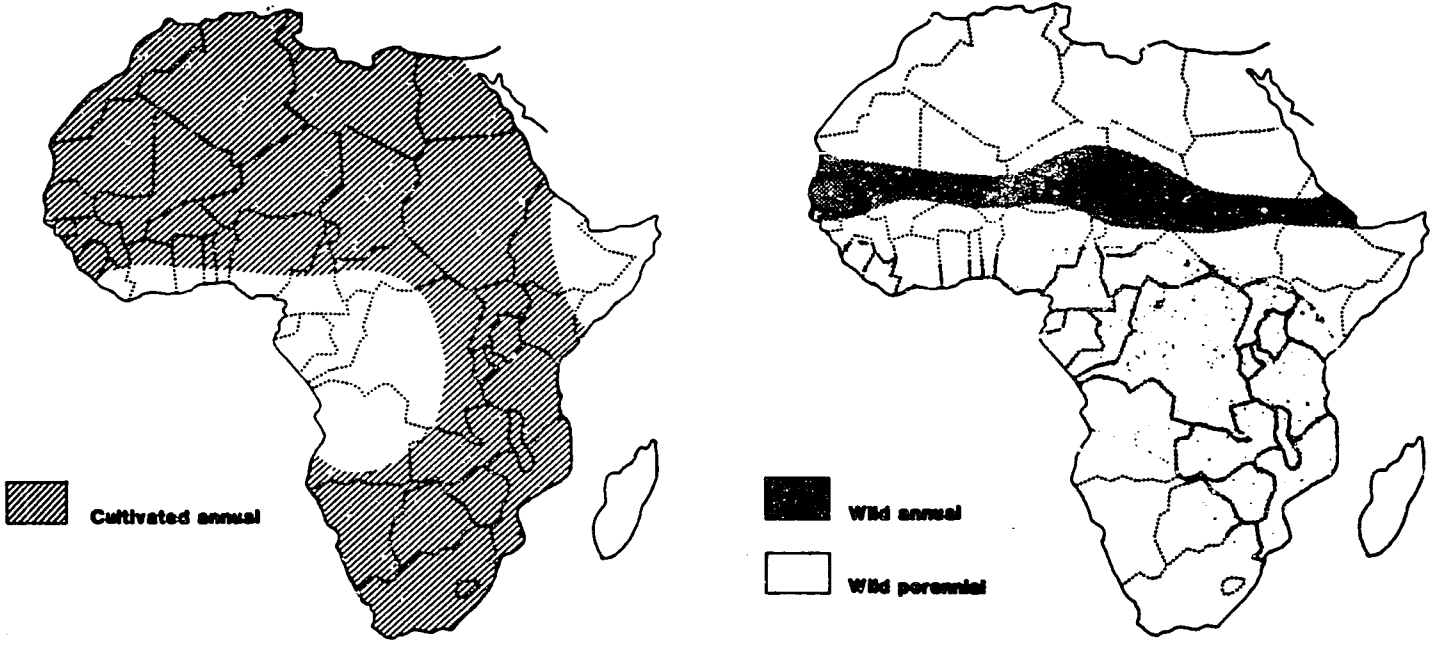


Fig. 4. Distribution of wild, weedy and cultivated pearl millet in Africa (modified from Brunken, 1977)

Cultivated pearl millet is highly variable and in most fields in West Africa mixtures of types are to be found. The crop is allogamous and only a few races are found in any given area although these may show considerable variability. There are early and late forms which are kept genetically separate by times of flowering. Times of maturity in pearl millet vary from 60-180 days. Although allogamous, the crop is markedly protogynous but when there is some overlap of male and female phases in the inflorescences, some self-pollination can occur and this can be used for the production of inbred lines.

Pennisetum collections

Table 5 shows the number of samples which have been collected during 1975-82 from particular priority countries and the numbers of samples held in the world collection at ICRISAT. Other collections are shown in Appendix IV.

The following can be concluded:

i) Of countries with first priority status, Cameroon, Mali, Niger, Nigeria, Senegal, Sudan, Togo and Upper Volta seem adequately covered for cultivars but more wild/weedy/spontaneous material should be obtained from Niger, Sudan and Upper Volta.

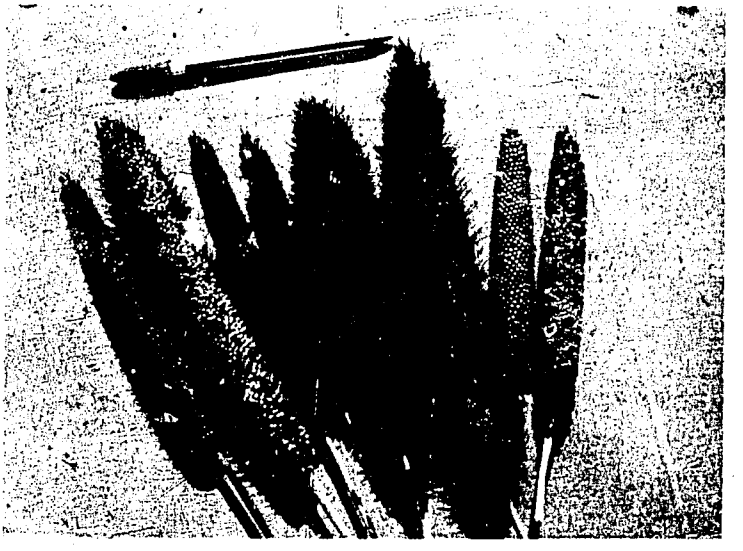
ii) First priority countries requiring urgent attention remain Central African Republic, Chad, Mauritania, Namibia and Sierra Leone.

iii) Of other priority countries in Africa, Benin, Ghana and Tanzania do not require urgent collection of cultivars.

Countries requiring attention can be grouped as:

a) those in the primary centre of diversity [other than those in (ii)]: Niger and Sudan;

b) areas representing peripheral diversity or old introductions, e.g. the oases of North Africa and Ethiopia; and



Variation of Pennisetum in one field, Darfur Province, Sudan

Table 5. Pearl millet collections in priority areas

	Country	Total	Cultivated Pearl millet	Wild Pearl millet	Weedy Pearl millet	Not Identified	Samples From The Country Held At ICRISAT (Dec.'82)
First Priority							
	Cameroon	150	144	4	2	-	171
	Central African Republic	62	58	-	-	4	58
	Mali	1022	931	54	37	-	873
	Niger	742	565	20	145	12	1,032 (3)
	Nigeria	278	177	23	8	-	610
	Senegal	264	228	18	18	-	306
	Sudan	132	20+	6	-	106	274
	Togo	165	150	2	13	-	58
	Upper Volta	590	462	10	97	21	34
First Priority (no IBPGR action 1975-82)							
	Chad	-	-	-	-	-	62
	Mauritania (limited)	-	-	-	-	-	1
	Namibia	-	-	-	-	-	-
	Sierra Leone	-	-	-	-	-	-
Other Priorities							
West Africa	Benin	221	183	1	37	-	17
	Gambia	17	-	-	-	17	17
	Ghana	135	-	-	-	135	256
	Guinea	72	72	-	-	-	-
North Africa	Algeria	-	-	-	-	-	-
	Egypt	-	-	-	-	-	-
East Africa	Burundi	1	-	1	-	-	-
	Kenya	48	45	3	-	-	47
	Tanzania	177	159	18	-	-	138
Southern Africa	Botswana	47	47	-	-	-	45
	Malawi	223	208	8	11	300	245
	Mozambique	13	-	-	-	-	28
	South Africa	30	-	-	-	-	16
	Zambia	94	38	-	-	-	77
	Zimbabwe	129	125	-	-	4	52
Asia	India	1,235	1,225	9	-	-	10,762
	Yemen	70	19	-	-	51	-
Other Priorities (no IBPGR action 1975-82)							
West Africa	Guinea	-	-	-	-	-	-
	Ivory Coast	-	-	-	-	-	-
North Africa	Morocco	-	-	-	-	-	-
	Tunisia	-	-	-	-	-	-
East Africa	Ethiopia	-	-	-	-	-	-
	Rwanda	-	-	-	-	-	-
	Uganda	-	-	-	-	-	48
Central Africa	Angola	-	-	-	-	-	-
	Zaire	-	-	-	-	-	-
Southern Africa	Lesotho	-	-	-	-	-	-
Asia	Burma	-	-	-	-	-	-
	Pakistan	4	-	-	-	4	5
	Yemen P.D.R.	-	-	-	-	-	-
Europe	Spain	-	-	-	-	-	-

c) others: Angola, Guinea, Ivory Coast, Kenya, Lesotho, Mozambique, Rwanda, South Africa, Uganda, Zaire and Zimbabwe.

iv) Of other priority countries in Asia, India has probably been sampled. Priority could be given to Burma, Pakistan and PDR Yemen.

Spain should be collected.

FINGER MILLET

Finger or African millet [Eleusine coracana (L.) Gaertn.] is widely cultivated in eastern Africa and in India. Seeds of Eleusine can be stored by farmers for ten years or more without deterioration or weevil damage and can therefore be used as a reserve food during a famine.

Domestication and origin

The cultivation and diversity of finger millet in North Africa and India led to controversy over the time and place of domestication, and also of its progenitor. The cultivated E. coracana is a tetraploid (2n = 36) and is morphologically allied to both E. indica (L.) Gaertn. (2n = 18) and E. africana O'Byrne (2n = 36). For many years it was considered to have originated from E. indica which is distributed from Africa eastwards to Java (Hilu and de Wet, 1976). However, recent cytogenetical and morphological data indicate that E. coracana and E. africana are genetically conspecific and gene-flow between them occurs in nature, suggesting that E. coracana could have originated directly from E. africana through selection and further cultivation of a large grain mutant (Chennaveeraiah and Hiremath, 1974; Hilu and de Wet, 1976). Karyotype studies of crosses and studies of flavonoid patterns separate E. indica from finger millet whereas subsp. africana displayed a very high affinity to the cultivated form (Hilu et al., 1978).

Two main cultivars of finger millet are recognized: an African highland race and an Afro-Asiatic lowland race (Purseglove, 1976). Hilu and de Wet (1976a) proposed that the highland race was derived from E. africana under cultivation and that this race then gave rise to the African lowland race which was later introduced into India. It is now recognized that finger millet originated in the East African highlands and a recent archaeological finding of finger millet from Ethiopia dated at about the third millenium BC (Hilu et al. 1979) supports this. The crop spread southwards and was cultivated as far south as South Africa.

Genepool and sampling

Both the wild progenitor (E. africana) and the cultivated E. corocana (now regarded as E. corocana subsp. africana and subsp. corocana respectively) require collection. In 1971 it was thought that the only adequate collections were from India and Uganda (Table 1). Material collected since 1975 is listed in Table 6.

The weedy and wild forms have all been restricted to the closely related annual subspecies. Virtually none of the secondary genepool (E. indica, E. floccifolia and E. tristachya) have been collected. Nor have the species of the tertiary genepool (E. intermedia, E. jaegeri, E. kigeziensis, E. multiflora, E. semisterilis or E. compressa).

Of the priorities identified in 1981 there has been no action to collect in Somalia, Sudan, Uganda and insufficient work done in China, Ethiopia, Nepal and Sri Lanka.

Extant collections are listed in Appendix V. Over a thousand samples are held by ICRISAT in the world collection.

FOXTAIL MILLET

Foxtail millet [Setaria italica (L.) Beauv.], is cultivated in both the Old and New World for hay, pasture and as a cereal. It is important in India, China and Japan. It

Table 6. Finger millet collections (1975-82)

Country	Cultivated	Weedy	Wild
Bhutan	14	-	-
Burundi	-	-	3
Ethiopia	9	-	-
India	228	-	-
Kenya	252	5	6
Malawi	262	3	2
Mozambique	2	-	-
Nepal	2	-	-
Sri Lanka	31	-	-
Tanzania	36	-	-
Zambia	173	-	-
Zimbabwe	286	-	6
Totals	1,415	8	17

is grown in North and South America, Australia and parts of Africa as a minor cereal. Foxtail millet makes up 24% of all millets produced in the world (FAO, 1981). It can be grown in regions of low rainfall and can tolerate a wide range of soil conditions.

This crop was formerly more important in many of its areas of cultivation, especially in Asia and Europe.

Origin and variation

The earliest archaeological record of the crop is from Pan p'o and several other archaeological sites in China. Jars filled with foxtail millet were dated at 4115 to 3635 BC, indicating that it was grown in Shaanxi (Shensi) soon after 5000 BC (de Wet et al., 1979). Foxtail millet was also common in Swiss Lake Dwelling sites in Switzerland and Austria (Werth, 1937). Foxtail millets recovered at southern European sites have been dated to the third millenium BC.

Genome analysis indicates that S. italica has the same genome formula as the wild S. viridis (L.) Beauv. 2n = 18 AA (Zeven and de Wet, 1982). The tetraploid S. pallidifusca is believed to be an allotetraploid with S. italica as one of its parents. Thus foxtail millet was most probably derived from S. viridis in China and introduced throughout Asia and Europe in prehistoric times. S. italica is not known in the wild state except as a weed which has escaped cultivation. Germplasm exchange between Europe and Asia could have been taking place for at least two millenia and this has somewhat masked the evolutionary history of the crop in its European and Asiatic centres of variability.

A number of species other than S. italica are harvested locally: S. phacelata areas in the savannah region of Africa, S. pallidifuaca in Upper Volta, S. verticillata around the oasis of Bilma (de Wet et al., 1979); other species are harvested by Aborigines of Australia (Blumer, 1964) and in times of scarcity in India.

De Wet and co-workers recognized two races of foxtail millet on the basis of panicle morphology. Race moharia is characterized by small (4-15 cm long) erect or slightly nodding inflorescences with short (1-3 cm long) branches on which the spikelets are arranged in clusters. This race is important in Czechoslovakia, Hungary, southwestern USSR and Afghanistan. In Europe, moharia is grown as a feed for caged birds. Race maxima is characterized by large panicles up to 35 cm long and 8 cm wide that become pendulous at maturity. The clusters of spikelets on the secondary branches give the inflorescence a lobed appearance. Race maxima is variable and has been divided into three complexes (Gritzenko, 1960):

i) The Manchurian complex characterized by relatively short inflorescences that nod at maturity: in Manchuria, eastern USSR and northeastern China;

ii) The Mongolian complex is similar to the Manchurian complex but has larger grains and better yields;

iii) The Korean complex is characterized by robust plants with pendulous panicles with high yields.

All three complexes are grown in Transcaucasian USSR.

Primitive races of foxtail millet often resemble its close wild relative S. viridis (L.) Beauv. and in Afghanistan the two species grade morphologically except for the natural seed shedding of the wild form at maturity. S. viridis is a native of temperate Eurasia but has been widely introduced as a weed in all warm temperate regions of the world. S. viridis and S. italica cross to produce fertile hybrids and have therefore been regarded as subsp. of S. italica (Li, Pao & Li, 1942; de Wet et al., 1979).

Collections

Slightly less than 10,000 samples are present in collections (Appendix VI) especially in China and India. However, these are almost totally S. italica. The materials from China need to be duplicated in the ICRISAT collection.

Only 65 samples have been collected by ICRISAT or IBPGR since 1975: Nepal (3), Sri Lanka (16) and India (46). However, over 1,000 samples are held in the world collection at ICRISAT.

PROSO MILLET

Proso or common millet (Panicum miliaceum L.) which is not known in the wild state, is of ancient cultivation and is now grown mainly in central, southern and eastern Asia, including Afghanistan, northern China, the USSR (Kazakstan Republic), Mongolia, Japan and India. It is also grown in parts of the Mediterranean region, the Balkans, Caucasia and Turkey.

Panicum miliaceum has one of the lowest water requirements of any cereal and can be grown on the poorest soils.

Archaeological records from China suggest that the crop was domesticated in southern Shanxi (Shansi) province shortly after 5000 BC (Ho, 1975 quoted by de Wet et al., 1979). Proso millet remains, from Swiss Lake Dwelling sites in Switzerland and Austria and other European archaelogical sites indicate that the crop had become cultivated in Europe during the third millenium BC. Proso millet was more important as a cereal in China until the introduction of wheat and barley (Li, 1970).

There are several diploid and tetraploid Asian Panicum species but a progenitor of P. miliaceum is not known. P. spontaneum Lysev, a weedy type of the species is thought to be derived from P. miliaceum rather than a progenitor (Purseglove, 1972).

Small collections exist, largely in India (Appendix VI). No active field work has been carried out by the IBPGR to date. ICRISAT holds 715 samples.

LITTLE MILLET

Little millet (Panicum sumatrense) Roth ex Roem. & Schult. is grown throughout India and sporadically by hill tribes in Southeastern Asia as a minor cereal crop. Little millet has often been mistakenly called P. miliare Lam. It has potential as a quick growing fodder as some types are reported to mature in 45 days. Little millet will produce a crop even in famine years. Panicum sumatrense occurs wild in northern India and Southeastern Asia. It is a close relative of P. psilopodium Trin. and is thought to have evolved from it. Two hundred and forty-three samples are held in the world collection at ICRISAT.

BARNYARD MILLETS

Several Echinochloa species (x = 9) including E. frumentacea (Roxb.) Link, E. colona (L.) Link, E. crusgalli (L.) Beauv., E. oryzicola Vasing and E. utilis Ohwi and Yabuno are cultivated as fodder and cereals in Asia, including China, the Koreas, Japan, the USSR and India. Some are also grown in the USA, and in the Central African Republic.

In Asia the grains of Echinochloa millets are eaten in times of scarcity and are consumed mostly by the poorer classes. In China and Japan they are used as a substitute for rice when the paddy fails. The young shoots of Echinochloa species are used as vegetables in Java.

The Echinochloa species are the quickest growing of all millets; some species can produce a crop in about six weeks.

The barnyard millets are believed to have all been domesticated in Asia, E. frumentacea in China, E. colona in India and E. crusgalli in Japan.

There are collections of E. frumentacea in India, of E. crusgalli in India (and a small collection in Japan) and a small collection of E. utilis in Japan (Appendix VI). Materials have not actively been collected by the IBPGR. ICRISAT holds 380 samples of Echinochloa species in the world collection.

KODO MILLET

Kodo millet (Paspalum scrobiculatum L.) is widely distributed in moist habitats across the tropics and sub-tropics of the Old World. The species is known to have been grown in western India for at least 3,000 years (Vishnu-Mittre, 1977). In West Africa, varieties polystachyum and commersonii grow as weeds in rice fields and are commonly harvested as wild cereals. In parts of Guinea, they are under pseudo-cultivation (Portères, 1976). P. scrobiculatum is also grown in China, Japan and Australia.

A substantial collection is held in India but collections from other parts of the world have not been made (Appendix VI). The Committee did not see any urgent need for material to be collected outside India.

FONIO MILLETS

Fonio [Digitaria exilis (Kippist) Stapf] is grown as a cereal throughout the savannah zone of West Africa from Senegal to Cameroon and is a staple crop in parts of Guinea and Nigeria. It is grown widely in areas where the rainfall does not exceed 400 mm. Fonio is a cultigen unique to West Africa and is believed to have originated in the central Niger delta in Mali (Portères, 1976). It is considered to be one of the oldest indigenous West African cereals. Its greatest diversity is in the Fouta Djalon region of Guinea and Mali. Digitaria exilis resembles D. longiflora Pers. and may have been derived from D. barbinodis Herr (Zeven and Zhukovsky, 1975).

Black fonio (Digitaria iburua, Stapf) is cultivated in northern Nigeria and in the Atakora Mountains of Togo and Benin between altitudes of 400 m and 1,300 m. It is used as a cereal in Nigeria and Benin and for making beer in Togo. The closest wild species is D. barbinodis and it may have been derived from it (Zeven and Zhukovsky, 1975).

Since 1975 the IBPGR has collected D. exilis in Mali, Togo and Upper Volta. Virtually no other collections exist.

TEFF

Ethiopia is the only country that grows teff [Eragrostis tef (Zucc.) Trotter] as a cereal crop. It forms the basic diet and it accounts for more than half the yearly grain production. Teff is believed to have been domesticated in Ethiopia before recorded history. There are two main types: one with white seeds which is preferred for food and one with brown-seeds which produces superior hay. Teff is grown at altitudes of 1,700-2,800 m (brown teff is usually grown above 2,500 m).

As might be expected, the only collection is held by PGRC/E and 23 samples were collected in Ethiopia by PGRC/E and IBPGR in 1980-81.

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Subsection Halepensia	Sorghum bicolor subsp. halepense	Sorghum halepense	Sorghum halepense
Sorghum almum Parodi	-	S. halepense	S. halepense
S. controversum (Steud.) Snowden	Sorghum bicolor subsp halepense	S. halepense	S. halepense
S. halepense (L.) Pers.	subsp. halepense	S. halepense	S. halepense
S. miliaceum (Roxb.) Snowden	subsp. halepense	S. halepense	S. halepense
S. propinquum (Kunth) Hitchc.	subsp. halepense	S. bicolor subsp. arundinaceum race propinquum	S. propinquum
Subsection Arundinacea	S. bicolor subsp. bicolor	S. bicolor	S. bicolor
Series Spontanea	subsp. bicolor	S. bicolor subsp. arundinaceum	*S. bicolor subsp. arundinaceum
S. aethiopicum (Hack.) Rupr.	var. aethiopicum	race aethiopicum	subsp. arundinaceum
S. virgatum (Hack.) Stapf	var. aethiopicum	race virgatum	subsp. arundinaceum
S. lanceolatum Stapf	var. aethiopicum	race verticilliflorum	subsp. arundinaceum
S. arundinaceum (Desv.) Stapf	var. arundinaceum	race arundinaceum	subsp. arundinaceum
S. vogelianum (Piper) Stapf	var. arundinaceum	race arundinaceum	subsp. arundinaceum
S. brevicarinatum Snowden	var. verticilliflorum	race verticilliflorum	subsp. arundinaceum
S. castaneum Hubb et Snowden	var. verticilliflorum	race verticilliflorum	subsp. arundinaceum
S. macrochaeta Snowden	var. verticilliflorum	race verticilliflorum	subsp. arundinaceum
S. panicoides Stapf	var. verticilliflorum	race verticilliflorum	subsp. arundinaceum
S. pugionifolium Snowden	var. verticilliflorum	race verticilliflorum	subsp. arundinaceum
S. somaliense Snowden	var. verticilliflorum	race verticilliflorum	subsp. arundinaceum
S. usambarense Snowden	var. verticilliflorum	race verticilliflorum	subsp. arundinaceum
S. verticilliflorum (Steud.) Stapf	var. verticilliflorum	race verticilliflorum	subsp. arundinaceum
S. atterimum Stapf	weed-crop hybrid	race shattercane	S. bicolor subsp. drummondii
S. drummondii (Steud.) Milisp et Chase	weed-crop hybrid	race shattercane	subsp. drummondii
S. elliotii Stapf	weed-crop hybrid	race shattercane	subsp. drummondii
S. hewisonii (Piper) Longley	weed-crop hybrid	race shattercane	subsp drummondii
S. niloticum (Piper) Snowden	weed-crop hybrid	race shattercane	subsp. drummondii
S. nitens (Bussey et Pilger) Snowden	weed-crop hybrid	race shattercane	subsp. drummondii
S. sudanense (Piper) Stapf	weed-crop hybrid	race shattercane	S. bicolor subsp. drummondii
Series Sativa	S. bicolor subsp. bicolor var. bicolor	S. bicolor subsp. bicolor	S. bicolor ssp. bicolor
S. bicolor (L.) Moench.	race bicolor	race bicolor	race bicolor
S. dochna (Forrsk.) Snowden	race bicolor	race bicolor	race bicolor
S. nervosum Schult. (pro parte)	race bicolor	race bicolor	race bicolor
S. nervosum (pro parte)	race bicolor	race caudatum-bicolor	-
S. nervosum (pro parte)	race bicolor	race kafir-bicolor	race kafir-bicolor
S. splendidum (Hack.) Snowden	race bicolor	race bicolor	race bicolor
S. exertum Snowden	race guinea	race bicolor	race bicolor
S. caudatum Stapf (pro parte)	race kafir	race caudatum	race caudatum
S. caudatum		race durra-caudatum	
S. caudatum		race guinea caudatum	
S. nigricans (R. et P.) Snowden (pro parte)	race kafir	race caudatum	race caudatum
S. nigricans	race kafir	race kafir-caudatum	race kafir-caudatum
S. cernum Host.	race durra	race durra	race durra

* Sorghum bicolor subsp. arundinaceum will probably cease and be changed to subsp. verticilliflorus (Steud.) Piper (de Wet pers. com.)

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APPENDIX I (Continued)

Snowden 1936	de Wet & Huckabay 1967	Harlan & de Wet 1972	de Wet 1978
S. durra Stapf	race durra	race durra	race durra
S. conspicuum Snowden	race guinea	race guinea	race guinea
S. gambicum Snowden	race guinea	race guinea	race guinea
S. guineense Stapf	race guinea	race guinea	race guinea
S. margaritiferum Stapf	race guinea	race guinea	race guinea
S. caffrorum Beauv.	race kafir	race kafir	race kafir
S. coriaceum Snowden	race kafir	race kafir	race kafir
S. notabile Snowden (pro parte)	race bicolor	race caudatum-bicolor	race guinea-caudatum
S. notabile Snowden (pro parte)	race bicolor	race guinea-caudatum	-
S. ankolib Stapf	race bicolor	race durra-bicolor	race durra-bicolor
S. rigidum Snowden	race durra	race durra-bicolor	race durra-bicolor
S. subglabrescens Schweinf. et Ascherson	race durra	race durra-bicolor	race durra-bicolor
S. dulcicaule Snowden	race kafir	race guinea-caudatum	race guinea-caudatum
S. elegans (Koern.) Snowden (pro parte)	race bicolor	race guinea-caudatum	race guinea-caudatum
S. elegans	race bicolor	race kafir-bicolor	race kafir-bicolor
-	-	race guinea-durra	race guinea-durra
S. roxburghii Stapf	race guinea	race guinea-kafir	race guinea-kafir
S. melaleucum Stapf	race bicolor	race guinea-bicolor	race guinea-bicolor
S. mellitum Snowden	race guinea	race guinea-bicolor	race guinea-bicolor
S. basutorum Stapf (pro parte)	race bicolor	race kafir-bicolor	race kafir-bicolor
S. milliforme (Hack.) Snowden (proparte)	race bicolor	race kafir-bicolor	race kafir-bicolor
S. simulans Snowden	race bicolor	race kafir-bicolor	race kafir-bicolor
-	-	race kafir-durra	-
S. membranaceum Chiov.	race bicolor	races with large-glumes	-

Country	Duplicates at	No. of Samples		Types of Material	Storage	Country of Origin
		Sorghum Bicolor	Sorghum spp.			
Algeria	Bari, Italy	35	-	Landraces	Active collection	Algeria
Argentina	-	2,700	-	-	Active collection	Unspecified
Australia	-	1,000	-	-	Active collection	Unspecified
Brazil	-	+	-	-	Active collection	Unspecified
China	-	3,000	-	Landraces + introductions	Active collection	China and introductions
Colombia	-	912	-	Cultivars	Medium-term	Unspecified
Ethiopia	-	5,000 +	-	+ Landraces and cultivars	Long and medium-term	Ethiopia,
France (ORSTOM)	ICRISAT	2,626	-	Landraces, wild and weedy cultivars	Medium-term	Benin, Mali, Niger, Nigeria, Senegal and Togo
France (INRA)	-	400	-	Cultivars	Unspecified	Unspecified
German Dem. Rep.	-	25 (includes S. almum)	+ (S. almum)	Cultivated and wild	Long and medium-term	China & other countries
Germany, Fed. Rep.	-	170	-	Landraces and cultivars	Long and medium-term	Mostly A.R. Yemen
Ghana	-	160 +	-	Unspecified	Active collection	Unspecified
Hungary	-	82	-	Cultivated and wild	Long and medium-term	Various countries of Europe, Asia, Africa & Australia
India (AICSIP)	ICRISAT & other stations	+	-	Unspecified	Active collection	World wide
India (NBPGR)	-	2,000 +	-	Landraces	Active collection	World wide
India (ICRISAT)		21,264	18 (S.halepense)	" cultivars wild and weedy	Medium-term	World collection
Iraq	-	+	-	Landraces, unspecified	Medium-term	Iraq

APPENDIX II
(Continued)

Country	Duplicates at	No. of Samples		Types of material	Storage	Country of Origin
		Surghum bicolor	Sorghum spp.			
Italy	Algeria, Tunisia, Spain	50	-	Landraces and cultivars	Long and medium-term	Algeria, Tunisia & Spain
Japan	PGI, Japan	466	-	Landraces and cultivars	Long and medium-term	Unspecified
Kenya	-	+	-	Landraces, wild and weedy	Medium-term	Kenya, Uganda and introductions
Madagascar	-	300	-	Unspecifed	Active collection	Unspecified
Malawi	ICRISAT, NSSL	483 +	-	Landraces and wild	Medium-term	Malawi
Mexico	-	3,000	-	Cultivars	Medium-term	Unspecified
Pakistan (ARC)	-	+	-	Unspecified	Medium-term	Pakistan and introductions
Pakistan (NSP)	-	174	-	Unspecified	Active collection	Pakistan
Romania	-	4,900	-	Landraces, wild and weedy	Active collection	Unspecified
Somalia	ICRISAT	94	-	Landraces	Active collection	Somalia
South Africa	South Africa	170	-	Landraces and cultivars	Long-term	World wide
Spain	Bari, Italy; VIR, USSR	+	-	Cultivars	Long and medium term	Unspecified
Sri Lanka	ICRISAT	28	-	Landraces	Active collection	Sri Lanka
Syria	-	21	-	Landraces	Active and medium-term	Syria
Thailand	-	1,500	-	Unspecified	Active collection	Unspecified
USSR (VIR)	-	9,615	-	Landraces, cultivars and wild types	Long and medium-term	Unspecified
USA (NSSL)	ICRISAT	15,000	-	Landraces, cultivars and wild types	Long-term	World wide
USA (SRPIS)	ICRISAT, NSSL	3,610	-	Landraces, cultivars, wild types and hybrids	Medium-term	World wide
USA (SCFS)	-	4,610	-	Lines	Active collection	World wide

Country	Duplicates at	No. of Samples		Type of material	Storage	Country of Origin
		Sorghum bicolor	*Sorghum* spp.			
USA (USDA)	-	4,000 +	-	Landraces and cultivars	Active collection	World wide
Venezuela	-	494	-	Landraces and cultiavrs	Active and medium-term	Venezuela and introductions
Yemen, AR	-	4,000	-	Landraces and cultivars	Active collection	Yemen and introductions
Yemen, PDR	-	+	-	Landraces	Active collection	PDR Yemen
Zambia	Zambia University, NSSL	292	-	Landraces and introduced cultivars	Active collection and medium-term	Zambia and introductions

SOME TAXONOMIC TREATMENTS OF GENUS PENNISETUM

APPENDIX III

(1) Stapf & Hubbard 1934	Clayton 1972*	Brunken 1977
Section Penicillaria		**Section Pennisetum**
Pennisetum purpureum Schum.	Pennisetum purpureum	Pennisetum purpureum
P. albicauda Stapf & Hubb.	-	Pennisetum americanum subsp. americanum
P. ancylochaete Stapf & Hubb.	P. americanum	subsp. americanum
P. cinereum Stapf & Hubb.	P. americanum	subsp. americanum
P. echinurus Stapf & Hubb.	-	subsp. americanum
P. gambiense Stapf & Hubb.	P. americanum	subsp. americanum
P. gibberum Stapf & Hubb.	P. americanum	subsp. americanum
P. leonis Stapf & Hubb.	P. americanum	subsp. americanum
P. maiya Stapf & Hubb.	P. americanum	subsp. americanum
P. malacochaete Stapf & Hubb.	-	subsp. americanum
P. nigritarum Durrand & Schinz	P. americanum	subsp. americanum
P. pycnostachyum Stapf & Hubb.	P. americanum	subsp. americanum
P. spicatum Koern	P. -	subsp. americanum
P. typhoides Stapf & Hubb.	P. americanum	subsp. americanum
P. darfuricum Stapf & Hubb.	P. violaceum	P. americanum subsp. monodii
P. fallax Stapf & Hubb.	P. fallax	subsp. monodii
P. mollissimum Hochst.	P. violaceum	subsp. monodii
P. ochrops Stapf & Hubb.	P. fallax	subsp. monodii
P. rogeri Stapf & Hubb.	P. violaceum	subsp. monodii
P. violaceum Rich.	P. violaceum	subsp. monodii
P. barteri Stapf & Hubb.	P. violaceum	P. americanum subsp. stenostachyum
P. chevalieri Stapf & Hubb.	-	subsp. stenostachyum
P. dalzielii Stapf & Hubb.	P. dalzielii	subsp. stenostachyum
P. gymnotrix Schum.	-	subsp. stenostachyum
P. hilotricum Stapf & Hubb.	P. stenostachyum	subsp. stenostachyum
P. orthochaete Stapf & Hubb.	-	subsp. stenostachyum
P. perrottetii Schum.		subsp. stenostachyum
P. perspectosum Stapf & Hubb.		subsp. stenostachyum
P. robustum Stapf & Hubb.		subsp. stenostachyum
P. sampsonii Stapf & Hubb.	P. stenostachyum	subsp. stenostachyum
P. sclerocladum Stapf & Hubb.	P. stenostachyum	subsp. stenostachyum
P. steberianum Stapf & Hubb.		subsp. stenostachyum
P. stenostachyum Stapf & Hubb.		subsp. stenostachyum
P. vulpinum Stapf & Hubb.		stenostachyum
Section Heterostachya		
P. proximum Leeke		
P. schweinfurthii Pilger		
P. squamulatum Fresen		
Section Brevivalvula		
P. atrichum Stapf & Hubb.	P. atrichum	
P. hordeoides Steud.	P. hordeoides	
P. pedicellatum Trin.	P. pedicellatum	
P. polystachyon Schult.	P. polystachyon	
P. subangustum Stapf & Hubb.	P. subangustum	
Section Gymnothrix		
subsection Pleurostigma		
Pennisetum beckeroides Leeke		
P. glaucifolium Rich.		
P. laxum (Engl.) Leeke		
P. trachyphyllum Pilger	P. trachyphyllum	
P. trisetum Leeke		
subsection Acrostigma		
P. adoense Steud.		
P. angolense Rendle		
P. catabasis Stapf & Hubb.		
P. devyi Stapf & Hubb.		
P. dichotomum Delile		
P. dowsonii Stapf & Hubb.		
P. exile Stapf & Hubb.		
P. franchatianum Stapf & Hubb.		
P. giganteum Rich.	P. giganteum	

* Include West African pennisetums only.

APPENDIX III

Stapf & Hubbard 1934	Clayton 1972*	Brunken 1977
subsection Agnostigma (cont'd.)		
P. glabrum Steud.	*P. glabrum*	
P. glaucocladum Stapf & Hubb.		
P. gossweileri Stapf & Hubb.		
P. glandiflorum Stapf & Hubb.		
P. haereri Stapf & Hubb.		
P. humile Rich.		
P. lendemanii Mez		
P. macropogon Stapf & Hubb.		
P. massaicum Stapf		
P. mezianum Leeke		
P. mildbraedii Mez		
P. monostigma Pilger	*P. monostigma*	
P. nodiflorum Franch.		
P. pumilum Engl.		
P. quartinianum Rich.		
P. ramosum Schweinf.	*P. ramosum*	
P. riparium Rich.		
P. riparoides Rich.		
P. salifex Edwards		
P. schimperi Rich.		
P. stamineum Peter		
P. stenorrhachis Stapf & Hubb.		
P. stotzii Mez		
P. thunbergii Kunth.		
P. togoense Mez	*P. giganteum*	
P. uliginosum Hack		
P. validum Mez		
Section Eu-Pennisetum		
P. clandestinum Chiov.	*P. clandestinum*	
P. erythraeum Chiov.		
P. foermecianum Leeke		
P. gracilescens Hochst.		
P. longistylum Rich.		
P. pappianum Chiov.		
P. setaceum Chiov.		
P. villosum (Salt) Fresen.	*P. setaceum*	

COLLECTIONS OF PEARL MILLET GERMPLASM

Country	Duplicates at	No. of Samples		Types of Material	Storage	Country of Origin
		Pennisetum americanum	*Pennisetum* spp.			
Canada	ICRISAT	500	-	Landraces, wild and weedy	Long-term	Botswana, Kenya, Malawi, Nigeria, Yemen, (AR) and Zambia
Ethiopia	-	?	+	Landraces	Long and medium-term	Ethiopia
France (ORSTOM)	ICRISAT	2,100	-	Landraces, wild and weedy	Medium-term	Benin, Cameroon, Central African Republic, Mali, Niger, Nigeria, Senegal, Togo, Upper Volta
India (ICRISAT)	Various places	14,340	+	Landraces, cultivars and lines	Medium-term	World collection
Italy	Tunisia	32	-	Landraces	Long and medium-term	Tunisia
Malawi	ICRISAT, PGRC/E	291	-	Landraces, wild and weedy	Medium-term	Malawi
Pakistan	-	36	-	Lines	Active collection	Pakistan
Poland		?	?	Landraces and wild	Active collection	Unspecified
Tunisia	Bari, Italy	32	-	Landraces	Active collection	Tunisia
USSR	-	+ (13,892 millets)	-	Landraces, cultivars, wild and weedy	Long and medium-term	World-wide
USA (CPS)	-	+	-	Landraces, cultivars, wild and weedy	Medium-term	Africa and Asia
USA (NSSL)	-	+	-	Landraces, cultivated, wild and weedy	Long-term	Unspecified
USA (SRPIS)	-	+	-	Unspecified	Long-term	Unspecified
Zambia	ICRISAT, PGRC/E, NSSL	24	-	Landraces	Active collection and medium-term	Zambia

COLLECTIONS OF FINGER MILLET

APPENDIX V

Country	Duplicates at	*Eleusine coracana*	*Eleusine* spp.	Type of Material	Type of Storage	Country of Origin
Czechoslovakia	-	+	+ (*E. indica*)	Unspecified	Long & medium-term	Czechoslovakia & other countries
Ethiopia	-	3+	+	Landraces	Long & medium-term	Ethiopia
German, D.R.	-	+ (264 minor millets)	-	Landraces, cultivars Wild and weedy	Long & medium-term	Unspecified
India (NBPGR)	-	+	+ (*E. indica*)	Unspecified	Active collection	Unspecified
India (ICRISAT)	Various places	1,241	106 (*E. indica*)	Landraces, cultivars wild and weedy	Medium-term	World collection
India (AICMIP) Maharashtra	Other centres in India	2,944	-	Unspecified	Active collection	Africa, China, USSR, India and other countries of South Asia
India (AICMIP) Bangalore		2,960	-	Unspecified	Unspecified	Africa, China, USSR, Sri Lanka
Japan (NIAS)	Japan PGI	31	-	Landraces	Long & medium-term	Japan, China, Korea, USSR, Bhutan, India, Nepal, Sri Lanka
Japan (PGI)	Japan NIAS	58	-	Landraces	Active collection, Medium-term	Unspecified
Kenya	ICRISAT, NSSL	252	11	Landraces, wild and weedy	?	Kenya
Malawi	ICRISAT, NBPGR, PGRC	277	12 (*E. indica*)	Landraces, wild and weedy	Medium-term	Malawi
Nepal	ICRISAT	2	-	Landraces	?	Nepal
Sri Lanka	ICRISAT	31	-	Unspecified	Active collection	Sri Lanka
USSR	-	+	-	Landraces, cultivars	Long & medium-term	World wide
USA (NSSL)	-	ca. 700	-	Landraces, cultivars, wild and weedy	Long-term	Unspecified
USA (SWPIS)	-	43	4 (*E. indica*)	Unspecified	Medium-term	World wide
Zambia	PGRC	173	-	Landraces	Medium-term Active collection	Zambia

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COLLECTION OF MINOR MILLETS

APPENDIX VI

ORIGIN / TAXON	*Setaria italica*	*S. viridis*	*Setaria* spp.	*Panicum miliaceum*	*P. miliare*	*Panicum* spp.	*Echinochloa frumentacea*	*E. crusgalli*	*E. colona*	*E. utilis*	*Echinochloa* spp.	*Paspalum scrobiculatum*	*P. commensonii*	*Paspalum* spp.	*Digitaria exilis*	*D. iburua*	*Eragrostis tef*	Total
Country																		
Afghanistan						18												18
China	3,206			+														3,226+
Czechoslovakia	+	+		+			+											+
Ethiopia																	+	+
France (ORSTOM)															215			215
German Dem. Rep.	+	+		+		+	+	+	+									+
Hungary	2			53				2										57
India (NBPGR)	+					+					+			+				+
India (AICMIP) (Maharashtra)	3,588			552	218		583					1,405						6,346
India (AICMIP) (Bangalore)	1,429			552	242		199					842						3,264
India (ICRISAT)	1,160			715	243			380				300						2,798
Japan (NIAS)	182			21				50										253
Japan (PGI)	274			62						65								401
Malawi			6				9							2				17
Nepal	3			8														11
Poland																		?
Sri Lanka				4								2						6
Tanzania																		?
Togo															62			62
USSR	+			+			+	+										+
USA (SRPIS)	16			8			2	22	5			12	4		1	1		72
Upper Volta		1													21			21
TOTAL*	9,880	1+	6	1,975	703	18+	793	454	5+	65	+	2,561	4	2+	299	1	+	16,[illegible]67

* Totals include replicates

\+ Information on the number of samples not available

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APPENDIX VII

ACRONYMS

AICMIP	-	All-India Coordinated Millets Improvement Project (India)
AICSIP	-	All-India Coordinated Sorghum Improvement Project (India)
CGIAR	-	Consultative Group on International Agricultural Research
CPS	-	Coastal Plain Station (Georgia, USA)
FAO	-	Food and Agriculture Organization of the United Nations
IBPGR	-	International Board for Plant Genetic Resources
ICAR	-	Indian Council of Agricultural Research
ICRISAT	-	International Crops Research Institute for the Semi-Arid Tropics (India)
INRA	-	Institut national de la recherche agronomique (France)
NBPGR	-	National Bureau of Plant Genetic Resources (India)
NIAS	-	National Institute of Agricultural Sciences (Japan)
NSSL	-	National Seed Storage Laboratory (USA)
ORSTOM	-	Office de la recherche scientifique et technique outre mer (France)
PGI	-	Plant Germplasm Institute (Japan)
PGR	-	Plant Gene Resources (Canada)
PGRC/E	-	Plant Genetic Resources Centre (Ethiopia)
SRPIS	-	Southern Regional Plant Introduction Station (Georgia, USA)
UNEP	-	United Nations Environment Programme
USDA	-	United States Department of Agriculture
VIR	-	N.I. Vavilov Institute of Plant Industry (USSR)

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