Finger millet blast management in East Africa

Creating Opportunities for Improving Production and Utilisation of Finger millet

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Genetic Resources Diversity of Finger Millet – a Global Perspective

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Abstract

Finger millet is a traditional grain cereal in Africa and South Asia. The crop has a wide range of adaptation, can withstand adverse soil and weather conditions, and is grown at altitudes from sea level to about 2,400 m. The grain yield potential is good, and the grain is highly nutritious, particularly rich in methionine, iron and calcium. However, finger millet has been neglected by mainstream research. One way to boost production and productivity and enhance acceptability is to assemble diverse germplasm resources, characterise them to identify traits of agronomic importance, and use them to breed superior varieties. ICRISAT's genebank in Patancheru, India, holds 5,949 germplasm accessions from 23 countries. Of the six races of finger millet, *Vulgaris* is the most predominant (61% of the total collections). The accessions have been characterised for five qualitative and 14 quantitative traits. The quantitative data show that the race *Africana* is more distinct than other races, and had the highest means for 10 out of 14 traits measured. To overcome the problems of managing a large collection and to enhance the use of germplasm in crop improvement, ICRISAT has developed a core collection containing 622 accessions (10% of the entire collection) based on geographical origin and quantitative traits. The core collection was evaluated in 2004 and a further mini-core collection (10% of the core or 1% of the entire collection) was constituted, with 65 accessions. In addition, a composite set of germplasm comprising 1,000 accessions has been developed under the Generation Challenge Program. This set is being characterised; microsatellite markers will be used to access the genes for beneficial traits.

Introduction

Finger millet [*Eleusine coracana* (L.) Gaertn.] is a traditional grain cereal cultivated in Africa and South Asia. The crop has a wide range of adaptation. It is cultivated from sea level in parts of Andhra Pradesh and Tamil Nadu in India to about 2,400 meters above sea level in hilly areas in northern India;

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and similarly at high altitudes in Nepal, Uganda, Kenya and Ethiopia. Its requirements for soil, water and climate are similar to upland paddy; but it can survive adverse soil and weather conditions better than most other food-grain crops. The reported grain yield potential is high, for example, 4,265 kg ha^{-1} in Uganda (Odelle 1993), 6,060 kg ha^{-1} in Zimbabwe (Mushonga et al. 1993), 3,700 kg ha^{-1} in Ethiopia (Mulatu and Kebebe 1993), and 4,789 kg ha^{-1} in India (Bondale 1993). The grain is highly nutritious. Protein content is about 7.4%, which is comparable to rice. Calcium content in whole seed is 0.34% compared to 0.01-0.06% in most cereals (Kurien et al. 1959). Iron content is also exceptionally high, 46 mg kg^{-1} (Serna-Saldivar and Rooney 1995), much higher than wheat or rice.

Precise data on area under finger millet are not available, because it is frequently reported with other millets including pearl millet (as in the FAO database). However, the Consultative Group on International Agricultural Research (CGIAR) assumes that of the total global millet area of 34.6 million ha (FAO 2004), 10% is finger millet. Information is available for some countries, for example, 1.68 million ha in India in 2001-02 (CMIE 2004). Other countries with large finger millet areas are China, Democratic Republic of Congo, Ethiopia, Eritrea, Kenya, Myanmar, Nepal, Uganda, Tanzania and Rwanda.

The ICRISAT genebank at Patancheru, India, holds 5,949 finger millet accessions from 23 countries. This paper describes how this collection was established, and strategies to enhance its use in crop improvement.

Assembly of finger millet germplasm

As finger millet is an important food crop, national research programs in several countries have assembled germplasm collections, for example, 4,490 accessions in India (Seetharam 1989), 778 in Nepal (Sherchan and Baniya 1993) and over 2,000 in Uganda (Odelle 1983), where finger millet is the number one cereal crop. ICRISAT began assembling germplasm in 1976. The collection now holds 5,949 accessions, of which 4,077 were received through donations and 1,872 were collected accessions. The germplasm collection represents 23 countries (Table 1).

Table 1. Finger millet germplasm accessions in the genebank at ICRISAT, Patancheru, India, Aug 2005.

Country	No. of accessions	Country	No. of accessions
Burundi	15 (0.25)*	Pakistan	1 (0.02)
Cameroon	8 (0.13)	Senegal	5 (0.08)
Ethiopia	31 (0.52)	South Africa	1 (0.02)
Germany	1 (0.02)	Sri Lanka	18 (0.30)
India	1365 (22.95)	Tanzania	42 (0.71)
Italy	7 (0.12)	Uganda	959 (16.12)
Kenya	946 (15.90)	UK	14 (0.24)
Malawi	252 (4.24)	USA	7 (0.12)
Maldives	4 (0.07)	Zaire	2 (0.03)
Mozambique	1 (0.02)	Zambia	136 (2.29)
Nepal	780 (13.11)	Zimbabwe	1154 (19.40)
Nigeria	19 (0.32)	Unknown	181 (3.04)
		Total	5949 (100)

* Figures in parentheses show accessions as a percentage of the entire collection

The genepool of finger millet germplasm consists of four cultivated races (*Compacta, Elongata, Plana and Vulgaris*) and two wild races (*Africana* and *Spontanea*). Race Vulgaris is most prevalent in the collection (61%) followed by race *Plana* (17%), *Compacta* (11%), *Elongata* (9%), *Spontanea* (2%), and *Africana* (<1%). The collection includes 136 better yielding selections from the landraces, 50 breeding lines, 5,658 landraces, and 105 wild accessions. Seeds are conserved in medium-term storage (4^0C, 30%RH, in airtight aluminum containers) and long-term-storage (-20^0C, in vacuumized aluminum foil). Seed viability is monitored at regular intervals, and the collection is safe and secure (Table 2). Accessions showing low germination are regenerated and the old seeds replaced with fresh, healthy seeds.

Table 2. Germination rates of finger millet germplasm conserved in the genebank at ICRISAT Patancheru, Aug 2005.

Germination %	No. of accessions
<75%	59
75-80%	36
81-85%	81
86-90%	202
91-95%	853
> 95%	3779
Accessions tested	5010

Characterization of germplasm resources

To facilitate its utilization by plant breeders, germplasm must be characterized for qualitative and quantitative traits of agronomic importance. Characterization should be done in standard and commonly understood language so that researchers in different institutes and countries can use this information easily and effectively. An expert committee sponsored by the then International Board for Plant Genetic Resources (IBPGR) formulated a list of Descriptors for Finger Millet (IBPGR 1985). This includes 30 passport data, 45 morphological data, and resistance to 32 stress factors (5 abiotic, 27 biotic) for describing finger millet germplasm accessions.

ICRISAT's large collection could not be characterized completely in one year. Accessions were therefore characterized in batches over the years at the ICRISAT research farm at Patancheru, India, during the rainy seasons. The site is located at 18^0N, 78^0E, altitude of 545 m, about 600 km inland. Annual rainfall is about 750 mm, most of which occurs between June and September. During the finger millet crop season, July to October, temperatures are 28-32^0C maximum and 20-22^0C minimum. Germplasm accessions were sown on red soil (alfisols) fields (pH about 7.0) on ridges, spacing 60x10 cm. Each accession was a single row of 4 m length. Basal fertilizer of 18 kg N and 46 kg P, and top dressing of 46 kg N ha^{-1} were applied. Sowing was in July every year using an augmented block design, with blocks of 30 plots that included 27 test accessions and three check cultivars; the latter were sown after each set of nine test accessions. The crop was protected from weeds and irrigated if needed. Data were recorded on five qualitative traits (description in discrete classes) and 14 quantitative traits (continuous variation) following the Descriptors of

Finger Millet (IBPGR 1985). Qualitative traits (plant pigmentation, growth habit, inflorescence compactness, lodging, overall plant aspect) and two quantitative traits (days to flowering, grain yield) were recorded on a plot basis. Number of basal tillers was measured from five representative plants per plot. The remaining 12 quantitative traits (plant height, number of culm branches, flag leaf blade length, flag leaf blade width, flag leaf sheath length, peduncle length, panicle exsertion, inflorescence length, inflorescence width, longest finger length, longest finger width and number of panicle branches) were measured on main culms of the five representative plants per plot. During field evaluation, accessions were also classified into six botanical races (*Africana*, *Spontanea*, *Compacta*, *Elongata*, *Plana* and *Vulgaris*) following Prasada Rao et al. (1993).

Qualitative traits. Three plant colors were found: green is most common, followed by purple, and violet plant color was of rare occurrence. Of the three growth habit classes, erect was predominant, followed by decumbent trait; prostrate growth habit was of rare occurrence. Grain color was recorded in four classes; dark brown, light brown, reddish brown and white. Light brown was most common, followed by reddish brown, dark brown and white. Lodging occurs in finger millet and there were differences between accessions. The proportion of accessions with no lodging, slight lodging or medium lodging was similar in all races. In about 3% of accessions, plant foliage remained fully green until grain maturity – a valuable trait if the crop is to be used for fodder. The trends in plant color, grain color, and distribution of accessions among different growth habits, lodging, and frequency of the staygreen trait, was similar in all races.

Spike shape and compactness was recorded in eight classes: compact, fisty, incurved, top-curved, short-open, long-open, pendulous and lax. In the entire collection, a large number of accessions had incurved spike, followed by top-curved. The remaining six spike types occurred less frequently. The formation of races is based primarily on spike type.

- Race *Compacta* – high proportion of fisty, compact, and incurved spikes
- Race *Elongata* – high proportion of long-open, pendulous and top-curved spikes
- Race *Plana* – mostly top-curved spikes
- Races *Spontanea* and *Vulgaris* – incurved or top-curved spikes.

Glume status is the distinguishing trait between cultivated and wild races.

The two wild races (*Africana* and *Spontanea*) had mostly prominent glume, while all three classes – prominent, non-prominent, medium – were found in cultivated races.

Quantitative traits. The mean of quantitative traits calculated across races indicated that *Africana* was more distinct compared to other races. It also had the highest means for all traits except days to flowering, flag leaf blade length and width, and width of longest finger (Table 3). The latter two parameters were highest in race *Plana*. *Compacta* had lowest means for eight out of the 14 quantitative traits estimated. In general, *Vulgaris* was the earliest to flower (short crop duration) and *Elongata* flowered last (longer crop duration).

Table 3. Means of quantitative traits in finger millet germplasm of different races, ICRISAT Patancheru.

	Entire collection	Africana	Compacta	Elongata	Plana	Spontanea	Vulgaris
Days to flowering	80.41	63.17	80.59	83.69	81.02	80.15	79.78
Plant height (cm)	100.66	115.00	100.37	101.44	107.50	96.68	98.80
No. of basal tillers	5.19	18.17	4.46	5.71	4.73	9.21	5.24
No. of culm branches	2.30	3.67	2.13	2.43	2.10	2.23	2.36
Flag leaf blade length (mm)	358.10	303.33	364.91	348.62	384.19	308.32	352.46
Flag leaf blade width (mm)	12.65	7.67	13.11	12.54	13.20	12.68	12.44
Flag leaf sheath length (mm)	102.53	143.33	98.88	104.92	99.91	111.82	103.26
Peduncle length (mm)	215.45	368.33	208.10	218.13	215.03	236.68	215.69
Panicle exsertion (mm)	113.47	183.33	111.84	113.14	112.95	124.49	113.52
Inflorescence length (mm)	93.12	181.67	82.60	116.86	104.86	95.75	88.29
Inflorescence width (mm)	78.41	112.33	69.04	105.56	83.03	96.45	74.50
Longest finger length (mm)	72.63	146.67	64.28	92.93	82.02	80.37	68.39
Longest finger width (mm)	11.58	2.83	11.96	11.07	12.06	9.46	11.52
Panicle branches number	7.74	10.67	7.67	8.00	7.56	7.79	7.76

Cluster analysis of races was performed on the first two principal components (95% variation). Three clusters were found. *Africana* was most distinct compared to the other races and formed its own cluster. *Spontanea* and Elongata formed a second cluster; *Plana*, *Compacta* and *Vulgaris* shared some similarities and formed the third cluster (Figure 1).

Developing a core collection for finger millet

Frequently, basic germplasm accessions are not adequately utilized in crop improvement. One of the main reasons is the large number of collections, and inability to evaluate a large number of accessions in replicated multi-locational trials, to identify traits of agronomic importance for utilization in breeding programs. The ICRISAT genebank at Patancheru holds 5,949 finger millet accessions – replicated multi-locational evaluations of this entire collection would be costly. To overcome this problem, Frankel (1984) proposed sampling of the collection to form a 'core collection' of manageable size. A core collection contains a subset of accessions from the entire collection but captures most of the diversity in the larger collection (Brown 1989). We have developed a core collection of 622 finger millet germplasm accessions, based on origin and data on 14 quantitative traits (Upadhyaya et al. 2006). Comparisons of means, variances, frequency distribution, Shannon diversity index (H`) and phenotypic correlations indicated that the core collection represented >85% diversity of the entire collection (Upadhyaya et al. 2006).

Identifying useful accessions from the core collection. The core collection was evaluated in an augmented design using three control cultivars during the 2004 rainy season. Genotypic variance was significant for 12 of the 15 quantitative traits. Genotypic variance was non-significant for number of basal tillers, culm branching, and flag leaf sheath length (Table 4). We identified five accessions (IEs 2288, 3280, 3952, 5066, 5179) for high grain yield (2.06-2.15 t ha^{-1} vs 2.08 t ha^{-1} for control cultivar), five accessions (IEs 501, 2322, 2957, 4759, 6013) for early flowering (49-52 days vs 68 days for control), and five accessions (IEs 2039, 4443, 4476, 4709, 6890) for high basal tillers (4.3-4.7 vs 4.2 tillers in control).

Table 4. Genotypic variance and heritability in finger millet core collection at ICRISAT Patancheru, 2004 rainy season.

	Genotype		Race				
	Variance	se	Wald statics	df	wald/df	x^2 probability	h^2
Days to flowering	64.41	4.11	49.94	5	9.99	<0.001	99.59
Plant height (cm)	242.72	20.17	61.91	5	12.38	<0.001	98.98
No. of basal tillers	0.06	0.06	116.25	5	23.25	<0.001	69.64
Culm branching	0.00	0.03	54.15	5	10.83	<0.001	0.24
Flag leaf blade length (mm)	1717.00	518.00	18.42	5	3.68	0.002	93.26
Flag leaf blade width (mm)	2.46	0.31	38.23	5	7.65	<0.001	97.83
Peduncle length (mm)	1012.00	149.20	7.68	5	1.54	0.175	97.12
Exsertion (mm)	831.70	111.20	4.59	5	0.92	0.468	97.43
Inflorescence length (mm)	445.30	40.30	184.15	5	36.83	<0.001	98.69
Inflorescence width (mm)	155.15	21.20	82.51	5	16.50	<0.001	97.53
Length of longest finger (mm)	406.93	28.48	223.59	5	44.72	<0.001	99.40
Width of longest finger (mm)	7.95	0.71	37.36	5	7.47	<0.001	98.77
Panicle branch number	1.13	0.19	11.08	5	2.22	0.05	96.68
Yield (kg ha^{-1})	104578.00	32443.00	17.58	4	4.40	0.001	93.21

We identified 20 high-yielding accessions (relative to yield of the control cultivars PR 202 and Kalyani). Cluster analysis based on the first five principal components (69.5% variation) resulted in four clusters, indicating diversity of the selected accessions compared to the controls (Figure 2). This work will facilitate use of these accessions in breeding programs to develop high-yielding cultivars with a broad genetic base.

A mini-core collection. When the entire collection is very large, even a core collection becomes unwieldy for evaluation by breeders. To overcome this, ICRISAT developed a 'mini-core' collection, which consists of 10% of accessions from the core collection, ie, 1% of the entire collection

(Upadhyaya and Ortiz 2001). This mini-core subset still represents the diversity of the core collection, and was developed in two stages. First, a representative core subset (about 10%) was developed from the entire collection, using information on origin and geographical distribution, as well as characterization and evaluation data. This core subset was then evaluated for various morphological, agronomic, and quality traits, and a further subset of about 10% of accessions was selected. At both stages, standard clustering procedures should be used to separate groups of similar accessions.

The size of our core collection (622 accessions) is not large. But considering the low priority given to finger millet in most breeding programs, it will be too large for breeders to conveniently exploit. We therefore developed a mini-core collection of 65 accessions following the approach of Upadhyaya and Ortiz (2001).

Developing a composite set of germplasm

We have developed a composite set of finger millet germplasm under the Generation Challenge Program. This set comprises 1,000 accessions selected using various criteria: representation in ICRISAT core collection and in Indian NARS collections, major agronomic traits, resistance to insect and diseases, etc (Table 5). Phenotypic and genotypic characterization of this composite set will help identify useful and unique germplasm resources, and greatly increase the scope and effectiveness of utilization in crop improvement.

Table 5. Composite set of finger millet germplasm developed for Generation Challenge Program.

	No. of accessions
From ICRISAT core	508
Selected for agronomic traits	222
One each from 114 clusters in ICRISAT core	114
Representing Indian NARS core	50
Selected for resistance to stresses	85
Selected for grain nutrition traits	12
Selected for genetic diversity	9
Total	1000

In the past, genetic improvement in finger millet has been very limited. The crop has several merits (eg, competitive in marginal environments, good yield potential, high dietary value), and deserves more attention. Finger millet could be made competitive by broadening the genetic base and increasing the productivity of the cultivars developed. Useful germplasm for breeding could be identified using two approaches: (i) identifying biological races in which accessions are more genetically diverse, and also have higher means for desired traits, (ii) systematically characterizing the core and mini-core collections. In the present study, we found that race *Africana* is very rich for several economic traits, namely plant height, basal tillers, number of culm and panicle branches, peduncle length, inflorescence length, and length of longest finger. The finger millet crop at ICRISAT Patancheru generally remains free from disease or insect damage. However, the crop is known to be affected by diseases such as blast (*Pyricularia grisea)*, leaf blight (*Helminthosporium* sp), and leaf spot (C*ercospora eleusine)* in Nepal, Kenya, Uganda and other countries. Germplasm accessions were screened against these diseases and resistant sources were found (Sherchan and Baniya 1993, Esele 1993). The availability of male sterility could be very useful to breeding programs, and one such line was produced recently through artificial mutation (Gupta et al. 1997). At ICRISAT, a number of accessions with desired agronomic traits have been selected using the core collection approach. These value-added germplasm lines, which are freely available to researchers, could form a good base for breeding programs in both Asia and Africa.

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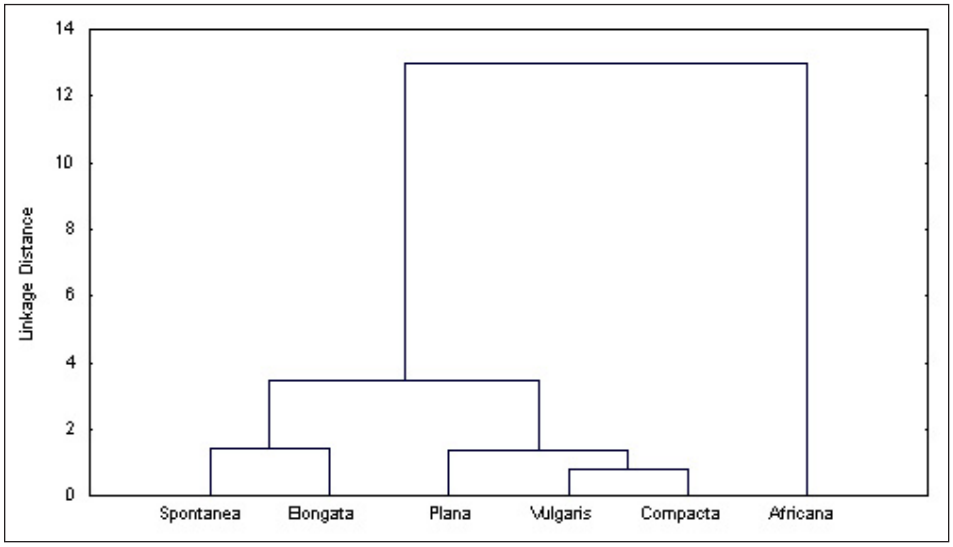

Figure 1. Dendrogram based on first two principal components of races in finger millet entire collection at ICRISAT Patancheru (variation captured 95%).

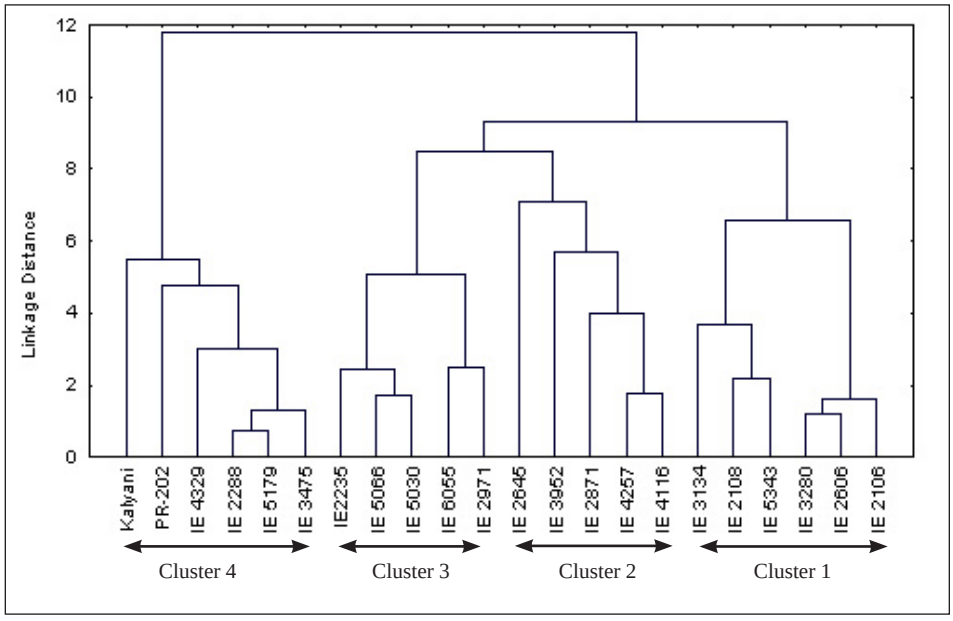

Figure 2. Dendrogram based on first five principal components (69.5% variation) of 20 High-yielding finger millet accessions (from core collection) and two control cultivars.