

## Characterization of eastern African finger millet germplasm for qualitative and quantitative characters at ICRISAT

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### Abstract

A total of 5949 finger millet (*Eleusine coracana*) germplasm accessions is conserved at ICRISAT genebank. Of these, more than 2000 accessions from five East African countries were evaluated for qualitative and quantitative traits at ICRISAT, Patancheru, India in the rainy season during 1977 to 2002. Substantial diversity was observed in all the characters studied. Diversity was more among the countries than within the country. Flowering time ranged from 50 to 120 days. The early flowering accessions are found in Burundi and late flowering accessions in Ethiopia. Plant height ranged from 55 to 240 cm with a mean of 104 to 120 cm. Dwarf accessions were from Kenya, whereas tallest accessions were from Uganda. Basal tillers per plant ranged from 1 to 40 and culm branches per plant ranged from 0 to 10. The range of other characters was also recorded: flag leaf blade length 100 to 700 mm, flag leaf blade width 5 to 20 mm, flag leaf sheath length 8 to 230 mm, peduncle length 80 to 450 mm, exertion 0 to 360 mm, inflorescence length 50 to 250 mm, inflorescence width 14 to 360 mm, length of longest finger 12 to 250 mm and width of longest finger 2 to 35 mm, and number of fingers per ear 4 to 23. Among the eastern African finger millet germplasm accessions, green plant types are dominant over pigmented with dominance of erect growth habit. Majority of lodging resistant accessions are from Uganda. When we considered overall plant aspect score, more than half of the accessions were of average type. The eastern African finger millet germplasm consists of all six races, ie, *Africana* and *Spontanea* (wild races) and four cultivated races namely *Elongata*, *Plana*, *Compacta* and *Vulgaris* with the dominance of race *Vulgaris*.

Principal component analysis revealed that basal tillers per plant, flag leaf sheath length, inflorescence length and width, length and width of longest finger and panicles per plant are the important traits, which contribute considerable diversity. Accessions from all five countries were grouped into three clusters; accessions from Kenya, Tanzania and Uganda in one cluster as these

had similar means for 8 traits; accessions from Ethiopia delineated from those of other countries based on higher means for 6 traits and higher variance for 7 traits; and accessions from Burundi separated from those of other countries based on higher means for 3 traits and higher variance for 7 traits.

### Introduction

Finger millet (*Eleusine coracana*; *ragi*), belongs to family *Poaceae* (*Gramineae*), and it ranks third in importance among millets after pearl millet (*Pennisetum glaucum*) and foxtail millet (*Setaria italica*) in the semi-arid tropics (SAT) and subtropics of the world. It is mentioned in archaeological records, pertaining to early African agriculture in Ethiopia, that date back 5000 years (<http://www.fao.org/ag/AGP/AGPC/doc/Gbase/safricadata/eleucor.html>). It is a staple food crop in the majority of drought-prone areas in several East African countries in the world, and is considered as an important component of food security. The grain can be stored for years without being affected by storage pests and this makes finger millet an important food grain commodity for famine-prone areas (National Research Council 1996). Finger millet grains are used for human consumption in countries such as Uganda, Kenya and Burundi as whole or ground with sorghum (*Sorghum bicolor*) or cassava (*Manihot esculenta*) and to make thin (*uji*) and stiff (*ugali*) porridges. In Ethiopia it is used for bread (*injera*) alone or in mixture with teff (*Ergrostis tef*). East Africa is a region of contrasts, where Africa's lowest and highest elevations are found. Differences in altitude, rainfall and temperature over short geographic distances provided varying environments suitable for crop diversification, early domestication and subsequent cultivation of landraces. Finger millet is indigenous to eastern Africa and the region has tremendous genetic variability. It is extensively grown in the uplands of Rift Valley. It is highly priced and valued for its nutrition (Mengesha et al. 1988). The crop residue is an excellent

source of dry matter for livestock, especially in dry season. Finger millet straw makes good fodder and contains up to 61% total digestible nutrients (National Research Council 1996).

The availability of diverse genetic resources is a prerequisite for genetic improvement of a crop including finger millet. Besides the availability of genetic resources, their characterization is essential for the effective utilization in the crop improvement programs. In this article, we report on the characterization of about 2000 finger millet accessions that have been collected/assembled from the East African countries.

## Material and methods

The material for this study consisted of 1993 finger millet germplasm accessions collected/assembled from five East African countries: Burundi (15), Ethiopia (31), Kenya (946), Tanzania (42) and Uganda (959). These accessions had been evaluated at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru (17° 25' latitude and 78° longitude, 545 m above msl) in Alfisols during rainy season, since 1977 till 2002, as and when they were received. Each accession was sown in a single row of 4 m length and 0.75 m apart. The plants were thinned 2–3 weeks after sowing while maintaining 0.1 m spacing between plants. Fertilizers were applied at the rate of 100 kg ha<sup>-1</sup> of diammonium phosphate as basal dose, and 100 kg ha<sup>-1</sup> of urea as top dressing after three weeks. Data were recorded on five qualitative characters such as plant pigmentation, growth habit, inflorescence compactness, grain color, lodging and overall plant aspect score and 14 quantitative characters such as plant height, basal tillers per plant, time to 50% flower, inflorescence length and width (five representative plants in each accession), and grain yield contributing traits such as number of fingers ear<sup>-1</sup> as per the descriptors for finger millet (IBPGR 1985). The germplasm accessions were classified into taxonomical races and subraces. The material was stratified according

to geographic origin and frequency distribution of accessions in different classes of qualitative traits was calculated. Means were compared using Newman-Keuls procedure (Newman 1939, Keuls 1952) and the homogeneity of variances was tested using Levene's (1960) procedure. The diversity index ( $H'$ ) of Shannon and Weaver (1949) was estimated and used as a measure of phenotypic diversity in different geographic origins. The mean values of all the 14 quantitative traits were standardized using range of each variable to eliminate scale differences. Principal component analysis (PCA) on 14 quantitative traits was performed to know the importance of different traits in explaining multivariate polymorphism. This analysis provides a reduced dimension model. A hierarchical cluster analysis (Ward 1963) was conducted on scores of first three principal components (PCs) delineating the geographic origins into 3 clusters.

## Results and discussion

### Qualitative characters

**Plant pigmentation.** Based on plant color, the entire eastern African finger millet germplasm accessions were classified as green and pigmented. Among the 1993 accessions, 65% were green plant types and the rest were pigmented types 35% (Table 1).

**Growth habit.** Two types of growth habit occurred in eastern African finger millet germplasm: erect types (77.92%), which were dominant followed by decumbent types (22.08%) (Table 1).

**Inflorescence compactness.** Inflorescence compactness is an important character in determining grain yield and is useful in subrace classification. Eight types of inflorescence shapes were recorded. These were laxa, long open, pendulous, short open, incurved, top curved, fisty and compact. Majority of accessions were top curved (46.26%) followed by incurved (30.86%), fisty (11.59%), short

**Table 1. Geographic diversity of plant pigmentation and growth habit of finger millet germplasm from East African countries.**

Country	Total accessions	Pigmentation			Growth habit	
		Green	Purple	Violet	Decumbent	Erect
Burundi	15	11	4		2	13
Ethiopia	31	27	4		21	10
Kenya	946	616	329	1	270	676
Tanzania	42	38	4		5	37
Uganda	959	565	394		142	817
Total	1993	1257	735	1	440	1553

open (4.62%), long open (3.96%), compact (2.31%), pendulous (0.30%) and laxa (0.10%). Most of the fisty, pendulous, short open and top curved accessions were from Kenya; incurved and long open accessions were from Uganda (Table 2).

**Grain color.** A wide range of grain colors was observed in eastern African finger millet germplasm accessions: light brown (71.65%), reddish brown (16.66%), dark brown (7.18%), *ragi* brown (4.26%) and white (0.25%) (Table 3). All types of grain color were observed in accessions from Ethiopia and Kenya.

**Lodging.** In this collection majority of accessions were lodging types (74.71%); and 25.29% accessions were non-lodging types (Table 4). Majority of non-lodging accessions were from Uganda and lodging accessions were from Tanzania, Kenya, Burundi and Ethiopia.

**Overall plant aspect.** Overall agronomic desirability of the accession as observed visually was based on inflorescence exertion, length, width and compactness and shape. The accessions were scored as very good, good, average, poor and very poor types. More than half of the accessions were average types (59.86%), followed by very good types (19.82%), good types (16.11%), poor types (3.66%) and very poor types (0.55%) (Table 5).

All types of accessions from very good to very poor were available in Kenya and Uganda.

### Races and subraces

Based on inflorescence compactness and shape, finger millet germplasm is classified into races and subraces. In this collection the species *E. coracana* consists of two subspecies *africana* and *coracana*. The subspecies *africana* consists of two wild races *Africana* (0.25%; 5 accessions) and *Spontanea* (0.40%; 8 accessions) and subspecies *coracana* consists of four cultivated races,

**Table 4. Geographic diversity of lodging in finger millet germplasm from East African countries.**

Country	Total accessions	Non-lodging accessions	Lodging accessions
Burundi	15	4	11
Ethiopia	31	1	30
Kenya	946	244	702
Tanzania	42	8	34
Uganda	959	247	712
Total	1993	504	1489

**Table 2. Geographic diversity of inflorescence compactness in finger millet germplasm from East African countries.**

Country	Total accessions	No. of accessions						
		Compact	Fisty	Incurved	Laxa	Long open	Pendulous	Short open
Burundi	15			3	1	3		8
Ethiopia	31			4		20	1	4
Kenya	946		148	195		5	4	63
Tanzania	42	4	3	13		1		3
Uganda	959	42	80	400	1	50	1	22
Total	1993	46	231	615	2	79	6	92

**Table 3. Geographic diversity of grain color in finger millet germplasm from East African countries.**

Country	Total accessions	No. of accessions				
		Dark brown	Light brown	<i>Ragi</i> brown	Reddish brown	White
Burundi	15	1	6	6	2	
Ethiopia	31	8	6	6	9	2
Kenya	946	53	649	54	187	3
Tanzania	42	2	34	4	2	
Uganda	959	79	733	15	132	
Total	1993	143	1428	85	332	5

**Table 5. Geographic diversity of overall plant aspect score in finger millet germplasm from East African countries.**

Country	Total accessions	Overall plant aspect score				
		Very Good	Good	Average	Poor	Very Poor
Burundi	15	—	1	9	—	5
Ethiopia	31	—	1	8	22	—
Kenya	946	150	255	500	40	1
Tanzania	42	7	5	29	1	—
Uganda	959	238	59	647	10	5
Total	1993	395	321	1193	73	11

namely *Elongata* (4.62%; 92 accessions), *Plana* (29.60%; 590 accessions), *Compacta* (14.90%; 297 accessions) and *Vulgaris* (50.23%; 1001 accessions) (Table 6). Further these races were divided into subraces. The race *Elongata* has three subraces: *laxa* (0.45%; 9 accessions), *reclusa* (3.86%; 77 accessions) and *sparsa* (0.30%; 6 accessions). The race *Plana* consists of three subraces: *seriata* (5.07%; 101 accessions), *confundere* (23.83%; 475 accessions) and *grandigluma* (0.70%; 14 accessions). The race *Compacta* has no subrace, while the race *Vulgaris* has four subraces: *liliacea* (1.30%; 26 accessions), *stellata* (7.73%; 154 accessions), *incurvata* (23.48%; 468 accessions) and *digitata* (17.71%; 353 accessions) (Prasada Rao et al. 1993). The race *Africana* accessions were from Burundi and Uganda, and the race *Spontanea* accessions were from Burundi, Kenya and Uganda. Majority of race *Compacta* and subraces *laxa*, *sparsa*, *confundere*, *stellata* and *digitata* accessions were from Kenya and *reclusa* and *incurvata* accessions were from Uganda (Table 6).

### Quantitative characters

Accessions from Uganda showed maximum range for 12 traits followed by Burundi for 2 traits. Accessions from Ethiopia had maximum range of 63 to 120 days for time to 50% flower and Kenyan accessions had maximum flag leaf blade length. Accessions from Tanzania had minimum range for 6 traits and those from Ethiopia, Burundi and Kenya had minimum range for 3 traits each (Table 7). Significant differences were found among the accessions with different geographic origins for means of all the 14 quantitative traits. Accessions from Ethiopia had greater means for 6 traits followed by those from Burundi for four traits. Accessions from Kenya had greater mean for flag leaf blade length and longest finger length. The accessions from Tanzania were late flowering (Table 7). Accessions from Ethiopia and Burundi were most heterogeneous and had higher variances for 7 traits each (Table 7). Shannon-Weaver diversity index ( $H'$ ) was highest in accessions from Uganda for 7 quantitative

**Table 6. Geographic diversity of races and subraces in finger millet germplasm from East African countries.**

Race	Subrace	No. of accessions					Total accessions
		Burundi	Ethiopia	Kenya	Tanzania	Uganda	
<i>Africana</i>		3	—	—	—	2	5
<i>Spontanea</i>		2	—	4	—	2	8
<i>Elongata</i>	<i>Laxa</i>	—	1	4	2	2	9
	<i>Reclusa</i>	—	17	4	—	56	77
	<i>Sparsa</i>	—	1	4	—	1	6
<i>Plana</i>	<i>Seriata</i>	1	—	32	2	66	101
	<i>Confundere</i>	4	1	257	5	208	475
	<i>Grandigluma</i>	—	—	13	—	1	14
<i>Compacta</i>		—	—	171	7	119	297
<i>Vulgaris</i>	<i>Liliacea</i>	—	1	23	—	2	26
	<i>Stellata</i>	—	3	103	2	46	154
	<i>Incurvata</i>	3	6	95	8	356	468
	<i>Digitata</i>	2	1	236	16	98	353
Total		15	31	946	42	959	1993

Table 7. Range, mean and variance of different traits in finger millet germplasm from East Africa.

Traits	Range					Mean <sup>1</sup>					Variance					F value	P
	Burundi	Ethiopia	Kenya	Tanzania	Uganda	Burundi	Ethiopia	Kenya	Tanzania	Uganda	Burundi	Ethiopia	Kenya	Tanzania	Uganda		
Time to 50% flower (days)	50-93	63-120	62-101	73-114	61-108	78.80d	86.71b	78.76d	95.45a	82.93c	170.31	230.08	51.73	90.11	38.60	50.98	<0.0001
Plant height (cm)	90-140	85-165	55-150	70-140	70-240	114.67a	118.87a	103.60b	115.12a	120.02a	330.24	511.18	183.46	173.77	242.80	4.42	0.0021
Basal tillers per plant	4-40	2-20	1-25	2-11	1-18	8.80a	7.39b	3.79d	5.12c	5.04c	78.89	19.25	2.58	6.16	5.84	32.47	<0.0001
Culm branches per plant	1-6	1-7	1-9	0-3	0-10	2.47ba	2.68a	1.82c	1.24d	1.98bc	1.41	2.56	1.09	0.48	1.32	2.27	0.0594
Flag leaf blade length (mm)	200-440	240-565	140-700	270-520	100-660	325.33b	398.87a	415.64a	398.10a	390.15a	4669.52	6027.85	6241.54	3504.82	5309.37	2.26	0.0604
Flag leaf blade width (mm)	5-20	10-20	10-20	7-20	5-20	10.73b	14.19a	14.12a	13.31a	12.58a	16.07	11.83	8.91	12.76	8.08	3.80	0.0044
Flag leaf sheath length (mm)	50-160	9-160	8-150	75-150	50-230	108.67a	108.19a	95.28b	106.31a	101.94ba	955.24	655.83	279.64	375.68	431.15	6.90	<0.0001
Peduncle length (mm)	160-450	100-300	80-370	140-380	90-450	248.67a	186.29c	216.35b	220.95b	224.07b	8655.24	1599.95	1971.55	2461.27	2179.58	12.09	<0.0001
Panicle exertion (mm)	70-260	0-210	0-220	50-280	10-360	130.67a	78.55b	113.17a	121.67a	127.35a	3706.67	1923.66	1243.27	2403.25	1635.31	7.07	<0.0001
Inflorescence length (mm)	70-200	85-240	50-200	50-210	100-250	121.33b	160.16a	97.16c	103.33c	92.20c	1626.67	1880.81	577.30	889.84	703.92	8.05	<0.0001
Inflorescence width (mm)	50-250	60-240	40-240	40-200	14-360	116.00a	122.10a	75.98b	69.88b	73.65b	3125.71	1969.62	490.60	761.57	700.78	6.93	<0.0001
Longest finger length (mm)	60-180	50-180	40-155	50-180	12-250	102.00b	117.42a	76.38d	88.21c	77.55d	1174.29	1401.45	300.18	516.86	428.99	11.72	<0.0001
Longest finger width (mm)	2-15	5-15	3-24	5-16	2-35	10.60ba	9.90b	11.98a	10.95ba	12.18a	24.54	7.16	6.36	8.44	10.52	6.65	<0.0001
Panicle per plant	5-14	6-16	4-14	5-11	4-23	8.20b	10.45a	7.25c	7.37c	7.18c	6.60	6.66	1.74	1.94	2.39	5.06	0.0005

1. Values followed by the same letter in each row do not differ significantly.

and two qualitative traits followed by Kenyan accessions for four quantitative traits and one qualitative trait and accessions from Ethiopia for one quantitative and three qualitative traits. Overall H' for all the quantitative and qualitative traits was highest in the accessions from Uganda (0.528) and lowest in those from Burundi (0.426). The lowest H' was in basal tillers per plant in accessions from Burundi (0.106) and highest in grain color in Ethiopian accessions (0.661) (Table 8).

**Time to 50% flower.** A wide range was observed for time to 50% flower (50 to 120 days) in the accessions of East African countries (Table 7). Accessions from Ethiopia had maximum and those from Burundi had minimum range for time to 50% flower. Some of the early flowering accessions which flower within 62 days were IE 4711, IE 4709, IE 5025, IE 7020 and IE 3537. On an average, accessions from Kenya were earliest flowering and Tanzania were late flowering. Variance for time to 50% flower differed significantly in accessions from different geographic origins. Variance for time to 50% flower was highest in Ethiopian accessions and lowest in the accessions from Uganda (Table 7). Highest H' was in the accessions from Kenya and lowest in those from Burundi. Overall H' for time to 50% flower across the geographic origins was  $0.568 \pm 0.02$  (Table 8).

**Plant height.** Plant height in the accessions of East African countries ranged from 55 to 240 cm. Accessions from Uganda had maximum and those from Burundi had minimum range for plant height. On an average, accessions from Uganda were taller and those from Kenya were short. The tallest accessions were IE 3721, IE 3650, IE 2799, IE 6451 and IE 6452. Variance for plant height differed significantly in accessions from different geographic origins. Variance for plant height was highest in accessions from Ethiopia and lowest in those from Tanzania (Table 7). Highest H' was in the accessions from Kenya and lowest in those from Burundi. Overall H' across the geographic origins was  $0.561 \pm 0.03$  (Table 8).

**Basal tillers per plant.** A wide range was observed for basal tillers per plant (1-40) in the accessions of East African countries. Accessions from Burundi had maximum range of basal tillers per plant and those from Tanzania had minimum range of basal tillers per plant. On an average, accessions from Burundi had highest and Kenya had lowest number of basal tillers per plant. The accessions with high number of basal tillers were IE 4712, IE 2568, IE 2796, IE 3789 and IE 908. Variance for basal tillers per plant differed significantly in accessions from different geographic origins. Variance was highest in accessions from Burundi and lowest in the accessions



from Kenya (Table 7). Overall  $H'$  across the geographic origins was  $0.437 \pm 0.08$ . Highest  $H'$  was in the accessions from Uganda and lowest in those from Burundi (Table 8).

**Culm branches per plant.** Culm branches per plant in the accessions of East African countries ranged from 0 to 10. Accessions from Uganda had maximum and those from Tanzania had minimum range of culm branches per plant. On an average accessions from Ethiopia had maximum while those from Tanzania had minimum number of culm branches. Variance for culm branches per plant was highest in accessions from Ethiopia and lowest in those from Tanzania (Table 7). Highest  $H'$  was in the accessions from Uganda and lowest in those from Kenya. Overall  $H'$  across the geographic origins was  $0.417 \pm 0.04$  (Table 8).

**Flag leaf blade length.** Flag leaf blade length ranged from 100 to 700 mm in the accessions of East African countries. For flag leaf blade length accessions from Uganda and Kenya had maximum, and those from Burundi had minimum range of flag leaf blade length. On an average, accessions from Kenya had maximum and

those from Burundi had minimum flag leaf blade length. Variance for flag leaf blade length was most heterogeneous in accessions from Ethiopia and least in those from Tanzania (Table 7). Highest  $H'$  was in the accessions from Ethiopia and lowest in those from Burundi. The highest pooled  $H'$  across the geographic origins was in flag leaf blade length ( $0.610 \pm 0.01$ ) (Table 8).

**Flag leaf blade width.** Flag leaf blade width in the accessions of East African countries ranged from 5 to 20 mm. Accessions from Burundi and Uganda had maximum, and those from Ethiopia and Kenya had minimum range of flag leaf blade width. On an average, accessions from Ethiopia had widest and those from Burundi narrow flag leaf blade. Variance for flag leaf blade width differed significantly in accessions from different geographic origins. Variance for flag leaf blade width was highest in accessions from Burundi and lowest in those from Uganda (Table 7). Highest  $H'$  was in the accessions from Tanzania and lowest in those from Kenya. Overall  $H'$  across the geographic origins was  $0.479 \pm 0.03$  (Table 8).

**Flag leaf sheath length.** A wide range was observed for flag leaf sheath length (8–230 mm) in the accessions of

**Table 8. Shannon-Weaver diversity index in finger millet germplasm from East Africa.**

Trait	Burundi	Ethiopia	Kenya	Tanzania	Uganda	Mean	SE $\pm$
<b>Qualitative traits</b>							
Plant pigmentation	0.252	0.167	0.284	0.137	0.294	0.227	0.03
Growth habit	0.171	0.273	0.260	0.159	0.182	0.209	0.02
Inflorescence compactness	0.504	0.477	0.509	0.615	0.578	0.537	0.02
Grain color	0.513	0.661	0.401	0.298	0.325	0.439	0.06
Lodging	0.443	0.653	0.628	0.627	0.581	0.586	0.03
Overall plant aspect	0.371	0.306	0.488	0.389	0.373	0.385	0.02
Mean	0.376	0.423	0.428	0.371	0.389	0.397	0.01
SE $\pm$	0.05	0.08	0.05	0.08	0.06	0.06	
<b>Quantitative traits</b>							
Time to 50% flower (days)	0.519	0.521	0.625	0.552	0.622	0.568	0.02
Plant height (cm)	0.453	0.542	0.638	0.542	0.629	0.561	0.03
Basal tillers per plant	0.106	0.494	0.473	0.521	0.591	0.437	0.08
Culm branches per plant	0.371	0.439	0.283	0.438	0.555	0.417	0.04
Flag leaf blade length (mm)	0.579	0.635	0.621	0.599	0.616	0.610	0.01
Flag leaf blade width (mm)	0.526	0.435	0.388	0.581	0.467	0.479	0.03
Flag leaf sheath length (mm)	0.575	0.541	0.593	0.544	0.631	0.577	0.01
Peduncle length (mm)	0.414	0.604	0.629	0.560	0.622	0.566	0.04
Panicle exertion (mm)	0.372	0.577	0.632	0.562	0.635	0.556	0.04
Inflorescence length (mm)	0.494	0.566	0.603	0.572	0.609	0.569	0.02
Inflorescence width (mm)	0.494	0.554	0.559	0.438	0.596	0.528	0.02
Longest finger length (mm)	0.468	0.531	0.589	0.537	0.606	0.546	0.02
Longest finger width (mm)	0.461	0.471	0.555	0.507	0.500	0.499	0.02
Panicle per plant	0.430	0.520	0.619	0.593	0.548	0.542	0.03
Mean	0.447	0.531	0.558	0.539	0.588	0.532	0.02
SE $\pm$	0.03	0.01	0.02	0.01	0.01	0.01	
Mean (all traits)	0.426	0.498	0.519	0.488	0.528	0.492	0.02
SE $\pm$	0.02	0.02	0.02	0.03	0.02	0.02	

East African countries. Accessions from Uganda had maximum and those from Tanzania had minimum range for flag leaf sheath length. On an average, accessions from Burundi had highest and those from Kenya had lowest flag leaf sheath length. Variance for flag leaf sheath length differed significantly in accessions from different geographic origins. Variance was highest in accessions from Burundi and lowest in those from Kenya (Table 7). Overall  $H'$  across the geographic origins was  $0.577 \pm 0.01$ . Highest  $H'$  was in the accessions of Uganda and lowest in those from Ethiopia (Table 8).

**Peduncle length.** Peduncle length ranged from 80 to 450 mm in the accessions of East African countries. Accessions from Ethiopia had minimum and those from Uganda had maximum range of peduncle length. On an average, accessions from Burundi had maximum and those from Ethiopia had minimum peduncle length. Variance for peduncle length differed significantly in accessions from different geographic origins. Variance for peduncle length was most heterogeneous in accessions from Burundi and least in those from Ethiopia (Table 7). Highest  $H'$  was in the accessions from Kenya and lowest in those from Burundi. The highest pooled  $H'$  for peduncle length across the geographic origins was  $0.566 \pm 0.04$  (Table 8).

**Panicle exertion.** Panicle exertion in the accessions of East African countries ranged from 0 to 360 mm. Accessions from Uganda had maximum and those from Burundi had minimum range of panicle exertion. On an average, accessions from Burundi had highest and those from Ethiopia had lowest panicle exertion. Variance for panicle exertion differed significantly in accessions from different geographic origins. Variance for panicle exertion was highest in accessions from Burundi and lowest in those from Kenya (Table 7). Highest  $H'$  was in the accessions from Uganda and lowest in those from Burundi. Overall  $H'$  across the geographic origins was  $0.556 \pm 0.04$  (Table 8).

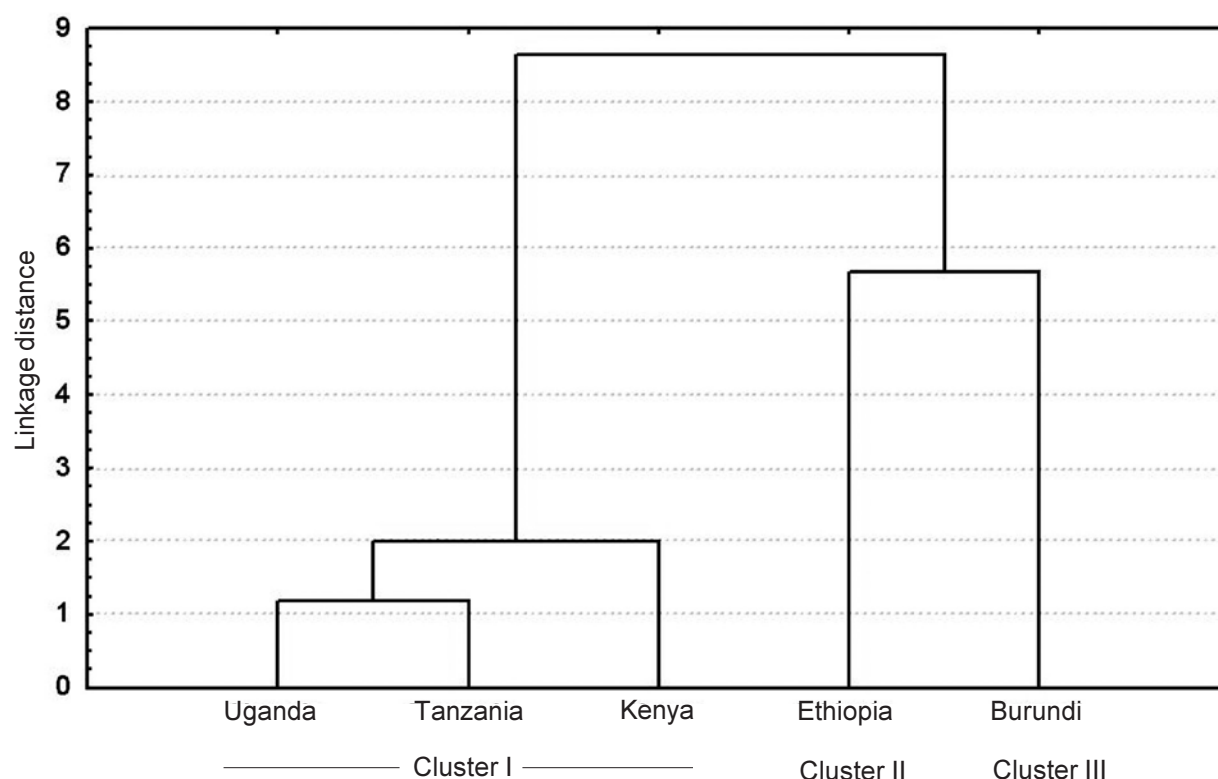
**Inflorescence length.** A wide range was observed for inflorescence length (100 to 250 mm) in the accessions of East African countries. Accessions from Uganda had maximum and those from Burundi had minimum range of inflorescence length. On an average, accessions from Ethiopia had maximum and those from Kenya had minimum inflorescence length. Variance for inflorescence length differed significantly in accessions from different geographic origins. Variance for inflorescence length was highest in accessions from Ethiopia and lowest in those from Kenya (Table 7). Highest  $H'$  was in the accessions from Uganda and lowest in those from Burundi. Overall  $H'$  across the geographic origins was  $0.569 \pm 0.02$  (Table 8).

**Inflorescence width.** Inflorescence width ranged from 14 to 360 mm in the accessions of East African countries. Accessions from Tanzania had minimum and those from Uganda had maximum range of inflorescence width. On an average, accessions from Ethiopia had maximum and those from Tanzania had minimum inflorescence width. Variance for inflorescence width differed significantly in accessions from different geographic origins. Variance for inflorescence width was highest in accessions from Burundi and lowest in those from Kenya (Table 7). Highest  $H'$  was in the accessions from Uganda and lowest in those from Tanzania. The highest pooled  $H'$  across the geographic origins was  $0.528 \pm 0.02$  (Table 8).

**Longest finger length.** Longest finger length in the accessions of East African countries ranged from 120 to 250 mm. Accessions from Uganda had maximum and those from Kenya had minimum range of longest finger length. On an average, accessions from Ethiopia had maximum and those from Kenya had minimum length of the longest finger. Accessions having longest finger length were IE 6451, IE 3710, IE 2806, IE 4712 and IE 3208. Variance for longest finger length differed significantly in accessions from different geographic origins. Variance for longest finger length was highest in accessions from Ethiopia and lowest in those from Kenya (Table 7). Highest  $H'$  was in the accessions from Uganda and lowest in those from Burundi. Overall  $H'$  across the geographic origins was  $0.546 \pm 0.02$  (Table 8).

**Longest finger width.** A wide range was observed for the width of longest finger (2–35 mm) in the accessions of East African countries. Accessions from Uganda had maximum and those from Ethiopia had minimum range of width of longest finger. On an average, accessions from Uganda had maximum and those from Ethiopia had minimum width of longest finger. Variance for longest finger width differed significantly in accessions from different geographic origins. Variance for longest finger width was highest in accessions from Burundi and lowest in those from Kenya (Table 7). Highest  $H'$  was in the accessions from Kenya and lowest in those from Burundi. Overall  $H'$  across the geographic origins was  $0.499 \pm 0.02$  (Table 8).

**Panicles per plant.** Panicles per plant in the accessions of East African countries ranged from 4 to 23. Accessions from Uganda had maximum and those from Tanzania had minimum range of panicles per plant. On an average, accessions from Ethiopia had maximum and those from Uganda had minimum panicles per plant. Variance for panicles per plant differed significantly in accessions from different geographic origins. Variance for panicles per plant was highest in accessions from



**Figure 1.** Dendrogram based on first three principle components capturing 95.1% variation in East African finger millet germplasm.

Ethiopia and lowest in those from Kenya (Table 7). Highest  $H'$  was in the accessions from Kenya and lowest in those from Burundi. Overall  $H'$  across the geographic origins was  $0.542 \pm 0.03$  (Table 8).

In general, accessions from Burundi had highest number of basal tillers per plant with longest peduncle length and highest panicle exertion. Accessions from Ethiopia had higher number of culm branches and panicles per plant, with highest flag leaf blade length and width and longest inflorescence. Kenyan accessions were earliest flowering and plants were short. Accessions from Tanzania were late flowering with fewer culm branches. Ugandan accessions were taller with more finger width and long flag leaf sheath.

### Principal component analysis

The mean values of each geographic origin were standardized for all the 14 quantitative traits, using range of each variable to eliminate scale differences. These standardized values were subjected to PCA. The first three principal components (PCs) scored 95.1% variation. First PC explained 52.8%, second 28.9% and the third PC 13.4% variation. The important traits in the evaluation of East African finger millet germplasm are basal tillers,

flag leaf sheath length, inflorescence length and width, longest finger length and width and panicles per plant, which explained the maximum variation in PC1.

### Clustering

Cluster analysis using Ward's (1963) method was performed on first three PCs. Accessions from all the five countries were delineated into three clusters. Accessions from Uganda, Tanzania and Kenya were grouped in cluster 1, those from Ethiopia in cluster 2 and from Burundi in cluster 3 (Fig. 1). The clustering is in accordance to the geographic locations of the countries. Uganda, Tanzania and Kenya are situated in the central region of East Africa and the accessions are grouped together in cluster 1. Ethiopia is in the extreme north of East Africa and the accessions are separated from other countries in cluster 2. Similarly, Burundi is adjacent to the Central African countries and the accessions are separated from other countries in cluster 3. Greater mean for 6 and variance for 7 traits in Ethiopia and greater mean for 3 and variance for 7 traits in Burundi resulted in delineating these countries from the others. Mean values were similar in accessions from Kenya, Tanzania and Uganda for 8 traits (flag leaf blade length and width,



peduncle length, panicle exertion, inflorescence length and width, longest finger width and panicles per plant), resulting in grouping of these countries in cluster 1.

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