Diversity among African Pearl Millet Landrace Populations

Botorou Ouendeba, Gebisa Ejeta, Wayne W. Hanna,* and Anand K. Kumar

ABSTRACT

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is widely grown in arid to semi-arid regions of Africa. The crop is particularly adapted to Sahelian West Africa where landraces have evolved in different ecological niches. These landraces have accumulated interpopulation diversity that has not been characterized. Evaluation of genetic diversity is a prerequisite for successful germplasm exploitation through breeding. The objective of this study was to characterize morphological and agronomic variability among African landrace populations of pearl millet. Ten pearl millet landrace populations widely grown in several African countries and two experimental F_1 hybrids were evaluated at two locations in Niger during the 1989 rainy season. Thirteen characters (downy mildew [*Sclerospora graminicola* (Sacc.) Schroet] incidence, days to flowering, primary spike length, peduncle exsertion, spike girth, flag leaf width, stem diameter, spike number per plant, non-productive tillers per plant, plant height, spike yield per plot, grain yield per plot, and 1000-seed weight) were measured on six replicates of each landrace populations. In the pooled analysis, all landrace populations were significantly different for one or more of the characters evaluated. The Niger landrace populations showed much less variation than the other African landrace populations for most characters investigated. Ward's cluster and principal component analyses were used to investigate the nature and degree of divergence in the landrace populations. The cluster analyses revealed similarities between Niger and Senegal and between Niger and Nigerian landrace populations. Four principal components were found to explain 92% of the total variation. Days to flowering, plant height, stem diameter, primary spike length, and grain and spike yield per plot were the major sources of diversity among the landrace populations. These results could be useful in choosing potentially heterotic pearl millet populations for intercrossing to develop improved cultivars, synthetics, and hybrids for use in Africa.

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PEARL MILLET has evolved in the dry and semi-arid regions of Africa. In Sub-Saharan West Africa, pearl millet landraces have been grown since the beginning of settled agriculture (Brunken et al., 1977). Introduction of improved pearl millet cultivars in the region is limited. Farmers rely on landraces with good production stability that are rarely out-yielded by improved cultivars. Farmers save seed from their own crop, often selecting for spike length, spike compactness, and kernel size. This artificial selection coupled with natural selection for survival in the local environment have led to establishment of ecologically well adapted landraces. Many of these local landrace populations have low yield potential with grain yield averaging 500 kg ha^{-1}. The low productivity of pearl millet landraces is largely due to the harsh environment in the region, characterized by low rainfall and low fertility soils.

The demand for cereals in West Africa calls for an increase in production of pearl millet, one of the major cereals grown on the continent. Breeding high yielding and adapted cultivars is one approach to resolving cereal grain deficits. Effective utilization of germplasm in breeding programs is enhanced if the variation is properly characterized and described.

Pearl millet populations growing in heterogenous environments, and therefore having to adjust to many ecological niches, could be expected to accumulate interpopulation diversity. Cluster analysis has been used to assess similarities among landraces in many breeding programs where genotypic and phenotypic repetition of several characters were found among a set of populations, lines, or accessions from which parents were selected for hybridization (Wilson et al. 1990; Veronesi and Falcinelli, 1988). Cluster analysis can be used as a method for the

Abbreviation: *, indicates significance at $P = 0.05$.

evaluation of genetic similarity in specific host-parasite interactions (Lebeda and Jendrulek, 1987).

The objective of this study was to characterize morphological and agronomic variability among 10 African landrace populations (hereafter referred to as populations) and two hybrids of pearl millet. The most diverse populations and those having complementary characters may be used as parents for hybrid development and enhancement programs in West Africa.

MATERIALS AND METHODS

Ten widely grown randomly mating pearl millet populations and two F_1 hybrids developed at ICRISAT Sahelian Center (ISC), Sadore, Niger (Table 1) were evaluated at two locations in Niger during the 1989 rainy season (June–October).

These populations were grown in a randomized complete block design with six replicates. The two locations (Sadore and Bengou, 45 km and 300 km southeast of Niamey, Niger, respectively) were chosen to provide differences in soil type and annual rainfall representative of the two main pearl millet growing areas in Niger. Rainfall in 1989 was 487 mm at Bengou and 623 mm at Sadore. The soil at Sadore has a pH of 4.1 and contains about 95% sand, 3.5% silt, 1.0% clay, and 0.2% organic matter. Bengou soil is characterized by a pH of 4.3 and 63% sand, 21% silt, 15% clay, and 0.5% organic matter. The cultivars were grown in five-row plots, 6.4 m long. All trials were hand planted. At Bengou, the trial was flat-planted in plots that received 5 t ha^{-1} of manure. Distance between rows and between plants within rows was 0.8 m. Ten to 15 seeds were sown by hand at Sadore on ridges 0.75 m apart with an interplant distance of 0.8 m. Plants were thinned to one plant per hill, 20 d after sowing at both locations.

Table 1. Source and origin of 10 landrace populations and two F_1 hybrids of pearl millet.

Cultivars	Source	Origin	Selection scheme
Souna 3	ICRISAT†	Senegal	Mass selection on adapted landrace
Iniari	ICRISAT	Togo	Mass selection on adapted landrace
Mansori	ICRISAT	Sudan	Mass selection on adapted landrace
Ex-Bornu millet	ICRISAT	Nigeria	Recurrent selection on local pearl
Ugandi	ICRISAT	Sudan	Recurrent selection that led to a composite
CIVT	INRAN‡	Niger	Recurrent selection on 4 local cultivars
P3Kolo	INRAN	Niger	Cross between two adapted landraces
Zongo Kolo (ZOK)	INRAN	Niger	Local population
Haini Kire Precoce (HKP)	INRAN	Niger	Intercrossing of earliest S1 lines from Haini Kire
Zanfarwa (XA)	INRAN	Niger	Mass selection on a local landrace
F_1 hybrid No.1 (1784-91×P3Kolo)§	ICRISAT	ICRISAT	Inbred × cultivar cross
F_1 hybrid No. 2 (1784-91×GB-8735)¶	ICRISAT	ICRISAT	Inbred × cultivar cross

† International Crops Research Institute for the Semi-Arid Tropics, Sahelian Center, Niamey, Niger (W. Africa).
‡ Institut National De Recherches Agronomiques Du Niger, BP429, Niamey, Niger (W. Africa).
§ 1784-91 is a downy mildew resistant dwarf inbred derived from a single plant from a backcross-1 F_2 population of the cross (Togo-2 × INMG-3) × INMG-2. Togo-2 is an early bold-seeded landrace from Togo. INMG-3 is a ICRISAT Niger millet Genepool-3 developed by random-mating several dwarf (d_2) entries.
¶ GB8735 is an early maturing cultivar derived from crosses between 'Iniari' from Togo and 'Souna' from Mali.

Plots at both locations received 36 kg P_2O_5 ha^{-1} and 23 kg N ha^{-1} preplant. At thinning, 30 d after sowing, a second application of 23 kg N ha^{-1} was applied as top dressing. Weeds were controlled by mechanical and manual means as necessary. Data were collected on the three center rows.

Observations were made on 12 agronomic traits and incidence of downy mildew (Table 2). Ratings were made on 10 random plants in each plot at maturity. Susceptible plants showed necrosis on leaves (loss of green color) and/or spikelets were transformed into green leaves at heading. Plants with one or more tillers showing downy mildew symptoms were considered susceptible.

A combined analysis of variance (SAS, 1988) was conducted based on individual plant values, when available, and on plot mean values for all characters (Ouendeba, 1991). The location × entry interaction was used to test entry effects. The phenotypic correlation (rp) between characters × and y was calculated as follows:

$$rp = \frac{Cov(P_X,P_Y)}{\sqrt{6^2P_X\,6^2P_Y}}$$

A hierarchical cluster analysis was run on the population means of the variables according to Ward's minimum variance method as executed by the cluster procedure of SAS (SAS, 1988). Population means were standardized within each location with a mean of zero and a standard deviation of one. The most similar objects were first grouped and these initial groups were merged according to their similarities. As the similarities decreased, all subgroups were fused into a single cluster. This method began with the computation of variances among the population means and produced a dendogram showing successive fusion of cultivars, which culminated at the stage where all cultivars belonged to the same cluster.

Variance between the pearl millet populations were further studied by using the Principal Component Analysis concerned with explaining the variance-covariance structure through a few linear combinations of the original variables. The variables were standardized and the *i*th principal component was given as described by Ouendeba (1991).

RESULTS

Populations were significantly different for one or more of the characters evaluated (Table 3). In the combined analysis, location × population interaction was significant ($P = 0.01$) only for peduncle exsertion, downy

Table 2. Characters evaluated on 10 landrace and two hybrid cultivars of pearl millet.

Characters	Method of measurement
Spike length	Base to tip of spike on the primary tiller (cm)
Peduncle exsertion	Tip of flag-leaf sheath to base of spike (cm)
Spike girth	Circumference of spike (cm)
Flag leaf width	Maximum width of flag leaf (cm)
Stem diameter	Diameter of the third internode below peduncle on primary tiller (cm)
Spike number	Number of productive tillers per plant
Non-productive tillers	Number of tillers not bearing spikes
Plant height	Ground level to tip of spike (cm)
Downy mildew incidence	Percent of plants infected at 40 d after planting. Ten random plants per replication were rated.
Days to flowering	Days after planting when 50% of primary spikes had emerged stigmas
Spike yield	Dry weight of unthreshed spikes (g/m^2) per plot
Grain yield	Dry weight of threshed grain (g/m^2) per plot
One thousand grain weight	g dry weight 1000^{-1} grains

Table 3. Mean squares for 13 characters in 10 populations and two F_1 hybrids of pearl millet grown at two locations in Niger during 1989 rainy season.

Source of variation	df	Spike length	Peduncule exsertion	Spike girth	Flag leaf width	Stem diameter	Spike number	Number of non-productive tillers	Plant height
Locations (L)	1	258.76**	44.71**	0.46	2.16	6.83**	42.81**	34.74**	68 868.3**
Replication/L	10	5.69	1.66	0.20	0.63**	0.55	0.69	1.86*	216.71
Entries (E)	11	1996.29**	95.68**	10.13**	0.97**	2.39**	4.41**	14.46**	10 294.4**
Hybrids (H) vs Populations (P)	1	1305.63**	337.95**	14.20**	0.55	3.78**	13.76**	0.03	7 555.3**
Cultivars (C)/H	1	1073.51**	39.54**	6.76**	0.83*	2.08**	0.47	17.96**	10 281.7**
NIG vs OA†	11	1925.46**	502.19**	11.00**	0.72*	8.92**	18.83**	6.44*	36 761.7**
C/in NIG	4	557.12**	3.41	2.05**	0.28	0.46**	0.97	13.27**	9 341.6**
C/in OA	4	1356.52**	39.78**	17.83**	1.86**	2.41**	2.89*	20.39**	5 318.1**
L × E‡	11	5.56	2.74**	0.15	0.11	0.03	0.51	0.76	213.92
Error	110	6.34	0.99	0.13	0.07	0.04	0.36	0.87	140.28
Means		39	4	8	4	4	4	4	200
C.V.		6	22	4	7	5	15	21	6

Source	DF	Downy mildew incidence	Days to flowering	Spike yield $plot^{-1}$	Grain yield $plot^{-1}$	Number of 1000 grain weight
Locations (L)	1	905.51*	1540.56**	19 363 226**	2 191 978*	6.67*
Replication/L	10	116.49	6.12	758 404	357 426	1.19
Entries (E)	11	1209.81*	230.69**	6 667 556**	3 665 276**	11.22**
Hybrids (H) vs Populations (P)	1	1467.47	817.07**	28 523 705**	23 252 317**	52.27**
Cultivars (C)/H	1	271.35	135.37**	8 783 632**	4 121 125**	1.50
NIG vs OA†	1	12.42	388.80**	5 185 414**	926 630	0.83
C/in NIG	4	501.68	97.64**	1 895 103*	921 828*	0.66
C/in OA	4	2387.49**	201.44**	5 817 488**	2 082 664**	16.56**
L × E‡	11	376.92**	5.93	296 356	200 597	2.18**
Error	110	77.04	4.30	379 583	184 668	0.74
Mean		22	57	3 058	2 096	9
C.V.		41	4	20	21	9

*, ** Significant at the 0.05, 0.01 levels of probability, respectively.
† NIG = Niger, OA = other Africa populations.
‡ Partitioning of population effects tested by location × entry mean squares.

mildew incidence and 1000-grain weight. Population main effects and their partitions were tested using the location × population mean square. Hybrids versus populations showed significant differences for all traits except for flag leaf width, non-productive tillers, and downy mildew incidence. The two hybrids showed similar spike number, downy mildew incidence and 1000-grain weight, but differed significantly for other traits (Table 4). No significant differences in downy mildew reaction, grain yield and 1000 grain weight were detected between the populations from Niger and West Africa. However, more variation was found among populations from West Africa than among Niger populations.

Niger Populations

The analysis of variance across two locations for the five Niger populations, CIVT, P3Kolo, ZOK, HKP, and ZA, showed no significant differences for peduncle exsertion, flag leaf width, spike number per plant, downy mildew incidence, and 1000-grain weight (Table 3). Population ZOK had the greatest mean for spike length, stem diameter (except for ZA), non-productive tillers, plant height, and days to flowering (Table 4). No significant differences in the grain yields among CIVT, P3Kolo, ZOK and HKP were found, whereas ZA produced significantly lower yields than P3Kolo and ZOK. The spike girth in ZA was significantly larger than that of all other populations. Niger populations had short peduncle exsertion. P3Kolo and ZA were the least susceptible to downy mildew. HKP and P3Kolo were the earliest populations and significantly different from CIVT, ZA and ZOK.

Other African Populations

The five African populations from outside Niger (Souna 3, Iniari, Mansori, Ex-Bornu and Ugandi) were significantly different ($P = 0.01$) for all traits except for the spike number where a difference was detected at the $P = 0.05$ level (Table 3). Souna 3 from Senegal had the largest spike length, flag leaf width, stem diameter, plant height, days to flowering, and spike yield (Table 4). Souna 3 also had the highest grain yield (except for Ex Bornu) and most non-productive tillers (except for Iniari). The Togo population, Iniari, characterized by the shortest spikes also had the largest spike girth. Ugandi had the smallest mean values for flag-leaf width and stem diameter. Ugandi also had the lowest or equal mean for height, maturity, and grain yield. Also, Ugandi had the largest mean value for downy mildew incidence. On the basis of plant height, days to flowering, spike yield, and 1000-grain weight, Ugandi (Sudan) and Iniari (Togo) were similar. Ex-Bornu, a cultivar grown in Nigeria, and Mansori, grown in Sudan, were similar for peduncle exsertion, flag leaf width, number of spikes per plant, number of non-productive tillers per plant, and days to flowering. Spike length was the only trait for which all West African cultivars were significantly different from each other.

Phenotypic Correlations

Phenotypic correlations among 13 traits were based on plot mean values among the 10 populations over two locations (Table 5). Grain yield and spike yield were

Table 4. Pearl millet cultivar means of 13 characters averaged across 2 locations in Niger during 1989 rainy season.

Origin	Cultivar	Spike length	Peduncule exsertion	Spike girth	Flag leaf width	Stem diameter	Plant height	Spike number	Number of non-productive tillers
		cm	cm	cm	cm	cm	cm	no.	no.
Niger populations									
	CIVT	47.5^{b}†	1.7^{abc}	7.8^{b}	3.9^{a}	4.6^{b}	220^{b}	3.3^{a}	3.3^{c}
	P3Kolo	47.3^{b}	2.4^{a}	7.7^{b}	3.7^{a}	4.6^{b}	209^{bc}	3.6^{a}	4.2^{b}
	ZOK	62.9^{a}	1.4^{bc}	7.8^{b}	3.9^{a}	5.0^{a}	269^{a}	3.2^{a}	5.8^{a}
	HKP	49.2^{b}	2.1^{ab}	7.7^{b}	3.6^{a}	4.7^{b}	208^{bc}	3.7^{a}	4.3^{b}
	ZA	47.0^{b}	1.1^{c}	8.7^{a}	3.6^{a}	4.9^{a}	198^{c}	3.0^{a}	3.2^{c}
Other African populations									
	Souna 3	48.8^{a}	2.9^{c}	7.9^{c}	4.2^{a}	4.9^{a}	216^{a}	3.5^{c}	6.4^{a}
	Iniari	22.3^{e}	7.8^{a}	10.5^{a}	3.5^{b}	4.2^{b}	172^{c}	3.8^{bc}	5.7^{a}
	Mansori	27.5^{c}	6.2^{b}	7.5^{d}	3.4^{b}	4.0^{c}	174^{c}	4.4^{ab}	3.8^{b}
	Ex-Bornu	31.3^{b}	6.8^{ab}	7.9^{c}	3.6^{b}	4.3^{b}	200^{b}	4.5^{ab}	3.5^{b}
	Ugandi	24.2^{d}	5.6^{b}	9.0^{b}	3.2^{c}	3.7^{d}	168^{c}	4.7^{a}	3.8^{b}
F_1 hybrids									
	Hybrid 1	39.4^{b}	6.3^{a}	8.6^{a}	4.0^{b}	4.4^{b}	205^{b}	4.5^{a}	5.2^{b}
	Hybrid 2	26.0^{a}	9.2^{b}	9.6^{b}	3.6^{a}	3.8^{a}	163^{a}	4.8^{a}	3.5^{a}

Origin	Cultivar	Downy mildew incidence	Days to flowering	Spike yield	Grain yield	1000-grain weight
		%	d	g	g	g
Niger populations						
	CIVT	28.4^{a}	59.9^{b}	2985^{ab}	1994^{ab}	9.4^{a}
	P3Kolo	17.2^{a}	57.7^{bc}	3304^{a}	2200^{a}	9.2^{a}
	ZOK	26.1^{a}	63.7^{a}	3539^{a}	2290^{a}	9.4^{a}
	HKP	27.6^{a}	56.1^{c}	3023^{ab}	1958^{ab}	9.5^{a}
	ZA	14.4^{a}	59.7^{b}	2481^{b}	1574^{b}	8.9^{a}
Other African populations						
	Souna 3	7.4^{c}	62.2^{a}	3704^{a}	2382^{a}	7.4^{c}
	Iniari	31.6^{b}	53.0^{c}	2484^{c}	1864^{b}	9.8^{a}
	Mansori	24.8^{b}	56.1^{b}	2070^{c}	1399^{c}	8.5^{b}
	Ex-Bornu	11.5^{c}	56.3^{b}	2955^{c}	2053^{ab}	9.7^{a}
	Ugandi	41.6^{a}	51.5^{c}	2037^{c}	1440^{c}	10.2^{a}
F_1 hybrids						
	Hybrid 1	10.5^{a}	53.6^{b}	4658^{b}	3408^{b}	10.6^{a}
	Hybrid 2	17.3^{a}	48.8^{a}	3448^{a}	2579^{a}	11.1^{a}

† Means with identical letters within a column and group are not significantly different at $P = 0.05$.

significantly ($P = 0.01$) correlated with spike length, spike girth, stem diameter, spike number per plant, non-productive tillers, plant height, and 1000-grain weight. All characters except peduncle exsertion, downy mildew incidence and days to flowering were significantly associated with grain yield. Spike length was not significantly correlated with number of spikes per plant, number of non-productive tillers, downy mildew incidence, days to flowering, or 1000-grain weight. Spike length was negatively correlated with peduncle exsertion, but positively correlated with spike girth, flag-leaf width, stem diameter, plant height, spike yield, and grain yield. Peduncle exsertion showed no significant correlation with any other trait. Spike girth was significantly correlated with grain yield, 1000-grain weight, plant height, stem diameter, and spike yield. Flag-leaf width also was significantly correlated with grain yield, spike number, stem diameter, and downy mildew incidence. No significant correlation was observed between days to flowering and other traits. Flag-leaf width was the only character that

Table 5. Phenotypic correlations among 13 agronomic and morphological characters measured on 10 populations and two F_1 hybrids of pearl millet.†

		SL	PE	SG	LW	STD	SN	NPT	HT	DM	FL	SY	GY
Spike length	(SL)												
Peduncle exsertion	(PE)	−0.23*											
Spike girth	(SG)	0.25*	−0.18										
Leaf width	(LW)	0.27**	0.09	0.16									
Stem diameter	(STD)	0.42**	−0.23	0.43**	0.38**								
Spike number	(SN)	−0.08	0.15	−0.15	0.26**	0.09							
Non-productive tillers	(NPT)	0.09	0.08	0.18	0.16	0.21*	0.24*						
Plant height	(HT)	0.31**	0.17	0.31**	0.15	0.22	0.25*	0.37**					
Downy mildew	(DM)	0.11	−0.01	−0.10	0.35*	0.18	−0.08	0.11	−0.21				
Days to flowering	(FL)	−0.12	0.04	−0.16	−0.21	−0.17	−0.16	−0.15	−0.11	−0.11			
Spike yield	(SY)	0.30**	−0.03	0.35**	0.26*	0.31**	0.54**	0.34**	0.48**	−0.09	−0.21		
Grain yield	(GY)	0.29**	−0.03	0.36**	0.28**	0.34**	0.52**	0.37**	0.48**	−0.04	−0.24	0.96**	
1000-grain weight	(TWT)	0.05	0.03	0.27**	0.28	0.14	0.18	0.33*	0.24*	0.13	−0.21	0.27**	0.38**

*, ** Significant at the 0.05, 0.01 levels of probability, respectively.

† Based on plot mean analyses across two locations in Niger in rainy season ($n = 12$).

Table 6. Principal component coefficients (e_i) of 13 characters in 12 pearl millet cultivars grown in Niger.

	PRIN 1	PRIN 2	PRIN 3	PRIN 4
Spike length	0.37	−0.03	−0.01	0.24
Peduncle length	−0.32	0.26	0.03	−0.17
Spike girth	−0.24	0.12	0.59	−0.02
Flag leaf width	0.30	0.32	−0.02	−0.10
Stem diameter	0.38	−0.06	0.15	−0.01
Productive tillers	−0.24	0.26	−0.36	−0.25
Non-productive tillers	0.13	0.14	0.64	−0.40
Plant height	0.36	0.01	0.04	0.26
Downy mildew incidence	−0.17	−0.33	0.27	0.36
Days to flowering	0.36	−0.16	−0.01	−0.13
Spike yield	0.18	0.49	−0.01	0.15
Grain yield	0.10	0.53	0.02	0.17
1000-seed weight	−0.23	0.22	0.11	0.64
Percent Variation	49.4	23.7	10.6	8.60
Cumulative percent of total variance	49.4	73.1	83.7	92.3

had a significant positive correlation with downy mildew incidence.

Principal Component Analysis

This procedure grouped the 13 variables into 10 components with eigenvalues lying between 0.013 and 6.42. By considering only the four components with eigenvalues greater than 1.00, more than 92% of the total variation could be explained (Table 6). Principal component 1 (PC1) accounted for 49% of the total variation and it was equally associated with spike length, stem diameter, days to flowering, and plant height (Table 6). PC2 consisted mainly of grain yield and spike yield and accounted for 24% of the total variation. PC3 explained 11% of the total variation and was mainly associated with nonproductive tillers and spike girth. PC4 accounted for 9% of the total variance and consisted mostly of downy mildew incidence and 1000-grain weight.

Cluster Analysis

Results of the cluster analysis showed that similar results were observed for the traits at both locations. Using the combined analysis across locations, 11 clusters were formed during the agglomeration process (Fig. 1). The smallest variance was detected between CIVT and HKP (Cluster 11). This result was expected because the two populations have been derived from the landrace Heini-Kire of Niger. The second group of similarities was Cluster 10 between P3-Kolo and Ex-Bornu. Cluster 11 was joined by Zanfarwa to form Cluster 9. Cluster 7 was formed between Souna 3 (Senegal) and ZOK (Niger). In the West African group, Ugandi and Mansori (both from Sudan) were first joined (Cluster 8) then followed by Iniari (Togo) to form Cluster 4.

Similarities between ZOK (Niger) and Souna 3 (Senegal) and those mentioned between Ex-Bornu (Nigeria) and P3Kolo (Niger) indicated that genetic diversity and geographical diversity were not necessarily related (Murty and Arunachalam, 1966).

DISCUSSION

The significant location effect for 11 of the 13 characters measured indicated diversity between locations. The

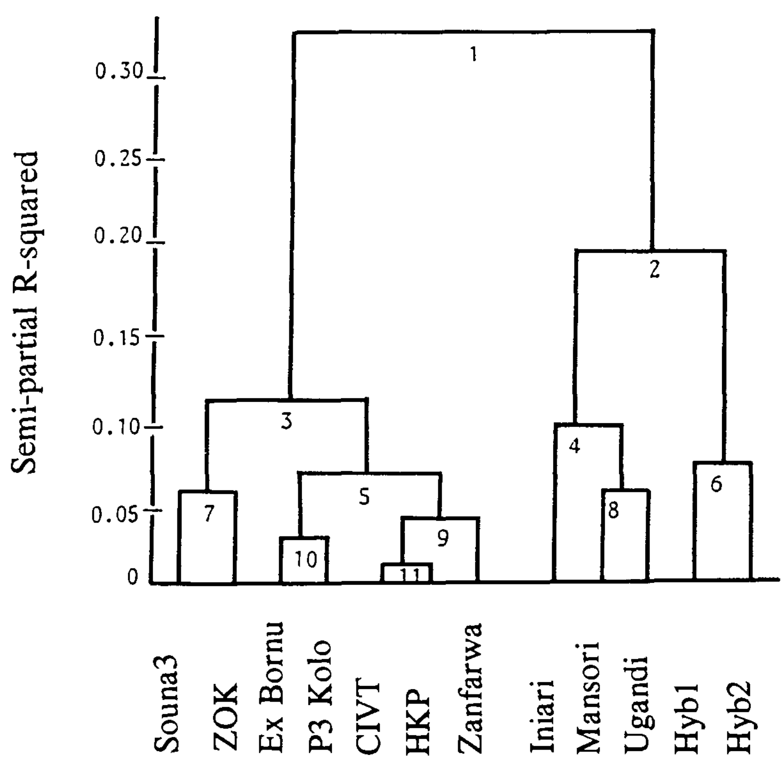

Fig. 1. Dendogram of the similarities among 10 populations and two F_1 hybrids of pearl millet grown at two locations in Niger during the 1989 rainy season using Ward's minimum variance method of cluster analysis.

small significant location × population effects for only three of the 13 characteristics measured indicated that the two locations were adequate for measuring the genetic diversity among the landrace populations.

Significant variability for a number of the characters was found between Niger and West African populations. The *other African* (OA) populations had more diversity for the traits than Niger populations. Variability in Niger populations were limited, particularly for peduncle exsertion, spike girth, flag-leaf width, stem diameter, spike number per plant, and 1000-grain weight. The long spikes (200 cm) uniquely found in Niger populations could be exploited in a selection program to lengthen the short spikes that characterize most other West African millet populations. The large variability in the West African populations for peduncle exsertion, spike girth, spike number and 1000-grain weight, indicated that it would be possible to develop improved cultivars from these populations. Both sets of populations had comparable grain yield. The analysis also showed that no significant grain yield differences existed between the Niger improved populations (CIVT, P3Kolo and HKP) and the local landrace population (ZOK) even with favorable growing conditions during the 1989 crop season at Bengou.

Among the vegetative and reproductive characters that were correlated with grain yield, number of productive tillers per plant and plant height showed the strongest associations ($r = 0.52^*$ and $r = 0.48^*$, respectively). These correlations along with the positive and significant correlation ($r = 0.25^*$) shown between number of productive tillers and plant height would be useful in the development of a cultivar with improved grain yield potential.

Results from the cluster analysis suggested that this method could be useful for determining the diversity among germplasm collections (Peters and Martinelli, 1989) or the similarity of an entry relative to other entries. It can be used to assign entries to their specific group of similarity. Tostain et al. (1987), showed that Niger cultivated unimproved landrace populations from different growing regions of the country showed large enzyme diversity. In this study the first agglomerations (minimum variance) formed were among Niger improved landrace populations. The lack of diversity is probably due to 'Haini Kire', the most widely grown pearl millet in western Niger, being the common parent in the improved Niger landrace populations. Cluster 7 revealed similarities between Souna 3 (Senegal) and ZOK (Niger). Bono (1973), Marchais (1982), and Tostain et al. (1987) found that both enzymatic and morphological characters demonstrated the proximity between Senegalese early maturing cultivars and Niger landraces. The expected relationship between the two hybrids was confirmed by Cluster 6. These hybrids contain germplasm from Togo, Niger, and Sudan (Table 1). Ugandi is derived from Serere Composite 2, an Iniari-type pearl millet obtained from Ghana, which is similar to Iniari from Togo. The clustering patterns obtained from different environments (Singh, 1988) will be useful to select genetically diverse genotypes to be included in hybridization programs to exploit greater heterosis. Sampling among cluster groups increased allelic diversity for selection following hybridization in a breeding program (Spagnoletti-Zeuli and Qualset, 1987). For instance, the best Niger pearl millet populations (CIVT and P3Kolo) could be used in a crossing program with Ugandi (Sudan) to take advantage of important complementary traits such as tillering capacity and seed size.

A significant amount of genetic diversity was observed in the 10 African populations. These results would be useful in choosing populations to use in a breeding program to improve productivity. The diversity could be effectively manipulated with appropriate breeding methods to develop improved cultivars, synthetics, and hybrids for West Africa.

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