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Full Length Research Paper

Evaluation of pearl millet for yield and downy mildew resistance across seven countries in sub-Saharan Africa

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Forty pearl millet germplasms consisting of traditional and improved open pollinated varieties, hybrids, and inbreds were selected to represent diversity for grain yield or quality, fertility restoration for specific cytoplasms, resistance to diseases or pests, variation in height and maturity, and origin. Evaluations were conducted in field trials in Ghana, Mali, Nigeria, and Senegal in 2003 and 2004 and in Burkina Faso, Niger, and Zambia in 2004. Data were collected on yield, downy mildew incidence, maturity, plant height, and panicle length. Variation occurred for all traits across locations and genotypes. Across locations and years, Sosat-C88, ICMV IS 89305, Gwagwa, NKK, Sosank, and CIVT were the highest yielding entries. Yields of Sosat-C88, Sosank, and CIVT were more stable across environments, and yields of ICMV IS 89305, Gwagwa, and NKK increased in response to more favorable environments. Sosank, CIVT, ICMV IS 89305, Sosat-C88, and Gwagwa were also among the most downy mildew resistant entries. Across locations and years, grain yield was negatively correlated with downy mildew incidence, and positively correlated with days to flowering, plant height, and panicle length. These correlations differed among some of the individual trials, with days to flowering having the least consistent correlations with grain yield. Further selection for improved yield and broad adaptation in pearl millet is likely to be possible, however, site-specific selection is necessary to identify other important traits in addition to yield. The high-yielding and downy mildew resistant pearl millets identified in this study will be useful to introgress new traits into preferred local varieties, or to serve as parental material for breeding and hybrid development.

Key words: *Pennisetum glaucum*, *Sclerospora graminicola,* multi-environment trials, yield potential, yield stability.

INTRODUCTION

Commercial markets for the traditional cereals of Africa will change as regional demand grows for processed foods and as consumption habits change from grains to animal products. Advances in food processing technology and an increasing demand for feed should lead to greater price stability for domestically produced grain (Vitale and

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Table 1. Pearl millet germplasm evaluated in multilocation trials in Africa in 2003 and 2004

Germplasm	Origin	Type
Kapielga	Burkina Faso	Local OP
P1449-2	Ghana	Improved OP
PT732B	Ghana	Improved OP
Arrow	Ghana	Local OP
Bongo Short Head	Ghana	Local OP
Manga Nara	Ghana	Local OP
Tongo Yellow	Ghana	Local OP
99-72	India	A4 restorer inbred
Guéfoué 16	Mali	Experimental OP
NKO x TC1	Mali	Experimental OP
Synthetic 1-2000	Mali	Experimental OP
Indiana 05	Mali	Improved OP
NKK	Mali	Improved OP
Sosat-C88	Mali	Improved OP
Toronio	Mali	Local OP
3/4 ExBornu	Niger	Experimental OP
3/4 HK	Niger	Experimental OP
3/4 Souna	Niger	Experimental OP
CIVT	Niger	Improved OP
GB 8735	Niger	Improved OP
HKP(GMS)	Niger	Improved OP
ICMV IS 89305	Niger	Improved OP
ICMV IS 90311	Niger	Improved OP
Sosank	Niger	Improved OP
Taram	Niger	Improved OP
Zatib	Niger	Improved OP
Sadoré Local	Niger	Local OP
Zongo	Niger	Local OP
DMR 15	Nigeria	A1 restorer inbred
DMR 68	Nigeria	Experimental inbred
DMR 72	Nigeria	Experimental inbred
LCIC 9702	Nigeria	Improved OP
Gwagawa	Nigeria	Local OP
68A x 086R	U.S.A.	A1 hybrid
TG102	U.S.A.	A1 hybrid
T99B	U.S.A.	A1 maintainer inbred
T454	U.S.A.	A1 restorer inbred
99M59043Mw x 68A4R4	U.S.A.	A4 hybrid
IBMV8401M x 68A4R4w	U.S.A.	A4 hybrid
01Miso NCD2-NE	U.S.A.	Experimental OP

OP = open-pollinated

Sanders, 2005). One challenge to developing the comercial potential of pearl millet [*Pennisetum glaucum* (L.) R. Br] is the ability of growers to provide a consistent product that meets market standards. Pearl millet varieties with high yield, tolerance to environmental stresses and disease and pest resistance are an integral part of meeting this challenge and variety improvement remains a goal of both national and international agencies. Pearl millet breeding programs are located throughout diverse agro-ecological zones in sub-Saharan Africa but function in relative isolation from each other.

Germplasm developed within individual programs often have superior performance within the region of selection. Research conducted with other crops suggests that greater gain and stability can be obtained when selecting for broad adaptation compared to site-specific performance (Jackson and McRae, 1998; Holland et al., 2002). Others suggest that broad adaptation may not be a preferred goal in developing crops (such as pearl millet) that are grown as landraces and in marginal production areas (Ceccarelli, 1996; Omanya et al., 2007).

Despite the conflicting schools of thought, multilocation testing remains an effective approach to rapidly assess germplasm for yield. Biotic and abiotic production constraints, such as downy mildew (caused by *Sclerospora graminicola* (Sacc.) Schroet.) and droughts are more likely to be encountered across the various trials. This study was designed to evaluate diverse pearl millet germplasms for yield and downy mildew resistance and stability of these traits over a range of production environments in sub-Saharan Africa, and to identify traits associated with yield. This information can be used to identify superior germplasm for further breeding of improved varieties.

MATERIALS AND METHODS

Forty diverse pearl millet germplasms were selected on the basis of traits such as grain yield, quality, fertility restoration for specific cytoplasms, resistance to diseases or pests, variation in height and maturity, and diversity of origin. These germplasms consisted of traditional and improved open pollinated varieties, hybrids, and inbreds (Table 1). The varieties used in this study were obtained from researchers at national and international programs. A single seed stock for each variety was distributed among collaborators to reduce inconsistency that might occur from the use of locally maintained seed stocks.

In 2003, field trials were grown in Ghana, Mali, Nigeria, and Senegal. In 2004, trials were grown in Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal, and Zambia. Experiments were arranged in a randomized complete block design. Four replications were sown in Mali, two in Nigeria, one in Niger. Three replications were sown in the other countries. The trials were grown with locally appropriate protocols for planting date, plot dimensions, and fertilizer applications.

The trial in Burkina Faso was planted at the INERA Kamboinse Research Station near Ouagadougou. The experiment was planted 29 July 2004. Plots were fertilized with 100 kg/ha of NPK (10-10-10) on 12 Aug 2004 and 50 kg/ha urea (46-0-0) was applied on 29 Aug 2004. Plots were two rows, 0.8 m long, with 0.8 m between rows and 0.2 m spacing between hills. The trial in Ghana was conducted at the SARI Manga Research Station. Tests were planted 9 June 2003 and 8 June 2004. Plot size was 5 x 3 m with inter- and intra-row spacing of 0.75 and 0.20 m, respectively. Fertilizer NPK (15-15-15) was applied in three applications at a rate of 40, 30, and 30 kg/ha at planting, and at three week intervals, respectively. The trials in Mali were sown at the IER Cinzana Research Station on 5 July 2003 and 10 July 2004. Plots were fertilized with 100 kg/ha ammonium phosphate (16-20-0) at planting, and with 50 kg/ha urea (46-0-0) two weeks after planting. Plots were 2 rows, 5 m long. Distance between rows was 0.75 m and hills were spaced 0.5 m. The trial in Niger was planted at the INRAN Research Station, Bengou on 8 July 2004. Plots were 10 m long and 4 rows wide. Hills were spaced 1 x 1 m. Fertilizer was applied at rate of 50 kg/ha NPK (15-15-15) after thinning, and 100 kg/ha of urea (46-0-0) three weeks later. The trials in Nigeria were planted at the Lake Chad Research Institute, Maiduguri. Plots were planted 26 June 2003 and 28 June 2004. Plots were 2 rows 5 m long with 75 cm between rows. Hills were spaced 50 cm within row. NPK fertilizer 20-10-10 was applied at 60 kg/ha at planting and supplemented by urea (46-0-0) four weeks after sowing. Trials in Senegal were conducted at the ISRA Station in Bambey. Plots were sown 22 July 2003 and 27 July 2004. Plots were 2 rows; 6.3 m long with 90 cm between rows and hills were spaced 90 cm within rows. Fertilizer was applied at 150 kg/ha of NPK (15-15-15) in 2003 and NPK (15-10-10) in 2004 at planting. Two applications each of 50 kg/ha of urea (46-0-0) were applied at 15 and 40 days after planting. The trial in Zambia was sown at the Longe Technological Assessment Site, Kamoa District, Western Province. Plots were 1 row, 4.2 m long. Rows were spaced 0.6 m apart, and hills within rows were spaced 0.3 m. Fertilizer was applied as NPK (10-20-10) at 100 kg/ha and top dressed with urea (46-0-0) at 50 kg/ha. Only a subset of the West African pearl millets was grown in Zambia (Table 2).

To standardize downy mildew ratings across locations, hills were thinned to a single plant per hill by three weeks after sowing. Plants were examined for the presence of downy mildew symptoms to assess incidence, rather than severity. The use of downy mildew incidence, rather than severity as an indicator of resistance was based on the premise that severity is affected by a number of variables, including the stage of plant growth at time of infection (Semisi and Ball, 1989), and environmental and soil factors (Gupta and Singh, 1999). Genetically susceptible plants are more likely to exhibit symptoms of infection than genetically resistant plants, regardless of environmental conditions and stage of maturation at time of infection. Other data recorded in the trials included days to 50% flowering (assessed on a per-plot basis), mature plant height (assessed on a per-plot basis), panicle length (average of five representative panicles per plot), and grain yield.

To assess broad adaptation over all locations and years, data were analyzed by the mixed models procedure of SAS (Cary NC, USA), with sums of squares partitioned into trial, replication (trial), entry and trial x entry interactions. Means were separated by Fisher's lsd at $P = 0.05$. To assess site-specific adaptation, data were also analyzed within locations. Regression analyses were conducted for grain yield and downy mildew incidence data to compare stability of the response across the different environments (Finlay and Wilkinson, 1963). The mean yield and downy mildew incidence of the individual entries in each trial was regressed on the mean response for all entries in each trial. Deviations of the calculated slope from 0 were determined by Student's *t*-tests. Regression equations with slopes not different from 0 were considered to indicate stable performance across trials.

Pearson's correlation coefficients were calculated within individual location x year trials to identify associations of grain yield with downy mildew incidence, time to flowering, plant height, and panicle length.

RESULTS

Grain yield

Across all locations and years, Sosat-C88 was the highest yielding entry, but yields of ICMV IS 89305, Gwagwa, NKK, Sosank, and CIVT were not significantly different from Sosat-C88 ($P < 0.05$) (Table 2). Sums of squares due to trial, entry, and trial x entry interactions were significant ($P < 0.05$). Among the highest-yielding entries, Sosat-C88, Sosank, and CIVT had regression slopes that did not differ from 0 ($P > 0.05$), and these entries could be considered to have more stable yield across environments, even in those environments with low yield potential. ICMV IS 89305, Gwagwa, and NKK had positive slopes indicating that their yields increased in response to improved yield potential of the environments.

Mean yield was low in the Burkina Faso 2004 trial. The local variety Kapielga was the highest yielding entry, but eighteen other entries were not significantly different ($P < 0.05$) in yield from Kapielga. The top yielding entries included the U.S. hybrids IBMV8401M×68A4R4w and TG102.

Mean yield was also low in the Ghana 2003-04 trials. Varieties GB 8735, Arrow, Sosat-C88, Bongo Short Head, and Manga Nara were the highest yielding entries ($P < 0.05$). Arrow, Bongo Short Head, and Manga Nara are local Ghana varieties that exhibited site-specific adaptation.

Mean yield was greatest in the Mali 2003-04 trials. NKO x TC1 was the top yielding entry, and 12 other entries were not significantly different in yield ($P < 0.05$). Varieties originating in Mali and Niger predominated among the top-yielding entries, but included Gwagwa from Nigeria and Kapielga from Burkina Faso.

In the Niger 2004 trial, Taram and Sosat-C88 were the highest yielding entries. The trial was not replicated in this location so statistical comparison among varieties was not possible.

Mean yield was lowest in the Nigeria 2003-04 trials. NKO x TC1, Synthetic 1-2000, NKK, Bongo Short Head, Sosat-C88, Indiana 05, Sosank, and IBMV8401M × 68A4R4w were the highest yielding entries ($P < 0.05$). These entries represent Malian varieties, a Ghana variety (Bongo Short Head) and a U.S. hybrid (IBMV8401M × 68A4R4w).

Yields were obtained from Senegal only in the 2003 trial. A severe grasshopper infestation decimated the 2004 trial before harvest. In the Senegal 2003 trial, ICMV IS 89305, Sosank, CIVT, Gwagwa, and Sosat-C88 were the highest yielding entries ($P < 0.05$).

Among the subset of entries evaluated in the Zambia 2004 trial, GB 8735, Gwagwa, and NKK were the highest yielding entries ($P < 0.05$).

Downy mildew

Across all locations and years, entries ICMV IS 90311, Synthetic 1-2000, Zatib, Sosank, Taram, CIVT, ICMV IS 89305, Sosat-C88, 3/4 Souna, Gwagwa, HKP (GMS), DMR 72, Guéfoué 16, and NKO × TC1 had the lowest in-

Table 2. Grain yield of pearl millets evaluated at diverse locations in Africa in 2003 and 2004**.**

Entry	Grain Yield (kg/ha) at Location								Slope	P> |t|
	Burkina Faso	**Ghana**	**Mali**	**Niger**	**Nigeria**	**Senegal**	**Zambia**	**Mean**		
	2004	**2003-04**	**2003-04**	**2004**	**2003-04**	**2003**	**2004**	**2003-04**		
Sosat-C88	**828**	**1057**	**2392**	3627	**932**	**2028**	899	**1556**	**0.309**	**0.2362**
ICMV IS 89305	**776**	669	**2525**	2558	396	**2331**	1625	**1533**	0.826	0.0006
Gwagwa	**806**	709	**2289**	1888	488	**2085**	**2128**	**1510**	0.564	0.0133
NKK	**810**	562	**2585**	1891	**968**	794	**1976**	**1453**	0.878	0.0009
Sosank	**933**	781	1894	2182	**860**	**2163**	1551	**1409**	**0.024**	**0.9062**
CIVT	**804**	811	**2123**	2023	621	**2128**	905	**1344**	**0.206**	**0.3617**
Taram	570	699	**2165**	3909	405	1472	1188	1318	0.601	0.0295
HKP (GMS)	**873**	882	**2129**	1761	617	1661	726	1287	**0.162**	**0.4076**
NKO x TC1	**847**	564	**2654**	1918	**1259**	375	830	1285	0.768	0.0104
Kapielga	**1036**	690	**2407**	1686	430	266	-	1239	0.638	0.0317
Indiana 05	632	569	**2487**	1819	**883**	782	813	1236	0.688	0.0156
GB 8735	**722**	**1234**	998	1209	346	1120	**2673**	1210	**-0.656**	**0.0838**
Synthetic 1-2000	532	425	**2273**	1748	**1077**	677	-	1191	0.591	0.0020
ICMV IS 90311	**982**	838	1877	2108	620	1342	664	1189	**-0.031**	**0.8774**
Toronio	**783**	427	2063	2252	810	755	-	1151	0.446	0.0344
Zatib	**741**	657	1975	1081	259	1624	804	1123	**0.231**	**0.2033**
Guéfoué 16	**753**	528	**2410**	1850	693	593	360	1117	0.608	0.0254
Arrow	594	**1103**	1250	587	525	1023	1515	1062	-0.556	0.0055
P1449-2	423	514	1967	1581	347	865	1092	1041	0.446	<0.0001
Manga Nara	**869**	**935**	1078	1466	266	987	1280	970	-0.599	0.0071
Zongo	353	469	**2144**	2078	383	555	432	969	0.577	0.0021
IBMV8401M x 68A4R4w	**715**	714	1400	1245	**859**	577	-	956	-0.350	0.0300
Sadoré local	292	299	1993	214	383	1039	-	936	0.505	0.0203
Tongo Yellow	**742**	769	1294	1127	456	702	-	903	-0.413	0.0217
DMR 15	295	280	1919	327	385	871	-	892	0.479	0.0399
Bongo Short Head	413	**1004**	835	407	**966**	952	-	844	-1.017	<0.0001
3/4 HK	252	246	1752	848	310	601	-	803	0.359	0.0081
3/4 ExBornu	399	333	1468	640	473	687	-	776	**0.000**	**0.9998**
PT732B	**722**	297	1415	507	589	702	569	766	**-0.142**	**0.4361**
DMR 72	492	537	1292	903	358	418	-	752	**-0.219**	**0.1805**
DMR 68	430	252	1385	85	492	632	-	704	**-0.084**	**0.5916**
LCIC 9702	568	674	724	444	22	691	1384	701	-0.671	0.0025
3/4 Souna	385	217	1391	1256	200	450	-	680	**0.076**	**0.4702**
68A x 086R	315	800	950	1129	44	498	-	676	-0.540	0.0215
99M59043Mw x 68A4R4	425	655	902	638	575	466	-	674	-0.669	0.0005
TG102	**736**	630	679	153	79	851	-	600	-0.878	<0.0001
01Miso NCD2-NE	291	444	890	770	67	672	-	563	-0.457	0.0246
T454	164	674	634	0	91	94	-	434	-0.795	0.0003
99-72	129	520	377	0	271	108	-	327	-0.971	<0.0001
T99B	155	164	159	0	268	497	-	209	-1.052	<0.0001

Table 2. cont.

lsd (P<0.05)	350	335	548	*	420	549	798	230		
Location mean	588	616	1629	1298	502	928	1171	1002		

Data are pooled for locations with 2 years of evaluations.
Mean values in bold do not differ significantly (P<0.05) from the highest yielding entry.
* the Niger test was not replicated, so yield data could not be statistically compared.
- indicates that the variety was not evaluated.
LSD for location means = 119 kg/ha
Slopes in bold do not differ from zero

incidence of downy mildew (Table 3). In nearly all trials, the U.S. entries were among the most susceptible to downy mildew. This result was expected, since *S. graminicola* is not found in the western hemisphere and these entries were developed in the absence of selection pressure from the pathogen. When considering the slopes of the regressions in the stability analyses of the most resistant entries, only Gwagwa had slope = 0 ($P > 0.05$). The other resistant entries had negative slopes, indicating a comparatively lower level of incidence occurred in environments with high disease pressure.

Mean downy mildew incidence was lowest in the Burkina Faso 2004 trial. No entry had more than 7% incidence. Sixteen entries were free of any downy mildew symptoms.

Mean downy mildew was comparatively high in the Ghana 2003-04 trials. Entries Gwagwa, Sosat-C88, Sosank, and ICMV IS 90311 had downy mildew incidence less than 5%, although the downy mildew incidence of 18 other entries did not differ from that of the most resistant entry ($P < 0.05$).

In the Mali 2003-04 trials, entries 99-72, ICMV IS 90311, Synthetic 1-2000, 3/4 Souna, IBMV8401M × 68A4R4w, and Zatib had downy mildew incidence less than 5%, although the incidence of 11 other entries did not differ from that of the most resistant entry ($P < 0.05$).

In the Niger 2004 trial, 26 entries had no downy mildew symptoms, while others (primarily the U.S. entries) were highly susceptible. Statistical comparison of incidence among varieties was not possible since the test was not replicated.

Mean downy mildew incidence was greatest in the Nigeria 2003-04 trials. Sosat-C88 had downy mildew incidence less than 5%, although the downy mildew incidence of 24 other entries did not differ from that of the most resistant entry.

Data on downy mildew incidence was recorded in Senegal only in the 2004 trial. Eleven entries had no downy mildew symptoms, although the downy mildew incidence of 20 other entries did not differ from that of the most resistant entries.

No downy mildew infection was observed on any of the pearl millet entries grown in Zambia.

Some evidence for site-specific selection for increased virulence to local varieties was indicated in the data. Zatib was developed in and is more widely grown in Niger. It had intermediate levels of susceptibility in Niger and Nigeria, but was relatively resistant elsewhere. Sosat-C88 and Toronio are widely grown in Mali. Both entries had intermediate levels of susceptibility in Mali, but were comparatively more resistant in most of the other locations. Gwagwa and DMR-15 were developed in Nigeria. Both were susceptible in the Nigeria trials, but comparatively more resistant in the other trials.

Correlated traits

Across all locations and years, grain yield was negatively correlated with downy mildew incidence, and positively correlated with days to 50% flowering, plant height, and panicle length (Table 4). This general pattern of correlations was not consistent within the individual trials. Yield was not correlated with downy mildew incidence in the Ghana 2003 and Nigeria 2003 trials. Days to flowering had the least consistent correlations with grain yield. Correlations of yield with days to 50% flowering were positive in both Mali trials, negative in the Senegal 2003 and Zambia 2004 trials, and were not significant in the remainder. Correlation of yield with plant height was negative in Ghana 2003 and was not significant in Nigeria 2003 and Zambia 2004. Grain yield was correlated with panicle length in the Mali and Niger trials, and in the Nigeria 2004 and Senegal 2003 trials, but the correlation was negative in the Zambia 2004 trial.

DISCUSSION

Although we did not identify varieties that consistently performed well in all environments, Sosat-C88, ICMV IS 89305, Gwagwa, NKK, Sosank, and CIVT were the highest yielding entries across all locations and years. Sosat-C88, Sosank, and CIVT had more stable yields across locations and years, and could be considered to be the most broadly adapted of the highest yielding entries in these trials.

Omanya et al. (2007) suggested that breeding should be directed toward specific zones or regions, rather than

Table 3. Downy mildew incidence of pearl millets evaluated at diverse locations in Africa in 2003 and 2004.

Entry	**Downy Mildew Incidence (%) at Location**							**Slope**	**P> |t|**
	Burkina Faso	**Ghana**	**Mali**	**Niger**	**Nigeria**	**Senegal**	**Mean**		
	2004	**2003-04**	**2003-04**	**2004**	**2003-04**	**2004**	**2003-04**		
ICMV IS 90311	**0**	**4**	**1**	0	**15**	**0**	**3**	-0.649	<0.0001
Synthetic 1-2000	3	**5**	**1**	3	**8**	**2**	**4**	-0.839	<0.0001
Zatib	**0**	**5**	**3**	10	**15**	**0**	**5**	-0.578	<0.0001
Sosank	**0**	**4**	**12**	0	**12**	**0**	**7**	-0.579	0.0010
Taram	**0**	**7**	**8**	3	**16**	**0**	**7**	-0.473	0.0011
CIVT	2	**6**	**7**	8	**17**	**2**	**7**	-0.588	<0.0001
ICMV IS 89305	2	**6**	**9**	0	**12**	**3**	**7**	-0.679	<0.0001
Sosat-C88	**0**	**4**	13	0	**2**	17	**8**	-0.942	<0.0001
¾ Souna	2	**11**	**1**	0	**23**	18	**8**	-0.490	0.0310
Gwagwa	**0**	**2**	**6**	0	43	**3**	**9**	**-0.428**	**0.2804**
HKP (GMS)	**0**	**10**	15	0	**6**	**4**	**9**	-0.490	0.0054
DMR 72	**0**	**11**	**9**	0	**27**	**0**	**10**	-0.228	0.0452
Guéfoué 16	2	**6**	21	0	**11**	**3**	**10**	-0.608	0.0166
NKO x TC1	**0**	**10**	18	0	**7**	**6**	**10**	-0.601	0.0088
Zongo	**0**	**6**	**11**	3	36	**0**	11	**-0.095**	**0.7403**
IBMV8401M x 68A4R4w	**0**	22	**1**	18	38	**0**	13	**0.145**	**0.6027**
¾ HK	3	**11**	**5**	19	34	22	13	-0.662	0.0131
Sadoré local	**0**	23	18	0	**13**	**0**	14	**-0.050**	**0.7774**
LCIC 9702	2	29	**10**	0	**16**	**1**	14	**-0.018**	**0.9342**
99-72	4	30	**0**	0	**30**	**5**	14	**0.399**	**0.3426**
Kapielga	5	**16**	31	0	**6**	**0**	15	**-0.514**	**0.0705**
Indiana 05	2	**8**	32	0	**19**	**3**	15	**-0.419**	**0.1668**
P1449-2	**0**	**12**	13	0	59	**0**	16	**0.231**	**0.4578**
NKK	4	**14**	34	0	**5**	**3**	16	**-0.571**	**0.0749**
Arrow	4	20	31	3	**8**	**1**	17	**-0.187**	**0.4280**
DMR 15	2	**19**	**8**	0	48	15	17	**0.185**	**0.5238**
¾ ExBornu	6	28	**5**	0	**18**	40	17	**-0.280**	**0.5380**
Toronio	5	**11**	48	0	**12**	**2**	20	**-0.573**	**0.1688**
DMR 68	5	31	25	0	**18**	**12**	21	**0.215**	**0.4510**
Bongo Short Head	5	33	26	0	**28**	**4**	22	**0.365**	**0.0723**
Tongo Yellow	**0**	28	33	0	39	**0**	24	**0.264**	**0.3679**
Manga Nara	**0**	42	43	0	**18**	**5**	28	**0.692**	**0.0964**
01Miso NCD2-NE	7	42	26	5	54	13	29	0.955	0.0140
GB 8735	3	39	38	0	55	**3**	30	0.822	0.0026
99M59043Mw x 68A4R4	3	69	22	8	31	**6**	32	0.846	0.0413
68A x 086R	7	58	36	58	72	**2**	41	1.366	0.0031
PT732B	**0**	68	40	0	87	18	45	2.180	<0.0001
T454	3	86	37	29	77	**4**	47	1.624	0.0015
TG102	2	77	43	44	74	13	48	1.559	0.0003
T99B	6	61	48	20	72	65	53	**-0.257**	**0.6894**

Table 3. cont.

lsd (P<0.05)	6	17	12	*	28	12	7		
Location mean	2	24	20	6	30	7	18		

Data are pooled for locations with 2 years of evaluations.
Mean values in bold do not differ significantly (P<0.05) from the most resistant entry.
* the Niger test was not replicated, so incidence data could not be statistically compared.
LSD for location means = 3 %
Slopes in bold do not differ from zero.

Table 4. Pearson's correlation coefficients of grain yield with significant covariates in diverse pearl millets evaluated in multilocation trials in Africa in 2003-2004.

Location	**Year**	**Correlation of Yield (kg/ha) With**			
		Downy mildew incidence (%)	**Days to 50% flowering**	**Height (cm)**	**Panicle length (cm)**
All locations	2003-04	-0.142**	0.091*	0.387**	0.185**
Burkina Faso	2004	-0.272**	-	0.387**	0.064
Ghana	2003	0.004	-	-0.191*	-0.086
Ghana	2004	-0.227**	-	0.427**	0.004
Mali	2003	-0.221**	0.535**	0.745**	0.526**
Mali	2004	-0.21**	0.486**	0.556**	0.354**
Niger	2004	-0.282	0.022	0.636**	0.494**
Nigeria	2003	0.019+	-0.286	0.238	0.002
Nigeria	2004	-0.506**	0.044	0.406**	0.314**
Senegal	2003	-	-0.275**	0.303	0.253**
Zambia	2004	-	-0.334**	0.028**	-0.307**

attempting to produce varieties for broad adaptation. Earlier research by the ROCAFREMI (Réseau Ouest et Centre Africain de Recherche sur le Mil) network identified specific varieties that performed well within countries and across ecological zones (Ouendeba and Kohli, 2002). Differential yield performance was observed across the experimental sites, indicating some environment-dependent constraints on yield exist. In the present study, varieties such as Sosat-C88, Gwagwa, and NKK were among the top-yielding entries at most of the locations. Selection for further improvement in broad-based yield is likely to be possible.

In spite of the possibility of selecting for high and stable yield across environments, site-specific selection is necessary for other important traits. The genetic diversity of *S. graminicola* within Africa is poorly defined (Viswanathan, 2003), so multilocation screening is necessary to identify resistance to genetically diverse local pathogen populations. Sosank, CIVT, ICMV IS 89305, Sosat-C88, and Gwagwa were high yielding entries that were also included among the most downy mildew resistant entries. These entries were not consistently resistant, and other entries should be used as complementary sources of resistance for breeding in certain locations.

Within the limits of our experiments, downy mildew resistance and plant height were most consistently correlated with pearl millet yield, although other factors such as days to flowering may affect performance in certain production environments. The U.S. varieties performed poorly in these experiments, in part due to their downy mildew susceptibility and their dwarf stature. Evaluation of dwarf plants under population densities appropriate for larger plants put them at an inherent disadvantage. The yield advantage of taller plants is known (Bidinger and Raju, 1993) but extremely tall plants are not compatible with the mechanized production systems of the U.S. Lodging is less of a consideration in systems where most production practices rely on manual labor.

Local preferences for other traits such as panicle length can differ dramatically across production sites. Because of traditional harvesting and marketing practices, smaller panicles tend to be preferred in Ghana, and extremely long panicles are preferred in Niger. The absence of a correlation between yield and panicle length in Ghana supported this local practice. These and other local preferences are highly important in the overall acceptance of a new variety in specific locations.

The rate of adoption of improved pearl millet varietiest ends to be very slow in some regions due to a combination of factors that include seed availability, variety per-.

formance, or household preference (Ndjeunga and Bantilan, 2005). As an alternative to cultivar replacement, new varieties can contribute to introgressing new traits into adapted landraces (vom Brocke et al., 2003). Nigerian landraces with the same name but maintained by farmers are often genetically diverse due primarily to intermating with other local populations and genetic drift (Busso et al., 2000). Distribution of new germplasm to farmers for testing can encourage some introgression of superior traits into locally grown varieties through cross pollination. Progeny derived from outcrossing would be subject to farmer approval through the process of selecting seed plants for the subsequent crop.

The entries in the present study may also have value in developing hybrids for some regions. Bongo Short Head and Sosat-C88 were identified as having good combining ability for yield in Nigerian hybrid trials (Izge et al., 2007). The general absence of well-functioning seed systems will slow hybrid development and introduction, but this technology should have future value in certain production environments.

To achieve the commercial potential of pearl millet, growers must be able to depend upon a reasonably consistent yield, but varieties must also have specific characteristics desired by producers and end-users. If use of pearl millet for a high-value poultry feed expands, nutritional composition and digestibility will be important factors to consider. However, if the goal is to improve varieties for use in processed food products, high yield and downy mildew resistance alone will not ensure the success of a variety. In some evaluations, distinct differences among varieties exist for their suitability in preparing traditional foods (Ndjeunga and Nelson, 2005), while other studies show fewer differences in taste and color among varieties (Omanya et al., 2007). More information concerning the processing quality and consumer preference of these genotypes and their derivatives will be useful in determining appropriate breeding objectives.

Conclusion

Across these 10 trials, Sosat-C88, ICMV IS 89305, Gwagwa, NKK, Sosank, and CIVT were the highest yielding pearl millet entries. Sosat-C88, Sosank, and CIVT expressed more stable yields among the high-yielding entries. Sosank, CIVT, ICMV IS 89305, Sosat-C88 and Gwagwa were also among the most downy mildew resistant entries. Grain yield tended to be negatively correlated with downy mildew incidence, and positively correlated with days to flowering, plant height, and panicle length, but these correlations differed among some of the individual trials. Further selection for improved yield and broad adaptation in pearl millet is likely to be possible. Downy mildew resistance is an important trait for broadly adapted varieties. Site-specific selection is necessary to identify other important traits such as such as maturity, panicle length, and processing quality, which may be highly dependent on local preferences.

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REFERENCES

Bidinger FR, Raju DS (1993). A test of the “tall-dwarf” hypothesis in pearl millet, *Pennisetum glaucum* (L.) R. Br. Plant Breeding 111: 306-311.

Busso CS, DevosKM, Ross G, Mortimore M, Adams WM, Ambrose MJ, Alldrick S, Gale MD (2000). Genetic diversity within and among landraces of pearl millet (*Pennisetum glaucum*) under farmer management in West Africa. Genetic Resources and Crop Evolution. 47:561-568.

Ceccarelli S (1996). Adaptation to low/high input cultivation. Euphytica 92: 203-214.

Finlay KW, Wilkinson GN (1963). The analysis of adaptation in a plant-breeding programme. Australian J. Agric. Res. 14: 742-754.

Gupta GK, Singh D (1999). Role of edaphic factors in the development of downy mildew (*Sclerospora graminicola*) in pearl millet. J. of Agric. Sci. 133: 61-68.

Holland JB, Bjørnstad Å, Frey KJ, Gullord M, Wesenberg DM (2002). Recurrent selection for broad adaptation affects stability of oat. Euphytica 126: 265-274.

Izge AU, Kadams AM, Sajo AA (2007). Agronomic performance of selected cultivars of pearl millet (*Pennisetum glaucum* L. R. Br.) and their hybrids in north-eastern Nigeria. J. of Agron. 6: 344-349.

Jackson PA, McRae TA (1998). Gains from selection of broadly adapted and specifically adapted sugarcane families. Field Crops Res. 59: 151-162.

Ndjeunga J, Bantilan MSC (2005). Uptake of improved technologies in the semi-arid tropics of West Africa: Why is agricultural transformation lagging behind? e-Journal of Agric. and Dev. Econ. 2:85-102.

Ndjeunga J, Nelson CH (2005). Toward understanding household preference for consumption characteristics of millet varieties: a case study from western Niger. Agric. Econ. 32:151-165.

Omanya GO, Weltzien-Rattunde E, Sogodogo D, Sanogo M, Hanssens

N, Guero Y, Zangre R (2007). Participatory varietal selection with improved pearl millet in west Africa. Exp. Agric. 43: 5-19.

Ouendeba B, Kohli D (2002). ROCAFREMI – WCAMRN, 1991-2001. A Network’s Lessons. Some results of P1 project (1991-1996). Selecting and supplying farmers with appropriate varieties and seeds. International Crops Research for the Semi Arid Tropics. Pp. 39.

Semisi ST, Ball SFL (1989). Infection of the pearl millet (*Pennisetum americanum*) inflorescence by the downy mildew fungus (*Sclerospora graminicola*). Plant Pathol. 38: 571-576.

Viswanathan A (2003). Phylogenetic analysis of *Sclerospora graminicola* using internal transcribed spacer region-2. M.S. Thesis. Texas A&M University. pp. 42.

Vitale JD, Sanders JH (2005). New markets and technological change for the traditional cereals in semiarid sub-Saharan Africa: the Malian case. Agric. Econ. 32:111-129.

vom Brocke K, Weltzien E, Christinck A, Presterl T, Geiger HH (2003). Effects of farmers’ seed management on performance and adaptation of pearl millet in Rajasthan, India. Euphytica 130: 267-280.