Sources of Resistance to Downy Mildew and Rust in Pearl Millet

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ABSTRACT

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A total of 3,163 germ plasm accessions from many pearl-millet-growing countries in the world were evaluated for resistance to downy mildew (DM) (caused by *Sclerospora graminicola*) and/or rust (caused by *Puccinia penniseti*). The highest frequency of DM-resistant sources was detected in accessions from West Africa, followed by East Africa, but the reverse was the trend for rust resistance. Forty-eight selections from 37 early- to medium-maturing accessions (45–60 days to 50% bloom) showed high levels of combined resistance to DM and rust in three experiments. Five selections, IP1481-L-2 (India), P2895-3 (Niger), IP6240-2 (Cameroon), IP8877-3 (Burkina Faso), and 700481-5-3 (Nigeria), developed no more than 5% DM and rust in all tests. Six selections, D322/1/-2-2 (Niger), P1449-3 (Senegal), IP6147-4 (Cameroon), P8695-1 and P8899-3 (Sudan), and P3281 (Togo), developed 5% or less mean DM severity across locations in 2–3 yr of multilocation tests in India and West Africa. Four late-maturing accessions (>60 days to 50% bloom), P310, P472 (Mali), P1564 (Senegal), and 700516 (Nigeria), developed no DM and performed well agronomically in Zambia, Zimbabwe, Malawi, and Tanzania.

Downy mildew (DM) (caused by *Sclerospora graminicola* [Sacc.] Schroet.) and rust (caused by *Puccinia penniseti* A. Zimmerm.) are two important foliar diseases of pearl millet (*Pennisetum glaucum* [L.] R. Br.). DM is more destructive and widespread than rust in India and West Africa (6,7,9,11). Grain losses up to 60% have been reported from various African countries (1–3). In India, several cultivars were recently withdrawn because of their susceptibility to DM (10), and an estimated loss of 30% in high-yielding F_1 hybrids was reported (10). Although the disease is under control with the use of new DM-resistant cultivars, it continues to be the major constraint to the commercial usefulness of high-yielding cultivars (13). Rust is a potentially important disease and probably a yield-reducing factor in India and in some African countries, including Uganda, Kenya, and Malawi. Although actual yield-loss data are not available, the yield and quality of fodder can be greatly reduced by rust (5).

The use of resistant cultivars is the best method of disease control in pearl millet. To develop cultivars resistant to DM and rust, sources of resistance to these diseases are needed. A large number of accessions maintained by the ICRISAT Genetic Resources Unit were screened from 1976 to 1984 at ICRISAT Center for their reactions to DM and rust. These accessions represented a significant proportion of the world collection and were from most of the important pearl-millet-producing countries. Accessions with resistance to individual diseases and to both of the diseases are identified.

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MATERIALS AND METHODS

Screening for resistance to DM. Screening for resistance to DM was done at the ICRISAT Center, Patancheru (17° north latitude, 78° east longitude), Hyderabad, India, with a spreader-row system (17) during the rainy and dry seasons. Spreader rows were planted every fifth row until the 1980 rainy season and every ninth row thereafter. High humidity (95–100%) necessary for the production of inoculum (12) and for the infection processes (Singh et al, *unpublished*) was provided by a perfospray irrigation system. Each accession was planted in a single row, 4 m long and spaced 75 cm apart unless otherwise stated. An accession had at least 30 plants; some accessions had up to 50 plants. Pearl millet cultivars NHB3 and 7042, both highly susceptible to DM, were planted as controls after every 10 rows. DM incidence (%) was recorded at 25–30 days after planting and at the soft dough stage.

Screening for resistance to rust. Resistance to rust was evaluated at Bhavanisagar (11° north latitude, 77° east longitude), Tamil Nadu, India, where rust is moderate to severe almost every year during the winter rainy season (September–December). Each accession was planted in a single 3-m-row plot. There were 25–40 plants per accession. Susceptible checks (cultivar NHB3) were planted after every 10 test entries. No artificial inoculation was done. At soft dough stage, accessions were assessed for their rust reactions on the lower and upper (top four) leaves separately with Cobb's modified scale (4). However, only severity on the top four leaves is presented here because they contribute significantly to yield (8).

Preliminary screening. A total of 3,163 accessions were screened for DM and/or rust resistance from 1976 to 1982. The number of accessions screened for DM, rust, and combined resistance to both were 2,752, 2,681, and 2,257, respectively (Table 1). For the sake of presentation and interpretation of data, these accessions were classified into four groups: West Africa, East Africa, India, and miscellaneous (Table 1). The number of accessions screened from these four groups were 1,807, 543, 664, and 149, respectively. Although these accessions are only about 17% of the total maintained by the Genetic Resources Unit, they are a good representation from the majority of the pearl-millet-growing areas of the world.

Advanced screening I and agronomic evaluation. Four hundred and twenty-six of the 3,163 accessions that showed combined resistance to DM and rust (<5% DM and rust) in a preliminary screening were reevaluated for DM resistance at the ICRISAT Center during the 1983 rainy season in single-row plots, 4 m long, with two replications. Evaluations were made for tillering, plant height, panicle length, early and medium maturity (45–60 days to 50% bloom), seed set, and grain color. At maturity, 48 single-plant selections were made from 37 accessions that were agronomically acceptable. Rust reactions of these accessions were determined in screening at Bhavanisagar.

Advanced screening II and agronomic evaluation. The 48 selections were planted in two-row plots in two replications arranged in a randomized block design in the DM nursery during the 1984 rainy season. BJ104 and NHB3 were planted as checks for yield and susceptibility to diseases, respectively. Ten randomly selected plants per replication were assessed for plant height, productive tillers, and panicle length. Total grain weight per plot was taken by harvesting both rows. Thousand-seed weight was taken. These selections were assessed for rust resistance at Bhavanisagar.

RESULTS

Preliminary screening. The highest frequency of DM resistance (0–5% DM) was detected in accessions from West African countries; approximately 90% of the accessions from these countries and 75% from other African countries had no disease or less than 5% DM (Table 1). The majority of the accessions from India and other countries were moderate to highly susceptible to DM (>10% DM). The percentage of accessions that showed 10% or more DM were 5, 11, 58, and 52% for West Africa, East Africa, India, and miscellaneous locations, respectively.

Different from the DM data, the highest frequency (68% of the accessions) of rust resistant sources (0–10% rust) was detected in accessions from East Africa, followed by West Africa and India. The majority of the accessions from the other countries were moderate to highly susceptible to rust (>10% rust; Table 1).

Advanced screenings. DM and rust reactions from preliminary (1976–82) and two advanced screenings (1983 and 1984), along with their agronomic traits (data from advanced screening II), are presented in Table 2. Twenty-four of the 48 selections were free of DM in all screenings (Table 2). The remaining accessions, except three (P120-1, P2819-1, and P2910-2), developed ≤7% DM in one of the three screenings. No selection was rust-free in all three screenings. However, five selections, IP6240-2, IP8877-3, 700481-5-3, P2895-3, and IP1481-L-2, developed 0–5 % rust and an additional 21 selections had 10% or less rust in the three screenings. Other selections had 25% or more rust in one or two of the screenings (Table 2). No selection was free of both DM and rust in all three screenings.

Agronomic traits. Considerable variation was observed for plant height (113–198 cm) and panicle length (12–64 cm; Table 2). The productive tiller number ranged from two to five for all accessions except three, IP8876-2 (Burkina Faso), RC-011-3 (Zambia), and P2947-2 (Niger), which had less than two tillers per plant. Thousand-grain weight ranged from 5 to 10 g, and the estimated grain yield from 13 (P462-4, Mali) to 36 qt/ha (IP8749-1, Botswana; Table 2).

Table 1. Summary of preliminary screenings of pearl millet germ plasm accessions from different locations/countries for their reactions to downy mildew (DM) and rust at the ICRISAT Center and at Bhavanisagar, respectively, 1976–1982

Origin[c]	Total tested	DM incidence[a] (%)				Total tested	Rust severity[a,b]			
		0	1–5	6–10	>10		0	1–10	11–25	>25
West Africa										
Cameroon	137	88	40	5	4	139	19	99	15	6
CAR[d]	60	39	18	2	1	61	40	14	6	1
Ghana	123	58	40	20	5	116	0	73	28	15
Mali	312	220	80	10	2	313	2	95	63	153
Niger	424	276	117	17	14	530	98	192	124	116
Nigeria	278	117	95	26	40	276	8	165	78	25
Senegal	227	158	60	5	4	230	7	82	63	78
Togo	11	10	0	0	1	11	8	3	0	0
Burkina Faso	8	6	2	0	0	11	5	4	2	0
Total	1,580	972	452	85	71	1,687	187	727	379	394
East Africa										
Botswana	40	21	15	4	0	40	25	15	0	0
Kenya	48	6	16	15	11	49	0	4	11	34
Malawi	212	62	120	20	10	213	19	122	59	13
Sudan	105	51	41	13	0	105	53	45	7	0
Tanzania	5	1	2	1	1	5	2	2	1	0
Uganda	47	3	18	10	16	49	3	20	17	9
Zambia	25	12	1	0	12	25	8	9	7	1
Zimbabwe	51	11	20	10	10	57	28	21	6	2
Total	533	167	233	73	60	543	138	238	108	59
India										
Total	523	64	79	76	304	302	71	78	57	96
Miscellaneous										
Total	116	17	24	15	60	149	2	40	77	30

[a] Mean DM incidence and rust severities on checks ranged from 65 to 75% and 40 to 75%, respectively.

[b] Based on estimation using a modified Cobb's scale of leaf areas covered by rust pustules (upper four leaves only).

[c] **West Africa:** Cameroon (139), Central African Republic (CAR) (61), Ghana (123), Mali (313), Nigeria (389), Niger (530), Senegal (230), Togo (11), Houte Volta (11); **East Africa:** Botswana (40), Kenya (49), Malawi (213), Sudan (105), Tanzania (5), Uganda (49), Zambia (25), Zimbabwe (57). **India:** Eastern Ghat (38), Gujarat (4), New Delhi (169), ICRISAT (90), India (49), Jamnagar (209), Madhya Pradesh (8), Maharashtra (3), Rajasthan (11), Rayalaseema (64), Tamil Nadu (5), Uttar Pradesh (10), Vijayanagaram (4). **Miscellaneous locations:** USSR (8), USA (7), Lebanon (78), West Germany (1), Anchan Takalifa (1), Gantuwa (1), Igabi Kangam (1), Mitigi Dabbam (1), Mauritania (1), North Rhodesia (1), Southern Africa (6), Unknown (43).

[d] CAR = Central African Republic.

DISCUSSION

A large number of DM- and rust-resistant sources were identified. Although resistance was available in accessions from all of the millet-growing areas, the greatest frequency of resistant sources for DM and rust were from countries in Africa. Many of these sources have good agronomic characteristics and some possess a high degree of combined resistance to both of the diseases.

The highest frequency of DM-resistant sources was detected in accessions from West African countries. This was expected because the pathogen is endemic in this area (16). What was more surprising was that a high frequency of rust resistance sources was also detected in accessions from West Africa where rust is not a major problem. Similarly, high levels of DM resistance were detected in a large proportion of accessions from East African countries where the prevalence and incidence of DM are extremely low. These examples clearly illustrate that genes for resistance to DM and rust are present in many African countries.

Many of the accessions have been tested in many locations in an International Pearl Millet Downy Mildew Nursery (IPMDMN) in India and West Africa. Several of the selections, including D322/1/2-2, IP8699-3, IP8695-1, P3281-1, P1449-3, and IP6147-4, developed less than 5% mean DM severity across locations in 2 yr of testing (15). Pearl millet line P1449-3 is of particular interest because it also has recovery resistance, a phenomenon in which plants systemically infected at the seedling stage produce symptomless leaves and shoots and normal panicles (14).

Many of the late maturing accessions that were not suitable for use in India were evaluated in southern African countries for disease resistance and agronomic characteristics from 1986 to 1988, after their preliminary evaluation at the ICRISAT Center. Several of these accessions (which were not included here because of their late maturity [≥60 days to flower]), including P310, P472, and 700516 in Zimbabwe (S. C. Gupta, *personal communication*); P310, P1564, P454, and 700516 in Tanzania and Malawi (W. A. J. de Milliano, *personal communication*); and P310 in Zambia (P. Singh, *personal communication*), have been DM-free and performed very well agronomically. One of the entries, 700516, is a component of two pearl mil-

Table 2. Downy mildew (DM) incidence (%), rust severity (%), and yield parameters[a] of 48 selections from pearl millet accessions evaluated three times from 1982 to 1984

Selections	Origin	DM[b] (%) 1976–82	DM[b] (%) 1983	DM[b] (%) 1984	Rust[b] (%) 1976–82	Rust[b] (%) 1983	Rust[b] (%) 1984	Height[c] (cm)	Productive tillers[c] per plant	Panicle length[c] (cm)	1,000-grain weight (g)	Grain yield[d] (qt/ha)
IP8749-1	Botswana	5	0	0	5	65	5	164	3.0	22	9.0	36.3
IP6147-2	Cameroon	0	0	0	0	10	5	162	3.0	23	8.0	23.8
IP6147-4	Cameroon	0	0	0	0	10	0	160	3.0	29	7.4	23.9
IP6249-4	Cameroon	0	2	0	5	10	5	145	3.0	27	8.0	21.2
IP6240-2	Cameroon	5	0	0	5	0	0	142	3.0	16	5.3	23.2
P120-1	Cameroon	0	9	0	5	25	10	113	2.3	14	8.3	14.4
IP6138-3	Cameroon	0	0	0	5	10	0	166	2.0	25	6.4	20.5
IP6140-1	Cameroon	0	0	0	0	40	0	193	3.0	31	6.2	30.0
P181-2	CAR[e]	0	0	0	3	25	10	181	3.3	20	6.5	29.7
P181-6	CAR	0	0	0	3	25	10	149	5.0	18	6.3	22.5
IP8877-3	Burkina Faso	0	1	0	0	5	0	120	4.0	16	7.0	24.3
IP8876-2	Burkina Faso	0	0	0	0	65	25	139	1.4	17	8.0	21.2
P462-4	Mali	0	0	0	5	10	5	137	2.4	24	7.3	13.2
P536-2	Mali	0	0	0	5	...[f]	0	160	2.2	27	7.1	17.9
700481-5-3	Nigeria	0	0	0	5	5	0	165	2.5	27	7.4	16.8
P2895-3	Niger	0	0	0	5	5	0	160	2.5	20	5.0	13.0
P2910-2	Niger	4	15	0	0	...	10	145	2.4	17	6.0	17.0
P2914-3	Niger	0	0	0	0	...	10	149	3.0	22	7.4	20.0
P2925-1	Niger	3	4	0	0	...	10	154	3.0	19	8.0	27.0
P2933-1	Niger	0	0	0	0	10	0	174	2.0	37	6.4	25.0
P2933-2	Niger	0	0	0	0	10	0	198	2.0	38	7.0	17.0
P2947-2	Niger	0	5	0	0	10	0	186	1.4	64	8.0	14.0
P94/1/2-1	Niger	2	6	0	0	25	0	165	2.0	23	6.4	17.0
IP8998-1	Niger	5	6	0	0	10	0	161	3.0	20	7.0	25.0
IP8998-2	Niger	5	6	0	0	10	0	143	2.1	22	7.4	21.0
D332/1/2-2	Niger	0	7	0	5	10	0	152	3.0	20	6.4	24.0
D332/1/2-3	Niger	0	7	0	5	10	0	164	3.0	19	7.4	31.0
D332/1/2-4	Niger	0	7	0	5	10	0	114	3.0	24	5.5	20.0
P2819-1	Niger	0	13	0	0	...	10	158	3.0	21	8.4	30.0
P1449-2	Senegal	0	0	0	0	25	5	133	2.5	25	6.0	18.2
P1449-3	Senegal	0	0	0	0	25	5	130	2.5	27	7.0	19.3
P1449-4	Senegal	0	0	0	0	25	0	143	2.5	31	6.0	24.3
IP8695-1	Sudan	0	0	0	0	10	5	134	5.1	16	10.0	26.2
IP8695-4	Sudan	0	0	0	0	10	0	158	5.3	16	6.5	28.0
IP8699-3	Sudan	2	1	0	0	...	10	148	2.0	21	8.5	27.9
IP8714-1	Sudan	0	4	0	0	10	0	160	2.3	23	8.0	22.8
IP8703-1	Sudan	2	0	0	0	10	5	132	6.0	12	7.5	22.7
IP8703-4	Sudan	2	0	0	0	10	0	128	3.4	17	8.0	24.1
IP8710-1	Sudan	2	0	0	0	10	10	146	7.0	19	8.0	25.2
IP8715-4	Sudan	0	0	0	0	25	25	175	4.0	21	9.0	26.9
IP8748-1	Sudan	4	2	0	5	0	10	165	3.4	25	6.2	28.4
P3281-1	Togo	0	0	0	0	25	5	157	3.1	20	8.5	24.1
P3346-1	Togo	0	0	0	0	10	5	120	4.2	17	7.2	26.2
RC011-2	Zambia	2	0	0	0	25	5	171	2.3	28	6.2	21.3
RC011-3	Zambia	2	0	0	0	25	10	143	1.3	31	8.0	24.5
IP8830-1	Zimbabwe	1	0	0	0	40	10	154	6.7	24	7.2	21.4
75-3	India	0	0	0	0	40	5	172	4.0	22	7.0	28.3
IP1481-L-2	India	0	0	0	5	0	5	139	2.1	22	6.4	19.2
BJ104		...	...	10	...	...	40	127	4.0	16	6.4	21.1
NHB3[g]	India	65–80	75	88	40–75	60	65	...	...	...	...	...

[a] Evaluated during 1983 and 1984 at ICRISAT Center.
[b] DM incidence and rust severity were recorded at ICRISAT center and at Bhavanisagar, respectively.
[c] Plant height, productive tiller number, and panicle length are based on 10 randomly selected plants in each of the two replications.
[d] Grain yield is estimated based on the mean of two replications.
[e] CAR = Central African Republic.
[f] Data not collected.
[g] DM and rust susceptible checks.

let cultivars, ICMV 2 and ICMV 3, which were bred for DM resistance and released for cultivation in Senegal.

The reactions of some selections for resistance to rust and to DM have not been consistent over the years (Table 2). The differences in rust reactions may be attributable to one or more of the following reasons: 1) error caused by experimental design, 2) error caused by the differences in evaluation, or 3) physiological specialization within the pathogens. The few differences in DM incidence values between years are not large and are considered unimportant. The importance of this work is that it identifies many selections that have combined resistance to both diseases. These should be used in breeding programs.

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