Development of Resistance to Ergot in Pearl Millet

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ABSTRACT

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Twenty pearl millet cultivars, identified from more than 4,000 germ plasm accessions as relatively less susceptible to ergot, were intermated, and the progenies of these crosses were screened for ergot resistance at each generation from F_2 to F_6, using an improved resistance screening technique. At F_2, no population had a mean ergot severity of less than 20%, but when individual inflorescences that had little or no ergot were selected at each generation to provide selfed seed for the next generation, resistance levels increased steadily. At F_6, 27 of 98 lines had no more than 1% mean ergot severity, an additional 29 F_6 lines had mean ergot severities of between 2 and 10%, and susceptible checks showed 76–95% severity. This assembly of resistance factors is indicative of the rich genetic diversity in the pearl millet germ plasm collection and of the potential for selecting increased levels of certain characters by appropriate screening and selection techniques.

Additional key words: Pennisetum americanum, Claviceps fusiformis.

Ergot, caused by *Claviceps fusiformis* Loveless, was a minor disease of pearl millet (*Pennisetum americanum* (L.) Leeke) in India until the early 1970s when it became a serious problem in crops of the recently developed and adopted commercial F_1 hybrids (1,7–10). Today, ergot is one of the principal factors preventing the realization of the high grain-yield potential of pearl millet hybrids in Asia and Africa. In addition, it reduces the quality of the grain in an infected crop by contaminating it with the alkaloid-containing sclerotia of the pathogen (2,3,5,6). Thakur and Williams (10) presented evidence of a negative relationship between pollen availability and ergot severity in pearl millet and suggested that F_1 hybrids were more vulnerable to ergot than traditional open-pollinated varieties due to several factors that reduce pollen availability in hybrids at the critical time for infection. This understanding of the role of pollination in ergot-escape in pearl millet led to the development of an improved resistance screening technique. This article describes the technique and the progress made in its large-scale use in developing pearl millet lines with a high degree of ergot resistance.

MATERIALS AND METHODS

Initial screening techniques. During the 1975 and 1976 monsoon (rainy) seasons and the 1976–77 dry (postrainy) season, pearl millet germ plasm accessions were screened in the field at the farm of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) near Hyderabad, India, by dipping pearl millet inflorescences into aqueous conidial suspensions made with fresh honeydew conidia from infected plants. Conidial concentrations were standardized at about 1×10^6 conidia per milliliter. Inoculated inflorescences were covered with brown paper bags, and ergot ratings were made 14–28 days after inoculation. In 1975 the ratings were a direct assessment of the proportion of florets infected; in 1976 and early 1977 the inflorescences were scored on a 1–5 scale in which 1 was no ergot and 5 was more than 20% ergot. The class scores were used to calculate percent infection indices by the following formula: $[(X_2 + 2X_3 + 3X_4 + 4X_5)/4N] \times 100$, where X_2–X_5 are the numbers of inflorescences in classes 2–5, respectively, and N is the total number of inflorescences examined. At the same time that the initial screening for resistance was being conducted, several factors thought to affect the success of inoculation were examined (4,10). The results of these latter studies led to the development of the improved resistance screening technique, which was used to screen F_2 and succeeding generations, testing two crops each year since the 1977 rainy season.

Improved screening technique. Planting of test material was timed so that crop flowering occurred during the period with highest probability of cool wet weather during the rainy season and cool weather during the postrainy season (based on analysis of 70 yr of daily weather records by ICRISAT agroclimatologists). The main shoots of all plants to be inoculated were bagged with semiopaque white parchment bags at the "boot-leaf" stage, with the bags stapled tightly around the stems at the base of the "boots," so that the inflorescences emerged into a pollen-free and inoculum-free environment. When the bagged inflorescences were at the full

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fresh-stigma stage, the bags were briefly removed and the inflorescences were inoculated by spraying to runoff with aqueous conidial suspensions (about 1×10^6 conidia per milliliter), derived from highly susceptible, infected inoculum-source plants. The bags were replaced immediately after inoculation to minimize possible contamination of the inflorescences with external pollen. Overhead sprinkler irrigation was used for three 30-min periods on rainfree days throughout the inoculation and disease-development period during the rainy season and daily during the postrainy season screening. Ten to 14 days after inoculation, the proportion of ergot-infected florets was estimated and recorded for each inoculated inflorescence, with the aid of standard drawings previously described (10). Single rows of highly ergot-susceptible lines, planted between every 10 test plots throughout the screening area each season, were similarly inoculated to provide a measure of success of the screening process.

Test materials, hybridization, and selection. More than 4,000 accessions from the ICRISAT pearl millet germ plasm collection were screened in single 4-m rows during the 1975 and 1976 rainy seasons and the 1976–1977 postrainy season. Most accessions developed high levels of ergot and none was consistently resistant.

TABLE 1. Percent ergot infection indices[a] of 20 pearl millet lines screened for ergot reactions in 1975[b], 1976, and 1977 and used as parents in a program to develop ergot resistance

Line[c]	Year	
	1976	1977
J 606-2	11	23
J 703-1	5	57
J 797-1	12	25
J 1553	0	44
J 1999	7	31
J 2210-2	3	14
J 2238	4	21
700142	4	21
700583	12	36
700599	0	19
700619	6	27
MPP 7135-3-1	12	32
IP 1926	18	32
IP 1941	0	32
IP 2253	2	52
SC-1 (S4)27-2	7	40
SC-1 (S4)27-3	9	35
SC-2(M)13-4	13	41
Ex Bouchi-700638-3-2	0	25
ND 2282-79-1	1	45
Susceptible check (5141A)	66	97

[a] Percent ergot infection index = $[(X_2 + 2X_3 + 3X_4 + 4X_5)/4N] \times 100$, in which $X_2 - X_5$ are the number of inflorescences in infection categories 2–5, respectively, and N is the total number of inflorescences examined.
[b] All lines were ergot-free in 1975.
[c] Origin of lines: J = Jamnagar (India), 700. . . = breeding lines from Kano (Nigeria), MPP. . . = Mycology and Plant Pathology selection at New Delhi (India), IP. . . = world collection accession, SC. . . = Serere composite-breeders population (Uganda), Ex Bouchi = from Bouchi (Nigeria), ND. . . = New Delhi (India).

However, 20 accessions (Table 1) appeared to be consistently less susceptible than others, and these were crossed in pairs, some pairs reciprocally, to provide 269 F_1 progenies. The F_1 plants were grown in the 1977–1978 postrainy season, and the resulting F_2 populations were screened during the 1978 rainy season. Seed from individual inflorescences with little or no ergot, selected from the inoculated F_2 plants, were used to produce F_3 lines that were screened during the 1978–79 postrainy season. The process was repeated at F_4 (rainy season 1979), F_5 (postrainy season 1979–1980), and F_6 (rainy season 1980), with only ergot-free inflorescences selected at the latter two generations. Additional relevant details of the screening process are provided in Table 2.

RESULTS

The mean ergot reactions of all lines screened at each generation are summarized in Table 3. The overall levels of ergot declined steadily at each generation from F_2 (no population with less than 20% mean ergot severity) to F_6 (about 70% of the lines with no more than 10% ergot). A similar decline occurred in the progeny from the two crosses that contributed the most resistance among the F_6 lines (Tables 4 and 5). No line was completely free from ergot at any generation, and considerable variability occurred in the range of reactions among the inflorescences within lines, even at F_5. But at F_6, many lines with very little variability (0–1% ergot severity) were identified (Table 6). Ergot severities (76–95%) in the susceptible checks (Table 7) indicate the efficiency of the screening technique.

DISCUSSION

Through a process of intermating relatively less susceptible cultivars and screening each generation from F_2 to F_6 with high inoculum and selection pressures, pearl millet lines with a high degree of ergot resistance were developed. The steady increase in resistant segregants at each generation, the continued occurrence of some highly susceptible plants, and highly susceptible F_1 plants from crosses between ergot-susceptible and resistant lines (R. P. Thakur and R. J. Williams, *unpublished*) indicate that resistance to ergot is recessive and polygenically controlled.

The absence of high levels of resistance in germ plasm accessions and the general unimportance of ergot in the regions from which they originate are consistent with the hypothesis that the variable pearl millet landrace cultivars escape ergot and thus have not been subjected to selection pressure for the assembly of genes contributing to ergot resistance into a single genome. The pollen-based escape mechanism recently described (10) and photoperiod sensitivity that often delays flowering till the rains diminish (when the environmental conditions are less conducive to ergot infection) are likely to be the major components of the ergot-escape phenomenon.

Pearl millet germ plasm is characterized by rich diversity for many evident and cryptic characters, and rapid progress can be made in assembling the required genes to strengthen or diminish these characters, provided appropriate screening and selection techniques are used. In the rapid and significant progress reported in this paper, the key factors were the availability of a large germ plasm collection, the development of an effective screening technique, and the availability of resources to enable the technique

TABLE 2. Numbers of lines screened, crosses represented, replications made, and inflorescences inoculated and selected in F_2–F_6 generations in a program to develop high levels of ergot resistance in pearl millet.

Generation	Lines screened	Crosses represented	Replications per line	Inflorescences screened		Inflorescences selected
				Minimum per line	Total per generation	
F_2	269	53	...[a]	150	40,350	657
F_3	657	49	...	40	26,280	472
F_4	472	18	...	40	18,880	220
F_5	220	11	3	180	39,600	98
F_6	572	6	2	80–160	15,680	2,667

[a] Single plots per entry; 10 rows per plot at F_2 and two rows per plot at F_3 and F_4.

TABLE 3. Percentage[a] of pearl millet lines[b] in seven ergot severity classes in five generations in which the seed for the succeeding generation was taken from the least infected plants in the preceding generation

Mean ergot severity (%)	Percentage of lines in each class at				
	F_2	F_3	F_4	F_5	F_6
<1	0	0	0	1	14
1–10	0	2	15	14	56
11–20	0	6	21	19	18
21–30	6	11	28	16	9
31–40	9	16	22	20	2
41–50	18	16	9	15	<1
>50	67	49	6	16	0

[a]Rounded off to whole numbers.
[b]The F_2 lines were from 53 crosses and the F_6 progeny were from only six of these crosses.

TABLE 4. Seven ergot severity classes in five generations of pearl millet from a cross[a] between J 2238 and J 2210-2

Mean ergot severity (%)	Percentage[b] of lines in each class at				
	F_2[c]	F_3	F_4	F_5	F_6
<1	0	0	0	4	31
1–10	0	0	63	36	59
11–20	0	7	21	24	5
21–30	0	16	16	4	0
31–40	33	36	0	13	3
41–50	33	10	0	2	0
>50	0	32	0	16	2
Total lines screened	3	31	19	45	64

[a]One of two crosses having the greatest resistance at F_6.
[b]Rounded off to whole numbers.
[c]Three populations screened but only two scored.

TABLE 5. Seven ergot severity classes in five generations of pearl millet from a cross[a] between J 606-2 and J 703-1

Mean ergot severity (%)	Percentage[b] of lines in each class at				
	F_2	F_3	F_4	F_5	F_6
<1	...[c]	,0	0	9	82
1–10	...	5	13	18	9
11–20	...	5	14	27	3
21–30	...	16	31	9	3
31–40	...	11	31	36	3
41–50	...	21	7	0	0
>50	...	42	4	0	0
Total lines screened	6	19	71	11	34

[a]One of two crosses having the greatest resistance at F_6.
[b]Rounded off to whole numbers.
[c]Ergot reactions were not recorded, but ergot-free inflorescences were selected for the next generation.

to be used intensively on a large scale over several seasons. The development of the ergot-resistant lines described is, however, only the first step. If the resistance is to be of use, it will have to be combined with resistance to downy mildew and smut, two other diseases of major importance in pearl millet, and it must be incorporated into parents for the production of F_1 hybrids. The ICRISAT pearl millet improvement team is working intensively on these aspects and will make available to any scientist on request small quantities of the newly developed ergot-resistant lines described.

TABLE 6. Variability of pearl millet F_6 lines from two crosses

Cross	No. of lines with maximum ergot severity (%) on any individual inflorescence of				
	0	≤1	2–10	11–20	>20
J 2238 × J 2210-2	0	7	22	6	29
J 606-2 × J 703-1	0	20	7	2	5

TABLE 7. Ergot reactions (%) of susceptible checks planted in every 11th plot throughout the ergot-screening nurseries

Season	Generation screened	Susceptible checks			
		5141-A		BJ-104	
		Mean	Range	Mean	Range
1978 rainy	F_2	95	60–100	81	60–95
1978–1979 postrainy	F_3	95	50–100	90	75–100
1979 rainy	F_4	85	50–100	91	70–100
1979–1980 postrainy	F_5	76	30–98	90	50–98
1980 rainy	F_6	85	75–98	94	75–100

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