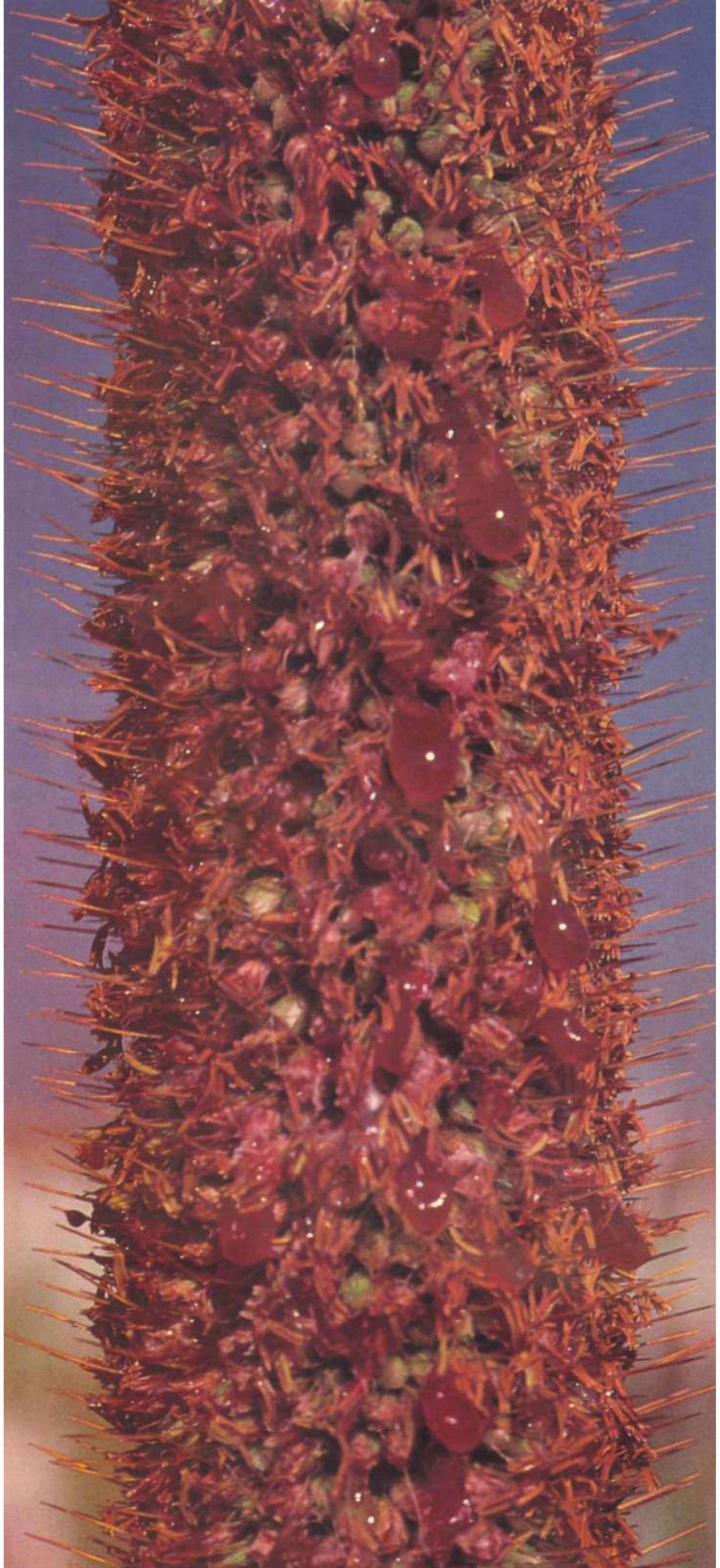
Identification and Utilization of Ergot Resistance in Pearl Millet



Research Bulletin no. 17

International Crops Research Institute
for the Semi-Arid Tropics

Abstract

Citation: Thakur, R.R, Rai, K.N., King, S.B., and Rao, V.P. 1993. Identification and utilization of ergot resistance in pearl millet. (In En. Summaries in En, Fr, Es.) Research Bulletin no. 17. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp. ISBN 92-9066-281-6. Order code: RBE 017.

Ergot *(Claviceps fusiformis)* is an important disease affecting pearl millet *(Pennisetum glaucum).* Host-plant resistance has been central to the disease management strategies at ICRISAT Center, and accordingly the identification, utilization, and deployment of resistance to ergot has been a major objective of pearl millet improvement research. This bulletin summarizes research work done at ICRISAT since 1977, which has led to the development of an effective field screening technique, based on a proper understanding of pathogen biology and disease epidemiology, and the role of pollination in ergot infection and resistance identification; development of ergot-resistance sources; determination of the stability of resistance; and utilization of some of these sources of resistance to breed agronomically elite ergot-resistant materials, especially hybrid seed parents.

More than 11 100 pearl millet entries were screened, and plants with <10% ergot severity were intermated to select lines with improved levels of resistance through pedigree breeding. About 280 ergot-resistant lines and populations were developed, and characterized for their reactions to smut, downy mildew, and rust, and for various agronomic traits. Some of the ergot-resistant lines and populations were used in breeding projects aimed at producing ergot-resistant male-sterile lines, hybrids, and open-pollinated varieties.

The information contained in this bulletin should be useful to breeders and pathologists involved in the genetic improvement of pearl millet. Small quantities of seed of ergot-resistant lines are available on request.

Résumé

Identification et utilisation de la résistance contre l'ergot du mil. L'ergot (*Claviceps fusiformis*) est une maladie importante qui affecte le mil (*Pennisetum glaucum*). La résistance de la plante-hôte a été l'axe principal des stratégies de lutte contre cette maladie au Centre ICRISAT. En conséquence, l'identification, l'utilisation, et le déploiement de la résistance à l'ergot a constitué l'objectif majeur des travaux de recherche sur l'amélioration du mil.

Ce bulletin fait un compte rendu des travaux de recherche effectués à l'ICRISAT depuis 1977 qui ont permis la mise au point d'une technique efficace de criblage au champ grâce à la connaissance approfondie de la biologie de l'agent pathogène et l'épidémiologie de la maladie, ainsi que du rôle de la pollinisation dans l'infection par l'ergot et l'identification de la résistance à la maladie. L'ouvrage expose également le développement des sources de résistance à l'ergot; la détermination de la stabilité de la résistance; et l'utilisation de quelques-unes de ces sources de résistance pour la sélection de matériel agronomiquement élite et résistant à l'ergot, en particulier des parents de semences hybrides.

Plus de 11 100 entrées de mil ont été criblées. Les plantes avec <10% de sévérité d'ergot ont été intercroisées pour la sélection des lignées ayant de meilleurs niveaux de résistance par la sélection généalogique. Environ 280 lignées et populations résistantes à l'ergot ont été créées et caractérisées pour leurs réactions au charbon, au mildiou et à la rouille, ainsi que pour des traits agronomiques divers. Quelques lignées et populations résistantes étaient utilisées dans des projets de sélection visant la production de lignées, d'hybrides et de variétés à pollinisation ouverte, ayant tous la résistance à l'ergot.

Les informations contenues dans ce bulletin devraient être utiles aux sélectionneurs et aux pathologistes travaillant pour l'amélioration génétique du mil. De petites quantités de semences des lignées résistantes à l'ergot sont disponibles sur demande.

Resumen

Identificación y utilización de germoplasma resistente al ergot en mijo. El Ergot (*Claviceps fusiformis*) es una enfermedad importante que afecta el cultivo de mijo (*Pennisetum glaucum*). El desarrollo de genotipos resistentes ha sido el enfoque clave de las estrategias de control de enfermedades en el ICRISAT. En efecto, la identificación, la utilización y el desarrollo de germoplasma resistente al ergot ha sido el objetivo principal de las investigaciones sobre el mejoramiento de mijo.

Este boletín resume las investigaciones realizadas en ICRISAT desde 1977, cuyos resultados han sido el desarrollo de una técnica eficaz llamada 'screening de campo', basada en la comprehensión apropiada de la biología patogénica y la epidemiología de enfermedades y el rol de polinización en la infección de ergot y en la identificación de resistencia; el desarrollo de fuentes resistentes al ergot; la determinación de la estabilidad de resistencia; y la utilización de algunas de estas fuentes de resistencia para engendrar agronomicamente materiales élites resitentes al ergot, especialmente semillas padres híbridas.

Mas de 11 100 mijos fueron sujetos a 'screening', y las plantas con menos de <10% de severidad de ergot fueron entreligados para seleccionar líneas con niveles mejorados de resistencia por métodos de pedigree. Casi 280 líneas y poblaciones resistentes al ergot fueron desarrolladas y caracterizadas por sus reacciones al carbón, al mildiu en el cultivo de mijo, al hongo, y para otras señales agronómicos. Algunas de las líneas resistentes al ergot se utilizaron para proyectos de mejoramiento para la producción de líneas resistentes al ergot, líneas estériles e híbridos y variedades de polinización abierta.

La información proporcionada por este boletín será de mucha utilidad a los mejoradores y a los fitopatólogos relacionados con el mejoramiento de mijo. Pequeñas cantidades de semillas de líneas resitentes al ergot están disponibles en el ICRISAT.

Cover : Pearl millet panicle infected by ergot.

Identification and Utilization of Ergot Resistance in Pearl Millet

R.P. Thakur, K.N. Rai, S.B. King, and V.P. Rao

ICRISAT

Research Bulletin no. 17

International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India

1993

Contents

Introduction

Ergot of pearl millet *[Pennisetum glaucum* (L.) R. Br.], caused by *Claviceps fusiformis* Loveless, is an important disease in many parts of the world (Rachie and Majmudar 1980, Thakur and King 1988a). F_1 hybrid cultivars based on cytoplasmic male-sterile lines are generally more susceptible to this disease than are open-pollinated varieties. Losses in grain yield as high as 65% in hybrids and 54% in open-pollinated varieties have been obtained in field experiments under artificial inoculation at ICRISAT Center (Thakur 1987). Grains contaminated with ergot sclerotia become unsafe for use as food and feed because of toxic alkaloids present in sclerotia (Bhat et al. 1976, Loveless 1967, Mantle 1968, 1992). Information is available on the geographical distribution, economic importance, pathogen biology, disease cycle, and various control measures (Thakur 1987, 1990, Thakur and Chahal 1987, Thakur and King 1988a). Short protogyny and rapid pollination were found to be associated with ergot resistance (Thakur and Williams 1980). Post-pollination stigmatic constriction may prevent infection of the ovary by the pathogen, and thus may provide resistance (Willingale et al. 1986). Susceptibility was found to be dominant over resistance (Thakur et al. 1983c).

Using a field-screening technique developed at ICRISAT Center (Thakur et al. 1982), we screened more than 11 100 entries (inbred lines, hybrids, populations, and germplasm accessions) from the genetic resources collection of the Genetic Resources Program and some breeding projects at ICRISAT Center, and the All India Coordinated Pearl Millet Improvement Project (AICPMIP). No entries with significant levels of ergot resistance were found. Nevertheless, resistance was developed by pedigree selection, followed by crossing among relatively less susceptible plants from several germplasm accessions and breeding lines. A number of ergot-resistant inbred lines and populations were developed.

Stability of resistance of some of these lines and populations was determined through collaborative multilocational testing at hot-spot locations in India and western Africa. All ergot-resistant entries were evaluated for agronomic traits and reactions to smut (*Tolyposporium penicillariae* Bref.), downy mildew (*Sclerospora graminicola* (Sacc.) Schroet.), and rust (*Puccinia penniseti* Zimm.). A number of ergot-resistant source lines and populations were used to breed male-sterile lines, hybrids, and open-pollinated varieties. Several agronomically elite, ergot-resistant male-sterile lines with high levels of resistance to smut and downy mildew were produced, and their potential use in breeding ergot-resistant hybrids was tested.

This bulletin describes the development of effective field screening techniques, and the progress made at ICRISAT Center from 1977 to 1991 towards the identification and utilization of ergot resistance in pearl millet. We hope that readers will find the information useful in developing a better understanding of the disease, and eventually in the management of ergot through host-plant resistance.

◄ *Left: Pearl millet panicle in the protogyny stage, during which plants are most susceptible to ergot. Center: Infected panicle; fungal spores of* Claviceps fusiformis *infect the ovary and prevent anthesis.* Right: *At anthesis; from this stage onwards, plants are immune to ergot infection.*

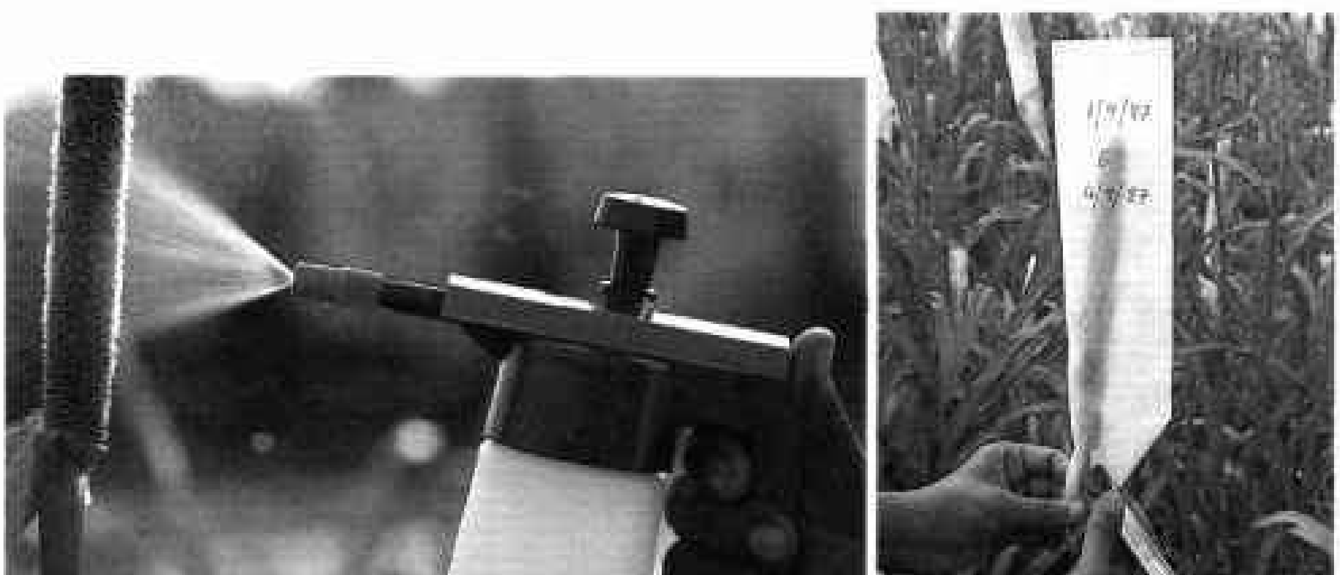
Field Screening Technique

The standard field-screening technique developed at ICRISAT Center (Thakur et al. 1982) was followed. Panicles are bagged at the boot-leaf stage, using selfing bags of parchment paper, and inoculated at the full protogyny stage (>75% stigma emergence) with an aqueous honeydew conidial suspension (approximately 10^6 conidia mL^{-1}) of C. *fusiformis* (Fig. 1). The suspension was obtained from the honeydew of previously inoculated panicles of a susceptible cultivar. High relative humidity (>80%) was maintained during flowering and early grain-filling by sprinkler irrigation, provided twice daily on rain-free days. The bags were removed 20 days after inoculation, and panicles were scored for ergot severity based on the percentage of florets infected (Fig. 2; Thakur and Williams 1980).

In the materials that we screened, the number of inoculated plants varied from 10 per entry in an inbred line or a progeny row to about 400 in a segregating F_2 population. We computed mean and range of ergot severity for each entry. Individual panicles and lines with low susceptibility to ergot (i.e., up to 10% severity) and good selfed seed set (>75%) were selected and advanced to the next generation for further evaluation and utilization.

B A

Figure 1. A. Bagging a pearl millet panicle at the boot-leaf stage with a parchment paper bag. B. Removing the bag at the maximum fresh-stigma stage, 3-4 days later. C. Spray-inoculating the panicle with a conidial suspension using a hand-held sprayer. D. Rebagging the panicle immediately after inoculation.



C D

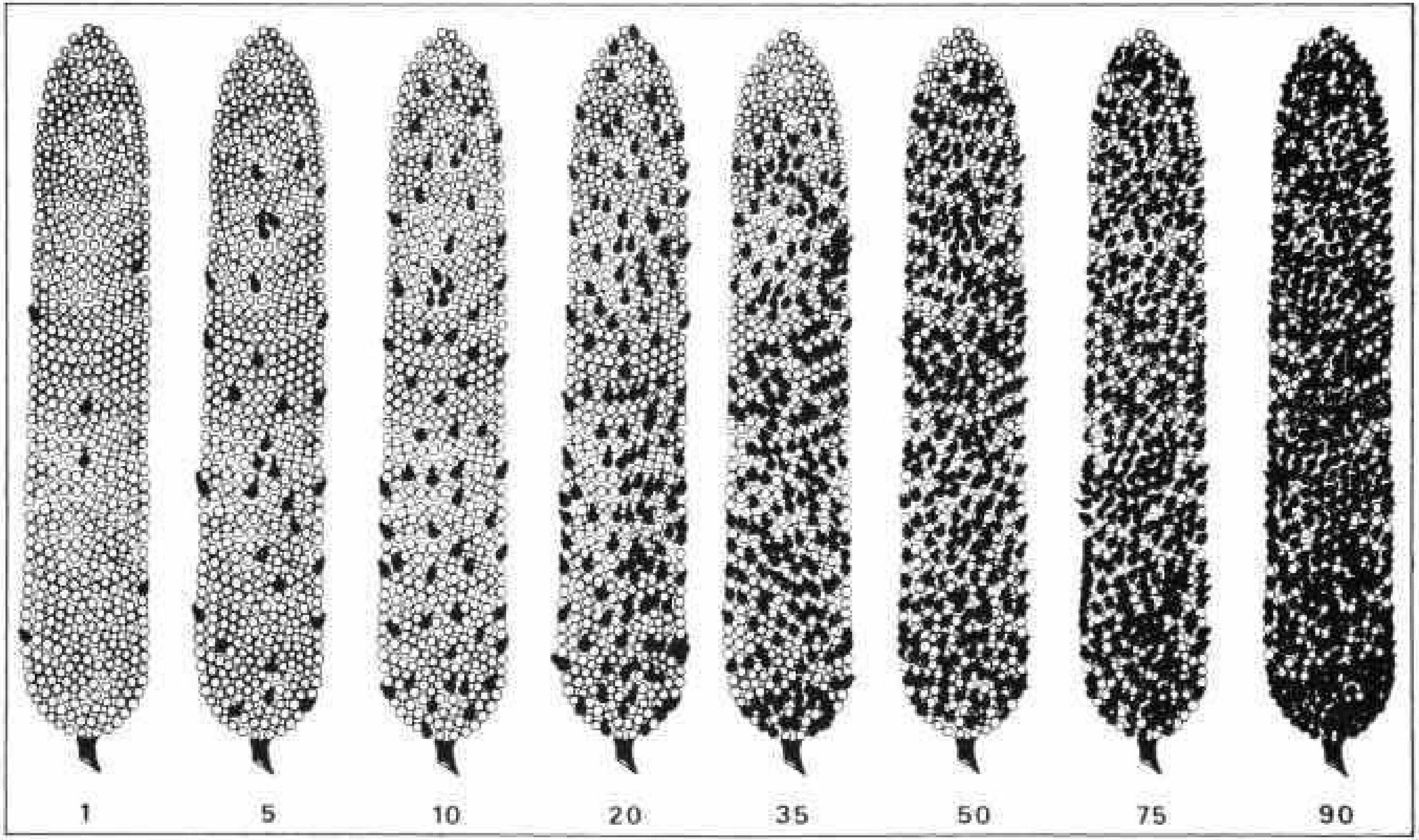


Figure 2. Severity rating scale for scoring the percentage of ergot-infected florets in a pearl millet panicle.

Identification and Improvement of Ergot Resistance

The various steps involved in the identification and improvement of ergot resistance in pearl millet are depicted in Figure 3.

Resistance in germplasm accessions

During the 1977-84 period, 2752 germplasm accessions from 19 countries and some unknown sources, obtained from the world collection of ICRISAT's Genetic Resources Program, were screened. No accession was found to have an acceptable level of resistance to ergot. However, 27 accessions originating from India (10), Nigeria (11), Togo (3), and Uganda (3) had varying frequencies of plants with 0-10% ergot severity and >75% selfed seed set (Table 1).

Seeds were harvested from panicles of plants belonging to these accessions, and used to produce head-to-row progenies, which were screened up to S_5 - S_8 following a pedigree breeding approach. A large number of individual plants were then selected for further evaluation and selection. Finally, crosses were made among selected progenies to develop higher levels of ergot resistance.

The geographical diversity of the 27 accessions that showed some degree of resistance (Table 2) may suggest a diverse genetic base for ergot resistance. However, genetic studies are needed to substantiate this.

Resistance in breeding materials

More than 8 350 entries from various ICRISAT and AICPMIP breeding projects were screened in the ergot nursery at ICRISAT Center during 1977-86. These included hybrids, male-sterile lines (A-lines), maintainer lines (B-lines), pollinator lines (R-lines), other inbred lines, and open-pollinated varieties and their S_1 progenies.

A large proportion of entries was susceptible to ergot. Hybrids in particular were more susceptible than open-pollinated varieties (Fig. 4); and in general, male-sterile inbred lines were more susceptible than male-fertile lines. A few inbred lines, populations, and hybrids showed up to 10% ergot severity, but their evaluation was complicated by two fac-

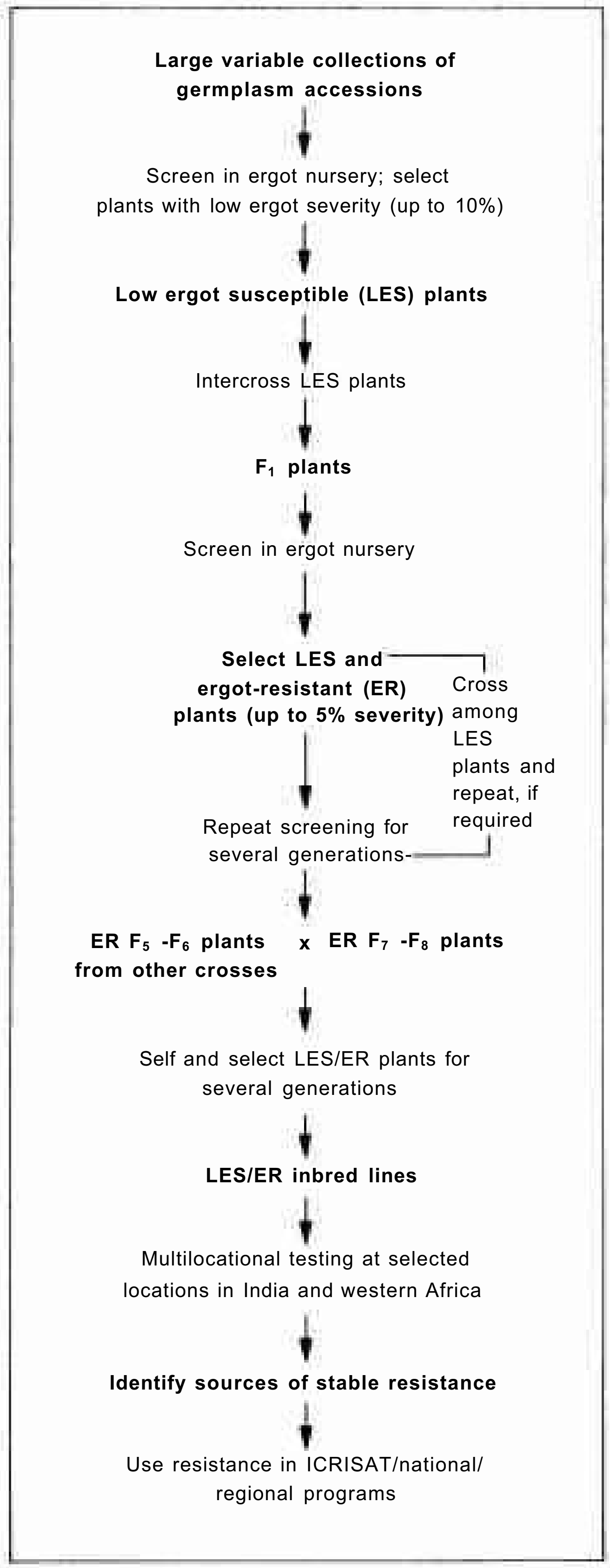


Figure 3. A scheme to identify and improve ergot resistance in pearl millet; adapted from Thakur and King *(1988a).*

Table 1. Origin of pearl millet germplasm accessions[1] screened for ergot resistance at ICRISAT Center, 1977-84.

Country of origin	Number of accessions: Screened	Resistant[2]
Botswana	3	0
Burkina Faso	5	0
Cameroon	45	0
Ghana	123	0
India	937	10
Lebanon	14	0
Mali	93	0
Mozambique	29	0
Niger	398	0
Nigeria	498	11
Senegal	123	0
Sierra Leone	52	0
South Africa	3	0
Sudan	46	0
Tanzania	129	0
Togo	178	3
Uganda	38	3
(Former) USSR	7	0
Zimbabwe	2	0
Others	29	0
Total	2752	27

1. Seed source: Genetic Resources Program, ICRISAT Center.

Table 2. Selected pearl millet lines used in crosses to generate high levels of ergot resistance.

Line	Country of origin
J 606-2	India
J 703-1	India
J 797-1	India
J 2238	India
J 2210-2	India
700448	Nigeria
700590	Nigeria
700599	Nigeria
700619	Nigeria
700687	Nigeria
700708	Nigeria
EB 700638-3-2	Nigeria
3/4 EB 77-2-1	Nigeria
SC-1 (S_4)-27-2	Uganda
Togo 29-9-2	Togo
Togo 35-1-1	Togo

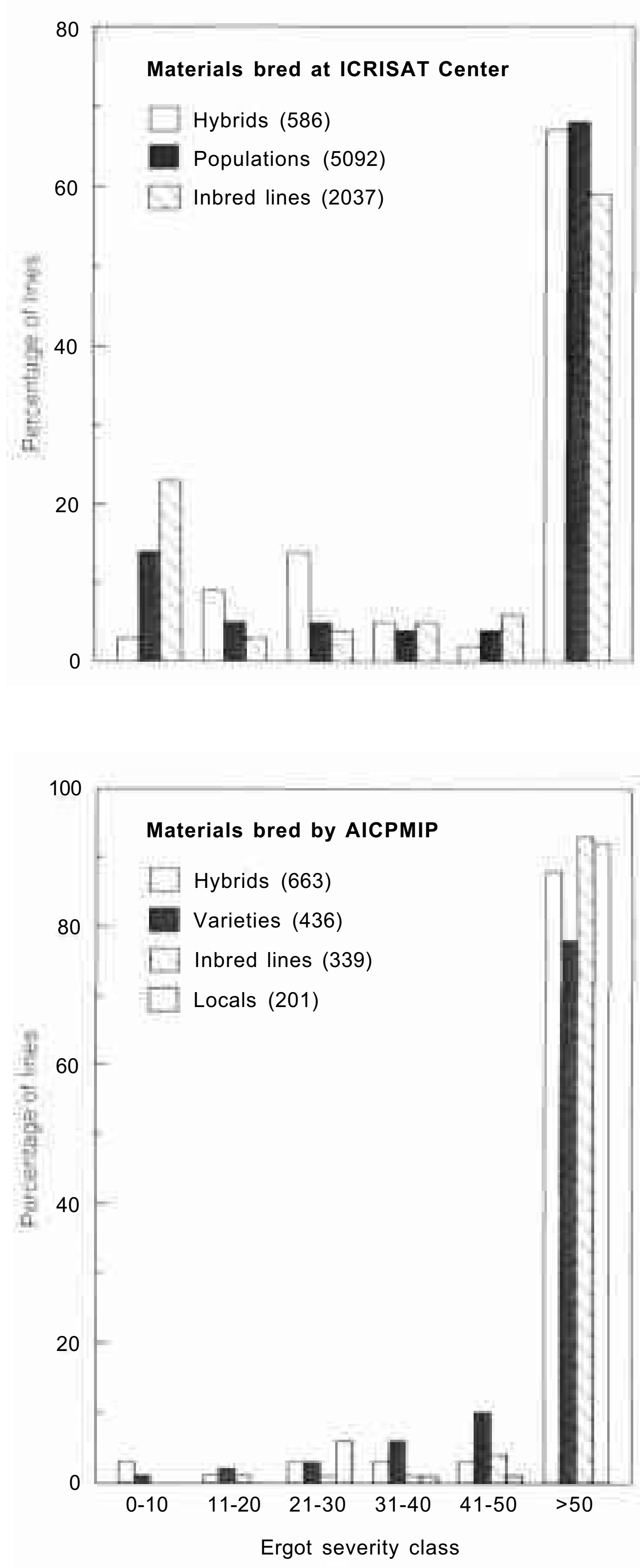


Figure 4. Ergot resistance in pearl millet breeding material from ICRISAT Center and the All India Coordinated Pearl Millet Improvement Project (AICPMIP), screened at ICRISAT Center, 1977-86. Number of lines shown in parentheses.

tors. Firstly, their reaction could not be confirmed as entries in the trials changed every year; and secondly, most of these entries also had poor selfed seed set, which prevented selection for further evaluation in the next generation. The frequency of lines in the 0-10% ergot severity range was generally greater in ICRISAT-bred materials than in those received from AICPMIP.

The screening of breeding materials for several consecutive years did not provide any positive results and therefore, in accordance with the recommendations of breeders and pathologists, routine screening of breeding materials for ergot resistance was discontinued after 1986.

Breeding materials are generally highly susceptible to ergot, probably because of a combination of two factors: lack of efforts to incorporate ergot resistance genes into breeding materials (possibly because ergot is seen as being less of a problem than downy mildew), and the inherent difficulty in breeding for polygenically controlled traits such as ergot resistance. Due to genetic heterogeneity, especially in flowering time, open-pollinated varieties suffer less from ergot under natural conditions than do homogeneous single-cross F_1 hybrids (Thakur and Williams 1980, Thakur et al. 1983a). The lack of genetic resistance coupled with the relatively longer protogyny periods, particularly in cytoplasmic male-sterile lines and their hybrids, further contributes to increased susceptibility.

A recent study (Thakur et al. 1991) has shown a significant positive relationship between ergot infection in cytoplasmic male-sterile lines and infection in their F_1 hybrids. All the male-sterile lines currently being used in India to produce commercial hybrids are highly susceptible to ergot and so are the hybrids based on them, irrespective of whether the pollinator is susceptible or resistant (Thakur et al. 1989b).

Development of resistant lines

Sixteen selections of germplasm accessions with relatively better ergot resistance (<10% severity) from India, Nigeria, Togo, and Uganda were used to make a number of plant x plant crosses. Of these, 16 crosses provided a high proportion of resistant plants in the F_3 to F_8 generations (Table 3).

Table 3. Crosses that provided a high proportion of ergot-resistant plants in F_3 to F_8 generations.

Origin	Cross
India x India	J 606-2 x J 703-1
	J 2238 x J 2210-2
	(J 606-2 x J 703-1) x (J 2238 x J 797-1)
	(J 2238 x J 797-1) x (J 606-2 x J 703-1)
Africa x Africa	700619 x 700599
	700599 x 3/4 EB 77-2-1
	700687 x 3/4 EB 77-2-1
	700448-1-E-2-3-7 x Togo 29-9-2-2
India x Africa	700708-1-E-3 x J 797-1-E-1-1
	700708-1-E-l x J 797-1-E-1-2
	J 2210-2-1-4-2-3 x Togo 29-9-2-1-1
	Togo 35-1-1-1 x (700708-1-E-l x J 797-1-E-1-2)
	(] 606-2 x] 703-1) x (700619 x 700599)
	(J 2238 x J 2210-2) x (700619 x 700599)
	(700638-3-2 x SC-l(S4)-27-2) x (J 2238 x J 797-1)
	(J 606-2 x J 703-1) x (700638-3-2 x SC-1(S_4)-27-2)

Pedigree breeding and selection for higher levels of ergot resistance and good selfed seed set were continued for several generations, until the lines showed uniformly high levels of resistance (<5% mean ergot severity). To improve the agronomic traits of resistant lines, double-crosses (involving four parental lines) were made, and pedigree selection followed for several generations until the lines were stabilized. These lines were maintained either by sibbing or by bulking the selfs, and were assigned ICMPE (ICRISAT Millet Pathology Ergot) numbers (Appendix 1). Lines with similar phenotypes were intermated to produce 52 random-mated bulk populations (ICMPES numbers). Some of these ICMPES populations were evaluated for reactions to smut and downy mildew in the respective disease nurseries at ICRISAT Center.

From 16 crosses among lines with low levels of ergot resistance (<10% mean severity), a number of resistant lines were derived at various segregating generations. Based on the stability of their resistance in multilocational testing, four lines (ICMLs 1, 2, 3, and 4) were identified as having relatively improved agronomic attributes (Table 4). These lines were registered as sources of stable resistance to ergot. The number of genes and the nature of resistance in these lines need to be determined.

Table 4. Ergot severity and agronomic traits of four inbred pearl millet lines identified as sources of stable resistance to ergot. Adapted from Thakur and King (1988a).

Line[1]	Reg. no.[2]	Ergot severity (%)[3]	Time to 50% flowering (d)[4]	Plant height (cm)[4]	Panicles per plant[4]	Panicle length (cm)[4]	1000-seed mass (g)[4]
ICML 1	GP-5	3	58	157	4	23	5.6
ICML 2	GP-6	2	57	158	4	23	5.4
ICML 3	GP-7	3	55	141	4	28	6.5
ICML 4	GP-8	4	56	166	3	27	6.7
Controls							
ICMS 7703		44	46	135	4	21	8.3
WC-C75		45	46	132	5	20	9.0
SE(m) (n = 12)			±1.0	±8.0	±0.4	±0.4	±0.2

1. ICML = ICRISAT Millet Line.
   ICML 1 = ICMPE 13-6-27, ICML 2 = ICMPE 13-6-30, ICML 3 = ICMPE 134-6-25, ICML 4 = ICMPE 134-6-34.
2. From Thakur and King (1988b).
3. Mean of 2-4 years of testing in the International Pearl Millet Ergot Nursery (IPMEN) at Samara (Nigeria), Aurangabad, Jamnagar, Patancheru, Ludhiana, New Delhi, and Mysore (India).
4. Based on a field experiment with two replications at Patancheru, 1983/84 postrainy season.

Similarly, four ergot-resistant populations (ICMPs 1, 2, 3, and 4) which showed combined resistance to ergot, smut, and downy mildew at ICRISAT Center and other locations in multilocational tests, also possessed relatively improved agronomic attributes (except plant height and maturity period) (Table 5). These populations were registered as sources of multiple disease resistance (Thakur et al. 1988). Further work is needed to understand the genetics of their resistance.

A total of 283 ergot-resistant lines and populations were identified, and designated as ICRISAT Millet Ergot Resistant (ICMER) numbers. The detailed pedigrees are provided in Appendix 1. These lines and populations were initially evaluated for resistance to ergot; subsequently for combined resistance to ergot, smut, downy mildew, and rust; and finally for general agronomic traits (Appendix 2).

Identification of stable resistance

At each stage in the development of ergot-resistant materials at ICRISAT Center, at least some entries were tested multilocationally in India and western Africa through an International Pearl Millet Ergot Nursery (IPMEN). The test locations were those where ergot is known to occur generally at a relatively high intensity under natural conditions: Aurangabad, Jaipur, Jamnagar, Ludhiana, Mysore, New Delhi, Patancheru, and Pune in India; and Kamboinse (Burkina Faso) and Samaru (Nigeria) in western Africa. These locations represent the major pearl millet growing areas from a latitude of 11° 11'N (Samaru) to 30°56'N (Ludhiana), with mean day temperatures of 17 to 33°C during the flowering period.

In collaboration with plant pathologists from research centers at these locations, 20-30 test entries and a susceptible control were evaluated in the IPMEN every year from 1977 to 1987. Some promising entries were tested continuously for 4-6 years to determine the stability of their ergot resistance across locations (environments and pathogen populations). Some of the less promising entries were replaced by other entries every 2-3 years.

A number of lines (ICMPE) and populations (ICMPES) were identified as having stable resistance over years and across locations (Tables 4 and 5; Thakur et al. 1985). These are probably the best sources of stable resistance available at present; some of these could probably provide durable resistance as well. This assumption is based on the fact that polygenically controlled traits (as in this case) are generally more durable than monogenically controlled ones.

Multiple disease resistance

A number of ICMPE and ICMPES entries were screened for several seasons for resistance to downy mildew and smut. Each entry was planted in 2-row, 4 m long plots in the downy mildew nursery at ICRISAT Center. Downy mildew screening followed the technique of Williams et al. (1981); infected plants were counted 30 days after emergence to determine the percentage incidence of downy mildew. Different tillers from mildew-free plants were inoculated with smut (Thakur et al. 1983b) and ergot (Thakur et al. 1982) to assess levels of resistance to these diseases. Seeds from plants showing resistance to all the three diseases were harvested, and their reactions confirmed during the next season. Seed stocks of these entries were increased by selfing, and stored for further use.

A large number of ICMPE and ICMPES entries have been identified as having adequate levels of field resistance to ergot, smut, downy mildew, and rust (Appendix 2, Tables 4 - 6).

Agronomic evaluation

ICMPE and ICMPES entries which showed combined resistance to ergot, smut, and downy mildew were evaluated for agronomic traits (plant height, time to 50% flowering, number of panicles per plant, panicle length, and 1000-seed mass) using standard methods, in different seasons at ICRISAT Center.

For more convenient selection of lines or populations for utilization in breeding programs, 168 ICMER numbers with multiple resistance to ergot (< 10% severity), downy mildew (< 10% incidence), and smut (< 5% severity), and with improved agronomic traits such as time to 50% flowering, plant height, panicle length, and 1000-seed mass (> 6 g), were classified into 19 groups (Table 6). The time to 50% flowering ranged from < 55 days

Table 5. Plant characteristics and disease reactions of four pearl millet populations identified as sources of multiple disease resistance.

Population[1]	Reg. no.[2]	Plant height (cm)	Time to 50% flowering (d)	Panicles per plant	Panicle length (cm)	1000-seed mass (g)	Ergot severity (%)[3]	Smut severity (%)[4]	Downy mildew incidence (%)[4]
ICMP 1	GP-1	170	57	4	25	6.5	1	0	3
ICMP 2	GP-2	152	55	4	26	6.8	1	0	2
ICMP 3	GP-3	157	60	4	32	8.2	2	0	1
ICMP 4	GP -4	158	57	4	27	8.6	4	0	1
Controls									
ICMS 7703		135	46	4	21	8.3	44	25	5
WC-C75		132	46	5	20	9.0	45	23	-
BJ 104		103	46	7	14	6.9	66	65	42
SE(m) (n = 42)		± 6.0	±1.0	±0.3	±0.7	±0.3	-	-	-

1. ICMP = ICRISAT Millet Population. ICMP 1 = ICMPES 1, ICMP 2 = ICMPES 2, ICMP 3 = ICMPES 28, ICMP 4 = ICMPES 32.
2. From Thakur and King (1988a).
3. Mean of 3 years (1981-83) of testing at 7-12 locations in India and western Africa.
4. Mean of 3 years (1981-83) of testing in multiple disease nursery at ICRISAT Center.

- = data not recorded.

Table 6. Nineteen groups of 168 ICMER (ICRISAT Millet Ergot Resistant) lines/populations based on agronomic traits[1] and disease reaction[2].

Group no.	Name of line			Time to 50% flowering (d)	Plant height (cm)	Panicle length (cm)	No. of lines
1	ICMER 027	ICMER 113	ICMER 131	≤55	≤150	21-25	4
	ICMER 132						
2	ICMER 021	ICMER 022	ICMER 030	≤55	151-180	21-25	13
	ICMER 034	ICMER 105	ICMER 112				
	ICMER 119	ICMER 127	ICMER 128				
	ICMER 138	ICMER 171	ICMER 286				
	ICMER 287						
3	ICMER 269	ICMER 270		≤55	151-180	≤20	2
4	ICMER 045	ICMER 046	ICMER 064	≤55	151-180	>25	11
	ICMER 068	ICMER 088	ICMER 103				
	ICMER 140	ICMER 181	ICMER 214				
	ICMER 215	ICMER 230	ICMER 231				
5	ICMER 018	ICMER 267	ICMER 275	≤55	>180	21-25	7
	ICMER 281	ICMER 285	ICMER 288				
	ICMER 289						
6	ICMER 098	ICMER 137	ICMER 204	<55	>180	>25	9
	ICMER 265	ICMER 266	ICMER 273				
	ICMER 276	ICMER 277	ICMER 278				
7	ICMER 114	ICMER 170	ICMER 203	56-60	≤ 150	≤20	4
	ICMER 205						
8	ICMER 085	ICMER 198	ICMER 202	56-60	≤ 150	21-25	5
	ICMER 242	ICMER 251					
9	ICMER 048	ICMER 069	ICMER 073	56-60	151-180	21-25	15
	ICMER 075	ICMER 097	ICMER 115				
	ICMER 141	ICMER 149	ICMER 157				
	ICMER 174	ICMER 178	ICMER 217				
	ICMER 222	ICMER 224	ICMER 234				
10	ICMER 011	ICMER 012	ICMER 017	56-60	151-180	>25	18
	ICMER 077	ICMER 091	ICMER 095				
	ICMER 123	ICMER 169	ICMER 216				
	ICMER 235	ICMER 237	ICMER 238				
	ICMER 239	ICMER 245	ICMER 250				
	ICMER 253	ICMER 255	ICMER 256				
11	ICMER 052	ICMER 057	ICMER 065	56-60	>180	21-25	5
	ICMER 104	ICMER 282					
12	ICMER 013	ICMER 060	ICMER 061	56-60	>180	>25	13
	ICMER 099	ICMER 101	ICMER 102				
	ICMER 107	ICMER 116	ICMER 124				
	ICMER 228	ICMER 229	ICMER 283				
	ICMER 284						

Continued....

Table 6. *Continued.*

Group no.	Name of line			Time to 50% flowering (d)	Plant height (cm)	Panicle length (cm)	No. of lines
13	ICMER 199	ICMER 200	ICMER 201	>60	≤150	≤20	5
	ICMER 208	ICMER 213					
14	ICMER 197	ICMER 209	ICMER 211	>60	≤150	21-25	5
	ICMER 218	ICMER 258					
15	ICMER 047	ICMER 086	ICMER 232	>60	≤150	>25	5
	ICMER 243	ICMER 252					
16	ICMER 003	ICMER 005	ICMER 074	>60	151-180	21-25	18
	ICMER 079	ICMER 125	ICMER 139				
	ICMER 156	ICMER 172	ICMER 187				
	ICMER 196	ICMER 206	ICMER 207				
	ICMER 210	ICMER 212	ICMER 219				
	ICMER 220	ICMER 246	ICMER 259				
17	ICMER 010	ICMER 023	ICMER 056	>6()	151-180	>25	20
	ICMER 058	ICMER 059	ICMER 078				
	ICMER 092	ICMER 093	ICMER 121				
	ICMER 223	ICMER 227	ICMER 233				
	ICMER 236	ICMER 240	ICMER 241				
	ICMER 244	ICMER 247	ICMER 248				
	ICMER 249	ICMER 254					
18	ICMER 063	ICMER 176	ICMER 280	>60	>180	≤20	3
19	ICMER 014	ICMER 096	ICMER 154	>60	>180	>25	5
	ICMER 163	ICMER 225					

1. Agronomic traits include 1000-seed mass > 6.0 g
2. Disease-resistant: <107% ergot severity, <10% downy mildew incidence, and <5% smut severity.

days in 47 entries to >60 days in 61 entries; plant height from <150 cm in 28 entries to >180 cm in 42 entries; and panicle length from < 20 cm in 14 entries to >25 cm in 71 entries. About 150 entries had very high levels of resistance (<5% severity/incidence) to ergot, smut, and downy mildew; and 26 of these entries were also resistant to rust (<10% severity) (Appendix 2).

Except for time to 50% flowering and plant height, most of these ergot-resistant lines/populations showed agronomic traits superior to those in lines/populations directly selected from germplasm accessions. A number of these lines/populations flower at least 8-10 days later and are 20-50 cm taller than popular cultivars. In areas where ergot is a recurring problem (e.g., southern Africa), these improved materials could be of value in developing ergot-resistant open-pollinated varieties.

In a preliminary multilocational trial in India during the 1984 rainy season, 18 ergot-resistant populations (ICMPES entries) were evaluated for natural ergot infection and grain yield at Pune, Aurangabad, Bhavanisagar, and Patancheru. Two popular open-pollinated released varieties, WC-C75 and ICMS 7703, were used as controls. The trial was conducted in a randomized complete block design in two replications with 4-row plots of 4 m length. Disease scores and grain yields were recorded.

Some of the ICMPES entries compared well in agronomic traits and grain yield with the control varieties (ICRISAT 1985). Ergot severity in 18 ICMPES entries under high ergot pressure ranged from 0 to 1% compared with 44% in ICMS 7703 and 45% in WC-C75. In addition, all the ICMPES entries showed very high resistance to downy mildew and smut. One of these populations, ICMPES 28, showed good grain yield potential and resistance to ergot in several years of testing in ergot-endemic areas in Zimbabwe and Tanzania (Walter de Milliano, pers. communication).

Inheritance of Ergot Resistance

Two ergot-resistant lines (ICMPE 13-6-9 and ICMPE 134-6-9) and two susceptible restorer lines (ICP 220 and J 104) were used to produce two crosses: ICMPE 134-6-9 x J 104 and ICP 220 x ICMPE 13-6-9. The parents, F_1S, F_2s, BC_1s, and BC_2s were generated and screened at ICRISAT Center during the 1982 rainy season using the standard ergot screening method (Thakur et al. 1982). Estimates of the components of genetic variance (Mather 1949) and genetic advance (Johnson et al. 1955) showed that resistance to ergot was inherited quantitatively, and controlled by recessive genes. Heritability estimates in a narrow sense were 0.55 and 0.31, and genetic advance 40% and 20% for ICMPE 134-6-9 x J 104 and ICP 220 x ICMPE 13-6-9, respectively (Thakur et al. 1983c).

This is the only study conducted so far on the inheritance of ergot resistance in pearl millet. Our attempts to select for agronomically elite breeding material, and to incorporate resistance into such material, confirm the complex nature of the inheritance of ergot resistance. However, more detailed genetic studies are needed to better understand the nature and inheritance of resistance to ergot.

Utilization of Ergot Resistance

Ergot-resistant lines were used at ICRISAT Center to breed male-sterile lines and open-pollinated varieties. Research was conducted in two phases. In the first phase (1981-84), the objective was to identify resistant lines which would be non-restorers on male-sterile lines (such as 81A, bred at ICRISAT), for conversion into male-sterile lines. In Phase II, which began in 1985, we selected resistant lines for hybridization with the maintainer of an elite commercial male-sterile line (843A). In addition, several other factors, such as floral biology and agronomic background of sources of resistance, were studied.

Male-sterile lines—Phase I

An ergot-resistant line (ICMPE 134-6-9) was identified as a non-restorer of 81A (a popular but ergot-susceptible A-line). Two plants of this line, in parallel backcross series (I and II), were converted into A-lines using the cytoplasm of 81A. Ergot severity was recorded in the F_1 and up to BC_4. Severity declined from 86% in F_1 to 5% in BC_4F_1 in series I, and from 76% in F_1 to 6% in BC_4F_1 in series II (Fig. 5). This shows how rapid progress can be made in recovering resistance to ergot when resistant lines are converted into A-lines.

81A and the partially converted resistant A-line at BC_3 were each crossed with seven resistant lines/populations (ICMPEs 13-6-27, 82-5, and 13-6-30; ICMPESs 1, 22, 38, and 16) to produce seven pairs of

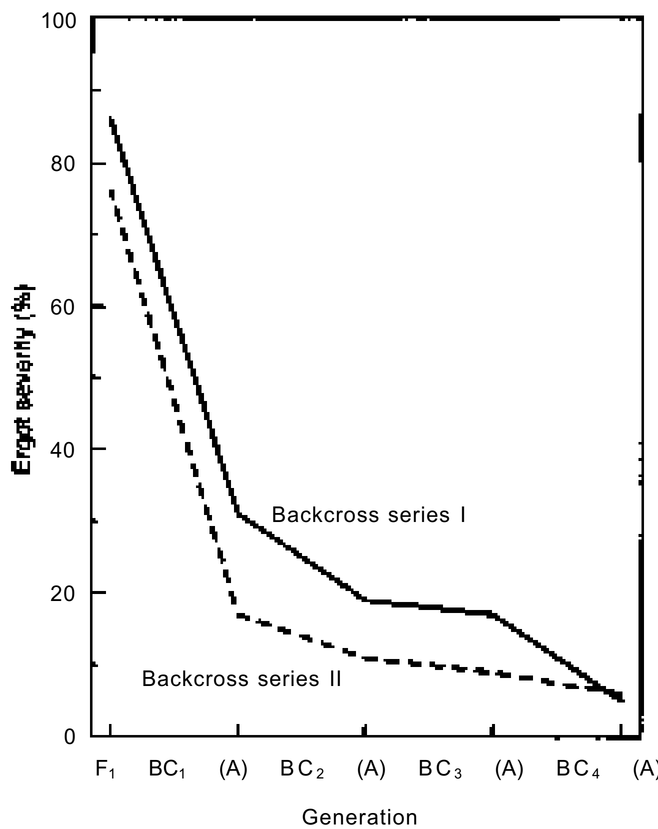


Figure 5. Ergot severity in two backcross series of 81A x ICMPE 134-6-9.
BC_1 *(A) -* BC_4 *(A) refer to male-sterile progenies at different backcross stages of conversion of the B-line ICMPE 134-6-9 into an A-line. Note that 81 A, used as a nonrecurrent donor of* A_1 *cytoplasm, had 867c ergot severity; the recurrent ergot-resistant parent ICMPE 134-6-9 had <1% ergot severity. Each data point is the mean of at least 40 inoculated panicles from two replications in the ergot nursery at ICR1SAT Center, 1984 rainy season.*

hybrids. Ergot reactions of A-lines, male parents, and their hybrids were determined in the ergot nursery during the 1984 rainy season. All F_1 hybrids of BC_3 A x resistant lines showed significantly less ergot (29-51% severity) than did F_1 hybrids of 81A x resistant lines (63-77% severity; Table 7). When the resistant line used as a pollinator was the same as the one converted into an A-line, ergot severity in the hybrid was as low as 5%.

These results clearly indicate the possibility of breeding hybrids with high levels of resistance, provided both parents have resistance from the same source. However, such an approach would tend to reduce the genetic diversity between male and female parents, leading to a reduction in heterosis for grain yield of the hybrid.

Individual plants selected from 30 F_5 progenies which showed <20% severity were used as pollinators to produce 642 test-cross hybrids during the 1982/83 postrainy season. The pollinators were derived as follows: 3 from J 606-2 x J 703-1, 1 from J 703-1 x J 606-2, 15 from J 2238 x J 2210-2, and 11 from 700619 x 7(X)599. Three ergot-susceptible A-lines were used: Pb 111A (76% severity), 5054A (80% severity), and 5141A (83% severity). The test-crosses were evaluated for ergot reaction during the 1983 rainy season. Another set of 89 test-cross hybrids was made between seven ergot-resistant (10-22% severity) sister A-lines (backcrossing of individual plants of ICMPE 134-6-9 into 81A cytoplasm) and ergot-resistant pollinators (1-8% severity) (Table 8). These were evaluated for ergot resistance during the rainy seasons in different years.

Ergot severity in the 642 test-cross hybrids of susceptible A-lines ranged from 63 to 98%. In contrast, severity in the 89 test-cross hybrids (of resistant A-lines) ranged from 7 to 81%; three hybrids showed a severity of <10% (Table 8). These results clearly demonstrate that in order to breed resistant hybrids in pearl millet, both parents must be resistant.

Table 7. Ergot severity of partially converted ergot-resistant male-sterile lines, pollinators, and their F_1 hybrids, ICRISAT Center, rainy season 1984.

Cross	Ergot severity (%)[1]		
A-line x pollinator	A-line	Pollinator	F_1
BC_3 (A)-1 x ICMPE 13-6-27	3	4	34
81 A x ICMPE 13-6-27	83	4	77
BC_3 (A)-1 x ICMPE 82-5	3	2	38
81 A x ICMPE 82-5	83	2	63
BC_3 (A)-2 x ICMPE 13-6-30	1	1	46
81 A x ICMPE 13-6-30	83	1	67
BC_3 (A)-3 x ICMPES 1	21	7	38
81 A x ICMPES 1	83	7	67
BC_3 (A)-4 x ICMPES 22	21	7	51
81 A x ICMPES 22	83	7	63
BC_3 (A)-5 x ICMPES 38	10	4	36
81 A x ICMPES 38	83	4	63
BC_3 (A)-5 x ICMPES 16	10	2	29
81 A x ICMPES 16	83	2	77
Control			
BC_3 (A)-8 x ICMPE 134-6-9	17	<1	5
SE	±9.7	±0.6	±5.2

1. Mean of 10 inoculated panicles from a single-row unreplicated trial.

Table 8. A summary of ergot reactions of test-cross hybrids using ergot-resistant pollinators.

A-line	No. of test-cross hybrids	Ergot severity[1] (%)		
		A-line	Pollinator	Hybrid
Set I[2]				
Pb 111A	189	76	<l-20	63-85
5054A	216	80	<l-20	84-98
5141A	237	83	<l-20	65-92
Set IP				
ER-A-1	10	14	1	19-49
ER-A-2	9	10	1	9-36
ER-A-3	11	14	1	22-59
ER-A-4	9	13	1	18-39
Set HI[4]				
ER-A-3	19	5	8	17-67
ER-A-4	16	3	8	7-64
Set IV[5]				
ICMA 91113	5	19	1-8	8-81
ICMA 91114	5	22	1-8	48-79
ICMA 91115	5	15	1-8	18-72

1. Mean of 10-30 inoculated panicles from 2-3 replications at ICRISAT Center ergot nursery. Set 1 1983, Set II 1985/86, Set III 1987/88, Set IV 1990 rainy season.
2. 3 selections from J 606-2 x J 703-1, 1 selection from J 703-1 x J 606-2, 15 selections from J 2238 x J 2210-2, and 11 selections from 700619 x 700599.
3. ER-A-1, A-3, A-2, A-4 = (81A x ICMPE 134-6-9)-9-2-4-3-6 BC5, (81A x ICMPE 134-6-9)-9-2-4-3-6 BC6, (81A x ICMPE 134-6-18)-9-2-4-5-2 BC5, and (81A x ICMPE l34-6-18)-9-2-4-5-2 BC6, respectively. Pollinator : ICMPES 23
4. Pollinator : Togo 54-5-4-5
5. ICMA 91113 = $81A_1$ x (843B x ICMPES 29)-23-5-2B
   ICMA 91114 = $81A_1$ x (843B x ICMPES 34)-56-2B
   ICMA 91115 = $81A_1$ x [ICMPES 34 x (843B x ICMPES 34)]-155-4-2
   Pollinators: ICMPES 1, ICMPES 2, ICMPES 33, ICMPE 1-1-14-4-2-1, ICMPE 2-2-2-1-4-2

Male-sterile lines—Phase II

The direct utility of ergot-resistant sources in breeding male-sterile lines was constrained by their later maturity, greater plant height, smaller seed size, and unknown combining ability. Therefore, an attempt was made in this phase to breed for ergot resistance in improved agronomic backgrounds. Two ergot-resistant sources (ICMPES 29 and ICMPES 34), planted in the 1984/85 postrainy season in isolation plots for seed increase, were crossed with 843B, which is the maintainer of a popular male-sterile line (843A). The latter is characterized by d_2 dwarf height, early maturity, large seed size, good tillering, excellent panicle exsertion, and good general combining ability. In the 1985 rainy season, both F_1s were selfed to produce F_2 populations and were also backcrossed to their respective ergot-resistant parents to produce BC_1F_1 populations.

Agronomic traits and disease resistance

Downy mildew is a serious disease of major concern in the breeding of hybrid parents in pearl millet. Selection for resistance to downy mildew became particularly important because 843B, which is used as an elite maintainer line in the ICRISAT hybridization program, is susceptible to the disease. The F_2 populations (843B x ICMPES 29 and 843B x ICMPES 34) and the BC_1F_1 populations [ICMPES 29 x (843B x ICMPES 29) and ICMPES 34 x (843B x ICMPES 34)] were screened for downy mildew resistance in the greenhouse by spray-inoculating seedlings at the coleoptile to 1-leaf stage with a suspension of sporangia, and incubating them for 12-16 h under 95% relative humidity (ICRISAT 1988). The disease-free seedlings (more than 5 000 from each F_2 and more than 1 000 from each BC_1F_1) were transplanted to the field in the 1985/86 postrainy season. Based primarily on shorter plant height, earlier flowering, and good exsertion, more than 1 600 plants in each F_2 population, and about 400 plants in each BC_1F_1 population, were screened for ergot resistance.

Plants that showed resistance to ergot coupled with large seed size, good selfed seed set, and good tillering were selected for advancement to the next generation. The proportion of plants selected for advancement varied from 1.9 to 3.4% in F_2 and 3.1 to 14.8% in BC_1F_1 populations (Table 9).

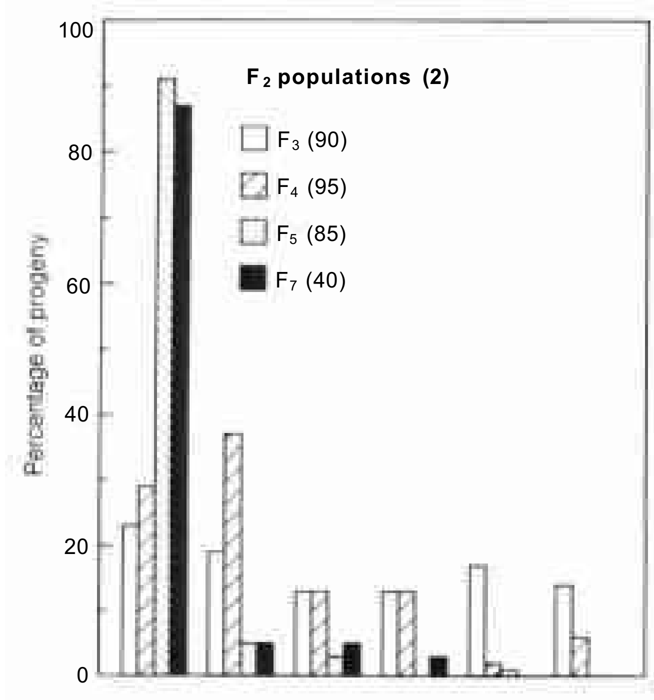
Pedigree breeding with simultaneous visual selections for agronomic traits and ergot resistance was continued until the F_7 and BC_1F_6 generations in the above crosses. Selection for downy mildew resistance, initially done in the F_2 and BC_1F_1 populations, was done twice more: at the F_5 and BC_1F_4, and F_7 and BC_1F_6 stages.

About 20-30% of the F_3/F_4 progenies derived from F_2 populations had <10% ergot severity, and 6-14% had >50% severity (Fig. 6). By the F_5/F_7 generations (F_6 progenies were not screened) about 90% of progenies had <10% severity, and very few had >30% severity. In BC_1-derived progenies, the proportion of lines with <10% severity was higher (45-50%) in the initial generations (i.e., F_2/F_3) than in F_2 -derived progenies. By the F_4/F_6 stage, however, the frequency of progenies with <10% severity increased to about 80%, which was slightly less than in F_5/F_7 progenies derived from the single-cross F_2 populations. Selections were made for a combination of high resistance levels and desirable agronomic traits. The number of F_7 progenies finally selected from F_2 populations was much higher than F_6 progenies derived from BC_1 populations. This was not unexpected, because BC_1-derived progenies consisted of a larger proportion of genetic materials from ergot-resistant sources, which had relatively poor agronomic backgrounds.

Table 9. Number of plants inoculated with ergot and selected for advancement in two F_2 and two BC_1F_1 populations, ICRISAT Center, 1985/86 postrainy season.

Population	Pedigree	Number of plants: Inoculated	Number of plants: Selected[1]	Percentage of plants selected
F_2	843B x ICMPES 29	1660	32	1.9
	843B x ICMPES 34	1741	59	3.4
BC_1F_1	ICMPES 29 x (843B x ICMPES 29)	475	15	3.1
	ICMPES 34 x (843B x ICMPES 34)	432	64	14.8

1. Plants showing <10% ergot severity, good selfed seed set, shorter plant height, and early flowering as in 843B were selected and harvested.



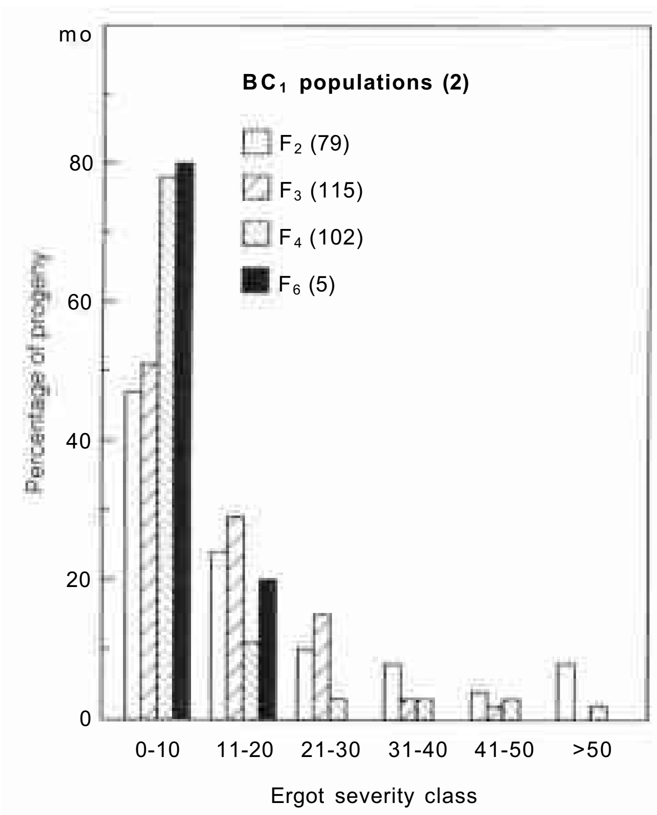


Figure 6. Ergot severity in progenies of various inbreeding generations derived from F_2 and BC_1 F_1 populations, ICRISAT Center, 1986.

F_2s: 843B x ICMPES 29; 843B x ICMPES 34. BC_1s: ICMPES 29 x (843B x ICMPES 29); ICMPES 34 x (843B x ICMPES 34). Number of populations or progenies shown in parentheses.

Fertility / sterility of hybrids

About 80 F_5 progenies derived from both single-cross populations and about the same number of F_4 progenies derived from one backcross population, were crossed with 81A in the 1987 rainy season. The hybrids were evaluated in the 1987/88 postrainy season for pollen fertility/sterility (based on a visual score of pollen shedding), and classified as fertile or sterile.

About 79% of the hybrids based on F_5 progenies from single-cross populations, and about 71% of those based on F_4 progenies from the backcross populations, were male-sterile (Table 10). Poor fertility restoration in hybrids is often associated with high ergot susceptibility. This was clearly reflected in earlier studies (Thakur et al. 1989b, 1991), where hybrids with poor selfed seed set were more susceptible to ergot than those with good seed set under selfing.

Bloral biology of resistant A-lines

Ergot resistance is closely associated with floral characteristics of the genotype (Thakur and Williams 1980, Willingale et al. 1986). To determine this association, four ergot-resistant A-lines at BC_5 and BC_6 were compared with their corresponding B-lines for stigma length, length of protogyny (time between stigma emergence and anther emergence), time between stigma initiation (SI) and 75% stigma emergence (SE), time between SI and stigma withering (SW), and time between SE and anthesis initiation (AI). A popular hybrid cultivar, BJ 104, was

Table 10. Fertility/sterility reaction of hybrids made by crossing ergot-resistant progenies onto a male-sterile line 81A, ICRISAT Center, 1987/88 postrainy season.

		Number of hybrids on 81A		
Cross	Progenies	Total	Sterile	Male-fertile
843B x ICMPES 29	F_5	64	51	13
843B x ICMPES 34	F_5	17	13	1
ICMPES 34 x (843B x ICMPES 34)		82	58	24

843B was ergot-susceptible; ICMPES 29 and ICMPES 34 were ergot-resistant populations.

used as a control. Nine entries (four A-lines, four B-lines, and a control) were tested in two replications during the 1985 rainy season at ICRISAT Center. In each replication, at least five panicles which had been covered with selling bags were examined for the above floral characteristics. These entries were also evaluated for ergot resistance and selfed seed set.

The two BC_5 and BC_6 ergot-resistant A-lines had significantly longer protogyny periods (55-65 h) than their respective B-lines (48-50 h). The control hybrid BJ 104 had the longest protogyny of 106 h (Table 11). The time from SI to *75%* SE was roughly similar in A-lines and their respective B-lines. The SI to SW period was considerably longer in A-lines and in BJ 104 than in B-lines; 75% SE to AI was longer in A-lines than in B-lines, and was longest in BJ 104. At AI, the occurrence of fresh stigmas on individual panicles was very low in BJ 104 (4%) and very high in A-lines and B-lines (87-96%). There was no variation in stigma length, but A- and B-lines had shorter stigmas than BJ 104. Ergot severity was lowest in B-lines (1%), significantly higher in A-lines (10-27%), *and* highest in BJ 104 (96%). Selfed seed set was strongly negatively correlated with ergot severity.

In a recent study (Thakur et al. 1991), significant positive correlations were found between protogyny, SE-AI period, and ergot severity in susceptible A- or B-lines and their F_1 hybrids, regardless of the susceptibility or resistance of pollinators. This study also showed that stigmas were longer in susceptible A-lines and their hybrids than in resistant A-lines and their hybrids. These results confirmed the earlier findings on the role of pollination and flowering biology in ergot infection (Thakur and Williams 1980, Willingale et al. 1986).

Agronomic traits of resistant B-lines

Forty-five B-lines [33 from 843B x ICMPES 29, 7 from 843B x 1CMPES 34, and 5 from (843B x ICMPES 34) x ICMPES 34] were evaluated in single-row plots of 4 m length, replicated three times at ICRISAT Center during the 1988 rainy season and 1988/89 postrainy season. Based on grain yield, plant height, time to 50% flowering, and agronomic scores, 13 B-lines (Table 12) were selected for further evaluation. This trial was conducted in 2-row plots of 4 m length, replicated four times at ICRISAT Center and Hisar during the 1989 rainy season.

Table 11. Floral characteristics and ergot severity of ergot-resistant A-lines and B-lines (ICMPE 134-6-9, ICMPE 134-6-18) in different backcross generations, ICRISAT Center, rainy season 1985.

	ICMPE 134-6-9				ICMPE 134-6-18						
	BC_5[2]		BC_6		B Q		B Q		BJ 104		
Floral characteristics[1]	A	B	A	B	A	B	A	B	Control	Mean	SE
Protogyny period (h)[3]	63	50	55	50	61	48	65	50	106	61	±2
SI to 75% SE (h)	35	35	29	38	36	29	36	28	28	33	±2
SI to SW (h)	115	80	115	93	114	81	119	88	120	103	±3
75% SE to AI (h)	28	15	26	12	28	19	29	22	78	29	±2
FS(%) at AI (h)	96	91	91	87	91	89	95	92	4	82	±1
Stigma length (1-3)[4]	2	2	2	2	2	2	2	2	3	2	-
Selfed seed set (%)[5]	2	98	2	94	1	98	2	99	1	44	±1
Ergot severity (%)	27	1	23	1	11	1	10	1	96	19	±2

1. Based on 10 inflorescences from 2 replications.
2. BC_5 and BC_6 A-lines were produced by backcrossing ICMPE 134-6-9 and ICMPE 134-6-18 into the cytoplasm of 81A.
3. Protogyny period (h) = Time between stigma initiation (SI) and anthesis initiation (AI). SE = Stigma emergence, SW = Stigma withering, FS = >75% stigma emergence.
4. Stigma length on a 1-3 scale where 1 = short stigma and 3 = long stigma.
5. Seed set was recorded on selfed panicles.

Some of the highest-yielding ergot-resistant B-lines in this trial were comparable to ICMB 841 (maintainer of a commercial male-sterile line ICMA 841) in grain yield and plant height, flowered 2-3 days earlier, and also had larger seed size than ICMB 841 (Table 12). Several of the progenies derived from the single-cross, involving ICMPES 29 as the ergot-resistant donor parent, were superior to the donor parent also in terms of grain yield, earlier flowering, shorter plant height, and larger seed size. Only seven lines had 1-6% ergot severity and these were all from single-cross populations. The remaining six lines had up to 28% ergot severity. The susceptible control (ICMB 841) had 49% ergot severity. Eleven B-lines had 2 to 7% downy mildew incidence, which was comparable to incidence in the donor lines and significantly less than in 843B (16%) and 81B (25%). Seven of the B-lines had resistance to both ergot and downy mildew.

The 13 ergot-resistant B-lines (Table 12) were among several that were used for conversion into male-sterile lines in the 1988/89 postrainy season. During the course of this program, selection was continued for agronomic desirability, stability of male-sterility maintenance ability, and resistance to ergot and downy mildew. Three male-sterile lines that were identified in the 1989/90 postrainy season for producing hybrids were later named as ICMA 91113 (maintainer line ERBL 4), ICMA 91114 (maintainer line ERBL 11), and ICMA 91115

Table 12. Agronomic traits and disease reaction in ergot-resistant B-lines (ERBL), 1989 rainy season.

B-lines[1]	Grain yield ($t\ ha^{-1}$)[2]	Time to 50% flowering (d)[2]	Plant height (cm)[2]	1000-seed mass (g)[3]	Ergot severity (%)[4]	Downy mildew incidence (%)[5]
ERBL 1	1.13	50	150	10.5	6	4
ERBL 2	1.58	49	163	10.9	6	7
ERBL 3	1.20	52	170	7.1	2	2
ERBL 4	1.83	49	153	8.6	28	5
ERBL 5	1.71	50	168	8.0	14	5
ERBL 6	1.46	50	172	7.6	15	3
ERBL 7	1.49	50	162	8.7	1	7
ERBL 8	1.36	49	152	9.3	1	2
ERBL 9	1.66	52	164	9.1	4	7
ERBL 10	1.25	55	145	5.4	27	12
ERBL 11	1.54	56	162	8.7	1	4
ERBL 12	1.39	49	149	8.7	14	3
ERBL 13	1.04	56	140	7.2	11	21
Controls						
ICMPES 29	1.43	62	208	7.8	1	5
ICMPES 34	1.75	59	211	6.3	1	10
ICMB 841	1.63	52	162	6.5	49	-
SE	±0.133	±0.49	± 4.4	±0.61	±1.7	
Mean	1.47	52	164.0	8.1	11.0	

1. ERBL 1-9: progenies from (843B x ICMPES 29)-23. ERBL 10-11: progenies from (843B x ICMPES 34)-56. ERBL 12-13: progenies from [ICMPES34 x (843B x ICMPES 34)]
2. Mean of two locations: ICRISAT Center and Hisar.
3. Data from ICRISAT Center.
4. Measured in the ergot nursery at ICRISAT Center from 10 inoculated plants in each of two replications.
5. Data from seedling inoculation in greenhouse at ICRISAT Center. Controls 843B and 81B showed 16 and 25% incidence respectively.

(maintainer line ERBL 12). Four other maintainers (ERBLs 1, 2, 8, and 10) were advanced to the BC_9 generation. One of the male-sterile lines, ICMA 91115 (short and early-maturing), was contributed as ICMA 92666 to the 1992 AICPMIP trial for further evaluation and utilization.

Hybrids of resistant A-lines

Five ergot-resistant lines and four ergot-susceptible pollinators were each crossed onto three ergot-resistant A-lines, ICMAs 91113, 91114, and 91115. The 27 hybrids along with three controls—two commercial hybrids (ICMH 423 and ICMH 451) and one commercial open-pollinated variety (ICMV 155)—were evaluated for grain yield and other agronomic traits. The trial was conducted in single-row plots of 4 m, replicated three times at 1CRISAT Center during the 1990 and 1991 rainy seasons.

Hybrids were classified as belonging to group 1 (resistant pollinators) or group 2 (susceptible pollinators). Considerable variation was observed in agronomic attributes and ergot severity (Table 13). Severity ranged from 8 to 87% (mean 66%) in group 1 hybrids, and between 56 and 97% (mean 79%) in group 2 hybrids. Ergot severity was 90-92% in the two control hybrids (ICMH 423 and ICMH 451), and 69% in the control open-pollinated variety ICMV 155. Thus, several of the group 1 hybrids were as susceptible as those in group 2, and several others were more susceptible than open-pollinated varieties. However, two hybrids from group 1 (ERH 4 and ERH 6), both involving ICMPES 2 as the pollinator parent, had only 8% and 20% ergot severity

Several hybrids had grain yields equal to or more than the highest-yielding commercial hybrid (ICMH 423). In comparison with ICMH 423, most of the hybrids based on ergot-resistant male-sterile lines had similar plant height and time to 50% flowering (some took 2-3 days less); six hybrids had 11-17% more grain yield than ICMH 423, and 15 had larger seed mass. All these hybrids, however, were either pollen-sterile or shed poor pollen (K.N. Rai and R.P. Thakur, unpublished data).

Based on agronomic scores, grain yield, and ergot severity, three of these hybrids ICMHs 91202, 91203, and 91204 (equivalent to ERHs 6, 12, and 14, respectively), were selected for evaluation in the ICRISAT Advanced Hybrid trial in the 1991 rainy season, where their yield potential was assessed in three environments. The highest-yielding hybrid, (ICMH 91203, where both parents were resistant) had 70% ergot severity in the ergot nursery, and

Table 13. Performance of hybrids based on three ergot-resistant male-sterile lines, ICRISAT Center, rainy season (mean of 1990 and 1991).

Hybrid	Pedigree	Grain yield ($t\ ha^{-1}$)	Time to 50% flowering (d)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)
Hybrids made from ergot-resistant pollen parents						
ERH 1	ICMA 91113 x ICMPES 1	3.23	44	186	8.5	86
ERH 4	ICMA 91113 x ICMPES 2	3.16	46	186	8.0	8
ERH 7	ICMA 91113 x ICMPES 33	3.18	43	174	9.8	72
ERH 10	ICMA 91113 x ICMPE 1-1-4-4-2-1	3.14	44	184	8.8	84
ERH 13	ICMA 91113 x ICMPE 2-2-2-1-4-2	3.47	47	188	9.2	70
ERH 2	ICMA 91114 x ICMPES 1	3.63	47	175	8.3	87
ERH 5	ICMA 91114 x ICMPES 2	3.48	47	186	8.2	45
ERH 8	ICMA 91114 x ICMPES 33	3.28	48	190	10.6	70
ERH 11	ICMA 91114 x ICMPE 1-1-4-4-2-1	3.54	48	193	8.2	80
ERH 14	ICMA 91114 x ICMPE 2-2-2-1-4-2	3.00	50	188	8.0	79
ERH 3	ICMA 91115 x ICMPES 1	2.97	44	173	8.3	77
ERH 6	ICMA 91115 x ICMPES 2	3.38	46	183	9.1	20

Continued...

Table 13. *Continued.*

Hybrid	Pedigree	Grain yield (t ha^{-1})	Time to 50% flowering (d)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)
ERH 9	ICMA 91115 x ICMPES 33	2.87	43	167	10.1	79
ERH 12	ICMA 91115 x ICMPE 1-1-4-4-2-1	3.26	46	183	9.2	70
ERH 15	ICMA 91115 x ICMPE 2-2-2-1-4-2	3.12	46	183	9.6	68
Hybrids made from ergot-susceptible pollen parents						
ERH 16*	ICMA 91113 x LCSN 71-2-1-1	3.23	43	178	10.2	56
ERH 19	ICMA 91113 x (NEP 7-5603 x BJ 104 ST)-1-2-M	3.10	43	160	9.9	85
ERH 22*	ICMA 91113 x (B 282 x J 104)-12-B-B-B-B	3.23	42	163	9.4	94
ERH 25*	ICMA 91113 x H 77/833-2	2.43	40	141	7.9	71
ERH 17	ICMA 91114 x LCSN 71-2-1-1	3.65	47	178	10.0	67
ERH 20	ICMA 91114 x (NEP 7-5603 x J 104 ST)-1-2-1-1	3.38	46	168	11.8	85
ERH 23*	ICMA 91114 x (B 282 x J104)-12-B-B-B-B	3.21	45	150	8.9	97
ERH 26	ICMA 91114 x H 77/833-2	3.46	43	148	7.5	94
ERH 18*	ICMA 91115 x LCSN 71-2-1-1	3.30	43	165	11.3	57
ERH 21	ICMA 91115 x (NEP 7-5603 x J 104 ST)-1-2-1-1	2.79	44	162	12.5	90
ERH 24*	ICMA 91115 x (B 282 x J 104)-12-B-B-B-B	3.27	43	146	9.8	95
ERH 27*	ICMA 91115 x H 77/833-2	2.90	40	138	8.2	58
Controls						
ICMH 423		3.11	45	160	8.4	92
ICMH 451		2.94	48	171	9.0	90
1CMV 155	(Open-pollinated variety)	3.17	46	178	9.7	69
SE		±0.167	±0.3	± 3.7	±0.2	-

* = Fertile; all the remaining are sterile hybrids.

yielded 15% less than the highest-yielding control hybrid ICMH 88088, but was on par with a commercial hybrid, Pusa 23 (Table 14). ICMH 91202, which had only 20% ergot severity, yielded 19% less than ICMH 88088. The three hybrids tested, however, had high pollen sterility and/or poor pollen shedding which would have increased their susceptibility to ergot.

Breeding resistant open-pollinated varieties

Open-pollinated varieties are generally less susceptible than hybrids to ergot under natural disease pressure; under artificial inoculation they can show equal susceptibility. Efforts were made to breed open-pollinated varieties using ergot-resistant lines.

Twelve ergot-resistant lines were used to make three synthetics (ICMSs 8031, 8032, and 8034). These were evaluated during the 1980 rainy season for ergot resistance in the ergot nursery at ICRISAT Center, and for grain yield in a replicated trial at three locations (low and high fertility at ICRISAT Center, and high fertility at Bhavanisagar).

Yields of the synthetic varieties were comparable to those of a popular open-pollinated commercial variety (WC-C75) and a hybrid (BJ 104). Ergot severity was 12-15% in the synthetic varieties, as compared to 24% in WC-C75 and 54% in BJ 104. Grain yields were 2.03 t ha^{1} in ICMS 8034, 1.92 t ha^{1} in WC-C75, and 1.84 t ha^{1} in BJ 104. The synthetic varieties were not evaluated and improved further because of a decreased emphasis on synthetic breeding at ICRISAT Center.

During the 1985 summer, an ergot-resistant composite (ERC) was constituted by random-mating 52 ICMPES populations at Bhavanisagar. A second random-mating was done during the 1985 rainy season at ICRISAT Center. Half-sib progenies (829) were screened for ergot resistance during the 1986 rainy season. Selfed seeds of 695 plants selected from

Table 14. Mean performance[1] of three hybrids based on ergot-resistant male-sterile lines and pollinators, 1991 rainy season.

Hybrid	Parentage: Female	Parentage: Male	Grain yield (t ha^{-1})	Time to 50% flowering (d)	Plant height (cm)	Ergot severity (%)
ICMH 91202	ICMA 91115	ICMPES 2	3.04	48	204	20
ICMH 91203	ICMA 91115	ICMPE 1-1-4-4-2-1	3.19	47	205	70
ICMH 91204	ICMA 91114	ICMPE 2-2-2-1-4-2	2.57	52	212	79
Controls						
ICMH 88088	81A	ICMR 88088	3.77	47	1 95	
ICMH 451	81A	ICSN 72-1-1-2-1	3.45	49	209	90
Pusa 23	841A	D-23	3.00	45	187	
SE (n = 18)			±0.120	±0.3	± 2.7	

1. Mean of three environments: ICRISAT Center high and low fertility, and Hisar.
- = Data not available.

392 half-sibs with <10% severity produced S_1 progenies that were evaluated for ergot reaction and grain yield during the 1986 postrainy season at ICRISAT Center. Using the remnant seed, 225 of the selected S-, progenies were re-evaluated for grain yield at three locations (ICRISAT Center, Bhavanisagar, and Gwalior) during the 1987 rainy season.

The results of the three trials during 1986 and 1987 showed a significant selection response for ergot resistance. Only 39% of the half-sib progenies showed 0-5% ergot severity whereas 53% and 82% of the S_1 progenies (from the two sets) showed 0-5% ergot severity (Fig. 7).

Although the ERC showed considerable ergot resistance, it was relatively late to flower. Improvements for grain yield and earliness were not attempted: research on ERC was discontinued due to a decreased emphasis on breeding for ergot resistance. However, ERC CO-bulk is being used at ICRISAT Center as a source material in crosses to form a Late Composite.

Functional field resistance to ergot

The results described in this bulletin provide a fairly complete account of the difficulties and the progress made in breeding ergot-resistant hybrids and open-pollinated varieties. We realize that yield potentials of these hybrids and varieties will be lower than those of the best-yielding hybrids and open-pollinated varieties. Under high ergot pressure, however, these hybrids might well have advantages

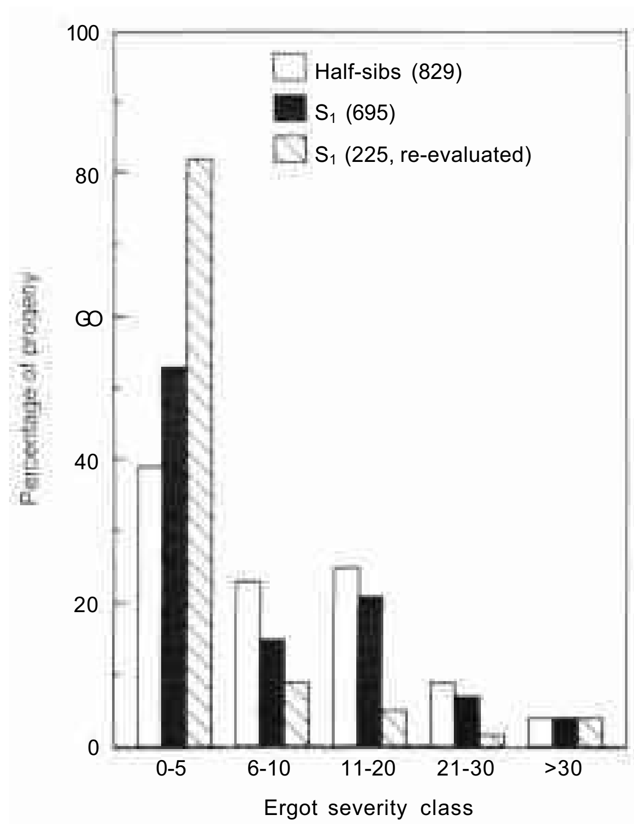


Figure 7. Ergot resistance in half-sib and S_1 progenies of an Ergot-Resistant* Composite (ERC), *ICRISAT Center, 1986 and 1987 rainy seasons. Number of progenies shown in parentheses.

over cultivars that have no ergot resistance. Here we argue that a level of 20% ergot severity under artificial inoculation is acceptable, based on the fact that pearl millet cultivars which showed 10-30% ergot severity under artificial inoculation remained highly resistant (<2% ergot severity) under high disease pressure in the field (Thakur et al. 1989a).

We envisage, therefore, that in the absence of major resistance gene(s) for ergot and in view of the difficulties of breeding hybrids with high levels of ergot resistance, hybrids with functional field resistance (20-30% ergot severity under artificial inoculation), and reasonable grain and forage yields, could be produced. Future research in this area, if any, should focus on increasing the level of ergot resistance, improving fertility restoration of ergot-resistant pollinators, reducing the maturity periods, and improving grain yield potential of hybrids and open-pollinated varieties and hybrids (especially topcross hybrids).

Conclusions

Soon after the introduction of cms-based single-cross hybrids in 1965, ergot disease of pearl millet began to cause significant economic losses in India. With a few reports of heavy ergot incidence, especially in hybrid cultivars, there was concern about the potentially serious impact on pearl millet production. This led to considerable research on this disease at ICRISAT Center after 1976. Substantial information was generated on various aspects of disease management, including identification and utilization of ergot resistance.

From the early 1980s onwards, however, the disease appeared not to increase in severity or scale in farmers' fields in India, and yield losses were not significant. Furthermore, there was strong evidence that additional research on genetic improvement for ergot resistance would not provide commensurate outputs, since breeding materials developed through such research would not be sufficiently competitive for grain yield.

The ergot-resistant lines and populations derived from susceptible germplasm sources as described in this bulletin, are probably the best sources of resistance to ergot in pearl millet available so far anywhere in the world. Further, many ergot-resistance sources are also resistant to downy mildew, smut, and rust, the other major diseases of pearl millet. The complex nature of ergot resistance, the availability of resistance sources in relatively narrow and poor agronomic backgrounds, and a perception of ergot as being less important than downy mildew led to a substantial reduction in breeding efforts on the utilization of resistance. Results, however, indicate that ergot resistance sources can be utilized to breed resistant cultivars should the disease become economically important in future. This, however, will require more research efforts than in the past. Ergot-resistant cultivars so developed will have specific advantages over other cultivars in areas where ergot occurs frequently. Host-plant resistance combined with other management practices such as pollen management (Thakur et al. 1983a) and biological control (Rao and Thakur 1988), can be used to reduce the menace of ergot in pearl millet. The sources of multiple disease resistance can be utilized to breed topcross hybrids and open-pollinated varieties to provide resistance to other major diseases such as downy mildew, smut, and rust, that affect pearl millet.

Acknowledgements

We would like to thank: the Genetic Resources Program and Pearl Millet Breeding Unit at ICRISAT Center, and AICPMIP, for providing seeds of diverse germplasm accessions and breeding materials for ergot screening; R.J. Williams, D.J. Andrews, K. Anand Kumar, B.S. Talukdar, S.B. Chavan, and Pheru Singh for their interest in and contributions to ergot resistance breeding; A.S. Rao, A.G. Bhasker Raj, and A.M. Rao for their help in field experiments; S.S. Chahal, H.S. Shetty, S.B. Mathur, N.B. Pawar, S. Nafade, G. Singh, and S.G. Bangar, our collaborators for multilocational testing; C.T. Hash for his review and useful comments on the manuscript; and V. Ravindranath Reddy for his typing assistance.

References

Bhat, R.V., Roy, D.N., and **Tulpule, P.G. 1976.** The nature of alkaloids of ergoty pearl millet or bajra and its comparison with alkaloids of ergoty rye and ergoty wheat. Toxicology and Applied Pharmacology 36:11-17.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. Pages 93-94 *in* Annual Report 1984. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Pages 85-86 *in* Annual Report 1987. Patancheru, A.P. 502 324, India: ICRISAT.

Johnson, C.H., Robinson, H.R, and **Comstock, R.E. 1955.** Estimates of genetic and environmental variability in soybeans. Agronomy Journal 147:314-318.

Loveless, A.R. 1967. *Claviceps fusiformis* sp. nov., the causal agent of an agalactia of sows. Transactions of the British Mycological Society 50:15-18.

Mantle, P.G. 1968. Inhibition of lactation in mice following feeding with ergot sclerotia (*Claviceps fusiformis* Loveless) from the bullrush millet [*Pennisetum typhoides* (Stapf and Hubbard)] and alkaloid component. Proceedings of the Royal Society B170:423-434.

Mantle, P.G. 1992. Ergot disease of pearl millet: toxicological significance and a mechanism of disease escape. Pages 129-132 *in* Sorghum and millet diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Mather, K. 1949. Biometrical Genetics. New York, USA: Dover Publications. 446 pp.

Rachie, K.O., and **Majmudar, J.V. 1980.** Pearl Millet. University Park, Pennsylvania, USA: Pennsylvania State University Press. 307 pp.

Rao, V.P., and **Thakur, R.P. 1988.** *Fusarium semitectum* var. *majus* - a potential biocontrol agent of ergot (*Claviceps fusiformis*) of pearl millet. Indian Phytopathology 41: 567-574.

Thakur, R.P. 1987. Diseases of pearl millet and their management. Pages 147-158 *in* Plant protection in held crops: lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 Jan 1986, Hyderabad, India (Veerbhadra Rao, M. and Sithanantham, S., eds.). Hyderabad, A.P, India: Plant Protection Association of India.

Thakur, R.P. 1990. Basic research on management of pearl millet diseases. Pages 343-358 *in* Basic Research for Crop Disease Management (Vidhyasekaran, P., ed). New Delhi 110 006, India: Daya Publishing House.

Thakur, R.P., and **Chahal, S.S. 1987.** Problems and strategies in the control of ergot and smut in pearl millet. Pages 173-182 *in* Proceedings of the International Pearl Millet Workshop, 7-11 Apr 1986, ICRISAT Center, Patancheru. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Thakur, R.P., and **Williams, R.J. 1980.** Pollination effects on pearl millet ergot. Phytopathology 70:80-84.

Thakur, R.P., and **King, S.B. 1988a.** Ergot disease of pearl millet. Information Bulletin no. 24, Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 24 pp.

Thakur, R.P., and **King, S.B. 1988b.** Registration of four ergot-resistant germplasms of pearl millet. Crop Science 28:382.

Thakur, R.P., King, S.B., and **Rao, V.P. 1989a.** Expression of ergot resistance in pearl millet under artificially induced epidemic conditions. Phytopathology 79:1323-1326.

Thakur, R.P., Singh, S.D., and **King, S.B. 1988.** Registration of four populations of pearl millet germplasm with multiple disease resistance. Crop Science 28:381-382.

Thakur, R.P., Rao, V.P., and **King, S.B. 1989b**. Ergot susceptibility in relation to cytoplasmic male sterility in pearl millet. Plant Disease 73:676-678.

Thakur, R.P., Rao, V.P., and **King, S.B. 1991.** Influence of flowering event factors in cytoplasmic male sterile lines and F_1 hybrids for infection by *Claviceps fusiformis* in pearl millet. Plant Disease 75:1217-1222.

Thakur, R.P., Rao, V.P., Williams, R.J., Chahal, S.S., Mathur, S.B., Pawar, N.B., Nafade, S.D., Shetty, H.S., Singh, G., and **Bangar, S.G. 1985.** Identification of stable resistance to ergot in pearl millet. Plant Disease 69: 982-985.

Thakur, R.P., Williams, R.J., and **Rao, V.P. 1983a.** Control of ergot in pearl millet through pollen management. Annals of Applied Biology 103:31-36.

Thakur, R.P., Subba Rao, K.V., and **Williams, R.J. 1983b.** Evaluation of a new field screening technique for smut resistance in pearl millet. Phytopathology 73:1255-1258.

Thakur, R.P., Talukdar, B.S., and **Rao, V.P. 1983c.** Genetics of ergot resistance in pearl millet. Page 737 *in* Abstracts of contributed papers of the XV International Congress of Genetics, 12-21 Dec 1983, New Delhi. Pt. 2. New Delhi, India: Oxford and IBH Publishing Co.

Thakur, R.P., Williams, R.J., and **Rao, V.P. 1982.** Development of ergot resistance in pearl millet. Phytopathology 72:406-408.

Williams, R.J., Singh, S.D., and **Pawar, M.N. 1981.** An improved field screening technique for downy mildew resistance in pearl millet. Plant Disease 65:239-241.

Willingale, J., Mantle, P.G., and **Thakur, R.P. 1986.** Post-pollination stigmatic constriction, the basis of ergot resistance in selected lines of pearl millet. Phytopathology 76:536-539.

Appendix 1. Identity and pedigree of ergot-resistant pearl millet lines and populations (ICMER) developed at ICRISAT Center.

ICMER no.	Identity	Pedigree
001	ICMPE 13-4-38	(J 606-2 x J 703-1)-4-4-5-4-38
002	ICMPE 13-6-17	(J 606-2 x J 703-1)-4-4-5-6-17
003	ICMPE 13-6-1-3	(J 606-2 x J 703-1)-4-4-5-6-1-3
004	ICMPE 13-6-2-2	(J 606-2 x) 703-1)-4-4-5-6-2-2
005	ICMPE 13-6-3-2	(J 606-2 x J 703-1)-4-4-5-6-3-2
006	ICMPE 13-6-12-1	(J 606-2 x J 703-1)-4-4-5-6-12-1
007	ICMPE 13-6-22-1	(J 606-2 x J 703-1)-4-4-5-6-22-1
008	ICMPE 13-6-27-5	(J 606-2 x J 703-1)-4-4-5-6-27-5
009	ICMPE 13-6-27-7	(J 606-2 x J 703-1)-4-4-5-6-27-7
010	ICMPE 73-4-2	(J 606-2 x J 703-1)-6-1-1-11-4-2
011	ICMPE 73-4-13	(J 606-2 x J 703-1)-6-M-11-4-13
012	ICMPE 82-5	(J 606-2 x J 703-1)-6-2-10-3-5
013	ICMPE 82-5-6	(J 606-2 x J 703-1)-6-2-10-3-5-6
014	ICMPE 82-5-5	(J 606-2 x J 703-1)-6-2-10-3-5-5
015	ICMPE 134-6-30	(J 2238 x J 2210-2)-3-3-4-6-30
016	ICMPE 140-1-34	(J 2238 x J 2210-2)-3-3-10-1-34
017	ICMPE 140-2-4	(J 2238 x J 2210-2)-3-3-10-2-4
018	ICMPE 140-6-10	(J 2238 x J 2210-2)-3-3-10-6-10
019	ICMPE 140-6-19	(J 2238 x J 2210-2)-3-3-10-6-19
020	ICMPE 140-6-29	(J 2238 x J 2210-2)-3-3-10-6-29
021	ICMPE 140-6-33	(J 2238 x J 2210-2)-3-3-10-6-33
022	ICMPE 140-6-8-2	(J 2238 x J 2210-2)-3-3-10-6-8-2
023	ICMPE 247-2-7	(J 2238 x J 2210-2)-3-3-2-6-2-7
025	ICMPE 261-2-5	(J 2238 x J 2210-2)-3-3-5-8-2-5
026	ICMPE 134-6-6	(J 2238 x J 2210-2)-3-3-4-6-6
027	ICMPE 134-6-9	(J 2238 x J 2210-2)-3-3-4-6-9
028	ICMPE 134-6-10	(J 2238 x J 2210-2)-3-3-4-6-10
029	ICMPE 134-6-11	(J 2238 x J 2210-2)-3-3-4-6-11
030	ICMPE 134-6-25	(J 2238 x J 2210-2)-3-3-4-6-25
031	ICMPE 134-6-31	(J 2238 x J 2210-2)-3-3-4-6-31
032	ICMPE 134-6-34	(J 2238 x J 2210-2)-3-3-4-6-34
033	ICMPE 134-6-38	(J 2238 x J 2210-2)-3-3-4-6-38
034	ICMPE 134-6-40	(J 2238 x J 2210-2)-3-3-4-6-40
035	ICMPE 134-6-41	(J 2238 x J 2210-2)-3-3-4-6-41
036	ICMPE 13-4-29	(J 606-2 x J 703-1)-4-4-5-4-29
038	ICMPE 13-6-13	(J 606-2 x J 703-1)-4-4-5-6-13
039	ICMPE 13-6-24	(J 606-2 x J 703-1)-4-4-5-6-24
040	ICMPE 13-6-27	(J 606-2 x J 703-1)-4-4-5-6-27
041	ICMPE 13-6-23	(J 606-2 x J 703-1)-4-4-5-6-23
042	ICMPE 13-6-30	(J 606-2 x J 703-1)-4-4-5-6-30
043	ICMPE 13-6-33	(J 606-2 x J 703-1)-4-4-5-6-33
044	ICMPE 13-6-29-1	(J 606-2 x J 703-1)-4-4-5-6-29-1
045	ICMPE 247-8-5	(J 2238 x J 2210-2)-3-3-2-6-8-5

Continued....

ICMER no.	Identity	Pedigree
046	ICMPE 247-16-2	(J 2238 x J 2210-2)-3-3-2-6-16-2
047	ICMPE 247-2-3	(J 2238 x J 2210-2)-3-3-2-6-2-3
048	ICMPE 247-6-2	(J 2238 x J 2210-2)-3-3-2-6-6-2
049	ICMPE 248-10-1	(J 2238 x J 2210-2)-3-3-2-7-10-l
050	ICMPE 248-10-2	(J 2238 x J 2210-2)-3-3-2-7-10-2
051	ICMPE 262-4-1	(J 2238 x J 2210-2)-3-3-5-9-4-1
052	ICMPE 262-4-9	(J 2238 x J 2210-2)-3-3-5-9-4-9
055	ICMPE 34-1-1	(700590 x 3/4 Ex Bornu 77-2-1)-2-7-1-1-1
056	ICMPE 34-1-3	(700590 x 3/4 Ex Bornu 77-2-1)-2-7-1-1-3
057	ICMPE 34-1-4	(700590 x 3/4 Ex Bornu 77-2-1)-2-7-1-1-4
058	ICMPE 34-1-6	(700590 x 3/4 Ex Bornu 77-2-1)-2-7-l-l-6
059	ICMPE 34-1-10	(700590 x 3/4 Ex Bornu 77-2-1)-2-7-1-1-10
060	ICMPE 34-2-12	(700590 x 3/4 Ex Bornu 77-2-1)-2-7-1-2-12
061	ICMPE 34-2-16	(700590 x 3/4 Ex Bornu 77-2-1)-2-7-1-2-16
063	ICMPE 34-3-9	(700590 x 3/4 Ex Bornu 77-2-1)-2-7-1-3-9
064	ICMPE 445-485	(J 2238 x J 2210-2)-3-3
065	ICMPES 1	(J 606-2 x J 703-1)-4-4-5-6
066	ICMPES 2	(J 2238 x J 2210-2)-3-3-4-6
067	ICMPES 4	(J 606-2 x J 703-1)-4-4-5-6
068	ICMPES 5	(J 2238 x J 2210-2)-3-3-4-6
069	ICMPES 6	(700708-1-E-1 x J 797-1-E-1-2)-1-2
070	ICMPES 7	(700708-1-E-1 x J 797-1-E-1-2)-1-2
072	ICMPES 9	(700708-1-E-1 x J 797-1-E-1-2)-1-2
073	ICMPES 10	(700708-1-E-l x J 797-1-E-1-2)-1-2
074	ICMPES 11	(700708-1-E-1 x J 797-1-E-1-2)-1-3
075	ICMPES 12	(700708-1-E-1 x J 797-1-E-1-2)-1-3
076	ICMPES 13	(700708-1-E-1 x J 797-1-E-1-2)-1-3
077	ICMPES 14	(700708-1-E-1 x J 797-1-E-1-2)-1-3
078	ICMPES 15	(700708-1-E-1 x J 797-1-E-1-2)-1-3
079	ICMPES 16	(700708-1-E-1 x J 797-1-E-1-2)-1-3
080	ICMPES 17	(700708-1-E-l x J 797-1-E-1-2)-1-3
081	ICMPES 18	(700708-1-E-l x J 797-1-E-1-2)-1-4
082	ICMPES 19	(700708-1-E-1 x J 797-1-E-1-2)-1-4
083	ICMPES 20	(700708-1-E-1 x J 797-1-E-1-2)-1-4
084	ICMPES 21	(700708-1-E-1 x J 797-1-E-1-2)-1-4
085	ICMPES 22	(700708-1-E-1 x J 797-1-E-1-2)-1-4
086	ICMPES 23	(700708-1-E-1 x J 797-1-E-1-2)-1-4
087	ICMPES 24	(700708-1-E-l x J 797-1-E-1-2)-1-4
088	ICMPES 25	(700708-1-E-1 x J 797-1-E-1-2)-1-4
089	ICMPES 26	(700708-1-E-1 x J 797-1-E-1-2)-1-4
090	ICMPES 27	(700708-1-E-1 x J 797-1-E-1-2)-1-4
091	ICMPES 28	(700708-1-E-1 x J 797-1-E-1-2)-1-4
092	ICMPES 29	(700708-1-E-1 x J 797-1-E-1-2)-1-4
093	ICMPES 30	(700708-1-E-1 x J 797-1-E-1-2)-1-4
095	ICMPES 32	(700708-1-E-1 x J 797-1-E-1-2)-1-4

Continued....

Appendix 1. *Continued.*

ICMER no.	Identity	Pedigree
096	ICMPES 40	(700708-1-E-1 x J 797-1-E-1-2)-1-4
097	ICMPES 33	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-5]
098	ICMPES 34	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51
099	ICMPES 35	[(J 2238 x J 2210-2)-3-3-10-7 x (700619 x 700599)-3-2-11-5]
100	ICMPES 36	[(J 606-2 x J 703-1)-4-4-5-6 x (J 2238 x J 2210-2)-3-3-4-6]
101	ICMPES 37	[(700619 x 700599)-3-2-11-5 x (J 2238 x] 2210-2)-3-3-4-6]
102	ICMPES 38	[(700619 x 700599)-3-2-11-5 x (J 606-2 x J 703-1)-4-4-5-6]
103	ICMPES 39	[(700619 x 700599)-3-2-11-2 x (J 2238 x J 2210-2)-3-3-10-7]
104	ICMPES 41	[(J 2238 x J 2210-2)-3-3-10-7 x (700619 x 700599)-3-2-11-2]
105	ICMPES 42	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
106	ICMPES 43	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
107	ICMPES 44	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
108	ICMPES 45	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
109	ICMPES 46	[(700619 x 700599)-3-2-II-5 x (J 2238 x J 2210-2)-3-3-4-6]
110	ICMPES 47	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
111	ICMPES 48	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
112	ICMPES 49	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6)
113	ICMPES 50	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
114	ICMPES 51	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
115	ICMPES 52	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
116	ICMPES 53	[(700619 x 700599)-3-2-11-5 x (J 2238 x J 2210-2)-3-3-4-6]
117	ICMPE 1-1-4-4-2-1	[(]606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-5]-1-4-4-2-1
118	ICMPE 1-1-4-4-3-1	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-51-1-1-4-4-3-1
119	ICMPE 1-1-4-4-5-3	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-5]-1-4-4-5-3
120	ICMPE 1-1-9-1-1-4	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-5]-1-9-)-1-4
121	ICMPE 1-5-8-3-3-1	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-51-5-8-3-3-1
122	ICMPE 1-8-1-5-4-2	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-51-8-1-5-4-2
123	ICMPE 1-8-2-2-1-2	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-5]-8-2-2-1-2
124	ICMPE 1-10-3-2-1-3	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-51-10-3-2-1-3
125	ICMPE 1-22-5-6-4-1	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-51-22-5-6-4-1
126	ICMPE 1-22-5-6-4-2	[(J 606-2 x J 703-1)-4-4-5-6 x (700619 x 700599)-3-2-11-51-22-5-6-4-2
127	ICMPE 2-2-2-1-4-2	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-2-2-1-4-2
128	ICMPE 2-6-1-5-4-1	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-6-1-5-4-1
129	ICMPE 2-10-6-2-5-3	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-10-6-2-5-3

Continued....

Appendix 1. *Continued.*

ICMER no.	Identity	Pedigree
130	ICMPE 2-11-1-1-3-3	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-5]-11-1-1-3-3
131	ICMPE 2-11-1-1-4-1	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-1 1-1-1-4-1
132	ICMPE 2-11-2-4-3-3	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-11-2-4-3-3
133	ICMPE 2-15-6-4-5-2	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-15-6-4-5-2
134	ICMPE 2-10-1-1-6-1	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-5]-10-1-1-6-1
135	ICMPE 2-20-1-4-5-1	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-20-1-4-5-1
136	ICMPE 2-24-2-2-2-1	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-24-2-2-2-1
137	ICMPE 2-24-2-2-4-2	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-24-2-2-4-2
138	ICMPE 2-26-5-3-4-2	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-5J-26-5-3-4-2
139	ICMPE 2-26-1-4-1-1	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-26-1-4-1-1
140	ICMPE 2-26-1-5-3-1	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-26-1-5-3-1
141	ICMPE 2-26-3-1-1-1	[(J 2238 x J 2210-2)-3-3-4-6 x (700619 x 700599)-3-2-11-51-26-3-1-1-1
142	ICMPE 1-1-1-2-2	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-2]1-1-2-2
143	ICMPE 1-1-1-2-6	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-21-1-1-2-6
144	ICMPE 1-1-1-2-8	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-21-1-1-2-8
145	ICMPE 1-1-1-2-9	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-2]-1-1-2-9
146	ICMPE 1-1-2-7-3	I(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-2]-1-2-7-3
147	ICMPE 1-1-3-4-4	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-21-1-3-4-4
148	ICMPE 1-1-3-4-8	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-21-1-3-4-8
149	ICMPE 1-22-2-1-2	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-21-22-2-1-2
150	ICMPE 1-22-2-1-3	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-21-22-2-1-3
151	ICMPE 1-22-2-1-10	[(J 2238 x J 797-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-21-22-2-1-10
152	ICMPE 1-22-2-2-3	[(J 2238 x J 797-1)-2-2-6-1x (J 606-2 x J 703-1)-4-4-5-21-22-2-2-3
153	ICMPE 1-22-4-1-4	[(J 2238 x J 797-1)-2-2-6-1x 0 606-2 x J 703-1)-4-4-5-21-22-4-1-4

Continued....

Appendix 1. *Continued.*

ICMER no.	Identity	Pedigree
154	ICMPE 2-9-2-4-2	[(Ex Bouchi 700638-3-2 x SC-I(S4)27-2)-I-10-19-6 x (J 606-2 x J 703-1)-4-4-5-2]-9-2-4-2
155	ICMPE 2-9-3-4-3	[(Ex Bouchi 700638-3-2 x SC-I(S4)27-2)-I-10-19-6 x (J 606-2 x J 703-1)-4-4-5-2]-9-2-4-3
156	ICMPE 2-9-2-4-7	[(Ex Bouchi 700638-3-2 x SC-1(S4)27-2)-1-10-19-6 x (J 606-2 x J 703-1)-4-4-5-2]-9-2-4-7
157	ICMPE 3-16-3-4-1	[(Ex Bouchi 700638-3-2 x SC-I(S4)27-2)-I-10-19-6) x (J 2238 x J 797-1)-2-2-6-1]-16-3-4-1
158	ICMPE 3-16-3-4-3	[(Ex Bouchi 700638-3-2 x SC-1(S4)27-2)-1-10-19-6 x (J 2238 x J 797-1)-2-2-6-1]-6-3-4-3
159	ICMPE 3-16-3-4-5	[(Ex Bouchi 700638-3-2 x SC-I(S4)27-2)-I-10-19-6 x (J 2238 x J 797-1)-2-2-6-11-16-3-4-5
160	ICMPE 4-26-3-5-1	[(J 606-2 x J 703-1)-4-4-5-2 x (J 2238 x J 797-1)-2-2-6-1]-26-3-5-1
161	ICMPE 4-26-3-5-2	[(J 606-2 x J 703-1)-4-4-5-2 x (J 2238 x J 797-1)-2-2-6-1]-26-3-5-2
162	ICMPE 4-26-3-5-4	[(J 606-2 x J 703-1)-4-4-5-2 x (J 2238 x J 797-1)-2-2-6-1]-26-3-5-4
163	ICMPE 5-16-6-4-4	[(J 606-2 x J 703-1)-4-4-5-2 x (Ex Bouchi 700638-3-2 x SC-1(S4)27-2)-1-10-19-61-16-6-4-4
164	ICMPE 5-23-3-5-3	[(J 606-2 x J 703-1)-4-4-5-2 x (Ex Bouchi 700638-3-2 x SC-1(S4)27-2)-1-10-19-6l-23-3-5-3
165	ICMPE 5-23-9-1-3	[(J 602-2 x J 703-D-4-4-5-2 x (Ex Bouchi 700638-3-2 x SC-I(S4)27-2)-I-10-19-6]-23-9-1-3
166	ICMPE 5-27-1-3-2	[(J 606-2 x J 703-1)-4-4-5-2 x (Ex Bouchi 700638-3-2 x SC-1(S4)27-2)-1-10-19-61-27-1-3-2
167	ICMPE 5-27-1-3-7	[(J 606-2 x J 703-1)-4-4-5-2 x (Ex Bouchi 700638-3-2 x SC-1(S4)27-2)-1-10-19-6]-27-l-3-7
168	ICMPE 1-1-4-5-1	[(J 2238 x J 703-1)-2-2-6-1 x (J 606-2 x J 703-1)-4-4-5-2)-1-4-5-1
169	ICMPE 12	(ICMPE 134-6 x 700590)-10-6-2
170	ICMPE 18	(ICMPE 13-2 x SDN 503)1-1-1
171	ICMPE 23	(ICMPE 13-2 x SDN 503)-I-I-6
172	ICMPE 3	(ICMPE 34-1-3 x ICMPE 41-1-1)-4-14-3-3
173	ICMPE 4	(ICMPE 34-1-3 x ICMPE 41-1-D-4-14-6-1
174	ICMPE 9	[(ICMPE 7-1-3)17-3-7-P5 x (ICMPE 1-46-P1)1-39-4-1
175	ICMPE 10	[(ICMPE 7-1-3)-17-3-7-P5 x (ICMPE 1-46-P 1)1-39-4-2
176	ICMPE 24	[(ICMPE 9-2-1)-13-1-1-P3 x (ICMPE 1-25-P3)]-39-9-4
177	ICMPE 22	(ICMPE 134-6-9 x ICMPE-16)-22
178	ICMPE 81	(ICMPE 16 x ICMPE 13-6-30)-14
179	ICMPE 89	[(ICMPE 134-6-9 x ICMPE (8-1-4)-14-6]-5
180	ICMPE 92	[(ICMPE 134-6-9 x ICMPE (8-1-4)-14-6]-8
181	ICMPE 141	[(ICMPE (8-1-4)-14-6 x ICMPE 134-6-9]-8
182	ICMPE (6-I-2)-3-3-4-3-I-I	(700708-1-E-I xJ 797-1-E-1-2)-1-2-3-3-4-3-M
183	ICMPE (6-I-2)-3-3-4-3-I-2	(700708-1-E-1 x J 797-1-E-1-2)-1-2-3-3-4-3-1-2
184	ICMPE (6-1-2)-3-3-4-3-1-3	(700708-1-E-1 x J 797-1-E-1-2)-1-2-3-3-4-3-1-3
185	ICMPE (6-I-2)-3-3-4-3-I-4	(700708-1-E-I x J 797-1-E-1-2)-1-2-3-3-4-3-1-4

Continued....

ICMER no.	Identity	Pedigree
186	ICMPE (6-1-2)-3-3-4-3-1-5	(700708-1-E-1 x J 797-1-E-1-2)1-2-3-3-4-3-1-5
187	ICMPE (6-1-2)-3-3-4-3-3-1	(700708-1-E-1 x J 797-1-E-1-2)-1-2-3-3-4-3-3-1
188	ICMPE (6-l-2)-3-3-4-3-3-2	(700708-1-E-l x J 797-1-E-1-2)-1-2-3-3-4-3-3-2
189	ICMPE (6-l-2)-3-3-4-3-5-l	(700708-1-E-l x J 797-1-E-1-2)-1-2-3-3-4-3-5-1
190	ICMPE (6-1-2)-3-3-4-3-5-3	(700708-1-E-1 x J 797-1-E-1-2)-1-2-3-3-4-3-5-3
191	ICMPE (6-1-1)-3-3-4-3-6-1	(700708-1-E-1 x J 797-1-E-1-2)-1-1-3-3-4-3-6-1
192	ICMPE (6-1-1)-3-3-4-3-6-2	(700708-1-E-1 x J 797-1-E-1-2)1-1-3-3-4-3-6-2
193	ICMPE (6-1-1)-3-3-4-3-6-3	(700708-1-E-1 x J 797-1-E-1-2)1-1-3-3-4-3-6-3
194	ICMPE (6-1-D-3-3-4-3-6-4	(700708-1-E-1 x J 797-1-E-1-2)-1-1-3-3-4-3-6-4
195	ICMPE (6-2-1)-3-3-4-7-5-2	(700708-1-E-1 x J 797-1-E-1-2)-2-1-3-3-4-7-5-2
196	ICMPE (7-l-3)-2-3-l-17-l-l	(700708-1-E-l x J 797-1-E-1-2)-1-3-2-3-1-17-1-1
197	ICMPE (7-1-3)-2-3-1-17-2-4	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-1-17-2-4
198	ICMPE (7-l-3)-2-3-l-17-2-6	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-1-17-2-6
199	ICMPE (7-l-3)-2-3-l-17-l-l	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-1-17-1-1
200	ICMPE (7-1-3)-2-3-1-17-3-6	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-1-17-3-6
201	ICMPE (7-l-3)-2-3-l-17-4-l	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-1-7-4-1
202	ICMPE (7-l-3)-2-3-l-17-5-6	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-1-17-5-6
203	ICMPE (7-1-3)-2-3-M7-6-1	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-1-17-6-1
204	ICMPE (7-l-3)-2-3-8-2-3-l	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-8-2-3-1
205	ICMPE (7-l-3)-2-3-8-2-3-2	(700708-1-E-l x J 797-1-E-1-2)-1-3-2-3-8-2-3-2
206	ICMPE (7-l-3)-2-3-8-2-5-l	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-8-2-5-1
207	ICMPE (7-l-3)-2-3-8-2-6-2	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-8-2-6-2
208	ICMPE (7-1-3)-2-3-8-2-6-4	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-8-2-6-4
209	ICMPE (7-l-3)-2-3-8-2-7-l	(700708-1-E-l x J 797-l-E-l-2)-l-3-2-3-8-2-7-l
210	ICMPE (7-l-3)-2-3-8-2-7-2	(700708-1-E-l x J 797-l-E-l-2)-l-3-2-3-8-2-7-2
211	ICMPE (7-l-3)-2-3-8-2-7-4	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-8-2-7-4
212	ICMPE (7-l-3)-2-3-8-7-3-l	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-8-7-3-1
213	ICMPE (7-l-3)-2-3-8-7-7-6	(700708-1-E-1 x J 797-1-E-1-2)-1-3-2-3-8-7-7-6
214	ICMPE (7-1-3)-13-6-2-4-4-3	(700708-1-E-1 x J 797-1-E-1-2)-1-3-13-6-2-4-4-3
215	ICMPE (7-1-3)-13-6-2-4-4-3	(700708-1-E-1 x J 797-1-E-1-2)-1-3-13-6-2-4-4-3
216	ICMPE (7-1-3)-13-6-2-7-4-1	(700708-1-E-1 x J 797-1-E-1-2)-1-3-13-6-2-7-4-1
217	ICMPE (7-1-3)-23-7-1-1-1	(700708-1-E-1 x J 797-1-E-1-2)-1-3-23-7-1-1-1-1
218	ICMPE (7-l-3)-23-7-l-l-l-4	(700708-1-E-l x J 797-1-E-1-2)-1-3-23-7-1-1-1-4
219	ICMPE (7-1-3)-23-7-1-1-5-1	(700708-1-E-l x J 797-1-E-1-2)-1-3-23-7-1-1-5-1
220	ICMPE (7-l-3)-23-7-l-l-5-7	(700708-1-E-1 x J 797-1-E-1-2)-1-3-23-7-1-1-5-7
221	ICMPE (7-1-3)-23-7-2-1-4-3	(700708-1-E-l x J 797-1-E-1-2)-1-3-23-7-2-1-4-3
222	ICMPE (7-1-3)-23-7-2-1-6-2	(700708-1-E-1 x J 797-1-E-1-2)-1-3-23-7-2-1-6-2
223	ICMPE (8-1-4)-14-5-1-4-3-3	(700708-1-E-1 x J 797-1-E-1-2)-1-4-14-5-1-4-3-3
224	ICMPE (8-1-4)-30-3-5-1-1-3	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-1-1-3
225	ICMPE (8-1-4)-30-3-5-1-1-4	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-1-1-4
226	ICMPE (8-1-4)-30-3-5-1-4-1	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-1-4-1
227	ICMPE (8-1-4)-30-3-5-1-5-1	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-1-5-1
228	ICMPE (8-1-4)-30-3-5-1-6-1	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-1-6-1
229	ICMPE (8-1-4)-30-3-5-1-6-2	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-l-6-2
230	ICMPE (8-1-4)-30-3-5-1-7-3	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-1-7-3

Continued....

Appendix 1. *Continued.*

ICMER no.	Identity	Pedigree
231	ICMPE (8-1-4)-30-3-5-1-8-2	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-1-8-2
232	ICMPE (8-1-4)-30-3-5-2-1-2	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-2-1-2
233	ICMPE (8-1-4)-30-3-5-2-3-1	(700708-1-E-l x J 797-1-E-1-2)-1-4-30-3-5-2-3-1
234	ICMPE (8-1-4)-30-3-5-2-3-2	(700708-1-E-l x J 797-1-E-1-2)-1-4-30-3-5-2-3-2
235	ICMPE (8-14)-30-3-5-2-3-3	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-2-3-3
236	ICMPE (8-1-4)-30-3-5-2-3-4	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-2-3-4
237	ICMPE (8-1-4)-30-3-5-2-4-2	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-2-4-2
238	ICMPE (8-1-4)-30-3-5-2-4-4	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-2-4-4
239	ICMPE (8-1-4)-30-3-5-2-5-3	(700708-1-E-1 J 797-l-E-l-2)-l-4-30-3-5-2-5-3
240	ICMPE (8-1-4)-30-3-5-2-5-4	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-2-5-4
241	ICMPE (8-1-4)-30-3-5-2-5-5	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-2-5-5
242	ICMPE (8-1-4)-30-3-5-2-6-l	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-2-6-1
243	ICMPE (8-1-4)-30-3-5-2-6-5	(700708-1-E-1 x J 797-l-E-l-2)-l-4-30-3-5-2-6-5
244	ICMPE (8-1-4)-30-3-5-4-M	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-1-1
245	ICMPE (8-l-4)-30-3-5-4-l-5	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-1-5
246	ICMPE (8-1-4)-30-3-5-4-2-4	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-2-4
247	ICMPE (8-1-4)-30-3-5-4-2-5	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-2-5
248	ICMPE (8-1-4)-30-3-5-4-2-6	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-2-6
249	ICMPE (8-1-4)-30-3-5-4-3-l	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-3-1
250	ICMPE (8-1-4)-30-3-5-4-3-2	(700708-1-E-l x J 797-1-E-1-2)-1-4-30-3-5-4-3-2
251	ICMPE (8-1-4)-30-3-5-4-3-3	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-3-3
252	ICMPE (8-1-4)-30-3-5-4-3-4	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-3-4
253	ICMPE (8-1-4)-30-3-5-4-3-6	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-3-6
254	ICMPE (8-1-4)-30-3-5-4-4-l	(700708-1-E-1 x J 797-l-E-l-2)-l-4-30-3-5-4-4-l
255	ICMPE (8-1-4)-30-3-5-4-4-2	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-4-2
256	ICMPE (8-1-4)-30-3-5-4-4-4	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-4-4
257	ICMPE (8-1-4)-30-3-5-4-4-6	(700708-1-E-1 x j 797-1-E-1-2)-1-4-30-3-5-4-4-6
258	ICMPE (8-1-4)-30-3-5-4-8-2	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-8-2
259	ICMPE (8-1-4)-30-3-5-4-8-4	(700708-1-E-1 x J 797-1-E-1-2)-1-4-30-3-5-4-8-4
260	ICMPE 2-1-2-3-5-1	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-3-5-1
261	ICMPE 2-1-2-6-2-1	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-6-2-1
262	ICMPE 2-1-2-6-2-2	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-6-2-2
263	ICMPE 2-1-2-6-2-3	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-6-2-3
264	ICMPE 2-1-2-6-5-1	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-6-5-1
265	ICMPE 2-1-2-6-5-2	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-6-5-2
266	ICMPE 2-1-2-6-5-3	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-6-5-3
267	ICMPE 2-1-2-6-5-4	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-6-5-4
268	ICMPE 2-1-2-7-1-5	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-7-1-5
269	ICMPE 2-1-2-7-6-1	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-l-2-7-6-l
270	ICMPE 2-1-2-7-6-2	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-7-6-2
271	ICMPE 2-1-2-7-7-2	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-7-7-2
273	ICMPE 2-1-4-3-4-4	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-4-3-4-4
274	ICMPE 2-1-4-3-5-2	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-4-3-5-2
275	ICMPE 2-1-4-3-6-1	(700448-1 -E-2-3-7-1 x Togo 29-9-2-2)-1-4-3-6-1

Continued....

Appendix 1. *Continued.*

ICMER no.	Identity	Pedigree
276	ICMPE 2-1-4-3-6-2	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-4-3-6-2
277	ICMPE 2-1-4-5-1-1	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-4-5-1-1
278	ICMPE 2-1-4-5-1-3	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-4-5-1-3
279	ICMPE 34-1-2-4-6-1	(J 2210-2-1-4-2-3 x Togo 29-9-2-1 -1)-1 -2-4-6-1
280	ICMPE 34-1-6-5-6-2	(J 2210-2-1-4-2-3 x Togo 29-9-2-1-)-1-1-6-5-6-2
281	ICMPE 102-4-4-3-1-5	[(Togo 35P1-M-1 x (700708-1-E-1 x J797-1-E-1-2)-7-2-3-7-3]-4-4-3-1-5
282	ICMPE 102-4-4-3-1-6	(700448 x Togo 29-2-1)-1-1-3-3
283	ICMPE 102-4-4-3-1-7	(700448 x Togo 29-2-1)-1-4-5-1
284	ICMPE 102-4-4-3-1-8	(700448 x Togo 29-2-1)-1-4-5-3
285	ICMPE 102-4-4-3-1-9	(700448 x Togo 29-2-1)-1-4-7-1
286	ICMPE 102-4-4-3-1-10	(700448 x Togo 29-2-1)-1-4-7-2
287	ICMPE 102-4-4-3-1-11	(700448 x Togo 29-2-1)-1-4-7-3
288	ICMPE 2-1-2-9-1-3	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-1-2-9-1-3
289	ICMPE 2-1-2-14-1-2	(700448-1-E-2-3-7-1 x Togo 29-9-2-2)-I-2-14-I-2
290	ICMPE 2-1-2-14-1-3	[(J 2210-2 x Togo 29-2-I)-8-I]-M
291	ICMPE 2-1-2-14-1-4	[(J 2210-2 x Togo 29-2-1)-8-1]-1-2

- = Bulk population of the crosses.

Appendix 2. Agronomic attributes[1] and disease reactions (ergot, downy mildew (DM), smut, and rust) of 283 ergot-resistant lines of pearl millet (ICMER), ICRISAT Center, rainy season 1986.

ICMER no.	Time to 50% flowering (d)	Panicles plant-[1]	Panicle length (cm)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)[2]	DM incidence (%)[3]	Smut severity (%)[4]	Rust severity (%)[5]
001	64	2.4	22	181	5.1	1	1	0	8
002	59	3.8	22	192	5.3	1	7	0	28
003	63	3.0	24	177	6.6	1	2	0	18
004	60	3.4	22	180	5.1	1	11	0	40
005	62	3.3	23	180	6.7	1	6	<1	40
006	59	3.3	21	185	5.2	2	1	0	25
007	63	3.0	23	187	5.4	1	10	0	33
008	61	2.9	22	191	4.7	1	3	0	30
009	51	3.9	23	187	5.5	<1	0	0	45
010	62	2.2	28	160	8.9	1	1	0	23
011	59	2.1	28	160	8.6	2	9	0	15
012	60	3.0	27	175	8.6	2	2	0	24
013	59	2.9	30	185	7.7	3	2	1	15
014	62	2.5	27	181	8.3	8	4	0	25
015	52	3.3	23	177	6.1	1	2	0	23
016	54	3.7	27	194	6.8	1	15	0	23
017	60	2.9	26	162	6.7	2	5	0	25

Continued....

Appendix 2. *Continued.*

ICMER no.	Time to 50% flowering (d)	Panicles plant-[1]	Panicle length (cm)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)[2]	DM incidence (%)[3]	Smut severity (%)[4]	Rust severity (%)[5]
018	51	3.0	24	193	7.1	9	4	0	38
019	58	3.6	21	172	6.4	<1	8	0	25
020	56	3.5	24	174	6.2	2	15	0	25
021	51	3.1	21	157	6.7	<1	6	0	63
022	52	3.2	24	168	6.7	0	3	0	38
023	63	3.4	29	165	6.8	1	4	0	20
025	58	3.7	26	151	6.3	2	7	<1	20
026	49	3.6	20	135	6.3	<1	4	0	29
027	50	2.9	23	143	6.5	5	2	0	29
028	49	2.9	20	145	6.4	<1	7	0	27
029	53	3.5	21	150	6.3	<1	<1	0	28
030	50	3.4	22	159	7.9	7	3	0	58
031	53	3.4	21	145	5.9	<1	0	0	28
032	52	2.8	21	152	6.1	<1	4	0	30
033	49	3.4	21	129	6.0	1	0	0	32
034	52	3.5	22	153	6.7	1	1	0	31
035	51	3.1	22	142	6.4	<1	4	0	29
036	62	2.1	22	182	5.4	1	4	0	8
038	60	3.2	22	168	5.7	<1	2	0	20
039	63	3.5	23	182	5.3	1	18	0	33
040	60	3.4	21	186	4.5	1	8	0	22
041	59	2.9	21	172	4.9	1	12	0	33
042	62	3.1	22	183	5.3	4	6	0	28
043	61	3.8	21	172	5.8	3	9	0	40
044	62	2.3	21	175	5.8	<1	0	0	25
045	54	3.0	28	180	6.8	1	4	0	32
046	53	2.5	27	175	7.5	2	8	1	33
047	61	2.8	26	149	6.6	1	2	0	27
048	57	3.5	25	155	6.5	<1	3	0	45
049	51	3.6	25	195	5.9	3	3	<1	23
050	51	2.8	25	185	6.4	1	10	1	40
051	58	2.2	25	191	7.5	2	12	3	65
052	58	1.8	25	187	7.2	4	8	4	60
055	62	2.2	26	152	6.5	<1	20	0	31
056	65	2.5	28	176	7.8	1	8	0	40
057	56	2.4	25	194	7.8	1	7	0	4
058	64	2.5	28	169	7.6	1	2	0	18
059	62	1.9	30	179	9.0	1	1	0	12
060	60	2.2	26	183	7.8	1	6	1	40
061	59	2.4	28	181	7.5	1	5	2	60
063	64	4.0	15	181	6.9	2	0	<1	17
064	51	2.8	29	172	7.8	8	0	0	25
065	57	2.9	23	182	7.5	6	7	<1	18
066	60	3.8	24	153	5.9	1	2	0	23
067	64	3.6	22	193	5.3	<1	2	0	30
068	51	3.9	27	166	6.6	1	4	0	23

Continued....

Appendix 2. *Continued.*

ICMER no.	Time to 50% flowering (d)	Panicles plant-[1]	Panicle length (cm)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)[2]	DM incidence (%)[3]	Smut severity (%)[4]	Rust severity (%)[5]
069	60	3.1	22	165	8.4	8	3	0	14
070	65	3.7	24	169	9.4	4	18	0	6
072	61	3.1	22	163	8.3	6	22	0	9
073	60	3.3	22	153	7.2	2	8	0	7
074	65	2.8	23	155	8.7	1	5	1	9
075	60	2.6	23	160	9.2	3	2	0	11
076	60	2.3	26	167	7.8	2	13	0	13
077	59	2.9	26	175	9.5	2	2	1	10
078	61	2.7	26	170	9.9	<1	5	0	13
079	62	3.3	23	155	7.7	<1	6	0	10
080	65	2.7	22	160	9.0	<1	11	0	7
081	64	2.8	27	156	7.5	2	16	0	6
082	63	2.5	28	150	9.4	2	32	0	3
083	59	2.7	28	177	9.3	6	46	0	14
084	60	2.5	28	151	8.8	1	13	0	8
085	58	2.9	23	148	8.3	2	7	0	8
086	65	3.3	28	149	8.3	1	4	0	7
087	64	3.2	30	136	8.0	2	13	0	7
088	54	2.8	31	174	8.8	1	3	0	12
089	56	2.0	29	145	9.4	1	14	0	14
090	62	2.6	26	144	8.8	<1	15	0	6
091	57	2.5	32	171	9.4	2	7	0	10
092	61	3.5	29	167	8.5	<1	4	0	5
093	64	3.4	29	177	9.2	2	8	0	7
095	56	2.9	29	174	8.5	3	4	0	16
096	62	2.7	28	208	9.8	4	3	0	8
097	56	2.6	25	175	8.0	3	0	<1	15
098	50	2.9	29	186	7.2	<1	3	0	22
099	59	2.1	27	202	6.6	<1	0	0	14
100	55	3.0	25	182	6.1	2	1	0	22
101	56	3.3	26	181	8.4	<1	6	0	17
102	58	2.6	28	195	8.0	2	2	0	14
103	53	2.3	26	166	8.0	1	3	0	24
104	59	2.3	25	192	7.0	<1	2	0	14
105	50	2.9	25	170	7.3	3	1	<1	23
106	54	2.4	22	135	5.2	0	0	0	41
107	59	2.3	28	182	7.6	0	4	<1	26
108	51	3.7	25	172	6.1	<1	2	0	16
109	56	2.4	24	165	6.1	<1	10	0	19
110	54	3.1	24	161	5.9	<1	10	0	21
111	57	3.3	22	156	6.0	<1	3	0	20
112	54	3.2	22	158	6.8	<1	8	0	25
113	50	2.8	21	149	6.5	<1	7	0	21
114	58	3.3	20	144	6.8	1	4	0	28
115	58	2.8	22	155	7.0	<1	9	0	29
116	59	2.6	27	182	7.5	2	1	0	22
117	61	3.0	23	170	5.8	1	13	0	19

Continued....

Appendix 2. *Continued.*

ICMER no.	Time to 50% flowering (d)	Panicles $plant^{-1}$	Panicle length (cm)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)[2]	DM inci-dence (%)[3]	Smut seve-rity (%)[4]	Rust seve-rity (%)[5]
118	53	3.0	26	173	6.3	1	13	0	27
119	54	2.6	25	159	6.9	0	10	0	19
120	63	3.4	20	168	5.5	1	5	0	16
121	63	2.1	28	177	8.5	3	2	0	20
122	67	1.5	27	148	6.4	<1	7	0	12
123	57	2.4	27	164	7.5	8	3	<1	40
124	57	2.8	26	186	9.1	3	1	0	20
125	63	3.5	22	161	8.2	1	8	0	24
126	64	3.1	21	147	6.3	1	15	0	28
127	52	2.9	25	177	7.0	3	1	1	43
128	51	3.3	22	157	8.5	5	2	<1	28
129	54	1.8	27	174	6.3	4	0	0	50
130	54	3.1	23	144	6.4	<1	3	<1	14
131	51	3.1	23	129	7.5	<1	6	0	50
132	54	3.0	22	144	6.9	1	1	<1	28
133	51	2.8	24	165	6.3	<1	2	<1	45
134	59	2.9	25	168	7.4	1	23	0	13
135	57	4.1	22	165	6.2	1	3	0	17
136	55	2.5	23	159	7.4	1	13	0	18
137	54	2.7	27	183	7.6	5	7	0	20
138	53	2.1	25	171	8.1	1	6	<1	8
139	61	2.3	24	177	8.0	0	3	0	9
140	50	3.0	26	158	8.0	2	10	0	18
141	59	2.7	23	178	7.1	3	1	<1	25
142	66	2.4	23	179	6.5	2	56	0	12
143	64	2.0	20	145	5.9	1	1	<1	13
144	67	2.4	23	166	6.0	1	63	0	10
145	65	2.1	23	170	6.2	<1	48	<1	7
146	64	2.4	25	175	8.0	1	14	0	25
147	64	2.6	22	170	6.3	1	94	<1	15
148	65	2.4	24	171	5.6	2	70	0	8
149	60	2.2	21	171	6.7	1	3	0	20
150	64	2.4	25	162	6.1	1	2	1	20
151	61	2.6	22	165	6.4	3	3	0	18
152	62	2.5	22	169	6.2	1	0	0	23
153	61	1.8	22	149	6.4	2	3	<1	8
154	63	2.9	28	194	9.0	1	5	0	15
155	66	2.5	28	173	7.4	1	14	<1	8
156	62	2.8	25	176	8.1	1	5	0	10
157	58	1.8	25	166	7.7	5	7	0	38
158	59	2.8	26	173	72	4	19	0	23
159	61	2.3	21	150	8.2	5	13	<1	45
160	63	2.6	19	148	5.1	1	4	0	22
161	62	2.5	21	164	4.9	1	2	0	28
162	66	2.8	23	162	5.4	2	12	<1	22
163	65	2.3	28	181	6.8	4	6	0	33

Continued....

Appendix 2. *Continued.*

ICMER no.	Time to 50% flowering (d)	Panicles plant[1]	Panicle length (cm)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)[2]	DM incidence (%)[3]	Smut severity (%)[4]	Rust severity (%)[5]
164	66	1.5	24	153	7.3	<1	45	0	8
165	61	2.4	25	164	6.7	1	11	1	23
166	58	2.5	30	155	8.1	7	88	<1	33
167	61	2.6	26	159	7.5	1	98	0	33
168	62	2.4	23	164	5.3	1	2	0	20
169	60	1.2	26	178	6.5	1	2	0	33
170	50	2.8	16	142	8.5	7	0	1	33
171	55	1.6	25	178	8.0	1	3	0	40
172	62	1.9	21	165	7.5	1	8	0	50
173	61	2.1	19	167	6.9	1	21	<1	33
174	57	2.6	22	178	8.3	1	8	0	40
175	59	1.9	23	184	8.3	2	15	0	23
176	63	2.2	20	189	10.5	3	2	0	5
177	53	3.2	27	185	6.6	<1	13	0	28
178	58	2.7	22	170	7.3	3	6	0	25
179	56	3.2	29	213	7.0	2	30	0	48
180	55	1.8	24	179	7.5	2	15	0	45
181	53	2.9	26	160	7.1	1	8	0	35
182	64	3.8	24	170	9.3	3	46	0	8
183	61	3.0	23	163	8.9	2	38	0	8
184	60	3.1	23	179	9.6	2	16	0	13
185	59	2.9	22	171	9.2	6	23	0	15
186	64	2.9	22	165	8.0	2	21	0	5
187	62	3.5	23	178	8.6	2	6	0	8
188	67	4.0	23	174	8.7	2	34	0	5
189	61	2.8	24	164	9.4	1	22	0	5
190	63	3.5	23	168	9.9	2	25	0	5
191	63	3.3	23	160	8.8	2	21	0	13
192	53	2.9	24	189	10.0	3	23	0	25
193	62	3.1	23	178	8.7	2	15	0	18
194	64	3.0	23	167	9.4	2	19	0	5
195	61	3.5	23	172	9.3	2	22	0	13
196	63	2.6	21	159	9.6	<1	2	0	15
197	63	1.9	22	146	9.0	<1	4	0	28
198	60	1.8	21	142	8.7	<1	10	0	18
199	62	2.0	18	146	7.6	1	6	0	10
200	64	1.3	17	128	6.7	2	3	0	8
201	64	2.4	19	143	8.7	1	0	0	5
202	58	2.1	22	149	8.2	1	8	0	5
203	58	2.2	20	145	9.1	<1	10	0	28
204	51	3.5	28	198	10.0	2	1	0	30
205	60	2.0	20	136	8.9	<1	2	0	38
206	61	1.8	23	152	8.5	<1	1	0	40
207	62	2.3	21	152	9.2	<1	3	0	15
208	65	1.9	17	128	7.8	<1	0	0	18
209	67	2.0	21	150	8.9	<1	3	0	13

Continued....

Appendix 2. *Continued.*

ICMER no.	Time to 50% flowering (d)	Panicles plant[1]	Panicle length (cm)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)[2]	DM incidence (%)[3]	Smut severity (%)[4]	Rust severity (%)[5]
210	63	2.1	22	153	9.2	2	7	0	20
211	61	2.9	22	147	7.5	<1	4	0	33
212	64	2.4	21	158	9.5	<1	1	0	8
213	62	2.2	20	141	8.7	0	1	0	25
214	55	1.9	28	166	8.5	2	7	0	20
215	49	2.1	27	162	8.3	7	3	0	18
216	57	2.4	27	165	8.5	1	3	0	40
217	59	2.5	22	155	8.2	<1	3	0	40
218	63	2.0	21	150	9.0	<1	1	0	40
219	61	2.5	21	151	6.9	1	2	0	23
220	63	2.7	23	154	7.5	<1	1	0	25
221	60	2.9	22	160	8.7	<1	11	0	18
222	59	3.0	22	159	8.5	1	4	0	33
223	65	2.8	31	155	8.1	<1	4	0	25
224	60	2.9	23	167	9.5	<1	2	0	25
225	63	2.7	30	211	9.2	1	1	0	5
226	57	4.0	29	185	7.0	1	20	0	13
227	61	2.6	27	153	8.9	1	3	0	5
228	59	2.8	28	192	8.8	3	4	0	5
229	57	2.3	27	199	10.3	<1	4	0	8
230	55	2.1	27	176	10.1	1	5	0	25
231	54	3.1	26	148	8.5	<1	10	0	28
232	62	2.2	26	148	7.8	3	7	0	28
233	63	3.3	27	151	9.5	<1	1	0	33
234	57	2.7	25	151	8.2	<1	4	0	33
235	58	2.4	26	146	8.8	<1	6	0	18
236	65	3.0	26	155	7.8	1	2	0	25
237	60	3.2	27	163	8.7	1	2	0	5
238	57	2.5	26	169	9.7	<1	4	0	10
239	60	2.4	28	172	8.8	<1	6	0	8
240	61	2.3	26	160	9.2	1	6	0	8
241	65	2.4	27	164	8.6	1	2	0	13
242	59	2.6	25	131	8.0	<1	6	0	23
243	65	1.9	27	150	8.3	<1	1	0	10
244	62	2.7	27	180	7.6	5	2	0	5
245	58	2.6	28	170	9.4	1	6	0	15
246	61	2.5	25	163	9.1	<1	5	0	5
247	63	2.7	27	155	10.2	<1	0	0	10
248	65	2.4	26	166	9.0	<1	5	0	5
249	64	2.7	27	157	8.7	<1	6	0	15
250	60	2.1	27	161	8.8	1	2	0	18
251	60	2.3	25	150	8.8	1	8	0	35
252	61	2.3	26	147	10.0	<1	6	0	8
253	60	2.2	27	157	9.9	1	8	0	15
254	61	2.8	26	157	9.2	<1	10	0	13
255	59	2.4	27	164	9.2	1	7	0	25

Continued....

Appendix 2. *Continued.*

ICMER no.	Time to 50% flowering (d)	Panicles $plant^{-1}$	Panicle length (cm)	Plant height (cm)	1000-seed mass (g)	Ergot severity (%)[2]	DM inci-dence (%)[3]	Smut seve-rity	Rust seve-rity (%)[5]
256	60	2.7	27	161	9.6	<1	4	0	5
257	63	2.8	26	155	9.8	<1	26	0	15
258	63	2.1	23	134	9.0	<1	5	0	8
259	63	3.2	25	151	9.6	<1	7	0	8
260	49	1.9	22	207	8.1	2	12	<1	40
261	48	1.6	23	204	8.9	1	13	0	40
262	46	2.0	24	211	8.7	1	12	0	40
263	45	1.9	22	187	8.7	3	19	0	40
264	53	1.9	25	219	8.5	1	13	0	40
265	52	1.7	26	224	8.2	1	6	2	40
266	52	2.4	26	235	8.7	9	10	4	30
267	53	1.4	25	226	9.4	1	8	1	40
268	49	2.2	22	180	8.3	2	41	0	35
269	47	3.2	20	173	6.9	4	1	0	40
270	48	2.5	20	180	8.0	1	2	2	40
271	48	2.6	18	190	6.9	1	21	3	35
273	53	1.3	27	223	9.7	1	4	1	40
274	55	1.9	25	227	8.6	5	13	2	35
275	51	1.7	25	225	8.4	1	3	0	30
276	53	1.5	26	230	8.2	4	3	0	35
277	50	1.7	29	215	8.4	3	6	0	40
278	49	1.8	29	209	8.3	1	4	0	40
279	57	2.8	20	175	6.0	2	4	<1	20
280	60	2.1	20	223	6.6	1	1	<1	8
281	53	1.8	23	195	9.5	10	3	<1	40
282	58	1.6	25	191	7.4	0	3	5	35
283	59	1.6	27	194	7.2	<1	1	2	40
284	56	1.6	26	190	7.0	<1	1	1	35
285	55	1.8	23	184	6.5	<1	1	1	35
286	54	2.3	24	177	6.5	<1	2	0	35
287	54	2.3	24	176	7.4	<1	9	0	40
288	55	2.5	22	199	7.3	<1	0	1	30
289	50	2.2	23	224	8.2	<1	1	1	30
290	63	1.3	18	174	6.8	3	48	2	30
291	65	1.1	19	174	6.6	3	57	3	40
SE	-	±0.4	±1.0	± 8.0	±0.6	±2.0	-	±1.0	±7.0

1. Based on 10 plants from 2 replications, except time to 50% flowering (one replicate)
2. Evaluated at both ICRISAT Center and Aurangabad.
3. Evaluated in the downy mildew (DM) nursery at ICRISAT Center.
4. Evaluated in the smut nursery at ICRISAT Center.
5. Evaluated in ergot nurseries under natural infection at Aurangabad and ICRISAT Center.

RA-00252

About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 18 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the World Bank, and the United Nations Development Programme (UNDP).

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India

ISBN 92-9066-281-6 Order code: RBE 017 93-395