Sources of Resistance to Downy Mildew, Smut and Ergot of Pearl Millet and their Stability in Ghana

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Resumé
Nutsugah, S. K., Atokple, I. D. K. & Afribeh, D. A. *Les sources de résistance au mildiou des céréales au charbon et à l'ergot du millet perlé et leur stabilité au Ghana.* Les maladies du mildiou des céréales, de la nielle et de l'ergot sont les contraintes majeures à la production du millet perlé au nord du Ghana bien que leur sévérité varie d'une localization à l'autre. Un total de 97 accesssions des plasma germinatifs des pays occidentaux notés pour la production du millet perlé étaient évalués pour la résistance au mildiou des céréales au charbon et/ou à l'ergot. Quelques sources de résistance rapportées à Manga et Nyankpala lors de la saison de culture 1993 à 1995 ont révélé des réactions variables aux deux localisations. Les réactions différentielles aux trois pathogènes dans les deux localisations ont indiqué la possibilité des races physiologiques des pathogènes respectives. Pourtant des résistances des maladies multiples étaient évidentes dans les lignes synth 16 C0 et synth 16 CI (Mali) SE 800 SE 2124 SE composite et 1NMV - 77 (Nigeria) et KMV 15 90309 et 1 CMV 15 90311 (Niger). Ces lignes ont dévéloppé à peu près 5%, en moyenne du mildiou des céréales et la sévérité du charbon dans la pépinière infectée à Manga lors de la saison des pluies 1995. Ils sont encore evalués soit pour l'usage direct ou soit comme sources de résistances en variétés adaptées.

Mots clés: Le mildiou des céréales, le charbon, l'ergot, résistance du millét perlé.

Abstract
Downy mildew, smut and ergot diseases are major constraints to pearl millet production in northern Ghana, although their severity varies from location to location. A total of 97 germplasm accessions from pearl millet growing countries in the West African sub-region were evaluated for resistance to downy mildew, smut and or ergot. Some sources of resistance reported at Manga and Nyankpala in 1993 to 1995 cropping seasons showed variable reactions at both locations. Differential reactions to the three pathogens at the two locations indicated that there may be physiological races of the respective pathogens. However, multiple disease resistance was evident in lines Synth 16 C0 and Synth 16 C1 (Mali), SE 360, SE 2124, SE composite and INMV-77 (Nigeria) and ICMV IS 90309 and ICMV IS 90311 (Niger). These lines developed not more than 5% mean downy mildew and smut severity in the disease nursery at Manga during 1995 rainy season. They are

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currently being evaluated for direct use and or as sources of resistance in adapted varieties.

Keywords: Downy mildew, smut, ergot, pearl millet-resistance.

Introduction

Pearl millet (*Pennisetum glaucum* [L.] R. Br.) is one of the most important staple cereal crops in northern Ghana. The crop is cultivated on about 220,000 ha in the savannah agroecological zones of northern Ghana (Ministry of Food and Agriculture, 2001; Nutsugah *et al.*, 2002) and is susceptible to many diseases (Nutsugah *et al.*, 1999). Downy mildew (caused by *Sclerospora graminicola* [Sacc.] Schroet), smut (caused by *Tolyposporium penicillariae* Bref.) and ergot (caused by *Claviceps fusiformis* Loveless) are the three most important diseases of pearl millet in northern Ghana. Downy mildew is more destructive and widespread than smut and ergot in the region. Severity of these diseases also varies from location to location. The yield losses attributed to these diseases range from 10 to 60% (Nutsugah and Atokple, 1994), with similar losses also occurring in other West and Central African countries (Nutsugah *et al.*, 2002).

The downy mildew organism induces systemic infection and systemic symptoms can appear at any growth stage, from seedling to flowering. Infection by *S. graminicola* generally produces malformed inflorescences with various degrees of transformation into leafy structures called green ears. This prevents development of inflorescence and consequently grain yield (Girard, 1976). Both millet and *S. graminicola* show high levels of outcrossing, and are thus highly variable genetically. In Upper East Region, local landraces and downy mildew have developed an apparently stable system whereby a consistent disease incidence (20-30%) occurs (Nutsugah and Atokple, 1994). However, many local landraces produce very low yields (200-700 kg ha^{-1}) (Froelich *et al.*, 1993). In addition to downy mildew, there are occasional to frequent incidences of smut and ergot diseases in the three regions of northern Ghana. Even though the incidence of ergot is low in many areas, as compared to smut, a slight incidence is worrying because of mammalian poisoning. The disease also reduces the quality of the grain as the concomitant sclerotia contain alkaloids that are harmful to man and animals (Bhat *et al.*, 1976; Loveless, 1967; Mantle, 1968). There is, therefore, the need to improve and stabilize yields through new improved cultivars.

The use of resistant cultivars is the most economic and efficient method of

disease control in pearl millet. To develop cultivars resistant to downy mildew, smut and ergot, sources of resistance to these diseases need to be identified. The objectives of this study, therefore, were to (i) evaluate local and elite millet lines for their reactions to the three diseases, (ii) determine the stability of resistance in the two "hot-spot" locations, Manga and Nyankpala and consequently (iii) provide the National Millet Improvement Programme with an opportunity to select lines for direct use or as sources of resistance in the breeding programme.

Materials and methods

Screening for resistance to downy mildew

Screening for resistance to downy mildew was done at the Savanna Agricultural Research Institute, Nyankpala (9° 42', 0° 55') and Manga Agricultural Research Station, Manga (11° 01', 0° 16'), from 1993 to 1995 rainy seasons with an infector-row system (Williams *et al.*, 1981). Infector rows (a 1:1 mixture of pearl millet cultivars Manga nara and 7042 seeds) were planted every third row and three weeks earlier than the test material. Each accession was planted in two replications; each plot was 5 m long and rows spaced 70 cm apart and organized in a randomised complete block design. Each accession had at least 26 plants. Pearl millet cultivar 7042, which is highly susceptible to downy mildew, was planted as a control. The incidence of downy mildew (percentage of plants infected) was scored 30 days after planting (DAP), 45 DAP and at the soft dough stage (60-70 DAP). A severity index was calculated based on the severity of the downy mildew symptoms of each test entry (1-5 scale) after completion of heading (Williams *et al.*, 1981).

Screening for resistance to smut

The technique of Thakur *et al.*, (1983) for screening smut-resistance was used. An aqueous suspension of sporidia was obtained by soaking spore balls in water overnight. This suspension was filtered through two layers of cheesecloth before being used as inoculum (ca. 10^6 sporidia ml^{-1}). To inoculate plants, a hand-held atomizer was inserted into the flag-leaf sheath at the boot stage and sprayed with the inoculum. Ten heads in the boot stage per test entry per replication were covered with parchment paper bags immediately after inoculation. Pearl millet cultivar BK 560, which is susceptible to smut was inoculated as a control. Severity of smut was recorded 20-25 days after inoculation by using a smut severity rating scale (Thakur and King, 1988b).

Screening for resistance to ergot

No artificial inoculation was done. At soft dough stage, entries were assessed for their ergot reactions on each entry per replication using the ergot severity rating scale (Thakur and King, 1988a).

Preliminary agronomic evaluation

Ten randomly selected plants per replication were assessed for productive tillers, panicle length and plant height. Thousand-grain weight was taken and the grain yield per plot was estimated.

Results and Discussion

Resistance in germplasm accessions

During 1993-95, a total of 128 entries were screened at Manga and 53 at Nyankpala (Table 1). A great deal of variability for downy mildew reaction was found among the cultivars. Of the 97 germplasm accessions screened, 65 and 58 accessions originating from pearl millet-growing areas in the West African sub-region were resistant to downy mildew and smut, respectively (≤ 10% mean downy mildew and smut severity) (Table 2). Sources of downy mildew resistance were detected in accessions from almost all the countries. This was expected because the pathogen is endemic in the West African sub-region (Williams, 1984). The reactions of some selections for resistance to downy mildew and smut were not consistent over the three-year period (Tables 3 and 4). The few differences in the incidence of downy mildew values between years are not large and are considered unimportant. The differences in reactions to smut may be attributed to physiological specialization within the pathogens. Smut is found in all millet-growing areas of northern Ghana, but yield losses are of less importance than those caused by downy mildew. Yield losses in pearl millet due to ergot are of minor importance in northern Ghana (Nutsugah and Atokple, 1995), but can be devastating on short-duration photoperiod-insensitive cultivars. The sclerotia of this pathogen contain alkaloids that can be hazardous if eaten (Bhat *et al.*, 1976; Loveless, 1967; Mantle, 1968). The geographical diversity of these sources of resistance could indicate a diverse genetic base of resistance to downy mildew and smut, although genetic studies are needed to confirm it. Several of these lines have been used to develop downy mildew- and smut-resistant lines.

Table 1. Number of pearl millet lines screened for downy mildew, smut and ergot resistance, 1993-95 rainy seasons.

Screening for resistance to	*Year 1993*	*1994*	*1995*
Downy mildew	Manga	Manga	Manga
Smut and Ergot	43	28	57
			Nyankpala 53

Identification of stable resistance

The screening has led to the identification of several lines as good sources of stable resistance to downy mildew and smut. These lines showed high levels of downy mildew resistance

Table 2. Summary of pearl millet accessions screened for downy mildew and smut resistance, 1993-1995.

	No. of Accessions		
	Screened	*Resistant*[1]	
Country of origin		*Downy mildew*	*Smut*
Burkina Faso	10	7	8
Cameroon	5	3	3
Cote d'Ivoire	12	10	4
Gambia	2	2	0
Ghana	1	0	1
Guinea Bissau	2	2	0
Mali	8	6	6
Mauritania	2	1	0
Niger	22	18	15
Nigeria	11	9	10
Tchad	4	2	2
Others	18	5	9
Total	97	65	58

[1] ≤ 10% mean downy mildew and smut severity.

(mean severity range of 1-13% compared with 24-100% severity in the susceptible controls) during 1993-95 screening at Manga (Table 3). These lines also showed high but variable resistance to smut (≤ 1-27% severity compared with 33% in the susceptible control) at the same location (Table 4).

Downy mildew resistance genes (6-22% downy mildew severity) in previously identified lines have been incorporated into the locally adapted variety, Manga nara during 1993 cropping year (Table 5). Several downy mildew-and smut-resistant populations have also been developed in 1995 cropping season (Table 6). One of these, SOSAT C-88 x Ex-Borno showed resistance to both downy mildew and smut (7 and 9% severity downy mildew and smut, respectively) (Table 6).

Several varieties derived from germplasm accessions showed stable resistance at Manga and Nyankpala. These varieties were Synth 16 C1 and ICMV IS 90311 (Table 7). The reactions of the standard checks in 1993-1995 trials provide a valuable measure of the reliability of the screening systems (Tables 3-7). The cultivar 7042 was consistently more susceptible than Manga nara over the years. The reaction of cultivar 7042 was similar during the three years of screening. Manga nara

appeared more susceptible than BK 560. Because the test materials varied from one year to another, within-year comparisons were more valuable in evaluating the screening system than between-year comparisons.

Generally, adequate levels of smut appeared (≥ 33% on the susceptible control) to clearly distinguish between susceptible and resistant plants. The downy mildew and smut pressure was highly variable, being greatest at Nyankpala and least at Manga (Table 7). Similar situation was observed in the case of ergot pressure at the two locations (Table 8). Generally, the incidence of ergot was extremely low at Manga.

Downy mildew and smut lines with improved agronomic traits

Over the three-year period, several downy mildew-and smut-resistant lines

Table 3. Performance of selected pearl millet germplasm for resistance to downy mildew at Manga during 1993-95 rainy seasons.

Entry	*Downy mildew severity*[1] *1993*	*1994*	*1995*
CMB-40	8	10	6
EX-BORNO	2	2	9
LOCALAM-DAM	6	5	8
CS-1	4	7	8
SE 360	1	3	6
SE 2124	1	5	3
SE-COMPOSITE	4	10	4
SOSAT C-88	6	7	13
INMV-77	1	7	3
SYNTH 16 C1	2	9	2
ICMV IS 90309	1	8	2
ICMVIS 88217	4	10	6
ICMV IS 90311	4	10	5
7042	90	100	97
BK 560	24	37	33
MANGANARA	31	33	49
Mean[2] (16 entries)	11.8	16.4	15.9

[1]Per cent infection index calculated from the incidence and severity ratings.
[2]Mean of two replications.

Table 4. Performance of selected pearl millet germplasm for resistance to smut at Manga during 1993-95 rainy seasons.

Entry	*Smut severity*[1] *1993*	*1994*	*1995*
CMB-40	15	23	1
EX-BORNO	7	16	2
LOCALAM-DAM	16	5	8
CS-1	7	24	1
SE 360	8	3	3
SE 2124	8	8	3
SE-COMPOSITE	8	27	2
SOSAT C-88	7	7	1
INMV-77	8	3	2
SYNTH 16 C1	7	15	1
ICMV IS 90309	9	2	4
ICMV IS 88217	8	6	3
ICMV IS 90311	8	7	3
BK 560	-[2]	-	33
MANGA NARA	25	9	7
Mean[3] (15 Entries)	10.1	11.1	5.3

[1] Per cent infection index calculated from the incidence and severity ratings.
[2]Data not taken.
[3]Mean of two replications.

were identified, representing the best sources of resistance to downy mildew and smut. This was made possible through disease screening (Tables 3 and 4), breeding (Tables 5 and 6) and preliminary agronomic evaluation (Table 9) nurseries. These lines originated from a wide range of ecogeographical regions, and represented a range of variability for agronomic attributes including tillering (3-4 effective tillers per plant), panicle length (4-34 cm), plant height (138-207 cm), 1000-grain weight (7-11 g) and the estimated grain yield (592-745 kg ha^{-1}) (Table 9). These provide perhaps the best available sources of resistance with diverse genetic base in reasonably good agronomic backgrounds for resistance breeding programmes. A number of these lines also possess a fairly good level of resistance to ergot (Table 8). This makes them easier and more attractive to use in disease resistance breeding programmes. They generally showed from moderate to high levels of resistance to downy mildew and smut, except IKMV 8201 and Manga nara

which exhibited high levels of susceptibility to downy mildew (42 and 33% downy mildew severity, respectively) (Table 9). However, evaluation of some of these lines was limited to Manga and agronomic expression and reaction to downy mildew and smut could differ considerably at other locations.

Many of the accessions have been tested in many locations in West African Downy Mildew and Smut Observation Nursery in West and Central Africa. Several of the selections, including Ex-Borno, SE 360, SE 2124, INMV-77, Synth 16 C1 and ICMV IS 90309, developed less than 5% mean downy mildew severity in Manga in 3 years of testing. Seeds of these lines are maintained at SARI and in small quantities and would be multiplied for on-farm and on-station agronomic and genetic studies.

Table 5. Reactions of selected breeding lines to downy mildew in the nursery at Manga during 1993 rainy season.

	70 days after sowing	
Entry	*Downy mildew incidence*[1] *(%)*	*DM severity*[2] *(%)*
MANGA NARA (MN)	37	55
ICML IS 84236	2	4
ICML IS 84259	10	12
GR-P1	6	7
ICML IS 82241	5	6
ICMV IS 89201	5	6
MN x ICML IS 84336 (S_5)	12	22
MN x ICML IS 84259 (S_5)	12	7
MN x GR-P1 (S_5)	10	13
MN x ICML IS 82242 (S_5)	11	13
MN x ICMV IS 89201 (S_5)	7	6
7042	100	100
Mean[3] (12 entries)	18.1	20.9

[1]Percentage of plants infected by downy mildew.
[2] Per cent infection index calculated from the incidence and severity ratings.
[3]Mean of two replications.

Table 6. Reactions of selected breeding lines to downy mildew and smut in the nursery at Manga during 1995 rainy season.

	70 days after sowing	
Entry	*Downy mildew incidence*[1] *(%)*	*Downy mildew severity*[2] *(%)*
SOSAT C-88	13	1
ICTP 8203	49	10
MANGA NARA (MN)	49	7
LOCAL AM-DAM (L A-D)	7	8
EX-BORNO	9	2
SOSAT C-88 x ICTP 8203 (F_1)	22	8
SOSAT C-88 x MN (F_1)	17	3
SOSAT C-88 x L A-D (F_1)	26	3
SOSAT C-88 x EX-BORNO (F_1)	7	9
EX-BORNO x MN (F_1)	26	19
7042	97	100
Mean[3] (11 entries)	29.3	15.5

[1]Per cent infection index calculated from the incidence and severity ratings.
[2]Per cent infection index calculated based on artificial inoculation of 10 randomly selected plants per plot.
[3]Mean of two replications.

Table 7. Downy mildew and smut reactions of promising pearl millet entries at Manga and Nyankpala during 1995 rainy season.

	Downy mildew severity[1] *(%)*		*Smut severity*[2] *(%)*	
Entry	*Manga*	*Nyankpala*	*Manga*	*Nyankpala*
SYNTH 16 C0	1	11	2	14
SYNTH 16 C1	2	9	1	8
SE 360	5	16	3	5
SE 2124	3	16	3	11
SE COMPOSITE	4	10	2	15
INMV-77	3	16	2	16
ICMV IS 90309	2	7	4	10
ICMV IS 90311	5	9	3	11
7042	97	93	-[3]	-
MANGA NARA	49	10	7	11
BK 560	-	37	33	21
Mean[4] (11 entries)	17.1	21.3	6.0	12.2

[1]Per cent infection index calculated from the incidence and severity ratings.
[2]Infection index determined by smutted heads per total plants x 100.
[3]Data not taken.
[4]Mean of two replications.

Table 8. Reactions of selected pearl millet germplasm to ergot at Manga and Nyankpala during 1994-95 rainy seasons.

Entry	*Ergot incidence[1] (%)*			
	1994		*1995*	
	Manga	*Nyankpala*	*Manga*	*Nyankpala*
EX-BORNO	0 (50)[4]	-[2]	0 (50)	6 (34)
LOCAL AM-DAM	0 (50)	-	*[3]	*
CS-1	10 (50)	-	0 (48)	16 (20)
SE 360	0 (50)	-	0 (49)	11 (29)
SE 21240	0 (49)	-	0 (49)	11 (29)
SE-COMPOSITE	0 (50)	-	0 (51)	14 (28)
SOSAT C-88	0 (50)	-	0 (46)	8 (34)
INMV-77	0 (49)	-	0 (53)	14 (30)
SYNTH 16 C1	10 (49)	-	0 (47)	8 (38)
ICMV IS 882171	10 (50)	-	0 (52)	9 (33)
BK 560	0 (48)	-	0 (29)	10 (31)
MANGA NARA	0 (50)	-	0 (36)	10 (32)

[1]Percentage of plants infected by ergot.
[2]No screening was conducted at Nyankpala.
[3]Entry was not included for screening.
[4]Figures in parentheses are means of total number of plants of two replications.

Table 9. Yield parameters of promising pearl millet entries screened in the downy mildew nursery at Manga during 1994 rainy season.

Entry	*Productive tillers[1] per plant*	*Panicle length[1] (cm)*	*Plant height[1] (cm)*	*1000-grain weight (g)*	*Grain yield[2] (kg ha^{-1})*
Synth 16 C1	3.0	4	197	9.5	745
Local Am-Dam	4.0	25	207	9.0	97
Kelague	4.0	30	186	8.5	611
Gouzouma	4.0	34	186	9.5	592
SE 2124	3.0	33	190	9.0	627
SE 360	3.0	30	182	9.0	614
Manga nara	3.0	23	155	10.0	627
Ex-Borno	4.0	28	162	7.0	607
IKMV 8201	3.0	20	138	11.0	643
Mean[3] (9 entries)	3.4	25.2	178.1	9.2	629.2

[1]Productive tiller number, panicle length and plant height are based on 10 randomly selected plants in each of the two replications.
[2]Grain yield is estimated based on the mean of two replications.
[3]Mean of two replications.

Conclusion

The downy mildew-, smut- and ergot-resistant source lines are selections from germplasm originating from diverse ecogeographical regions of pearl millet-growing areas in the West and Central African region. These provide perhaps the best available sources of resistance with diverse genetic bases in reasonably good agronomic backgrounds for resistance breeding programme. A good number of these lines possess a fairly good level of multiple resistance to the three diseases. This makes it easier and more attractive for them to be used in breeding programmes.

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