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Breeding for Resistance to the Sorghum Shoot Fly[1]

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ABSTRACT

Screening sorghum (*Sorghum bicolor* (L.) Moench) varieties for seedling resistance to the sorghum shoot fly (*Atherigona varia*, Meigen) gave inconsistent results, and "recovery resistance" (tolerance) proved a better character. When levels of pest attack were high, infestation levels exceeded 90%, indicating that there was little worthwhile seedling resistance in the sorghums being tested. In contrast, good recovery resistance was shown by the cultivars 'Serena' and 'Namatare,' and more than 70% of the infested plants recovered and yielded normally. Recovery resistance was associated with good yield from tillers, and heritability was fairly high. 'Namatare' proved a successful parent, and grain sorghums with a combination of good shoot fly recovery resistance and yield were developed from crosses between Namatare and susceptible sorghums.

Additional key words: **Sorghum shoot fly, Recovery resistance.**

THE sorghum shoot fly, probably *Atherigona varia* (Meigen), causes serious losses in yield in East Africa. The pest is most troublesome in delayed plantings, but is sometimes a pest in earlier plantings when the preceding dry season has been interrupted by frequent showers of rain. The behavior of the fly has been described (6).

Two main types of resistance to shoot fly may be distinguished. The first is seedling resistance, which is indicated by differences in the number of seedlings attacked by the pest. The second type of resistance, termed "recovery resistance" by Doggett and Majisu (3), is really plant tolerance and involves the ability of the injured plant to recover successfully from this primary attack. The incidence of seedling damage may depend upon the number of adult flies present, their egg-laying preferences, and larval survival and feeding activity; however, recovery resistance depends upon the ability of the plant to produce a good yield of grain after an attack by the pest — a yield that must be produced within about 2 weeks after the usual time of uninfested plants to be of practical value in our limited growing season.

Seedling resistance has been reported from India (4, 5) and from Israel (1). Langham[3] in Nigeria reported that the resistant Indian cultivar 'M 35-1' had percentages of shoot fly attack ranging from 78 to 89; those of susceptible cultivars ranged from 93 to 99. However, some of the best Indian cultivars such as M 35-1 have proved difficult to grow successfully and have not been adequately tested at Serere, because they are so susceptible to disease. Recovery resistance was considered the main mode of protection available in East Africa by Doggett and Jowett (2).

Blum (1) reported large differences in numbers of eggs oviposited on susceptible cultivar 'Tx 7078' and on resistant lines which were suggestive of preferential egg laying. These differences in 1965 could have accounted for all of the differences in shoot fly attack he observed. In 1966, a year of heavier infestation, the number of eggs on Tx 7078 averaged 3.3 plant and for the trial as a whole the average was 1.9 eggs plant. Our results at Serere have proved far too variable to be of practical use. Egg counts increase very rapidly throughout the season and are greatly influenced by rain storms, which wash many eggs off the plants. Mean counts have varied from 5.5 to 20.3 eggs/plant in trials where shoot fly infestation had been encouraged.

MATERIALS AND METHODS

The main problem encountered in screening for resistance to shoot fly in East Africa is the difficulty in obtaining a high, uniform incidence of the pest because of local and patchy fly distribution. In earlier tests, shoot flies were encouraged by planting a border of the susceptible sorghum 'Combine Kafir 60' (CK 60) about 2 weeks before the first seed was sown. However, the need for small plots with adequate replication and the low incidence of damage (less than 60%) in such screening tests made these procedures inadequate. Therefore, we used the method developed by Starks[4] wherein strips of CK 60 were planted throughout the test field at right angles to the plot rows, and borders of CK 60, and the shoot flies were attracted into the plots by spreading meat meal down the rows of sorghum (*Sorghum bicolor* (L.) Moench). Average incidence of damaged plants with this procedure was always over 90%; moreover, the uniformity of infestation was so much improved that a lattice design gave no increase in efficiency over a randomized block design. Stands were usually counted early since the shoot fly attack can kill plants of susceptible varieties.

Recovery resistance was assessed by counting the plants attacked by shoot fly that still produced a satisfactory yield of grain on tillers. There was a subjective element in assessing which plants belonged in the "recovered" category, but results were similar between replications and between observers. Also, it proved rather easy to discriminate between the damage of shoot flies and borers.

Many derivatives of the Buganda beer cultivar, 'Namatare,' were used in the earlier trials. CK 60 was crossed to Namatare, and the F_1 was backcrossed to the CK 60 because Namatare itself is tall, rather late maturing, and unsuitable as a grain type. This backcross is referred to here as "CK-N." At a very early stage of selection for recovery resistance, CKN was crossed to a range of the better Serere Research Station lines. Numbers preceeded by CSF identify the crosses which resulted in resistant derivatives.

The 3DX, 4DX, and 5DX numbers were taken from those selected during the traditional-type breeding program for increased yield and are derivatives of crosses made in 1963-1965. These had been screened for yield only, without deliberate attention to shoot fly resistance. Sorghum entries used in the breeding program are listed in Table 1.

RESULTS

Seedling resistance. One trial of CSF 1 to 79 in the 1965 first rains achieved only 7.5% infestation at

[1] Contribution from the East African Agriculture and Forestry Research Organization, East African Community with the Agricultural Research Council, British Overseas Development Ministry, U. S. Agency for International Development, and Entomology Research Division and Crops Research Division, U. S. Department of Agriculture cooperating. Received Feb. 26, 1970.

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[3] Langham, R. M. 1968. Inheritance and nature of shoot fly resistance. M.Sc. Thesis. Ahmadu Bello Univ., Nigeria.

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Table 1. Parentage of the sorghum lines screened and selected for resistance to sorghum shoot fly.

Entry	Origin or parentage
Namatare	A Buganda (Lake Victori area) Uganda beer sorghum.
'Dobbs'	A Western Kenya cultivar, presumably selected locally.
'L 25'	A cultivar from Lango, Uganda.
Serena, 'SB 65', 'SB 77'	Strains selected from a cross between 'P. 127', a dwarf kafir from Swaziland, and Dobbs.
'SUK 1'	A white grain selection from a cross between the Congo hegari type 27 U.T., and 'Wiru', and indigenous Tanzanian sorghum.
'Combine Type 2'	A Serere selection from natural crosses in Caprock.
Combine Kafir 60 (CK 60), 'Caprock'	Developed in Texas, U.S.A.
'Redlan'	Developed in Oklahoma, U.S.A.
'CSH-1'	Hybrid sorghum developed in India
CSF 62 to 79	$(CK\ 60)^2$ × Namatare
CSF 104 to 157	Serena × CK^2N
CSF 158 to 165	SB 77 × CK^2N
CSF 169 to 193	SB 79 × CK^2N
H × 60	CK 60 × SB 77
3DX 57	$Serena^2$ × CK 60
4DX 34	$SUK\ 1^2$ × CK 60
5DX 18	SB 65 × CK^2N
5DX 36	SB 77 × (CK 60 × Serena)
5DX 50	$SB\ 79^2$ × CK 60
5DX 61 and 5DX 63	SB 79 × CK^2N
5DX 73 and 5DX 76	SUK 1 × CK^2N
5DX 87	CK 60 × CK^2N
5DX 142	Serena × (SB 79 × CK^2N)
5DX 162	Dobbs' × (CK 60 × SB 79)

5 weeks after planting, and differences in seedling infestation were not significant. A similar trial in the second rains of that year recorded only 13.5% mean incidence at the first seedling count, but significant differences between entries were obtained. More precise differences were obtained from counts of recovered plants, and the mean incidence of damage was also higher at this stage (57%) than at the seedling stage. There was a small but significant negative association between the incidence of seedling attack and the number of recovered plants which produced a crop. Selection was therefore based on the frequency of recovered plants.

In 1966, the selected material from CSF 1 to 79 was screened in two 11^2 balanced lattice trials (A and B). Two similar 13^2 trials (C and D) were used for selected material of CSF 80 to 248, which had received some preliminary screening in unreplicated bulks. Shoot fly incidence on seedlings was again too low in the first rains but was satisfactory in the second rains trials. Data from the second rains trials, B and D, have been summarized in Table 2. The data illustrate the problems of working with shoot fly damage on seedlings at Serere. The relationship between the classification on seedling incidence and the number of plants which later contributed to grain yield, though significant, was low, so seedling screening was of little value in selecting for yield. Adjacent trials in the same field planted at the same time gave a completely different picture of the relationship between Namatare and Serena.

Recovery resistance. The sorghum lines shown in Table 3 were screened for recovery resistance in a series of trials. Among the varieties, Serena with about 68 to 79% of plants recovering and Namatare, with recovery ranging from 59 to 72%, always rated better than CK 60 at all levels of infestation. Many of the original crosses did not survive the screening. Among

Table 2. Summary of seedling damage of data from shoot fly trials B and D.

Item	B (121 entries)	D (169 entries)
Mean incidence of shoot fly damage	32.2%	29.7%
Range, individual plots	9.4–72.7%	0.0–54.6%
Range, entry mean (adjusted)	21.1–45.2%	19.4–41.6%
Correlation between seedling attack and mature plants yielding grain	-0.473	-0.335
Mean damage in Namatare	35.7	20.1
Mean damage in Serena	26.6	29.7
Mean damage in CK 60	30.6	32.1
LSD .05, damage	9.8	13.2
CV, damage	20.0%	34.0%

Table 3. Percentage of plants showing recovery resistance in screening trials.

	Trials*									
CSF no.	A	B	C	D	E	F	G	H	I	J
63/1**	83	74	--	--	--	--	80	--	--	67
63/2**	79	87	--	--	--	80	--	--	--	65
63/3**	77	91	--	--	80	84	85	80	93	83
68/3**	86	86	--	--	--	--	--	82	81	83
68/9**	86	71	--	--	--	90	--	--	--	72
73/1**	71	95	--	--	81	--	59	83	79	81
73/2**	87	80	--	--	78	60	53	57	--	77
123**	--	--	82	79	89	--	94	78	78	71
128**	--	--	76	46	--	89	80	--	--	80
131**	--	--	60	73	76	--	59	86	--	76
150**	--	--	74	61	80	79	75	75	--	66
163**	--	--	62	71	--	65	--	--	56	69
174/3**	--	--	60	67	84	60	--	84	--	79
174/6**	--	--	--	55	--	69	--	--	--	74
190**	--	--	76	81	79	84	90	84	--	75
192**	--	--	84	70	--	--	80	--	--	73
194**	--	--	100	80	74	94	55	75	--	79
SB 77	--	--	--	--	--	--	--	--	-	53
SB 79	--	--	--	--	--	--	--	--	--	62
Namatare	72(2)	59	59(2)	64	--	--	--	--	--	72
Serena	74(2)	68(6)	78	79	73(6)	76(6)	77(5)	75(5)	76(5)	76
CK 60	58(2)	47	56(2)	39	25(5)	34(3)	36(6)	43(5)	32(5)	34
LSD .05	16	19	19	21	23	29	22	26	29	12
No. of Rep.	6	6	7	7	2	2	2	2	2	10
% Infes.	26	35	37	53	92	92	92	92	92	91
CV	19	26	23	36	19	20	16	20	23	20

* Numbers in parenthesis are the number of time entries appeared in a replicate if more than once. ** These entries have CK^2N in their parentage.

derivatives of CK^2N hybrids, crosses to SUK 1, to CK 60, and to SB 65 were completely eliminated. The most successful of the crosses were SB 79 × CK^2N (174-194) and 'Serena' × CK^2N (123-157). Single crosses between CK60 and either Serena or SB 79, and the backcross $(CK\ 60)^2$ × Serena provided no resistant lines. The heritability of recovery resistance is evidently quite high. For example, the estimated values of environmental and genetic variances for percentage recovered plants were $\sigma^2_e = 85.0$, $\sigma^2_g = 35.5$.

Other sources of resistance. Some visual screening was done with a part of the world collection, and this was followed in 1967 by a shoot fly test in a 13^2 simple lattice. The tral was made up from a total of 130 varieties from the world collection, 14 entries chosen from CK^2N derivatives (Table 3), and 25 control entries. Some of the results are shown in Table 4.

The data show useful shoot fly resistance in sorghum from the Lake Victoria area, the Chad area of Africa, and also in India. The tests did not include sufficient entries to locate other sources of recovery resistance and did not indicate resistance levels superior to that of Serena.

Certain of the entries from the trial reported in Table 4 were intercrossed, and the F_1 was assessed for recovery resistance. Results are shown in Table 5. Although the trial was not very accurate, owing to difficulties in establishment, there was no indication of superior recovery resistance levels in the F_1 generations. Recovery resistance in crosses and the influence of hybrid vigor are more thoroughly discussed in a separate paper (7).

Table 4. Percent recovered plants in entries from the world collection and control varieties.

Entries					
Serere name	IS number	Origin	% recovery	Control entries	% recovery
L 23	8621	Uganda	93	Serena (5)	80
Framida	8763	Chad	81		
Mn 715	2470	?	81	CK^2N lines (14)	65
E 1	8548	Uganda	80		
Maldandi 35-1	1031	India	75	L 28 (5)	45
PI 221572	2119	?	75		
E 317	8852	W. Kenya	75	CK 60 (7)	24
E 334	8969	W. Kenya	73		
L 17	8619	Uganda	73	Namatare	73
G 15	8577	W. Kenya	73	Dobbs	62
L 20	8610	Uganda	71	SB 63	57
E 520	8853	W. Kenya	69	Combine Type 2	44
	5210	India	67	Caprock	13
STR 3/16	9250	W. Kenya	67	Redlan	6
STR 5/2	8718	W. Kenya	67		
	3371	?	65	LSD .05	34
STR 3/6	8720	W. Kenya	66	% Infestation	97
				CV, %	38

* Two replications - numbers in parenthesis are the number of times entry appeared in a replicate if more than once, and the mean recovery value is given.

Table 5. Recovery resistance estimates for parents and intercrosses of some lines listed in Tables 3 and 4.

Parent lines $P_1 \times P_2$	Recovery resistance of parents (1967) P_1	P_2	Recovery resistance of F_1 hybrids (1968)
E 534 × CSF 192	73.2	54.5	63.3
L 33 × IS 2149	92.9	75.0	62.0
CK^2N 63/2 × STR 5/5	50.0	60.7	60.8
CSF 190 × E 139	69.0	59.7	59.6
CSF 190 × CK^2N 63/3	69.0	65.6	59.3
E 135 × STR 3/7	16.7	50.9	58.3
CSF 192 × CSF 194	54.5	62.5	54.3
Serena × CSF 131	70.6	53.7	50.8
Serena	79.6		73.3
CS 50	24.2		31.7
LSD .05	34.3	34.3	21.8

Table 6. Grain yields and shoot fly recovery ratings on sorghum varieties — randomized block, 12 replications.

Variety	Shoot fly, % recovered	Heads per 100 plants	Yield in q/ha
Serena	75.0	146	25.6
Namatare	72.9	159	18.3
5DX 87/1	63.3	132	27.0
5DX 18/2	63.3	141	23.8
5DX 142/1	62.5	173	29.1
5DX 61/2/1	58.2	145	23.5
SB 79	57.5	147	28.0
L 28	57.5	148	24.9
Dobbs	57.5	158	25.8
5DX 142/4	55.9	139	30.2
4DX 34/1/4	51.7	134	22.4
5DX 30/4/1	50.0	124	19.0
5DX 142/9	50.0	121	16.8
5DX 36/1/2	49.5	132	21.3
h × 60/7/2	47.5	88	13.2
5DX 61/6/2	45.8	112	16.8
SB 77	44.2	88	13.6
Combine Type 2	42.5	68	10.9
Redlan	40.8	78	12.3
SUK 1	29.2	97	11.6
CK 60	25.0	51	7.8
Caprock	16.0	37	5.1
LSD .05	0.5	23	3.2
CV, %	23.1	27.0	32.1

Yield. The relationship between yield and recovery resistance to the shoot fly is not always easy to establish because of the influence of other pests, especially stem borers. A small combined survey was therefore made of some of the best lines from the yield breeding program. The trial was conducted with an induced heavy shoot fly attack which gave about 90% infestation, and every plant was also infested with an egg mass of a spotted stem borer, *Chilo partellus* (Swinhoe). No attempt was made to discourage any additional natural stem borer infestation that occurred. Results are shown in Table 6. (The borer data will be published elsewhere.)

The data in Table 6 show a genetic correlation between yield and shoot fly recovery resistance of .831, and there is a tendency for good yield to be associated with good recovery resistance, though Namatare is analomous in this respect.

Table 7. Recovery resistance estimates on material of Namatare parentage selected for yield but not subjected to deliberate selection for shoot fly resistance.

Line	% recovered	Line	% recovered
5DX 63/1/5/2	73.0	5DX 87/2/1/1	43.8
5DX 61/2	72.2	5DX 76/3/13	39.7
5DX 63/1/5/4	67.6	CSH 1	39.0
5DX 63/1/5/5	63.0	5DX 76/3/2	37.0
5DX 61/6/2/13	62.9	Serena	76.5
5DX 63/1/1	58.0	Namatare	67.8
5DX 87/2/1/3	48.3	CK 60	20.2
5DX 61/6/2/15	47.6	LSD .05	10.6
5DX 73/3	49.2	CV, %	16.6
5DX 76/3/2	44.9	% Infestation	98.6
5DX 76/3/5	43.8		

In 1969 a group of lines from the yield breeding program having the variety Namatare in their parentage was chosen and tested for recovery resistance. The results are shown in Table 7. The data indicate that certain of the lines selected for yield also possess good shoot fly resistance, but this is not always the case. Thus, a line of 5DX 61/2 showed good recovery; 5DX 61/6 did not. However, there is a tendency for 5DX 61 and 5DX 63 derivatives — both SB 79 × CK^2 crosses — to be superior to 5DX 76 and 5DX 87, which are crosses of CK^2N with SUK 1 and CK 60, respectively. The Indian hybrid CSH 1 had poor recovery.

The estimated values of environmental and genetic variance for percentage recovered plants were $\sigma^2_e = 85.0$, $\sigma^2_g = 176.8$.

DISCUSSION

Improved techniques for developing high levels of shoot fly attack have demonstrated that there is no worthwhile seedling resistance in the sorghum types available at Serere since infestation levels of 90% and above can be easily obtained. Langham[3] found a similar situation in Nigeria where seedling infestation of the most resistant variety tested, the Indian variety, M 35-1, reached 89%. The range of material surveyed at Serere has certainly not been wide enough to demonstrate that good levels of seedling resistance do not occur.

The data reported here demonstrate the existence of good levels of recovery resistance. The variety Serena showed more than 70% recovered plants in 11 out of 12 trials; in the 12th trial, the level was 68%. In contrast, CK 60 did not produce more than 43% recovered plants with high infestations and has produced as low as 6%. The CK 60 data indicate that in this variety, percentage recovery declines with increasing infestation. Namatare has not been as consistent as Serena in the trials though it has often exceeded the 70% recovery level. It is tall, late in maturing, and has small, bitter grains surrounded by tight glumes. However, Namature has proved a satisfactory parent, and types with a good level of recovery resistance have been bred from the susceptible CK 60 crossed to Namatare and backcrossed to CK 60 (CK^2N, Table 3). In contrast, none of the Serena crosses has yielded resistant lines other than those which also involved Namatare in their parentage. This may be a reflection of the selection techniques since the Namatare phenotype is easy to identify and appears to be associated with recovery resistance. Crosses between CK^2N and Serena or CK^2N and SB 79 gave rise to lines

possessing good recovery resistance (Table 3), and SB 79 tended to be a better parent than Serena in such crosses though the indications are that Serena is the more resistant cultivar, (Tables 3 and 6). A very limited screening of a small part of the world collection did not show anything superior in recovery resistance to Serena or Namatare although a few introductions, such as M 35-1 had good resistance.

Selection for recovery resistance involves selection for high yield since a plant that does not produce well after shoot fly infestation is not regarded as having recovered well. Any sorghum types possessing seedling resistance would also be favored by such selection procedures. Recovery resistance is partly related to tillering as the primary shoot is usually killed. However, many cultivars, such as CK-60, produce several tillers but these in turn do not produce large, grain-filled heads.

The data from Table 7 confirm that selection for yield without deliberate selection under heavy shoot fly attack can be effective but is not very rapid. Thus, Serena is a sucessful product of this system, but many of the entries in Table 7 have an unacceptable level of shoot fly resistance when they are subjected to heavy attack though all have yielded well in numerous trials. Those which do show a reasonable level of shoot fly resistance have Namatare or Serena in their parentage, with but one exception (5DX 162). Presumably these would emerge as the best in due course, once enough screening trials had coincided with seasons in which the incidence of shoot flies was high.

Heritability of recovery resistance is apparently high, and there is a high genetic correlation between recovered plants and yield. The population breeding method now being developed at Serere should prove adequate for the development of enhanced levels of resistance to the sorghum shoot fly.

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