Advances in screening methods and breeding for resistance to downy mildew and stem borers in maize*

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Maize is the most important cereal in sub-Saharan Africa. It is relatively inexpensive and provides many families with much-needed nutrients. For the farmers, it matures early and is a source of ready income. Maize production is being threatened by some diseases and pests, among which are downy mildew and stem borers. Serious yield losses often occur. This paper summarizes two studies that report the efforts of IITA scientists to screen and breed maize varieties for resistance to downy mildew and stem borers.

Introduction

Downy mildew on maize, caused by the fungal pathogen *Peronosclerospora sorghi* (Weston and Uppal) Shaw, has been widely reported in Africa (Frederiksen and Renfro 1977) and has become a serious threat to maize production in parts of Mozambique, Nigeria, Uganda, and Zaire. It can be effectively and efficiently controlled by host plant resistance.

Lepidopterous stem borers are among the most important insect pests of maize in Africa. In West Africa, *Eldana saccharina* Walker (Pyralidae) and *Sesamia calamistis* Hampson (Noctuidae) are the most damaging and widespread stem borer species (Bosque-Pérez and Mareck 1990a; Shanower et al. 1991; Gounou et al. 1994). Control of stem borers can only be achieved through the integration of various control practices, such as biological and cultural control, as well as host plant resistance. Resistance breeding has been an effective approach for the control of insect pests in other parts of the world (Gracen 1989; Smith et al. 1989). Scientists at IITA have been conducting research on stem borers and developing control practices for several years. Screening and breeding for resistance to *E. saccharina* and *S. calamistis* are an integral part of these efforts.

This paper describes and compares methods for downy mildew inoculation and artificial infestation with stem borers which have been used in the maize breeding program at IITA. Progress in developing resistant varieties adapted to the lowland tropics of Africa is also reported.

Epidemiology of downy mildew

Symptoms of downy mildew include white, powdery conidia on the underside of maize leaves; half leaf chlorosis; narrow, stiff, erect leaves; and malformations of both male and female inflorescences referred to as "crazy top" (Williams 1984).

In Nigeria, there appear to be two distinct strains of *P. sorghi* which infect maize: a "sorghum" strain in the northern savanna regions and a "maize" strain in some of the more humid southern states. The latter is so aggressive that infected plants produce no grain. Incidence of downy mildew in susceptible maize varieties may be as high as 90% under natural conditions, resulting in up to 90% yield loss in farmers' fields. In contrast, symptom remission of the sorghum strain has been observed on maize (Olanya and Fajemisin 1992). The sorghum strain produces two types of spores: conidia and oospores. Oospores can withstand desiccation and can be seed transmitted. In the south, where the maize strain occurs, the more ephemeral conidia predominate, which germinate and lose viability within hours after sporulation. Maize seed that is dried to less than 12% moisture content is unlikely to transmit this strain of downy mildew. It is thought to survive the dry season in hydromorphic areas, where maize is produced throughout the year.

P. sorghi is an obligate parasite and, therefore, cannot be cultured. For screening purposes, inoculum must be collected and applied directly to test material. It requires high relative humidity (RH) (>85%) and cool temperatures (20–21 °C) to sporulate. Conidia are released at night when the necessary combination of RH and temperature normally occur. Although spores can only be produced in the dark, at least 1 hour of light is a prerequisite for sporulation, which begins 7–8 h after the light is removed.

To cause systemic infection, downy mildew spores must germinate and penetrate meristematic tissue. Since the maize strain does not commonly produce oospores, the earliest possible infection under natural conditions occurs when the seedling emerges from the ground and is exposed to airborne conidia, which penetrate leaves through open stomata. Probability of infection is greatest when the temperature is dropping and there is condensation on leaf surfaces. By about 30 days after planting (DAP), depending on the developmental stage of the plant, systemic infection with DM is no longer possible.

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Damage due to stem borer infestation

S. calamistis adults lay their eggs between the leaf sheaths of young maize plants and, upon hatching, most larvae penetrate the stem below the growing point. Larvae may also penetrate the whorl, resulting in leaf, tassel, and upper stem damage. Serious yield reduction from *S. calamistis* occurs as a result of deadhearts, stem tunneling, lodging, and direct damage to the ears. Tunneling of the stem commonly results in early leaf senescence, reduced translocation, and lodging (Bosque-Pérez and Mareck 1990a, 1991). In contrast to *S. calamistis*, *E. saccharina* begins to infest maize plants around flowering time. Direct damage to the ears is also common.

Inoculation and infestation methods

Downy mildew

Field inoculation and use of spreader rows. Consistent, high levels of infection in breeding trials are essential for progress in breeding for downy mildew resistance (DMR). To achieve a high level of infection, plants are inoculated 10–14 DAP. When spreader rows are utilized, test materials are planted about 10 days after inoculating the spreader rows. A mix of susceptible varieties should be used for the spreader rows to attain a consistent, high level of spore production during the period when test materials are susceptible to systemic infection. Pool 16-SR and TZESRW are recommended as varieties which produce large quantities of spores, beginning about 2 weeks after inoculation and continuing for 3 weeks or more (Cardwell et al. 1994). Test material can be evaluated for percent downy mildew by 4 weeks after planting, when spreader rows are utilized. For the maize strain of *P. sorghi*, it is sufficient to record incidence of DM, since infected plants produce no grain. In other regions, it may be desirable to obtain yield data to assess the severity of the disease.

Spray inoculation methods. Until recently, resistance breeding at the International Institute of Tropical Agriculture (IITA) depended entirely on a nighttime infestation method which utilizes the natural cycle of spore production (Siradhana et al. 1976; Fajemisin 1988). The method was adopted from procedures developed in Thailand in 1968. To use this technique, large quantities of infected leaves are collected at 1700 hrs. The leaves are washed to remove old spores and debris, and incubated in large trash barrels with water at the bottom. At about 0300 hrs, the leaves are washed in water to collect new conidia. The spore suspension is transferred to backpack sprayers, carried to the field, and sprayed into the whorls of the plants. This technique is labor intensive and costly in terms of manhours. If there is rainfall shortly after inoculation, the procedure must be repeated. Dry conditions also reduce infection. Spreader rows need to be inoculated up to three times to attain acceptable levels of infection (Fajemisin 1988).

In 1991, an incubator was purchased and laboratory space was made available at the Federal College of Agriculture in Akure, in the endemic DM zone in southern Nigeria. A daytime inoculation method was adopted (Schmitt and Freytag 1974), which has been shown to provide levels of infection as high as those for the nighttime procedure (Cardwell et al. 1994).

Spray inoculation methods can be further improved by using boiled or distilled water to make initial, concentrated suspensions, which can be diluted to a concentration of 1×105 conidia ml^{-1} immediately before inoculation, and by keeping the suspension at 4–6 °C to reduce the germination rate of conidia and consequent losses in viability in solution (Cardwell et al. 1994).

Seedling inoculation method. To overcome some of the limitations of spray inoculation, a method for inoculating germinating seeds has been developed. Craig (1980) observed that incidence of downy mildew was highest when maize was exposed to conidia at the seedling stage. That approach has been modified and simplified at IITA for use in large-scale breeding programs.

Maize seeds for spreader rows are germinated in an incubator in the laboratory. After 72 h, when the radical and coleoptile have just emerged, infected leaves are placed on a wire mesh above the seedlings and allowed to sporulate overnight. Seedlings are transplanted to the field the following day and test rows are planted 10 days later. High disease incidence has been obtained in susceptible test rows with this method, and requirements for labor and inoculum have been greatly reduced. The method may be applied without an incubator, making it readily transferable to national agricultural research systems (NARS).

Incubator screening method. A modified version of a system developed by Craig (1987) for collecting spores and inoculating 7-day old seedlings in an incubator was adopted at IITA in 1992 (Cardwell et al. 1994). It requires some relatively expensive equipment, which may limit its use by NARS. The system makes year-round screening possible. Also, less than 5% of susceptible plants escape infection. Plants are scored 1–2 weeks after inoculation. At this stage, symptomless plants can be transplanted to a crossing block or isolated for selfing or recombination.

Stem borers

Work conducted by IITA scientists in the early 1980s demonstrated that controlled, uniform, artificial infestations are needed to develop borer-resistant germplasm (Bosque-Pérez et al. 1989). Mass rearing of stem borers is required to provide insects for artificial infestation. Methods to mass rear *S. calamistis* and *E. saccharina* have been developed at IITA and improved over the years. At present, our laboratory produces 150,000 eggs of *S. calamistis* or 500,000 of *E. saccharina* per week at the peak of the production cycle.

Screening methods for *Eldana saccharina*. In order to increase the number of breeding materials that can be screened for resistance to *E. saccharina*, a new infestation method was developed (Bosque-Pérez and Mareck 1990b). Strips of a susceptible maize variety are planted 1 month prior to planting test materials, which are then planted perpendicular to the strips, using 3 m rows and 1 m alleys. Plants in the spreader rows are infested at silking with *E. saccharina* egg masses (65–75 eggs per plant) obtained from the laboratory colony. Adults that emerge from the spreader rows move to the test plants, resulting in a natural infestation. Test materials are checked regularly to ensure that a uniform level of infestation has been achieved. The method has proven to be efficient.

At maturity, the following assessments are made: percent of plants with broken stalks, ear aspect (size, uniformity, freedom from diseases, etc.), and plant aspect (plant and ear height, uniformity, freedom

from diseases, etc.) using a 1–5 scale; ear damage (an estimate of the percentage of grain consumed or damaged by the borer using a 1–5 scale: 1= 0–5; 2 = 6–25; 3 = 26–50; 4 = 51–75; and 5 = 76–100%); and grain yield. Measurements of agronomic characteristics (days to silk, plant and ear height) are also taken. The relative weights assigned to agronomic characteristics and *E. saccharina* resistance traits for selection vary, depending on the population and severity of infestation in a particular year.

Screening methods for *Sesamia calamistis*. The development of screening methods and the selection of *Sesamia*-resistant materials were enhanced by the identification of resistant (TZi 4) and susceptible (TZi 19 or TZi 25) inbred line checks (Mareck et al. 1989). To screen for resistance to *S. calamistis*, 21-day old plants are infested with 25–30 eggs (black head stage) obtained from a laboratory colony. Eggs are placed between the leaf sheaths at the base of the plant. Damage ratings are taken 2 and 6 weeks after infestation, using a 1–9 rating scale (Bosque-Pérez et al. 1989).

Screening and breeding for resistance at IITA

Downy mildew

Development of downy mildew resistant varieties for the lowland ecologies of West and Central Africa has been a major priority in the breeding program at IITA since the early 1980s (Fajemisin et al. 1985; IITA 1987; Kim et al. 1990). DM resistance breeding was initiated in Nigeria by the national maize program in the late 1970s. Collaborative activities with IITA were soon initiated and continue presently with the Institute of Agricultural Research and Training (IAR&T), Ibadan and the Federal College of Agriculture, Akure. The sources of resistance used in the breeding program were introduced from the national programs in Thailand and the Philippines in the late 1970s. Resistance sources developed in southeast Asia have been successfully deployed and utilized to control DM throughout the world, and generally appear to be effective against different *Peronosclerospora* species. In addition, they are stable under a wide range of environmental conditions (Frederiksen and Renfro 1977; Renfro 1985). Nonetheless, there are reports of species and strain specificity, and genotype by location interactions for resistance (Williams 1984), which imply that we should continue to incorporate additional genes for resistance into improved materials as they become available. Some new introductions obtained from Thailand and the Philippines have recently been introgressed into some of our DMR populations.

Although results of studies on the mode of inheritance of resistance to *P. sorghi* in maize have varied depending on the material used, experience has shown that the trait is relatively easy to manipulate through selection, provided that reliable screening methods are available. Singburaudom and Renfro (1982) determined that a polygenic system was responsible for resistance in a study of 10 inbred lines under heavy disease challenge in Thailand. Susceptibility was dominant for 7 of the resistant lines and incompletely dominant in one resistant line, indicating additive gene action for *P. sorghi*. The authors agreed with the conclusions of Kaneko and Aday (1980) in studies with *P. philippinensis* that downy mildew infection is mediated by threshold conditions. Expression of the disease depends on the inoculum load, genetic background, condition of the maize plant, and environmental factors. Experience in Nigeria has shown that under mild disease pressure, resistance appears to be dominant, whereas under heavy infection, resistance is recessive. Resistance is additive at intermediate levels of infection (Fajemisin, unpublished data).

Once a relatively high level of resistance is attained, it is essential to have high, uniform levels of infection in screening nurseries to make further progress in selection and resistance breeding. Using a combination of the inoculation methods now available, levels of infection achieved in susceptible checks in the population improvement program have been consistently high since 1992 (Table 1). The major emphasis in the population improvement program since 1989 has been to convert four heterotic breeding populations, which are being improved for general adaptation through reciprocal recurrent selection. These are TZE Comp. 3 (early, flint), TZE Comp. 4 (early, dent), TZL Comp. 3 (late, flint), and TZL Comp. 4 (late, dent). All open-pollinated varieties and hybrids derived from these composites should then have acceptable levels of DMR.

To assess the current status of DMR in elite maize varieties available from IITA,

Table 1. Summary of downy mildew screening in the populations improvement program, 1989–1993.

Year	Season†	Material	Entries	Reps.	Mean % DM	Susc. check % DM
1989	A	EV8443-DMRSR BC_2 S_1	127	2	19.0	53.1
		EV8443-DMRSR BC_3 S_3	148	2	32.8	57.4
1989	B	DMR-LSRW S_1	227	2	0.4	6.0
		DMR-LSRY S_1	188	2	0.4	6.0
		DMR-ESRW S_1	262	2	1.0	16.3
		DMR-ESRY S_1	146	2	0.1	26.0
		Pop. 28-DMRSR S_1	238	2	0.3	9.0
1990	A	TZL Comp. 3 C0 S_2	1023	1	–††	–††
		Pop. 28-DMRSR S_1	79	1	1.9	20
		Pop. 22-DMRSR BC_4 S_1	182	1	6.5	30
1991	A	TZE Comp. 4-DMRSR BC_1 S_1	300	2	41.4	66
		TZE Comp. 3 C1 S_1	1125	2	11.2	52
		DMR levels	15	6	28.9	67
1991	B	DMR levels	15	6	8.7	26
1992	A	TZL Comp. 4 C0 S_2	450	2	63.3	85
		TZE Comp. 3 C1 S_1	900	2	22.2	86
		DMR levels	20	8	39.8	84
1993	A	Pop. 31-DMRSR S_1	225	2	35.1	94
		Pop. 22-DMRSR S_1	265	2	33.8	90
		Acr. 90 DMR-LSRW S_1	200	2	12.4	89
		Acr. 9028-DMRSR S_1	200	2	15.4	85

†. A and B represent the first and second rainy seasons, respectively, in a bimodal pattern.
††. Data not collected due to low incidence of DM.

Table 2. Summary of downy mildew resistance level trials in Akure in 1991 and 1992.

Cultivar	Downy Mildew % 1992	1991
Suwan 1-SR BC5	9.2	5.2
Suwan 2-SR BC4	9.4	11.2
Acr 89 DMR-ESRW	11.3	13.7
DMR-LSRW	17.5	20.5
DMR-LSRY	22.0	21.8
8644-27 (KU1414 × TZi18)	10.1	22.3
DMR-ESRY	14.6	29.8
TZE Comp 3 C1	28.3	30.1
Acr 9028-DMRSR	-	32.0
Pop 22-DMRSR	20.7	32.1
Pop 31-DMRSR	21.5	33.4
TZ 9043-DMRSR	40.7	39.8
TZ 8843-DMRSR	35.6	40.0
TZL Comp 3 C0	29.5	41.2
8644-31 (KU1414 × TZi25)	30.8	43.0
TZL Comp 4 C0	51.8	65.7
Funtua 88 TZSR-W-1	70.6	73.9
8321-18 (TZi3 × TZi15)	-	74.0
EV8443-SR	-	82.0
Acr 88 Pool 16-SR	67.0	84.3
Mean	28.9	39.8
LSD (0.05)	13.1	12.4
Prob.> F	0.000	0.000
CV%	35.8	31.4

20 varieties, including susceptible checks, were tested under artificial infestation of downy mildew at Akure, Nigeria in 1991 and 1992 (Table 2). Three DMR varieties, Suwan 1-SR (late, yellow, flint), Suwan 2-SR (intermediate, yellow, flint), and Across 89 DMR-ESRW (early, white, flint/dent), showed the highest levels of resistance. The first two varieties were developed in Thailand and were converted for resistance to maize streak virus (MSV) at IITA in 1990 (Eberhart et al. 1991). Two late-maturing varieties, DMR-LSRW (white) and DMR-LSRY (yellow), which were developed at IITA, are still about 20% susceptible. Our goal is to bring the level of resistance in existing DMR varieties up to the 90–95% level.

In the hybrid breeding program, inbred parents of elite hybrids are being converted for DMR. A major achievement has been the development of a DM resistant single-cross hybrid, 8644-27, which is marketed commercially by Pioneer Seeds in Nigeria as "Oba Super 2." One of the parent lines is KU1414, a DMR inbred from Thailand. The hybrid has about 22% susceptibility under heavy disease pressure (Table 2). By 1992, the other inbred parent, TZi18, had been converted for DMR and KU1414 had been converted for resistance to MSV. Now both parents confer resistance to DM and MSV. Crosses between KU1414 from Thailand and MIT2, a resistant inbred line from the Philippines, have shown very high levels of resistance. Incorporation of new sources of resistance into the breeding program can thus enhance the levels of DMR and increase the durability of resistance.

Stem borers

Since 1985, a wide diversity of germplasm has been screened for reaction to infestation by either *S. calamistis* or *E. saccharina*. This includes the BR (borer resistant) population of IITA (developed by screening for *S. calamistis* under natural infestation), CIMMYT's MBR (multiple borer resistant) and MBRT (multiple borer resistant tropical) populations, a portion of the MIR (maize inbred resistant) lines from Hawaii, and a wide range of germplasm from North and South America which has shown resistance to other species of maize stem borers. Sources of resistance to *S. calamistis* or *E. saccharina* have been found among some of these germplasm groups.

Three populations with moderate resistance to *S. calamistis* were formed between 1987 and 1988 (Table 3). The population TZBR Sesamia 2 was eventually discontinued, as it did not show adequate levels of resistance to this pest. The other two populations, TZBR Sesamia 1 and 3, are undergoing selection for resistance to *S. calamistis*.

Screening for resistance to *E. saccharina* has received major emphasis. After intensive screening from 1985 to 1987, three populations with moderate resistance to *E. saccharina* were formed between 1988 and 1989 (Table 3). In 1985, 102 accessions introduced mostly from CIMMYT were screened for resistance as test crosses with the hybrid 8338-1; superior materials were selected and backcrossed to their original introduction. TZBR (tropical zea borer resistant) Eldana 1 was formed from the best 14 of these backcrosses. Additionally, inbred lines with tropical adaptation were screened for resistance, and the best five recombined to form the population TZBR Eldana 2. Tropically adapted, early, intermediate, and late-maturing open-pollinated populations were also screened for resistance during 1988–89 (Fig. 1, Table 4). S1 lines from the three most resistant late populations (La Posta, DMR-LSRW, and TZSR-W-1) were screened and superior lines were selected and recombined to form the TZBR Eldana 3 population. Because TZBR Eldana 3 was developed from elite, adapted populations, it may be transferred to national programs for direct use by farmers. Cycle 2 of this population performed well in multilocational yield trials in Nigeria and Côte d'Ivoire in 1993, and it was advanced to international trials. TZBR Eldana 1 is derived from exotic germplasm and is less adapted to the region. It is intended for use as a source of *E. saccharina* resistance by national breeding programs.

Among the early, tropically adapted populations screened in 1988, two early composites undergoing improvement at IITA (TZE Comp. 3 and 4) and an experimental variety from CIMMYT's population 30 (EV 8730-SR) showed the least ear damage under *E. saccharina* infestation

Table 3. Genetic background of stem borer resistant populations.†

Population	Genetic background
TZBR Eldana 1††	14 testcrosses with hybrid 8338-1
TZBR Eldana 2	TZi 2, 10, 12, 15, and ICAL 27
TZBR Eldana 3	S1 lines from DMR-LSRW, La Posta, and TZSR-W-1
TZBR Sesamia 1	CM 116, INV 575, Cateto Grande Mil, Cateto Assis Brazil RGS × IV, Costeño Mag. 350, and Cubano Cateto Ecuador 339 crossed to TZi 4
TZBR Sesamia 3	29 lines, mostly from the CIMMYT MBR population, crossed to TZi 4.

†. TZBR Eldana 3 has white grain; all others are of mixed grain color; all populations are late maturing (115–120 days).

††. Fourteen entries used for testcrosses: MP496 × VG-ECB-24X; MP702 × ECB PI 3; PRMO × PRMOSQB 87-4-1; PRMO$_2$ (S$_1$) C6 88-3; PRM O$_2$ (S$_1$) C6 88-12; Pool 24 × (MP496 × MP706); PRM O2 (S$_1$) C6 752X-2; PRM O2 (S$_1$) C6 × (MP496 × MP701); PRM O2 (S$_1$) C6 752-1; 100-5 × 44-6 (2); PRM O$_2$ (S$_1$) C6 752X-4; MP701; MP68; and MP704.

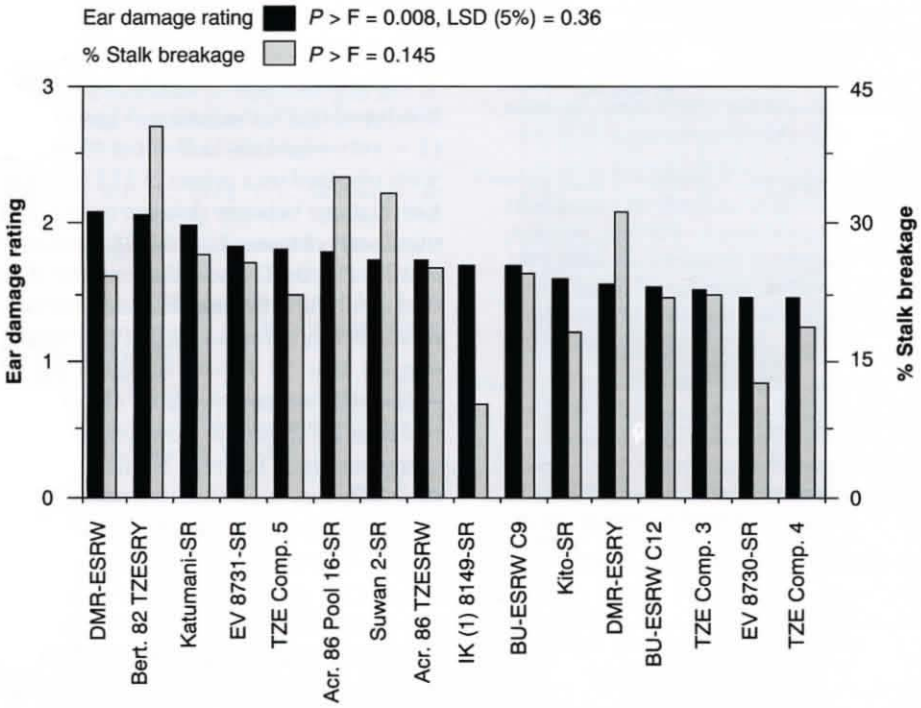

Figure 1. Resistance to *Eldana saccharina* in early germplasm, 1988.

Table 4. Performance of elite, late, and intermediate germplasm under *E. saccharina* infestation, Ibadan, Nigeria, 1989[1].

Cultivar	Days to midsilk	Frass rating[2]	Ear damage[2]	Penetrometer reading (kg)[3]
La Posta C8	53.0	1.67	2.39	11.87
IK 83 TZSR-W-1	58.7	1.33	2.89	11.30
DMR-LSRW	54.2	2.17	2.61	9.27
LB 8227	55.8	2.17	2.67	8.87
EV 8725-SR	54.0	1.50	3.33	8.48
ACR 8224	55.3	2.00	3.86	8.38
PR 8536	54.7	2.33	3.34	8.22
LB 8232	55.5	2.67	3.39	7.49
PR 8326	51.2	2.33	3.17	6.42
Ferke 8223	53.8	2.00	3.06	6.31
8338-1	52.8	1.33	3.28	11.72
8329-15	54.8	2.33	2.28	9.54
Mean	54.5	1.99	3.02	8.99
LSD 5%	1.56	0.66	-	2.36
Prob. > F	0.000	0.001	0.139	0.000
CV %	2.5	28.9	30.3	22.7

1. RCBD with 6 replications.
2. Rating scale: 1 = resistant to 5 = susceptible.
3. Penetrometer readings were taken at the base of the stem at flowering; larger values indicate that greater force was required to penetrate the stem.

(Fig. 1). An experimental variety derived from CIMMYT population 49 (IK (1) 8149-SR) had very low stalk breakage. The resistance of TZE Comp. 4 is probably derived from the parental sources used in forming the composite, populations 30 and 49. The parents of TZE Comp. 3 are TZESR-W and DMR-ESRW, which are more susceptible to ear damage than the composite. In this case, there appears to have been some indirect improvement in *E. saccharina* resistance while selecting for yield, ear aspect, and reduced lodging in our normal breeding trials. Ear damage and percent stalk breakage were significantly correlated in this experiment ($r = 0.52, P < 0.05$).

To evaluate levels of *E. saccharina* resistance in tropically adapted intermediate and late populations (Table 4), ratings of the amount of frass in the leaf axils and extent of ear damage were recorded (1 = resistant to 5 = susceptible). Penetrometer readings were taken at the base of the stem at flowering; larger values indicate that greater force was required to penetrate the stem. There was a significant correlation between the penetrometer reading and the frass rating ($r = -0.66, P < 0.05$). There was some indication of a relationship between ear damage and penetrometer reading ($r = -0.40$, ns), but the estimate of the correlation between frass and ear damage rating was close to zero. This suggests that different mechanisms may be involved in determining *E. saccharina* resistance in the stalks and ears.

Borer resistant populations are being improved for adaptation and resistance levels primarily through S_1 family testing. Mass selection for resistance to maize streak virus is carried out when individual plants are selfed to make new S_1 families.

To evaluate the progress achieved in selecting for resistance to *E. saccharina*, cycles of selection trials are periodically conducted. In 1991, Cycles 0 to 4 of TZBR Eldana 1 and C0 to C2 of TZBR Eldana 3 were evaluated under infestation along with a susceptible check and two hybrids. Ratings for ear damage were significantly lower ($P < 0.05$) for later cycles compared to early ones, showing that increased levels of resistance to this pest have been obtained in these populations (Fig. 2). Time to maturity has also increased in TZBR Eldana 1. Use of a selection index should prevent further inadvertent increases in maturity in the future.

We had observed that plant vigor influences the plants' reaction to *S. calamistis* attack and were concerned that differences in inbreeding depression among S_1 families could mask resistance that would be expressed in a noninbred background. A split-plot experiment was conducted in the screenhouse to simultaneously compare the resistance performance of S_1 families from TZBR Sesamia 1 C1 with test crosses derived from the same families (TC). Although inbreeding usually increases susceptibility to stem borers, there was no difference in mean damage ratings between 176 S1 families and their TCs (Table 5). This may be because a highly susceptible inbred was used as the tester, in order to maximize expression of resistance among the test crosses. Highly significant differences were observed among families for resistance, but the family × type (S_1 or TC) interaction was not significant. Analysis within types showed that genetic differences were significant among the S1

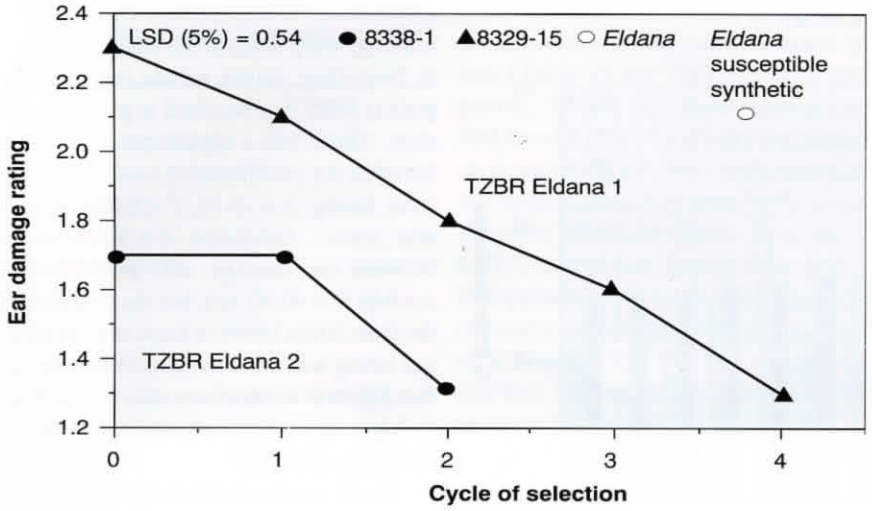

Figure 2. Cycles of selection for resistance to *Eldana saccharina*, 1991.

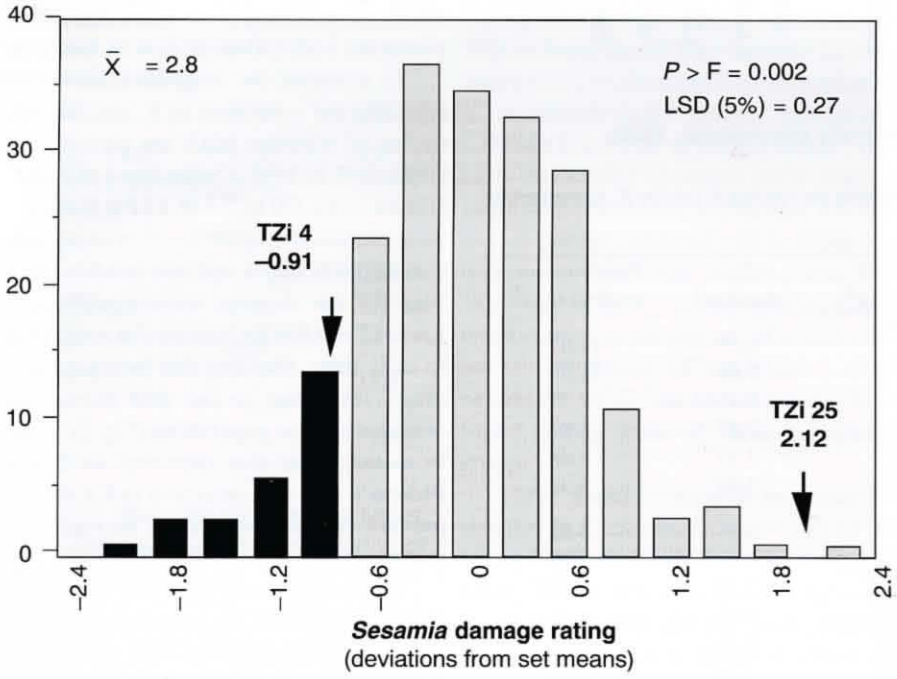

Figure 3. Distribution of 204 S1 families from TZBR Sesamia 3 C0 for *Sesamia* damage ratings.

Table 5. Analysis of variance[1] for S_1 families and the related S_1 testcrosses[2] (TC) in TZBR Sesamia 1 C1.

	Damage rating[3]		Vigor rating[4]	
Source of variation	MS	*P* > F	MS	*P* > F
Type (S_1 vs. TC)	11.34	0.339	177.51	0.026
Error a	5.81		12.28	
Family	1.88	0.007	2.65	0.063
Family × Type	1.46	0.281	2.05	0.495
Error b	1.36		2.06	
Mean S_1	4.35		4.38	
Mean TC	4.60		3.12	
No. of families	176		112	

1. Split-plot arrangement of treatments with two replications.
2. S1 families were crossed to the susceptible inbred tester TZi 28.
3. Rating scale: 1 = resistant to 5 = susceptible.
4. Rating scale: 1 = vigorous to 5 = weak plant growth.

families, but not among the TCs. More replication would, therefore, be required to make comparable progress from selection based on TC evaluation. Vigor ratings (1 = very vigorous to 9 = not vigorous) were obtained on a subset of 112 families. Correlations between damage ratings and vigor were obtained both for S1 families (r = 0.39, $P < 0.01$) and TCs (r = 0.51, $P < 0.01$), but the difference between the correlations was not significant. These results suggest that S1 family selection for *S. calamistis* resistance will be more effective than TC selection. However, since the correspondence between S1 families and their TCs was very poor, we only carried out one cycle of selection for each type of family, to determine the actual progress that can be obtained from the two selection methods.

Owing to the relationship between *S. calamistis* resistance and plant vigor, hybrids tend to be more resistant than open-pollinated varieties. Among the *Sesamia* populations, TZBR Sesamia 3 C0 appears to have the greatest resistance, which was comparable to that of hybrid 8321-18 in one experiment (data not shown). When the distribution of S1 families from this population was observed (Fig. 3), averaged over two replications, genotypes to the left of the distribution were most resistant. Twenty families had better ratings than the resistant check, TZi 4. One limitation of TZBR Sesamia 3 is that it is relatively susceptible to *Puccinia polysora*. Some attention will be given to agronomic traits and disease resistance in the future, while continuing to place the greatest emphasis on developing *Sesamia* resistant source populations for national breeding programs.

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