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**Insect and Disease Resistance
from Tropical Maize for Use
in Temperate Zone Hybrids**

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and A. R. Hallauer

Kim, S. K., J. L. Brewbaker and A. R. Hallauer. 1988. Insect and Disease Resistance from Tropical Maize for Use in Temperate Zone Hybrids. Proc. 43rd Annual Corn and Sorghum Research Conf. 194-226.

CONTENTS

INSECT AND DISEASE RESISTANCE FROM TROPICAL MAIZE FOR USE IN TEMPERATE ZONE HYBRIDS[1]

S.K. Kim[2], J.L. Brewbaker[3] and A.R. Hallauer[4]

Abstract

Biotic constraints (insects, diseases, parasitic weeds) and abiotic stresses (drought) are widespread and pose a constant threat to maize production worldwide. Tropical environments provide the greatest opportunity for evolution of insects and diseases because of the favourable year-round climatic conditions. Year-round breeding programs permit selection of stable general resistance against specific or combined challenges. The IITA Maize Program initiated a line-development project in 1979. The major objectives of this project were to develop vigorous, tropically adapted inbreds that confer general resistance or tolerance against specific African as well as common tropical production constraints. Important constraints in Africa are stem borer *(Sesamia calamistis, Eldana saccharina* and *Busseola fusca),* storage insects (*Si-*

S. K. KIM

tophilus spp.), foliar diseases (Maize Streak Virus, *Puccinia polysora, Helminthosporium maydis, Exserohilum turcicum, Curvularia pallescens,* downy mildew), stalk and ear rots *(Fusarium moniliforme, Botryodiplodia theobromae, Macrophomina phaseoli), Striga hermonthica,* and drought. Some of these problems occur in the U.S. Corn Belt and in other parts of the world.

The Maize Inbred Resistance (MIR) project of the University of Hawaii tested 120 tropically adapted inbred collections at 27 locations worldwide, including tropical, subtropical and temperate regions. Sources for high levels of general resistance were found for most insects and diseases. The selected inbreds could be valuable sources of resistance for developing inbreds and hybrids adapted to the Corn Belt. This paper presents current results regarding general resistance to the major production constraints of maize worldwide and introduces a pioneering approach for testing combining ability of tropical inbreds for temperate as well as tropical regions.

Introduction

Although maize (*Zea mays* L.) is the species of tropical origin, it is the world's most widely distributed crop, with more than 70 countries growing maize on more than 100,000 ha (CIMMYT, 1981). Tropical maize production involves about 60 million hectares and 70 million tons of grain, with an average yield of 1.2 t/ha. The vast majority of this is rain-fed and low-input, and is often produced as a subsistence food crop in an unfavourable tropical environment (Brewbaker, 1985; Renfro, 1985).

When maize breeders in the U.S. Corn Belt introduced sources of exotic germplasm, usually only germplasm from Central and South America were considered (Hallauer, 1978). Nelson (1972) and Lonnquist (1974) indicated the usefulness of exotic germplasm in a commercial maize improvement program for adaptation, combining ability, drought and disease resistance. Efron and Everett(1969) and Eberhart (1971) explored the potential of exotic germplasm for improving maize hybrids for the short season temperate zones of the United States, and concluded that the materials observed were not so promising for grain production. The major reason for this is the problem of daylength sensitivity, which is characteristic of most tropical maize. Goodman (1985) suggested that the entire set of available materials (composites and hybrids) should be systematically screened for daylength insensitivity.

After about 50 years of attempting to use tropical and semitropical sources of maize germplasm in the temperate region, it is still not known

with certainty which are the best sources to use, how to use them, or how they combine with known elite temperate germplasm. Furthermore, few of the basic data on yield, standability, pest and disease resistance and adaptation have been acquired and published. There is no scientific information on which to base the choice of future breeding materials (Wellhausen, 1978). Goodman (1985) suggested that more attention be focussed upon the choice of breeding materials rather than upon breeding methodology.

Africa is the continent with the world's lowest average yield of maize (1.0 t/ha). Occasional crop failure caused by drought, diseases, insects and parasitic weeds has aggravated food shortage and famine problems which put sub-Saharan Africa at the center of world concern. Maize is grown intensively in the U.S. Corn Belt and is considered to be the premier economic crop. The germplasm base in the Corn Belt is narrow, and some believe this results in genetic vulnerability of this important crop (Sprague,1971; Zuber and Darrah, 1979). Tropical germplasm has maintained wide genetic diversity which can provide better opportunities to select for insect and disease resistance (Kramer and Ullstrup, 1959; Hooker, 1962; Goodman, 1965; Sprague, 1977; Ullstrup 1979; Buddenhagen, 1985; Duvick, 1985; Monteagudo, 1985), and it is being used to widen genetic diversity of the U.S. Corn Belt hybrids (Brown, 1953; Wellhausen, 1956; 1965; Hallauer, 1972; 1978; 1985; Goodman 1985). Because of the short history of line development programs in the tropics, most tropical germplasm available are open-pollinated varieties.

Perhaps the most promising of the populations containing substantial tropical germplasm and improved by recurrent selection in the Corn Belt are the "ETO" selection by Hallauer (1978), and the "West Indian Composite" by Brown (Goodman, 1965, Eberhart, 1971, Troyer and Brown, 1972). Griffin and Lindstrom (1954) and Nelson (1972) reported the potential use of tropical inbreds as exotic germplasm. Homozygous tropical inbreds can be considered as superior germplasm for general resistance (Buddenhagen, 1985; Kim, 1986).

Year-round corn nurseries at most tropical breeding stations result in frequent epiphytotics of insects and pathogens and provide an excellent opportunity to select for general resistance. Race specific resistance based on single genes is readily overcome and has little value in controlling prevalent insects and diseases in the tropics. Tropical conditions also provide a good opportunity to select for drought tolerance (Fischer et al., 1981; Bolanos and Edmeades, 1988).

A goal of special interest to temperate maize breeders is the identifica-

tion of specific sources of exotic germplasm that have resistance to local stresses, wide adaptability, and excellent general combining ability as well. Unfortunately, virtually no data are available for such a purpose. This paper discusses the potential use of tropical maize germplasm, especially inbreds, as the sources of resistance to major insects, diseases and other production constraints for the development of the temperate zone hybrids.

MIR—Worldwide

A total of 120 selected tropical inbred lines were tested under specific biotic conditions of insects and diseases worldwide. The trials were designated MIR (maize inbred resistance) and coordinated by J. L. Brewbaker and M. Logrono of the University of Hawaii. Temperate inbreds converted for tropical adaptation were also included. Data were collected on 15 morphological characters and on reaction to 19 pests and diseases including - corn borers (second-generation European corn borer, Asian corn borers), storage weevils (*Sitophilus* spp.), viruses (MDMV, MCDV, MBSDV, MSV, MMV and corn stunt), blight (southern and northern leaf blight), rust (southern and common rust), *Curvularia* leaf spot (similar to gray leaf spot), downy mildew, ear and stalk rots, head and tassel smuts, the parasitic weed *Striga,* and drought. All data were handled with the d.BASE III database management system at the University of Hawaii (Brewbaker et al., 1989) and a preliminary unpublished report sent to all collaborators in 1987. The averages and ranges for each of the 15 traits of the MIR lines from 25 locations, mostly in the tropics, are summarized in Table 1. Considerable variability was observed among inbred lines for most traits, indicating the genetic potential for improvement through conventional breeding approaches.

Data for the MIR in temperate zones are limited. The 120 lines were planted at Ames, Iowa, in 1987. The results were analyzed according to three origins : (a) tropical (55 lines), (b) subtropical (38 lines) and (c) temperate (27 lines). All inbreds developed for the southern U.S., Hawaii and IITA -converted temperate germplasm were classified as subtropical. Most temperate lines were either Corn Belt inbreds or converted Corn Belt lines, i.e., backcrossed 5-6 generations in the subtropics for specific conversion, such as MMV in Hawaii. Under the long-day Corn-Belt conditions, tropical maize was characterized by daylength sensitivity and late flowering, tall plants with many leaves, with root lodging, and smut susceptibility. As reported below, however, (Table 2), many of these inbreds

TABLE 1—Morphological and agronomic traits of 120 tropical maize inbred resistant (MIR) lines tested in 25 locations.

| Trait | Mean | Range | Inbred for two extremes | |
			Lowest	Highest
Days to silk (days)	60	53–71	R 168	AR258
Plant height (cm)	148	103–189	AR258	H632G
Ear height (cm)	68	38–100	AR258	H632F
Stalk lodging (1–5)[1]	2	1.0–2.5	CI64(Hi)+[2]	CIM.T-IIES
Root lodging (1–5)[1]	2	1.4–3.0	Hi25	Fla2BT73
No. husks	10	6–17	SC43	Hi28
Husk cover (1–5)[1]	2	1–3.1	Tx29A(Hi)	ArgF872
Leaves/plant	19	16–23	Va35(Hi)+	CIM.A6 (Hi)
Yield (t/ha)	2	0.5–5.1	TZi 22	SR52F
Ear length (cm)	14	9–20	SC55	H632F
Ear diameter (cm)	4	3.4–5.4	AR258+	SR52F
No. kernel rows	14	11–19	H632F	H55(Hi)
Kernels/row	28	16–40	SC213	CM116
Wt. 100 kernels (gm)	30	18–53	SC55	SR52F
Drought (1–5)[1]	3	2–4	TZi 9	Hix4283+

[1]Ratings (1–5); 1 = resistant, 5 = susceptible.
[2]More inbreds, which are not listed here, received the same ratings as the inbred listed.

TABLE 2—Mean of nine traits of 120 maize lines from tropical (55), subtropical (38) and temperate (27) origins grown in Iowa, 1987.

Trait	Tropical	Sub-tropical	Temperate	Mean	SE
Mid-tasseling (days)	102	91	83	92	0.5
Mid-silking (days)	114	97	86	100	0.7
Plant height (cm)	230	220	200	219	1.5
Ear height (cm)	149	125	98	126	1.6
Inter. no. ear[1]	12.5	10.1	8.3	10.5	0.1
Inter. no. above ear	6.9	7.1	6.9	7.0	0.1
2-ECB[2] (1–9)[3]	4.3	5.1	5.6	5.0	0.1
Smut (1–9)	3.8	3.5	2.2	3.3	0.2
Root lodging (1–9)	5.0	3.4	2.5	3.7	0.2

[1]Internode number up to ear.
[2]European corn borer.
[3]Rating scale (1–9): 1 = no damage; 9 = severe damage.

could serve as excellent sources of resistance for most biotic problems in the temperate zones and they could be converted with relative ease to low daylength sensitivity.

Insects

1. European Corn Borers

Two generations (first and second) of the European corn borer, *(Ostrinia nubilalis)* thrive on maize in the temperate zone. Most of the present-day commercial hybrids and their parental inbreds in the U.S. Corn Belt are resistant to the first generation, but susceptible to the second generation (Klenke et al., 1986; Guthrie and Russell, 1987). Depending on the environmental conditions, the second-generation corn borer can become serious in certain years if the resistance of high combining inbreds is not improved. Klenke et al. (1986) estimated yield reductions of 40% with the use of susceptible hybrids. Sullivan et al (1974) reported source of resistance and Kim et al. (1988a) reported 19 new sources of resistance in material with tropical and subtropical genetic backgrounds (Table 3).

A 9×9 diallel cross involving five resistant (TZi 4, Narino330, Hi34, Hi29, AntC5), and four susceptible (Hi32, Tx601, B73, Oh43) inbreds was used to determine the genetic control of resistance (Kim et al., 1988b). The results are summarized in Table 4. Ratings (1-9) of the 36 individual F1 crosses varied significantly ranging from 1.8 (TZi 4 $\times$ Narino330) to 5.3 (B73 $\times$ Oh43). Hybrids were more resistant than their mid-parental value and ranged from -42.9% (more resistant) to $+14.9\%$ (more susceptible). General combining ability (GCA) and specific combining ability (SCA) were highly significant for resistance, accounting for 82% and 18% of the variance among crosses respectively, indicating the importance of additive gene effects. Among the nine parents, four resistant parents (TZi 4, Narino330, Hi34, AntC5) showed higher GCA effects for resistance, while the other five parents showed higher GCA effects for susceptibility.

2. African Stem Borers

Three maize stem borers, *Sesamia calamistis, Eldana saccharina* and *Busseola fusca,* occur only in Africa. The first two are widespread in the lowland humid areas of almost all the countries of sub-Saharan Africa. Farmers in West and Central Africa seldom plant maize as a second season crop (July - November) and the main reason for this is the crop damage

TABLE 3—Tropical maize inbreds resistant to second-generation European corn borers in Iowa (1987).

Inbred	% mean[1]	Origin	Parentage	MT at Ames[2]
TZi 4	45.4	IITA	Pop. 29 x TZSR	110
Fla2AT116	45.4	Florida	Fla. Pop. A.	104
CIM.A.-6 (Hi)	50.5	CIMMYT	PR-69B-148	115
TZi 3	55.5	IITA	Pop. 21 x TZSR	120
CM118	55.5	India	PTR-1-605	102
SC123	60.6	S. Carolina	(GT112xNC33)GT112	98
ICAL36	60.6	Colombia	Eto-25-5	97
CIM.A.21 (Hi)	60.6	CIMMYT	PR69B-149	106
SC301D (Hi)	60.6	S. Carolina	S. Carolina Comp.	89
INV534	60.6	Texas	Batan x Ph. DMR-10	100
KU1418	60.6	Thailand	Suwan 1	120
T258	60.6	Tennessee	Tenn. Late Low ear 10	87
CM116	65.6	India	Puerto Rico Gr.1	94
Hi27	65.6	India	CM104 = A *Theo* 21#	97
CM103 (Hi)	65.6	Hi	Col. 1 x 38-11	102
TZi 18	65.6	IITA	Pop28 x TZSR	105
MP496	65.6	Mississippi	Antiqua	88
Narino 330	65.6	Thailand	Narino 330	103
TZi 25	75.8	IITA	B73BC3 x RPPSR	94

[1]Percentage of the trial mean rating.
[2]MT: days to mid-tasseling.

TABLE 4—Average second-generation ECB ratings (1-9)[1] of nine corn inbreds (diagonal) and their 36 F1 diallel crosses (above diagonal).

Parent	TZi[4]	Narino	Hi34	Hi29	AntC5	Hi32	Tx601	B73	Oh43	Array mean
Tzi 4	2.5	1.8	2.2	3.0	3.0	3.3	2.7	4.3	2.8	2.9
Narino		3.2	2.2	3.3	2.3	4.0	2.5	4.0	3.3	2.9
Hi34			3.2	4.5	2.8	3.2	4.0	3.8	3.7	3.3
Hi29				4.7	3.7	4.2	4.7	4.2	4.5	4.0
AntC5					5.0	3.8	3.8	4.2	3.8	3.4
Hi32						5.3	4.7	4.7	5.2	4.1
Tx601							5.3	4.8	5.2	4.1
B73								5.5	5.3	4.4
Oh43									6.7	4.2

Grand mean = 3.9; Parental mean = 4.6 and F1 mean = 3.7.
LSD (0.05) = 0.91.
[1]Rating scale (1-9); 1 = no damage; 9 = severe damage.

(U.S. Corn Belt)

Tester   Tester

[3-4 testing sites]

Caribbean Mix/Lancaster

Tuxpeno/SSS

[Temperate]

B73 x B84   Mo17 x MBS 2040

TZi15 x TZi17   TZi3 x TZi4

[MIR]
(Maize
inbred resistance)

[Tropics]   [Sub tropics]

(Nigeria)
3 testing sites   (Hawaii)
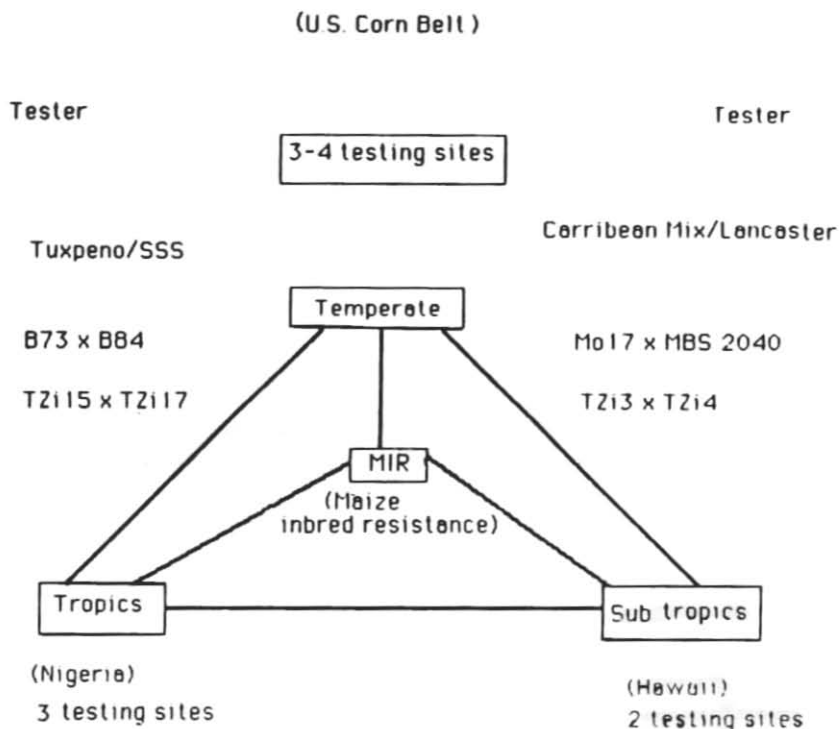   2 testing sites

Figure 1. Integration of tropical disease and insect resistant maize inbreds for the U.S. Corn Belt.

anticipated from these two insects. *S. calamistis* attacks maize at an early stage, resembling in some respects the first generation European corn borer, except that it often causes dead hearts as well as overall plant damage. While *E. saccharina* attacks maize at a late growing stage, in a similar manner to the second-generation European corn borer, damaging the stem and ears.

IITA scientists initiated breeding for resistance to *S. calamistis* in the late 1970s. The identification and confirmation of sources of resistance to the two insects were recently achieved (Bosque-Perez et al., 1988). This success was the result of the development of uniform and efficient artificial infestation techniques.

TABLE 5—Tropical maize inbreds moderately resistant
to *Sesamia calamistis* at IITA, Nigeria.

Inbred	Rating (1-9)[1]
TZi 4	3.9
Across 7624 (S3 line)	4.1
CM116	5.2
INV. 575	5.3

Source: IITA Maize Research Program Ann. Report
(1986).

Rating Scale (1-9), 1 = resistant; no visible injury,
9 = susceptible; dead heart or plant killed.

An inbred developed at IITA (TZi 4) showed a moderate level of resistance to *S. calamistis* (Table 5). The inbred TZi 4 was developed from Guana Caste 7729 (CIMMYT) × TZSR(IITA), and it possesses multiple resistance to maize streak virus (MSV), *Helminthosporium maydis* and *Puccinia polysora* (Kim et al., 1987a). Additional sources of resistance to *S. calamistis* were also identified in a multiple borer resistant (MBR) population from CIMMYT (Mareck, unpublished). A source population with resistance to this insect was formed and additional inbred lines are being developed from the various sources identified.

Sources of resistance to *E. saccharina* have also been identified (Bosque-Perez et al., 1988) and some of the sources are summarized in Table 6.

TABLE 6—Maize genotypes moderately resistant to African sugarcane stem borer, *Eldana saccharina*, at IITA, Nigeria.

Genotype[1]	1985 % stalk tunnelled	1986 % stalk tunnelled	1986 % stalk lodging
MP704	9.3	14.2	0
PRMo2(S1)C6752-1	8.1	16.8	13
MP496	8.3	17.6	20
PRMo2xPR MpoSQB874	9.0	10.3	27
PRMo2(S1)C688-8	7.6	14.7	33
8338-1 (Tester)	16.1	19.3	33

Source: Bosque-Pérez et al., 1988.
[1]Testcrossed with 8338-1.

These are two lines from Mississippi (Mp704 and Mp496), three lines from Missouri (PRMo2 series), and an IITA hybrid (8338-1). The original source for the PRMo2 materials was derived from Nigerian composite-B (Barry et al., 1985), and it is one of the base populations of the IITA maize breeding program. In addition, several IITA hybrids, such as 8321-18 etc., have shown some resistance to *E. saccharina* when grown during the second rainy season.

3. Asian Corn Borer

The Asian corn borer (*Ostrinia furnacalis*) is the most serious insect pest of maize in Southeast Asia and the Pacific (Brewbaker et al., 1989). Out of the 120 MIR lines tested against *O. furnacalis* in Guam and Taiwan, eight inbreds showed moderate levels of resistance (Table 7). The parentage of these lines are Cuban flint and Antigua groups.

4. Weevils (*Sitophilus* spp.)

Sitophilus weevils damage maize grain worldwide. Infestations with weevils are more intense in warm climates and tropical areas where the problem begins in the field and continues through the storage period. Tightness of husk cover and many husks are considered to be major morphological traits that minimize field infestation of the insects that damage grain in storage (Dicke, 1977). Selection for increased yield of maize in the tropics often results in poor husk cover. However, there is evidence that the traits can be improved simultaneously. Maize plants of tropical germ-

TABLE 7—Tropical maize inbreds resistant to Asian corn borer *(Ostrinia furnacalis)*.

Inbred	% mean[1]	Origin	Parentage
Hi32	53.3	Hawaii	Oh545
ICA L25	58.7	Colombia	Cuban flint
NC248	66.2	N. Carolina	(NC601 x GT112) BC4
H₁ x 4231	67.5	Hawaii	(Hi34 x Hi25)
PAC 90038	67.6	Australia	Pacific Seeds
CIM.T.IIES	67.8	CIMMYT	PR-70B-659
Mo5	69.7	Missouri	(N6 x K55)BC2
Hi34	70.2	Hawaii	Antigua 2D

Source: Brewbaker et al., 1989.
[1]Percentage of the trial mean rating.

plasm have an average of 12 husk leaves compared to seven for temperate inbreds (Kim, 1974; Brewbaker and Kim, 1979). Grain texture appears to have some correlation with *Sitophilus* spp. damage. Popular tropical maize populations with dent grain texture such as Tuxpeno and its related La Posta are highly susceptible (Kim, Logrono and Brewbaker, unpublished).

Resistance to weevil attack of some MIR and other inbreds has been observed in Nigeria and Hawaii. Significant genetic variation for resistance to weevil damage was observed among tropical inbreds and hybrids. Among the MIR inbreds, three Hawaiian inbreds with Antigua background (Hi41, Hi34 and Hi39), two Colombian inbreds (ICA L29 and ICA L 221) and one inbred from Thailand (KU1409) showed less damage (Table 8). In a study of weevil damage at IITA, an IITA inbred (TZi 18) with mixed background also showed some resistance. Hybrids with this inbred as a parent, such as 8329-15, showed a high level of resistance to weevils (IITA, 1986; Kim, Bosque-Perez and Alam, unpublished). The list of less susceptible genotypes developed at IITA is presented in Table 9. Recently, IITA and CIMMYT scientists have increased their selections for tight husk cover to minimize yield losses caused by *Sitophilus* spp..

Diseases

1. Virus Diseases

Plant viruses are among the most complex and economically important causal agents of disease for maize worldwide. More than 25 viruses have been reported (Williams et al., 1976). Maize viruses occurring in the trop-

TABLE 8—Tropical maize inbreds resistant to weevils (*Sitophilus* spp.) (two trials in Hawaii).

Genotype	% Mean[1]	Origin	Parentage
Hi41	43.7	Hawaii	Ant. Gr.2 x Hi25
Hi34	55.4	Hawaii	Ant.2D
ICA L29	57.0	Colombia	Pop.29
KU1409	65.6	Thailand	Suwan 1
Hi39	65.6	Hawaii	Ant. Gr.2 x Hi25
ICA L221	69.9	Colombia	Cuban x br2

[1]Percentage of the trial mean rating.

TABLE 9—IITA Inbred and hybrids resistant to weevil (*Sitophilus* sp.)
in Nigeria.

Genotype	Type[1]	% Mean[2]	Parentage
TZi 18	I	30.0	Pop 28 BC2 x TZSR
TZi 15-1	I	48.6	N28 x TZSR
TZi 15-2	I	48.9	N28 x TZSR
8329-15	H	15.2	(TZi 18 x TZi 30)
8524-5	H	14.0	(TZi 18 x 7261)
8434-11	H	15.4	(8329-15 x TZi 28)
TZSR-Y-1	O.P	16.9	TZSR-Y, etc.
8644-27	H	23.6	(TZi 18 x TZi 35)
8321-18	H	44.9	(TZi 3 x TZi 15)
TZSR-W-1	O.P	44.9	TZSR-W, etc.

[1]I = Inbred; H = Hybrid; O.P = Open-pollinated.
[2]Percentage of the trial mean rating.

ics are quite different from those in the U.S. Corn Belt. Three major vi-
ruses threatening maize production considerably are maize streak virus
(MSV) in Africa, corn stunt (CS) in Latin America, and maize chlorotic
dwarf virus (MCDV) in the U.S. Corn Belt. Other important viruses are
maize dwarf mosaic virus (MDMV) in the U.S., maize mosaic virus
(MMV) in Hawaii and the Carribean, and maize black streaked dwarf vi-
rus (MBSDV) in Korea.

Breeding for resistance has been very successful in attacking virus prob-
lems. Breeding efforts are centered in the regions of epiphytotics. Three
outstanding successes that have been achieved in breeding for resistance
are to MDMV in the U.S. Corn Belt, to MMV in Hawaii and to MSV in
Africa. Many commercial hybrids grown in the Corn Belt are known to be
resistant to MDMV (Gordon *et al.*, 1979; Ullstrup, 1979). Brewbaker
(1974) converted many tropical inbreds with high combining ability to
MMV resistance. The IITA Maize Program in collaboration with CIM-
MYT and African national programs developed over 100 different MSV
resistant open-pollinated varieties and hybrids. These varieties are suited
to different ecological conditions and farmers' preferences throughout
sub-Saharan Africa (Fajemisin *et al.*, 1985, Kim *et al.*, 1985a; IITA,
1987; Kim *et al.*, 1987a; Efron *et al.*, 1989).

The 120 MIR tropically adapted maize inbreds were evaluated in four
countries for virus resistance and/or tolerance (Brewbaker et al., 1987,
Logrono et al., 1989). A relatively high proportion of the tropical inbreds

showed resistance to MDMV-a strain (49%), MDMV- b strain (33%), MMV (42%), CS (23%) and MSV (17%). None of the MIR inbreds were classified as highly resistant to two temperate viruses, MCDV in Ohio, and MBSDV in Korea. Few inbreds exhibited combined resistance to more than two viruses (Table 10).

Correlations for resistance among all seven viruses were low (Table 11). Only two are highly significant ($p < 0.01$); these are between MDMV strain a and strain b in Ohio and between MSV in Nigeria and MCDV in Ohio. Other significant correlations ($p < 0.05$) were between MMV and CS and between CS and MDMV-a. Resistant inbreds were selected for five viruses; MDMV-a , MDMV-b, MSV, MMV and CS. Difficulties in finding high levels of resistance to MCDV have been reported (Gordon et al., 1979). However, it would be worthwhile to test additional inbreds, especially those with resistance to MSV from Africa. Only five streak resistant inbreds developed at IITA were included in the MIR trials screened in Ohio.

TABLE 10—Tropical maize inbreds highly resistant to major virus diseases.

Virus[1]	Testing site	Inbred selected for resistance
1. MDMVa	Ohio	A632(Hi), C17116, Emb38, Emb345, Emb402, Hi31, Hi40, Hi41, Hix4239, Hix4243, Hix4287, ICAL223, KUCP3-X, X16G(Hi), Oh514(Hi), Tzi 3, TZi 4, TZi 14, TZi 17, TZi 18, TZi 23 (21 inbreds).
2. MDMVb	Ohio	A632(Hi), B84(Hi), CM119, Emb38, Ga209, Hi27, Hi31, Hi32, Hi41, Hix4239, Hix4243, Hix4283, Hix4287, ICA L25, INV36, KU1403, KUCP3x, Narino330, Phil. DMR-6, N28(Hi), SC213, (21 inbreds).
3. MCDV	Ohio	None. Moderate resistance: Hi27, MIT-2, CM116, Fla 2AT 114, Fla 2AT 116 and F44(Hi).
4. MBSDV	Korea	KL27, Moderate resistance; Kl 16A/KL1-9BC4, KL10, KL16, KL19, KL26, KL45, KL49, KL54.
5. MMV	Hawaii	A632, GA209(Hi), Hi25, Hi26, Hi27, Hi28, Hi29, Hi31, Hi34, Hi40, Hi41, ICAL27, ICAL29, Narino330, NC246, Oh43(Hi), T232(Hi), Tx29A (19 inbreds).
6. MSV	Nigeria	TZi 1, TZi 3, TZi 4, TZi 7, TZi 13, TZi 17, TZi 23, (8 inbreds and over 70 O.P's and hybrids).
7. CS	Mexico	CIM.A-6(Hi), CIM.T-IIES(Hi), CIM>A.21(Hi), EMBRAPA 345, Hix4269, ICAL219, ICAL223, KU1414, TZi 17, W64B(Hi), TZi 4 (11 inbreds).

[1]MDMVa = maize dwarf mosaic virus-strain a; MDMVb = maize dwarf mosaic virus-strain b; MCDV = maize chlorotic dwarf virus; MBSDV = maize black streak dwarf virus; MMV = maize mosaic virus; MSV = maize streak virus; CS = corn stunt.

TABLE 11—Correlation coefficients (r) among seven viral diseases based on mean inbred ratings for each disease.

	MSV	CS	MDMV-a	MDMV-b	MCDV	MBSDV
MMV	0.04	−0.32*	−0.03	0.22	0.08	−0.03
MSV		0.04	0.09	0.14	0.46**	0.04
CS			0.28*	0.15	0.06	0.21
MDMV-a				0.49**	0.16	0.05
MDMV-b					0.16	−0.06
MCDV						0.19

*, **, Significant at the p = 0.05 and 0.01 levels, respectively.

2. Southern and Northern Corn Leaf Blight

In the tropics, southern corn leaf blight (SCLB), caused by *Helmintho-sporium maydis*, is prevalent in lowland areas and northern corn leaf blight (NCLB) caused by *Exserohilum turcicum*, is prevalent in midalti-tude and highland areas. Both diseases occur throughout the year. Many tropical inbreds offer high levels of general resistance. Some sources for specific resistance have been found in tropical germplasm (Hooker 1962; 1979). Many temperate inbreds show some resistance to SCLB in both tropical and temperate zones (Kim, unpublished). A list of sources of high resistance from the MIR trials conducted in eight locations is presented in Table 12. Many lines developed in Florida (Populations A and B) and IITA (TZi lines) showed high levels of resistance. Among the temperate germplasm, inbred TZi 11 (derived from Mo17) showed a high level of resistance.

The same MIR lines were tested for NCLB resistance at five sites (three in Nigeria, and one each in Kenya and Hawaii). Lines with high resistance to NCLB included Fla2AT 116, ICA L27, H55(Hi), Hi39 and Fla2AT 115. A total of 35 lines (mostly tropical origin) showed high resistance (Table 13). The IITA maize program has developed many new inbreds for mid-altitude environments in Africa and the selected inbreds are summarized in Table 14. Those inbreds confer combined resistance to maize streak vi-rus, *E. turcicum* and ear rot (Kim *et al.*, 1985b). A similar disease resis-tance breeding program is also being carried out by CIMMYT scientists in East Africa. Most specific Ht genes do not hold their resistance to NCLB under African conditions. Experience also shows that resistance genes se-lected in Mexico do not provide adequate resistance in Africa, suggesting

TABLE 12—Tropical maize inbreds resistant to *H. maydis* (Cameroon, Hawaii, India, Korea, Mexico, and three trials in Nigeria).

Inbred	% Mean[1]	Origin	Parentage	MT at Ames[2]
Fla2BT106	51.1	Florida	Fla. pop. B	?
Fla2AT115	53.9	Florida	Fla. pop. A	?
Fla2AT116	54.7	Florida	Fla. pop. A	94
Fla2BT 73	55.5	Florida	Fla. pop. B	?
TZi 5	59.3	IITA	Pop. 29 x TZSR	110
TZi 3	62.2	IITA	Pop. 21 x TZSR	120
Fla2AT114	62.3	Florida	Fla. pop. A	90
TZi 8	62.6	IITA	TZB x TZSR	95
KU1414	64.3	Thai	Suwan 1	120
TZi 11	64.6	IITA	Mo17 x RPPSR	?
Fla2AT113	68.9	Florida	Fla. pop. A	93
Hi27	69.8	Hawaii	CM104(India)	97
INV534	70.3	Texas	Batan x P.DMR-10	100

[1]Percentage of the trial mean rating.
[2]MT: days to mid-tasselling.

that either more aggressive races of blight may be present in Africa (Kim *et al.*, 1985b) or that the environment is more conducive to severe attacks. Some lines selected for general resistance in other parts of the tropical world such as in Hawaii also do not have adequate resistance under African conditions.

TABLE 13—Tropical maize inbreds resistant to *Exserohilum turcicum* (Kenya, Hawaii, and two trials in Nigeria).

Inbred	% mean[1]	Inbred	% mean[1]
Fla 2AT16	41.0	INV. 534	61.2
Hi39	45.3	T232 (Hi)	61.3
ICA L27	46.3	Phil. DMR6-S5	61.6
IU1414	48.1	MIT2-S6	64.4
SR52F	48.2	Fla2AT114	66.4
Narino330	50.7	Hi40	67.0
H632G	54.6	Hi28	67.5
CM118	55.4	Hi41	68.1
KU1409	56.2	Fla2BT106	68.3
HS5 (Hi)	59.9	Fla2BT73	68.7
H632F	59.9	Hi29	68.8
Fla 2BTS4	69.9		

[1]Percentage of the trial mean rating.

TABLE 14—Characteristics of IITA mid-altitude inbred (TZMi) lines.

TZMi no.	Parentage	Grain color[1]	Grain texture[2]	Maturity[3]	Resistance[4] MSV[5]	Resistance[4] NCLB[6]
101	MSR-dent	W	F	L	R	MR
102	MSR-dent	W	F	I	R	MR
103	Inb. MSR-dent	W	F	I	R	MR
301	Zambia x SR	Y	F	I	R	MR
406	National Variety x SR	W	F	I	R	R
501	Comm. x SR	W	D	I	R	MR
502	Comm. x SR	W	F	I	R	MR
504	Comm. x SR	Y	F	L	R	MR

[1] W = white, Y = yellow.
[2] F = flint, D = dent.
[3] L = late, I = intermediate.
[4] R = resistant, MR = moderately resistant.
[5] MSV = maize streak virus.
[6] NCLB = northern corn leaf blight *(Exserohilum turcicum)*.

3. Southern and Common Rust

When U.S. Corn Belt materials are introduced into the tropics, their susceptibility to rust is a major problem. None of the U.S. Corn Belt inbreds showed adequate levels of resistance to southern rust (*Puccinia polysora*) in West Africa. A list of the 21 resistant lines from the 120 MIR lines tested in four sites (three in Nigeria and one in Texas) is presented in Table 15, and these would be outstanding sources for resistance to rust.

Most of the inbreds used in the U.S. Corn Belt confer general resistance to common rust caused by *Puccinia sorghi* (Hooker, 1979). Details of the *P. sorghi* resistance from the MIR trials are summarized in Table 16. Several temperate inbreds such as H98, C103, and B73 (Hi), showed high levels of general resistance to *P. sorghi* across five testing sites. Additional sources of resistance and results of genetic studies on *P. sorghi* resistance have been reported elsewhere (Kim, 1974; Kim and Brewbaker, 1977).

4. *Curvularia lunata* Leaf Spot

Curvularia lunata leaf spot has become serious in West Africa. In the past it was considered a cosmetic disease in the tropics. This disease occurs occasionally in the southern United States, but it has not assumed eco-

TABLE 15—Tropical maize inbreds resistant to *P. polysora* (three trials in Nigeria and one in Texas).

Inbred	% Mean[1]	Origin	Parentage	MT at Ames[2]
Hi34	51.8	Hawaii	Antigua 2D	101
ICA L219	54.0	Colombia	Cuban x br2	104
ICA L223	54.0	Colombia	Cuban x br2	105
Narino330	56.3	Thailand	Narino	103
INV534	58.4	Texas	Bat. x Ph. DMR-2	100
Tzi 14	58.4	IITA	N28 x TZSR	?
MIT 2	58.9	Thailand	MIT 2 (Phil)	104
ICA L224	60.7	Colombia	Cuban x br2	105
INV138	61.3	Texas	Bat. x Ph.DMR-2	92
CIM.A.-21 (Hi)	61.3	CIMMYT	PR69B-149	106
INV302	62.1	Texas	Bat.Ph.DMR-2	93
ICA L221	62.5	Colombia	Cuban x br2	97
TZi 4	62.9	IITA	Pop.29 x TZSR	110
CM116	63.6	India	Puerto Rico Gr1	94
Mp496	64.3	Mississippi	Antigua Gr2	88
ICA L210	65.6	Colombia	Cuban Flint LC	94
Fla2AT114	65.9	Florida	Fla pop. A	90
ICA L36	66.9	Colombia	Eto	97
ICA L25	66.9	Colombia	Cuban flint	?
INV36	66.9	Colombia	Bat x Ph. DMR-2	93
CM103 (Hi)	68.8	India	Col. 1 x 38-11	102

[1]Percentage of the trial mean rating.
[2]Days to mid-tasseling at Ames, Iowa.

nomic importance (Ullstrup, 1977). The symptom of its expression in the tropics are quite similar to gray leaf spot in the U.S. Among the tropical MIR inbreds, only 11 inbreds showed high levels of resistance (Table 17). The lines developed in Thailand (KU1414 and KU1409) confer the highest resistance. An IITA inbred, TZi 25, derived from B73 proved to be resistant to gray leaf spot in North Carolina (M. Goodman, personal communication). A careful study is underway to compare the correlation between leaf spot in Nigeria and gray leaf spot in North Carolina.

Genetic studies on the resistance of the tropical inbreds to *P. polysora*, *H. Maydis* and leaf spot have been conducted. Among the IITA tropical inbreds, TZi 4, TZi 8 and TZi 18 showed relatively high general combining ability (GCA) effects for all three diseases (Table 18). Another 13 tropical lines were also studied for their combining ability for the same three foliar

TABLE 16—Tropical maize inbreds resistant to *P. sorghi* (Kenya, S. Africa, three trials in Hawaii).

Inbred	% Mean[1]	Origin	Parentage	MT at Ames[2]
KU1418	44.9	Thailand	Suwan 1	120
Pa762	46.0	Pennsyl.	Oh43 x Pa70L	?
H98(Hi)	51.9	Indiana	Hy x Oh45	79
Hi33	52.0	Hawaii	Mo17	79
C103	52.1	Connecticut	Lan. Surecrop	?
B73(Hi)	55.5	Iowa	Iowa SSS	78
Va35(Hi)	58.8	Virginia	(C103 x T8) T8	75
Hi32	60.2	Hawaii	Oh545	77
R168	63.8	Illinois	360 (Ill. Syn)	?
Tx601(Hi)	64.7	Texas	Yellow Tuxpeno	94
CM118	66.5	India	PTR-1-605	102
H632F	68.8	Kenya	Tuxpeno	91
Hi34	69.1	Hawaii	Ant. 2D	101
ICA L27	70.8	Colom.	Eto b-2053-11	97

[1]Percentage of the trial mean rating.
[2]Days to mid-tasseling at Ames, Iowa.

TABLE 17—Tropical maize inbreds resistant to *Curvularia lunata-* (five trials in Nigeria).

Inbred	% Mean[1]	Origin	Parentage
KU1414	53.1	Thailand	Suwan 1
KU1409	63.4	Thailand	Suwan 1
ICA L223	63.4	Colombia	Cuban x br2
ICA L221	70.9	Colombia	Cuban x br2
Hi41	71.9	Hawaii	Ant. Gr2 x Hi25
Fla2AT114	74.6	Florida	Fla. Pop. A
INV138	75.7	Texas	Texas
ICA L36	78.4	Colombia	Batan x P. DMR-2
TZi 28	78.8	IITA	F44 x RppSR
SC55	80.3	S. Carolina	L501-L503 x L548-L569
Tzi 17	80.4	IITA	RppSR

[1]Percentage of the trial mean rating.

TABLE 18—General combining ability effects of ten TZi (IITA) lines for resistance to three foliar diseases based on 1-5 rating scale[1] in Nigeria (mean of three seasons, 1985/86).

Inbred	*P. Polysora*	*H. Maydis*	*C. lunata*	Parentage
TZi 3	0.0	−0.1	0.4	Across 7721 x TZSR
TZi 4	−0.2	−0.2	−0.2	Gua. Caste 7729 x TZSR
TZi 8	−0.1	0.0	−0.2	TZB x TZSR
TZi 18	−0.2	−0.4	−0.1	SETE LAG. 7728 x TZSR
TZi 30	0.0	0.1	−0.2	Hi29 x RPPSR
TZi 12	0.0	0.2	−0.3	N28 x TZSR
TZi 15	0.0	0.0	0.4	N28 x TZSR
TZi 24	0.0	−0.1	−0.2	H95 x RPPSR
TZi 25	0.1	0.1	−0.2	B73 x RPPSR
TZi 28	0.5	0.3	0.4	F44 x RPPSR

[1]Ratings (1-5): 1 = resistant, 5 = susceptible.

diseases (Table 19). High GCA effects for resistance were observed in two inbreds from Colombia (ICA L210, ICA L221) and three inbreds from Thailand (KU1409, KU1414, Narino330).

5. Downy Mildew

Downy mildew (DM), caused by *Peronosclerospora* spp., is among the most important maize disease in Southeast Asia. It also occurs in some

TABLE 19—General combining ability effects of 13 tropical lines of maize for three foliar diseases based on 1-5 rating[1] scale in Nigeria, (IITA) 1986.

Inbred	*P. Polysora*	*H. Maydis*	*C. lunata*	Origin
CM103(Hi)	0. 85	0.90	0.75	India/Hawaii
CM116(Hi)	0.12	0.18	0.60	India/Hawaii
FL2BT	0.10	−0.31	0.22	Florida
Hi26	0.21	−0.18	0.42	Hawaii
ICA L210	−0.13	−0.31	−0.31	Colombia
ICA L221	−0.22	−0.21	−0.49	Colombia
KU1409	−0.28	−0.12	−0.49	Thailand
KU1414	−0.13	−0.41	−1.28	Thailand
Narino330	−0.20	−0.11	−0.28	Thailand
SC12	0.13	0.14	0.33	S. Carolina
TZi 18	−0.52	0.04	0.67	IITA
TZi 25	0.10	0.21	0.13	IITA
TZi 30	0.27	0.75	0.23	IITA

[1]Ratings (1-5): 1 = resistant, 5 = susceptible.

African countries including Zaire, Nigeria, Mozambique, Somalia, Ethiopia, Sudan, Zambia and South Africa. The best source for downy mildew resistance worldwide is Suwan 1, a DM resistant composite developed by recurrent S_2 selection in Thailand. The 120 MIR inbreds were screened for DM resistance in Nigeria and Taiwan. Most resistant lines are derived from Suwan 1 (Table 20). A few lines from Texas (Tx601, INV 138 and INV 36) showed some resistance. The MIR inbreds selected for high combining ability for grain yield and DM resistance are being converted for MSV resistance at IITA. KU1414, derived from Suwan 1, confers the highest resistance. Three hybrids with combined resistance to downy mildew and streak were developed in Nigeria. Genetic studies for downy mildew resistance have been initiated.

Maize streak virus (MSV) and downy mildew (DM) occur in the same ecological areas in different African countries. A breeding program to combine resistance to MSV and DM has been carried out using a shuttle breeding approach between two locations in Nigeria (MSV at Ibadan and DM at Owo). Sources of resistance used in Nigeria are from the Philippines and Thailand (Fajemisin et al., 1985). Scientists from IITA and the Nigerian Cereals Research Institute (NCRI) have developed four maize

TABLE 20—Tropical maize inbreds resistant to downy mildew
Perenosclerospora spp. (two trials in Nigeria, one in Taiwan).

Inbred	% Mean[1]	Origin	Parentage
KU1414	19.9	Thailand	Suwan 1
KU1403	38.1	Thailand	Suwan 1
Oh514(Hi)	39.1	Ohio	(Eto 59 x B14)Bi4
KU1409	40.6	Thailand	Suwan 1
Ph. DMR-S6	41.2	Thailand	Phil. Comp. DMR6
KU1418	46.4	Thailand	Suwan 1
ICA L29	47.5	Colombia	Col. Pop 29
TZi 4	48.2	IITA	Pop 29 x SR
MIT2-S6	51.3	Thai/Phil.	MIT-2 (Phil)
Narino330	54.1	Thailand	Narino330
MIT11-S3	59.1	Thailand	MIT-11
TZi 18	64.6	IITA	Pop28 x SR
Hi41	65.2	Hawaii	Antigua Grip2 x Hi25
AntC5	66.8	Thailand	Ant. Comp. 2
Hi25	69.3	Hawaii	B14A
INV138	70.0	Texas	MTB x Phil DMR2

[1]Percentage of the trial mean rating.

populations which are resistant to both MSV and DM diseases. The resistant populations are late white (DMRSR-LW), late yellow (DMRSR-LY), early white (DMRSR- EW), and early yellow (DMRSR-EY). These populations showed 20-70% yield advantage under the pressure of either one of the two diseases (Fajemisin *et al.*, 1985). Over 200 inbred lines resistant to the two diseases have been developed from the four populations. Ten lines with high resistance and high combining ability for grain yield were selected based on the combining ability test of the lines at the S3 and S5 stages. Selected inbreds with high combining ability and resistance to downy mildew, MSV and other foliar diseases will be released soon.

6. Stalk /Ear Rots

Stalk and ear rots are common diseases wherever maize is cultivated. The 120 MIR lines were tested against *Fusarium spp.* in Hawaii and a mixed ear rot inoculum in Nigeria. The data are summarized in Table 21. Nine inbreds, ICA L36 (Colombia), INV302 and Tx601 (Texas), Mo20W (Missouri), TZi 4, TZi 3 and TZi 18 (IITA), KU1403 (Thailand), and CIM.A.21 (CIMMYT) showed high resistance.

Major causal agents for stalk rot in the lowlands of Africa are *Fusarium moniliforme, Botryodiplodia theobromae,* and *Macrophomina phaseoli.* In Nigeria, nine MIR inbreds showed high resistance to these diseases. The

TABLE 21—MIR maize inbreds resistant to *Fusarium* spp. in Hawaii and ear rots in Nigeria.

Fusarium spp.		Ear rot	
Inbred	% Mean[1]	Inbred	% Mean[1]
ICA L36	39.8	Hi 35	56.9
Tx601(Hi)	41.0	INV 534	58.3
INV302	43.9	KU1418	58.7
Mo20W	44.7	Pa91	59.9
TZi 4	49.9	T258	67.6
KU1403	52.4	B77(Hi)	63.4
TZi 3	52.7	F44(Hi)	67.6
CIM.A-2(Hi)	54.2	Fla2AT114	68.7
TZi 18	56.2	H632G	70.4

Source: Brewbaker et al., 1989 IITA Maize Research Program Annual Report, 1986.

[1]Percentage of the trial mean rating.

resistant lines were Hi35 (Hawaii), INV534 (Texas), KU1414 (Thailand), Pa91, B77 (Iowa), T258, F44, Fla 2AT114 and H632G (Kenya).

Eleven inbreds developed at IITA were inoculated with spore suspensions of the three stalk rot pathogens (*Fusarium, Botryodiplodia and Macrophomina*) separately, and with a mixture of the three (Fajemisin *et al.*, 1987). The stalks were split longitudinally for rot evaluation four weeks after inoculation. Disease reaction was evaluated on the basis of the rate of rot spread from the point of inoculation using a 1-6 scale (1 = less than one-fourth of the inoculated internode rotten and 6 = rot spreading to two or more internodes). Results are presented in Table 22. Fusarium was consistently the most virulent pathogen. Inbreds TZi 3, TZi 7 and TZi 17 were resistant to all the pathogens while inbred TZi 27 was susceptible to all. On the other hand, some inbreds showed differential reaction to the pathogens. For instance, TZi 25 is susceptible to *Fusarium* but resistant to *Botryodiplodia* and *Macrophomina*. Therefore, even though it appears that the pathogen mixture does not give higher rot scores than inoculating only with Fusarium, the pathogen mixture has been used for routine germplasm evaluation. This technique of stalk rot resistance screening is being used by the IITA maize breeding program (Fajemisin *et al.*, 1987).

Twenty-eight inbred lines were evaluated for ear rot infection. The pathogen treatments were *Botryodiplodia*, *Fusarium*, and *Macrophomina*. Inoculation was done by inserting infected toothpicks through the middle of the ear. The inbreds were treated in three groups so as to

TABLE 22—Stalk rot scores[1] of five tropical maize inbreds inoculated with *Fusarium moniliforme, Botryodiplodia theobromae*, and *Macrophomina phaseoli*, and a mixture of the three pathogens at Ibadan, Nigeria.

Maize Inbreds	Parentage	Pathogens			
		F. moniliforme	*B. theobromae*	*M. phaseoli*	Mixture
TZi 3	Pop.21 x SR	1.8	1.5	1.4	1.4
TZi 7	TZB x SR	2.0	1.5	1.6	2.0
TZi 17	RPPSR	2.0	1.7	1.7	2.3
Tzi 25	B73BC3xRPPSR	4.1	1.6	2.2	4.3
TZi 27	F44xRPPSR	5.6	4.3	4.2	5.0

Source: IITA Research Highlights (1986) and Fajemisin *et al.*, (unpublished).

[1]Stalk rot rating (1-6): 1 = less than 25% internode rot; 6 = two or more internode rot and causes premature death.

TABLE 23—Ear rot scores (1-6) of tropical maize inbreds for *Fusarium*, *Botryodiplodia* and *Macrophomina* at IITA, Nigeria.

| Inbreds | Parentage | Pathogens | | | Mean |
		Fusarium	*Botryodiplodia*	*Macrophomina*	
TZi 3	Pop. 21 x SR	2.0	4.0	1.3	2.4
TZi 5	Pop. 29 x SR	1.3	1.5	1.0	1.3
TZi 6	TZPB	4.3	3.8	3.8	4.0
TZi 7	TZB x SR	2.5	3.5	1.3	2.4
TZi 11	Mo17 x RPP	4.8	5.0	5.0	4.9
TZi 35	KU1414 x SR	4.0	2.3	2.3	2.9

Ear rot rating 1 = no kernel rot; 6 = over 150 kernels rotten per ear.
Source: IITA Research Highlight (1986) and Fajemisin et al., (unpublished).

allow inoculation at a physiologically comparable time, 10-14 days after silking (Fajemisin *et al.* 1987). There were significant differences among the lines in reaction to each of the rot pathogens (Table 23). *Botryodiplodia* was the most severe rot and the one for which there was the least genetic variability. Although inbred TZi 5 gave low rot scores for all of the pathogens, there is no strong indication of correlations among the pathogens. Inbred TZi 3 was moderately resistant to Fusarium and Macrophomina but susceptible to *Botryodiplodia*. Inbred TZi 11 was very susceptible to all three pathogens. TZi 35 was susceptible to *Fusarium* but moderately resistant to *Botryodiplodia* and *Macrophomina*.

In addition to the above three stalk and ear rot pathogens, anthracnose caused by *Colletotrichum graminicola* was also identified as a causal pathogen for stalk rot on some inbred lines; TZi 6, derived from Tuxpeno TZPB Eps., showed the most susceptibility (IITA 1988, Fajemisin unpublished).

7. Corn Smuts

Common smut, caused by *Ustilago maydis*, is common in the temperate zone (Ullstrup, 1977). Most of the U.S. Corn Belt inbreds and hybrids are known to be resistant to common smut. However, this disease showed unusually high infestation in Iowa during the 1987 cropping season. Common smut infection was observed in the 120 MIR nursery at Ames, Iowa. Sixteen inbreds showing the least infestation with the average percent mean of 30.3 are A632Ht, B84, B73, B77, CI64, Ga209, H55, H60, Hi26,

TABLE 24—MIR lines resistant to common smut *(Ustilago Maydis)* in Iowa, 1987.

Inbred	% Mean[1]	Inbred	% Mean[1]
A632 Ht	30.3	Hi26	30.3
B84	30.3	Hi32	30.3
B73 Hi	30.3	Hi33	30.3
B77 Hi	30.3	TZi 28	30.3
C164 Hi	30.3	KY 226 Hi	30.3
Ga209 Hi	30.3	Va35 Hi	30.3
H55 Hi	30.3	Tuxpeno S5	30.3
H60 Hi	30.3	TZi 4	30.3

[1]Percentage of the trial mean rating.

Hi32, Hi33, TZi 28, Ky226, Va35, Tuxpeno S5 and TZi 4. With the exception of Tuxpeno S5 and TZi 4, these inbreds were bred in the Corn Belt or were from temperate materials converted for tropical adaptation (Hi26, Hi32, Hi33, TZi 28).

Tassel smut caused by *Sphacelotheca reiliana* is not important on maize in the U.S. Corn Belt and is confined to only California, Idaho, Oregon and Washington. However, this disease is widespread elsewhere in the world and it is of appreciable economic importance in some countries (Ullstrup, 1977). The 120 MIR inbreds were screened for resistance against tassel smut in South Africa (Brewbaker *et al.*, 1989). Most of the 18 inbreds classified as highly resistant were developed in the tropics (Table 25). The resistant inbreds of Corn Belt origin are Oh514, Mo5, N6G, SC43 and B77. Four lines from Thailand (KUCP3-x, KU1418, MIT-2, and KU1403) showed high resistance.

Other Stresses

1. Parasitic Weed, *Striga*

The parasitic weed, *Striga*, becomes a serious threat to maize production in areas with high yield potential in the savanna belt of sub-Saharan Africa. More than five species of *Striga* can damage maize and other cereal crops. *Striga hermonthica* is the most widespread in Africa, and *S. asiatica* is the most widespread in Asia. The latter species is present in North Carolina. It is generally known that it is very difficult to breed for resistance to

TABLE 25—Tropical maize inbreds resistant to tassel smut *(Sphacelotheca reiliana)* in South Africa.

Inbred	% Mean[1]	Origin	Parentage
KUCP3-X	0.0	Thailand	KCP.3-1-S5-125-5-3
KU1418	0.0	Thailand	Suwan 1
Oh514 (Hi)	4.9	Ohio	(Eto 59-272-1-7xB14) B14
MIT2	12.3	Thailand	MIT-2 (Phil.)
KU1403	13.1	Thailand	Suwan 1
MoS (Hi)	16.0	Missouri	(N6 x K55) BC2
N6G (Hi)	16.6	Nebraska	Mays Golden
Arg. F872	18.3	Argentina	?
KU1409	21.2	Thailand	Suwan 1
MIT11	22.1	Thailand	MIT 11 (Phil.)
Hi39	23.4	Hawaii	Ant Gr2 x Hi25
PAC 90038	25.3	Australia	Pacific Seeds
SC 43	26.1	S. Carolina	SC246C x Pioneer 3009
TZi 17	26.2	IITA	RppSR
Fla2BT106	26.8	Florida	Florida Pop. B
ICA L25	28.4	Colombia	Cuban flint Desc. 2
B77 (Hi)	29.6	Iowa	Iowa Stiff Stalk Syn, 11
T250	29.9	Tennessee	Va35 x Mo17

[1]Percentage of the trial mean rating.
Source: Brewbaker et al., 1989.

Striga in maize (Ramaiah, 1987). The U.S. strategy to combat *S. asiatica* has been through erradication, using chemicals such as ethylene gas that stimulates germination.

The IITA maize program initiated a breeding program for resistance or tolerance to *Striga* in Nigeria in 1982. Tolerant sources were identified from U.S. Corn Belt materials (Kim *et al.*, 1985c). Inbreds tolerant of *Striga hermonthica* are being developed (Table 26). All of these inbreds are also resistant to maize streak virus (MSV) and other major diseases prevalent in the tropics (Kim et al., 1987a). The emphasis is now on developing an efficient artificial screening method and identifying sources with high levels of resistance (Efron *et al.*, 1986; Kim, 1988).

2. Drought

Drought is a universal problem for maize production. In Africa famine is often associated with drought. In recent years, drought has occurred in all ecological zones in Africa. Crop production in humid forest areas in West and Central Africa was severely damaged by an unexpected drought in 1987. In contrast, the Sudan savanna belt in West Africa had too much

rain in 1988. A severe drought hit the U.S. Corn Belt area in 1988. These incidents demonstrate that drought resistant or tolerant materials are needed across all ecological zones.

The IITA maize program initiated drought resistance breeding work through the Semi-Arid Food Grains Research and Development (SAF-GRAD) project in drought-prone Burkina Faso in 1980. Three approaches were used.

The first approach was to develop an agronomic method to maximize soil water use. A tied ridge system was developed which resulted in significant yield increases under droughty conditions (Rodriguez, 1988). Its efficiency varies depending on soil properties, texture and toposequence. A simple tiedridging machine has been developed to save labour input.

The second approach was to develop very early varieties to escape drought at the late growing stage. A few experimental varieties were developed (Diallo and Rodriguez, 1986, IITA 1987). The SAFGRAD project selected for early maturity in CIMMYT Pool 16 to improve the drought tolerance. Streak resistance has also been integrated into Pool 16 at IITA.

A third approach was to develop drought tolerant hybrids and synthetics. The 120 MIR lines were screened under drought condition at IITA, Ibadan and Bagauda in Kano in 1986. The best drought tolerant inbreds were KU1414, a downy mildew resistant inbred developed in Thailand, followed by two IITA inbreds, TZi 9 and TZi 28 (Table 27). One important factor to be considered is that combined multi-resistance to major production constraints is necessary to combat drought. Drought, MSV, *Striga* and termite resistance must be combined with high yield and savanna adaptation in the populations, varieties and hybrids targeted for drought tolerance in Africa. Intensive research on drought resistance is being carried out at CIMMYT in Mexico (Bolanos and Edmeades, 1988).

TABLE 26—Rating scores[1] for tropical maize inbreds resistant to *Striga hermonthica* in Nigeria.

Inbred	Rating	Origin	Parentage
TZi 14	1.5	IITA	RPPSR x N28
TZi 24	1.5	IITA	H95BC3 x RPPSR
TZi 12	1.0	IITA	N28 x TZSR
TZi 11	1.6	IITA	Mo17 x RppSR
TZi 30	2.0	IITA	Hi29BC2 x RPPSR
TZi 25	2.6	IITA	B73BC3 x RppSR

Rating (1-5): 1 = resistant, 5 = susceptible.

TABLE 27—Drought tolerance scores[1] of selected inbreds at Ibadan (field and glasshouse) and Bagauda in Nigeria.

| Line | Origin | Field observations | | | Glasshouse | Mean |
| | | Ibadan[2] | | Bagauda | | |
		1986A	1986B	1986		
Ku 1414	Thailand	1.5	1.5	2.3	1.5	1.6
TZi 9	IITA	2.5	2.0	1.7	2.0	2.1
TZi 28	IITA	2.0	2.5	2.0	2.5	2.4
TZi 6	IITA	2.7	2.5	2.3	2.5	2.5
SC 213	S. Carolina	4.2	3.8	3.5	3.0	3.4
ANTC	Thailand	4.2	4.3	3.3	3.5	3.7
B73	Iowa	4.2	4.2	3.2	4.0	3.9
Mo20w	Missouri	4.5	4.3	2.7	4.5	4.2

Source: IITA, Maize Research Program Ann. Report (1986).

[1]Rating scale: 1 = tolerant, 5 = susceptible.

[2]A = first season, B = second season.

3. Day-length Sensitivity

Most tropical maize genotypes are day-length sensitive and flower very late under Corn Belt conditions, causing pollination difficulty with temperate materials (Goodman, 1985). Most tropical populations segregate for flowering date under long day conditions. Selection for earliness has been carried out with 'Eto' in Iowa (Hallauer and Sears, 1972). Days to tasseling and silking, and number of leaves and internodes are considered to be agronomic characteristics that reflect day-length sensitivity. Recent studies have shown that conversion of sensitive tropical lines to day-length neutrality is possible (Brewbaker, 1974; Salamini, 1985). All MIR inbreds were classified for dates of flowering under 12 vs 16-hr days in Hawaii (Brewbaker et al., 1989).

Breeding Methods

1. Conversions of Temperate Germplasm for the Tropics

Temperate maize germplasm cannot be grown in the tropical lowland of Africa because of the lack of adaptability and local biotic resistance against *Puccinia polysora*, maize streak virus, stem borers (*Sesamia* and

Eldana). However, experiences in the tropics prove that temperate maize exhibits high heterosis in crosses with well-adapted tropical germplasm. All high yielding hybrids developed in Hawaii and Nigeria are crosses between tropical and temperate line conversions (Brewbaker, 1974; Efron, 1985; Kim *et al.*, 1985a, 1987b). Inbreds such as B14, N28 and B73 showed high heterotic effects with tropical inbreds with Carribean mixed background.

Resistance to local diseases and insects must be secured simultaneously with maintaining the high general combining ability of elite temperate inbreds. For conversion of temperate germplasm in the tropics, it would be best to use donor parents of the same heterotic group, e.g., stiff stalk synthetic (SSS) inbreds derived from Tuxpeno can be crossed with Tuxpeno-tropical lines, which will maintain the Tuxpeno background. The converted line may then exhibit high heterosis when crossed with inbreds from the nonTuxpeno Carribean tropical group.

2. Conversion of Tropical Germplasm for Temperate Areas

The history of line development in the tropics is relatively short and much tropical germplasm still represents an unexploited reservoir of genetic diversity. The potential value of the less-exploited tropical germplasm for maize improvement programs in the Corn Belt is great. Most of the tropical germplasm are in broad based open-pollinated populations and composites. Direct selection of tropical populations in Corn Belt has been successful in improving populations for adaptation (Hallauer and Sears, 1972; Hallauer, 1978; Goodman, 1985),and for second-generation-ECB resistance (Barry *et al.*, 1985). There are many other examples of the use of tropical populations and composites under the Corn Belt conditions. However, inbreds developed in the tropics with special emphasis on tropical diseases and insects have not been exploited, and these can provide more specific genes for use in the Corn Belt. For example, 19 new sources of second-generation-ECB resistance were discovered from the 120 tropical inbreds tested in Iowa in 1987 (Kim *et al.*, 1988a). After two backcrosses with the tropical inbred, selections can be made for earliness, daylength insensitivity, and local adaptation under Corn Belt conditions.

Two backcrosses, with a maximum three, are suggested with the unadapted susceptible U.S. Corn Belt germplasm. These 2 to 3 backcrossed inbreds will be sufficient to introgress tropical genes into the narrow-based Corn Belt inbreds. In field trials in the Corn Belt, TZi 25 with three backcrosses of B73 showed two weeks delay in flowering, but was resistant to

second generation-ECB, gray leaf spot, smut and *H. maydis*. A gradual introgression of genetically diverse, but less exploited tropical germplasm into Corn Belt maize breeding programs is suggested.

The authors have been producing testcrosses of the 120 tropical MIR lines in Hawaii and in Nigeria. The two testers used are B73 x B84 for the Iowa Stiff Stalk group and Mo17 x MBS2040 for the Lancaster group. We used sister crosses as the testers to provide better pollen in the isolation field. The day-neutral environment in Hawaii is used to produce seeds for testing in Hawaii and Corn Belt. Additional testcross seed has been produced in Nigeria for testing in different ecological locations (forest, savanna and mid -altitude) in Africa. In Africa, two additional testers, representing the Tuxpeno and Carribean tropical mixed groups are also used to select inbreds with good combining ability for the Corn Belt as well as for tropical conditions. Most tropical germplasm has been developed without much emphasis on the heterotic groups (Wellhausen, 1978). The proposed study will provide information on the heterotic classification of the tropical inbreds for hybrid programs in both temperate and tropical zones. As previously discussed, it would be better to use inbreds from the same heterotic group as donors to convert inbreds for specific genes. A diagram of the proposed tropical MIR inbred testing scheme is shown in Fig.1. Similar collaborative work has been undertaken to introduce tropical genes, especially from TZi 25 and other lines into European germplasm. The European collaborators are Dr. Peter Goetz and Prof. Hartwig Geiger in Germany.

Acknowledgement

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About IITA

The goal of the International Institute of Tropical Agriculture (IITA) is to increase the productivity of key food crops and to develop sustainable agricultural systems that can replace bush fallow, or slash-and-burn, cultivation in the humid and subhumid tropics. Crop improvement programs focus primarily on cassava, maize and cowpeas. Yams, soybean and plantain are also major research concerns. Research findings are shared through international cooperation programs which include training, information and germplasm exchange activities.

IITA was founded in 1967. The Federal Government of Nigeria provided a land grant of 1,000 hectares at Ibadan, for a headquarters and experimental farm site, and the Rockefeller and Ford foundations provided financial support. IITA is governed by an international Board of Trustees. The staff includes nearly 200 scientists and professional staff from about 40 countries, who work at the Ibadan campus and on substations and outreach programs in many countries of sub-Saharan Africa.

IITA is one of 13 nonprofit, international agricultural research centers and programs supported by the Consultative Group for International Agricultural Research (CGIAR). Established in 1971, CGIAR is an association of about 50 countries, international and regional organizations and private foundations. The purpose of the research effort is to improve the quantity and quality of food production in developing countries. The World Bank, the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Development Programme (UNDP) are cosponsors of this effort.