SORGHUM RESISTANCE TO INSECT PESTS

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CHAPTER I

INTRODUCTION

Insect pests are a limiting factor in sorghum production and cause economic losses annually. The sorghum midge, *Contarinia sorghicola* (Coquillet), the greenbug, *Schizaphis graminum* (Rondani), and the chinch bug, *Blissus leucopterus leucopterus* (Say) are the major insect pests of sorghum, *Sorghum bicolor* (L) Moench, in the United States (Webster, 1915, Thomas, 1969, and Young and Teetes, 1977). These insect pests can cause tremendous damage to sorghum from the seedling stage through flowering.

Sorghum midge is difficult to control by chemical application, since the midge spends most of its life within the spikelets. No effective natural enemy has been reported for this pest. Chemical control of the greenbug has resulted in a new strain resistant to certain insecticides (Peters et al., 1975 and Teetes et al., 1975). Some insecticides cause sorghum phytotoxicity (Chada et al., 1965) and chemical residues. Consequently, the use of varietal resistance in sorghum could overcome many of these problems and is therefore badly needed.

Developing resistance in sorghum is the effective way to protect plants against insect pests without deleterious effects to the ecosystem. Plant resistance can increase yields by providing the plant with tolerance to injury that the pests would normally inflict. Also, the capability of plants to withstand insect attack could delay economic injury long enough for parasites and predators to become more effective. Plant resistance could significantly reduce sorghum production costs.

In breeding sorghum for insect resistance, there is a need to identify sources of resistance and determine the genetic basis for the resistance. Understanding the resistant traits inherited from various sources for insect pests at different growth stages of sorghum could contribute to the development of multiple resistance in the same sorghum cultivar.

The purposes of these studies were:

1. To study varietal resistance and inheritance of resistance in sorghum to the sorghum midge, the greenbug biotype E, and the chinch bug.
2. To investigate the mechanisms of resistance in sorghums to greenbug biotype E.
3. To determine the probability of transferring the resistance to three kinds of insect pests to high yielding sorghum varieties.

CHAPTER II

SORGHUM RESISTANCE TO THE SORGHUM MIDGE

Sorghum Midge

The sorghum midge, *Contarinia sorghicola* (Coquillet), is probably the most important insect pest that attacks the sorghum head and developing grain. The sorghum midge is found nearly everywhere that sorghum is grown in the world. Its major hosts are members of the genus *Sorghum*. It is thought to have been transported with sorghum around the world (Young, 1970). Damage to sorghum was first reported by Tryon (1894) in Queensland, Australia. Coquillet (1898) recorded midge damage in the United States and first described the pest under the name *Diplosis sorghicola*.

The sorghum midge occurs in the southern United States. The areas of most severe infestation occur in the more humid sections of the South and East. Injury is normally less severe in the drier, hotter and more upland sections of northern Texas, Oklahoma, and Kansas. Every year damage by the midge to sorghum in the U.S. amounts to several million dollars. Damage to Texas grain sorghum alone has been estimated at more than $10 million annually (Thomas, 1969).

The adult sorghum midge is a minute, orange-colored fly (length less than 2 mm). The female is more robust than the male and has much shorter antennae. Mating occurs soon after emergence. Flying females choose suitable sorghum heads and begin to lay eggs with long extensile ovipositors which are inserted between the glumes. Each female lays from 30 to 100 tiny white eggs. They seldom live more than a day in the summer; the males live only a few hours. Under normal summer temperatures, 14 to 16 days are required for the complete life cycle. Throughout the season continual emergence produce female midges that are very active, laying their eggs on the flowering heads of any available host plant. Approximately 13 generations occur during the growing season in Texas (Walter, 1958). The economic threshold in Texas is considered to be one adult per head (Bottrell, 1971).

The injury to the grain is done by the larvae, or maggots, which feed on the juices of the developing seed, causing seeds to dry up and become discolored. The infested heads appear blighted or blasted; they resemble sterile heads and produce practically no grain. An infestation of one larva per spikelet is sufficient to cause total loss of the grain. Serious injury to a field of sorghum does not occur unless there is a nearby infestation from which an influx of female midge may come. Johnsongrass (S. halepense), a common weed, when allowed to head provides an excellent place for the development of the midge and becomes a source of infestation in the sorghum field. Johnsongrass blooms very early, thus permitting the early spring individuals to breed and thus increase in numbers before the sorghum fields bloom.

The midge overwinters in the cooler climates as a larva within a cocoon in a state of facultative diapause. Factors influencing diapause termination are brought about by exposure of larvae to high relative humidity and temperature between 20 and 30°C. Days to first adult emergence is influenced by temperature in that at the optimum temperature (25-30°) adults emerge in about 23 days. At higher or lower temperatures, adults emerge in about 35 days (Baxendale et al., 1979). Summers (1975) observed that adult emergence is a single phase diel rhythm with peak eclosion 1-2 hours after sunrise. Males began emerging 30-45 minutes earlier than females. Males began emerging at 12.8-15.6^{o}C and females at 18.4-20.1^{o}C. Emergence of both sexes ceased at 35^{o}C.

Sorghum Midge Resistance and Inheritance

Sorghum midge resistance was first reported to exist in cleistogamous sorghum such as Nunaba cultivars (S. membranaceum) in West Africa (Bowden and Neve, 1953). Glumes of these cultivars are long, papery, and are not forced apart by lodicules at anthesis which make it physically more difficult for female midge to insert eggs into the spikelets (Harris, 1961). Berquist et al. (1974) also found that sorghum selections IS 2663 and IS 2660 from the Indian-Rockefeller sorghum collection were resistant to midge in Hawaii. The glumes of spikelets of both cultivars remained closed throughout anthesis while glumes of susceptible controls remained open during anthesis. This character is likely to be an exclusion mechanism that confers resistance to midge. Plants of F_1 generation from a cross between a cytoplasmic sterile selection and IS 2660 did not express the closed-glumed character at anthesis suggesting that this character is recessive, incompletely dominant, or regulated by cytoplasmic factors.

But, resistance in cleistogamous sorghum broke down in the absence of more favorable alternative variety (Harris, 1961). Later, several reports have indicated the discovery of resistance among noncleistogamous sorghums. AF-28 is the sorghum line that showed a high level of resistance in field trials in Brazil (Rossetto and Banzatto, 1967). This was the most stable source among resistant lines that were tested in Brazil (Faris et al., 1979). Ovipositional nonpreference appeared to be the responsible mechanism for AF-28 (Teetes, 1980).

Harding (1965) conducted variety tests from twelve sorghum types. Planting dates of these sorghums were varied among varieties, in an effort to have each type bloom at the same time. Differences in emergence of midge adults were found. He indicated that emergence of adults from TX09 (Feterita) and Sorghum almum varieties was significantly less than emergence from other varieties. This type of resistance could well affect sorghum midge population increases. The florets were dissected in the laboratory to determine the cause of differential emergence. He found pupae and larvae in the late instars dead within the florets. It was apparent the larvae destroyed the seeds, but insect development could not be completed. It was suggested that this could be due to a nutritional phenomenon.

Johnson et al. (1973) evaluated 60 sorghum lines selected from sorghum conversion program for midge damage. Eight entries showed less damage; IS 12612C (SC0112), IS 12666C (SC0175), IS 2508C (SC0414), IS 2816C (SC0120), IS 3574C (SC0239), IS 12608C (SC0108), IS 12664C (SC0173), and IS 2579C (SC0423). Of these 8 selections, IS 12612C, IS 12666C, and IS 2508C sustained the least damage since seed loss was less than 20 percent. A further report by Johnson (1974) indicated that TAM2566 or SC0175-9, IS 2501C (SC0052), IS 2549C (SC0228), IS 1309C (SC0322) and IS 8100C (SC0424) exhibited the highest level of resistance at Lubbock, Texas. He further observed that the most obvious morphological difference between the resistant and susceptible types was their small glumes. All the lines with high levels of resistance were Caudatum types. The number of midge counted on resistant and susceptible plants were similar. In the resistant lines, midge larva were observed on maturing seed. The larvae were not covered by the glumes as they normally are but were fully or partially exposed. From his inheritance study based on an F_2 population, he indicated that the resistance of TAM2566 is controlled by more than one gene.

Widstrom et al. (1972) studied inheritance of sorghum midge and webworm resistance from parental, F_2, and F_3 and selfed backcross populations. The results indicated additive gene effects. Dominance effects were significant only for the cross SGIRL-MR-1 x 130. Dominance conditioned susceptibility to insect injury. Epistatic effects were also present and may tend to interfere with selection. From their results they suggested that simple backcrossing techniques will not be sufficient to transfer midge resistance into breeding lines.

Materials and Methods

Three susceptible and four resistant sorghums were used as parents in this study. The sorghum sources resistant to midge were SGIRL-MR-1, a selection from MB-10 which was derived from AF-28, SC0175 (IS 12666C), and SC0423 (IS 2579C). The susceptible parents were cultivars being used in the Oklahoma Agricultural Experiment Station sorghum breeding program: B Wheatland, B OK94, and Caprock.

SGIRL-MR-1 is a restorer, R-line. Its progenitor, ODC-19, was selected from an unknown South African hegari line by Pacific Oilseeds, Inc., in South Africa. ODC-19 was sent to the Texas Agricultural Experiment Station where a dwarf selection was made and designated ODC-19 (select). Beginning in 1964, the Host Plant Resistance team of the Southern Grain Insects Research Laboratory at Tifton, Ga., evaluated and selected within ODC-19 (select) for resistance to the sorghum midge. The most resistant heads each year were selected and exposed to heavy populations of the midge in successive years. SGIRL-MR-1 is the product of 7 years of this type of selection. It exhibits the nonpreference type of resistance and in field tests rates highly resistant. The pericarp color is tan and a testa is present (Wiseman et al., 1973).

AF-28 derivative (MB 10-21-7-1) was derived from PI383856 which was probably an introduction from Sudan via Chillicothe, Texas, in 1958. The original AF-28 was a tall photoperiod-sensitive plant and the seeds had a white pericarp with a dark testa (Faris et al., 1979).

The exotic parent of SC0175 (IS 12666C) was introduced from Ethiopia. It was classified as a Caudatum type. SC0175 was reported in 1973 to be the least damaged by midge among tested entries (Johnson et al., 1973).

The exotic parent of SC0423 (IS 2579C) was introduced from Sudan. It is also a Caudatum type and it was reported by Johnson et al. (1973) to be resistant to midge damage.

B Wheatland is a selection from the cross of milo x kafir. It was the first combine-type cultivar developed by breeding. It has a high yielding and good combining ability. It was developed by J. B. Sieglinger and released by Oklahoma Agricultural Experiment Station.

B OK94 originated from the cross Tan Redlan x witch weed resistant Kafir-E10 developed at the Oklahoma Agricultural Experiment Station.

Caprock resulted from a cross of kafir x milo. It has high yielding ability and was found to be a restorer. Caprock was developed by the Texas Agricultural Experiment Station at Lubbock.

All three susceptible and four resistant parents were placed in the greenhouse and crosses were made by hand emasculation in the spring of 1980. The crossed seeds and their parents were planted in a sorghum midge test in the experimental field at Lake Carl Blackwell, Stillwater, OK (Agricultural Research Service), in the summer of 1980. The 18 entries were planted in three replications. Unfortunately, the midge population was too low to assess midge damage in this year. Days to 50% bloom, plant height, and panicle exertion were recorded (Appendix, Table XXIII). Plant type, height of plant, awn, type of head, and some marked characteristics of the F_1 hybrids were checked to affirm that plants were not from selfed seed. Some F_1 heads were selfed by bagging and used for the F_2 generation. Additional F_1 plants were grown in the greenhouse for use in backcrossing with both resistant and susceptible parents.

Greenhouse techniques for screening sorghums for resistance to the sorghum midge are not available because techniques for artificially rearing the insect have not been developed. Presently, naturally occurring infestations in field plantings must be relied upon. In the summer of 1981, F_1, F_2, and backcross populations were planted in a sorghum midge test at two locations: the experimental field at Lake Carl Blackwell, Stillwater, OK, and Texas Agricultural Experiment Stational, College Station, TX. In Stillwater, the midge populations were too low to inflict sufficient damage for ratings to be made. Only the experiment at College Station had a naturally occurring uniform infestation of midge and could be used to study inheritance of sorghum midge resistance (Table I). Parents, F_1, F_2 and backcrosses were planted in single rows,

TABLE I

SORGHUM ENTRIES USED FOR TESTING FOR SORGHUM MIDGE

Entry	Identification	Generation	Description
1	SC0175	P	Resistant
2	SGIRL-MR-1	P	Resistant
3	SC0423	P	Resistant
4	AF-28 (derivative)	P	Resistant
5	B Wheatland	P	Susceptible
6	B OK94	P	Susceptible
7	Caprock	P	Susceptible
8	B Wheatland x SGIRL-MR-1	F_1	Susceptible x Resistant
9	B OK94 x SC0175	F_1	Susceptible x Resistant
10	B Wheatland x SC0423	F_1	Susceptible x Resistant
11	B OK94 x SC0423	F_2	Segregating
12	B OK94 x SGIRL-MR-1	F_2	Segregating
13	B Wheatland x SGIRL-MR-1	F_2	Segregating
14	B Wheatland x AF-28 (derivative)	F_2	Segregating

TABLE I. (Continued)

Entry	Identification	Generation	Description
15	Caprock x SC0175	F_2	Segregating
16	SGIRL-MR-1 x (SGIRL-MR-1 x B Wheatland)	BC	Resistant x F_1
17	Caprock x (Caprock x SGIRL-MR-1)	BC	Susceptible x F_1
18	B OK94 x (B OK94 x SC0423)	BC	Susceptible x F_1
19	Caprock x (Caprock x SC0175)	BC	Susceptible x F_1
20	SC0175 x (Caprock x SC0175)	BC	Resistant x F_1
21	B Wheatland x (B Wheatland x AF-28)	BC	Susceptible x F_1
22	AF-28 x (B Wheatland x AF-28)	BC	Resistant x F_1

6 meters long, spaced 1 meter apart. F_2's had ten rows which were composed of two populations.

For measuring sorghum midge resistance, heads of individual sorghum plants were rated visually for the percent of "blasted" seed. The rating scheme was as follows: 1 = 0 to 10 percent blasted seed, 2 = 11 to 20 percent blasted seed, and so on to 9 = 81 percent or more blasted seed. Damage ratings of 1 through 3 were considered to be resistant, 4 through 6 were moderately resistant, and 7 through 9 were susceptible. For calculating segregation ratios, resistant and moderately resistant plants were pooled in a "resistant" category. F_2 and backcross populations were tested for goodness of fit to an expected ratio by chi-square.

After damage rating, heads of F_2 generation were selected for midge resistance and good agronomic type (short plant type, big head, etc.). These were used as F_3 generation pedigree lines in the next year to check the stability of resistance. Sorghum lines which were not uniformly damaged by midge in Stillwater were selected on the basis of agronomic character and then they were planted to screen for midge resistance at College Station in the next year.

At harvesting time, the summer 1982, the open-pollinated heads of individual plants were selected based on a high level of resistance to sorghum midge and good agronomic type. The characteristics of the glumes of resistant heads were recorded.

Results and Discussion

Frequency distributions of the resistant and susceptible parental, F_1, F_2, and backcross populations were developed utilizing nine damage rating classes from sorghum midge attacks (Table II). All plants of SC0175, a resistant variety, were classified into damage rating classes 2 and 3. The average sorghum midge damage rating for SC0175 was 2.52 (Table II). In the resistant variety, SGIRL-MR-1, the plants were classified into resistant categories 2, 3, and 5 (Table II). However, there was also one plant in susceptible class 8. This plant was probably a seed mixture from threshing or planting or a diseased plant. All plants of SC0423 were classified into classes 1 and 2 except one plant which fell into susceptible class 8. The average midge damage ratings for SGIRL-MR-1 and SC0423 were 3.38 and 2.13, respectively (Table III). There were 8, 20, and 4 plants of resistant AF-28 (derivative) placed in resistant classes 2, 3, and 5 (Table II). The average damage rating of AF-28 (derivative) as shown in Table III was 3.0. SC0423 and SC0175 exhibited the highest levels of resistance to sorghum midge injury in this test.

B Wheatland, B OK94, and Caprock were severely damaged by sorghum midge. All plants of the three varieties were rated into classes 7, 8, or 9 (Table II). The average damage rating of B Wheatland, B OK94, and Caprock was 8.76, 8.36, and 9, respectively (Table III). Therefore, these three varieties were classified as susceptible. Caprock appeared to be the most susceptible variety to sorghum midge in this study.

F_1 Populations

All F_1 hybrids of susceptible B Wheatland and B OK94 with resistant varieties SGIRL-MR-1, SC0175, and SC0423 were rated into susceptible damage classes 7, 8, and 9, except for five plants of the cross B OK94 x SC0175 which were rated into class 4 (Table II). These five plants in

TABLE II

FREQUENCY DISTRIBUTION OF PLANTS TO SORGHUM MIDGE DAMAGE, COLLEGE STATION, TX

Entry	Identification	Generation	No. of Plants in Damage Rating Classes[1]								
			1	2	3	4	5	6	7	8	9
1	SC0175	P	-	10	11	-	-	-	-	-	-
2	SGIRL-MR-1	P	-	4	6	-	2	-	-	1	-
3	SC0423	P	4	11	-	-	-	-	-	1	-
4	AF-28 (derivative)	P	-	8	20	-	4	-	-	-	-
5	B Wheatland	P	-	-	-	-	-	-	-	8	25
6	B OK94	P	-	-	-	-	-	-	5	8	15
7	Caprock	P	-	-	-	-	-	-	-	-	28
8	B Wheatland x SGIRL-MR-1	F_1	-	-	-	-	-	-	-	-	27
9	B OK94 x SC0175	F_1	-	-	-	5	-	-	5	4	5
10	B Wheatland x SC0423	F_1	-	-	-	-	-	-	1	9	20
11	B OK94 x SC0423	F_2	3	15	14	27	25	22	27	50	76
12	B OK94 x SGIRL-MR-1	F_2	-	3	9	5	4	7	6	7	33

TABLE II (Continued)

Entry	Identification	Generation	No. of Plants in Damage Rating Classes[1]								
			1	2	3	4	5	6	7	8	9
13	B Wheatland x SGIRL-MR-1	F_2	-	2	11	1	2	1	2	3	16
14	B Wheatland x AF-28 (derivative)	F_2	3	10	20	38	47	20	42	30	84
15	Caprock x SC0175	F_2	2	7	11	17	20	22	22	30	97
16	SGIRL x (SGIRL x B Wheatland)	BC	3	3	3	2	1	1	4	5	6
17	Caprock x (Caprock x SGIRL)	BC	-	-	-	-	-	-	-	9	20
18	B OK94 x (B OK94 x SC0423)	BC	1	-	-	2	1	1	5	3	10
19	Caprock x (Caprock x SC0175)	BC	-	-	-	-	-	-	-	10	19
20	SC0175 x (Caprock x SC0175)	BC	2	1	-	4	2	2	4	-	1
21	B Wheatland x (B Wheatland x AF-28)	BC	-	-	-	-	1	1	-	5	11
22	AF-28 x (B Wheatland x AF-28)	BC	2	3	5	3	1	2	1	2	5

[1]Damage Rating Scale: 1 = 0 - 10% blasted seed to 9 = more than 80% blasted seed.

TABLE III

AVERAGE SORGHUM MIDGE DAMAGE CLASS FOR SORGHUM ENTRIES, COLLEGE STATION, TX

Entry	Identification	Generation	Average Damage Class[1]
1	SC0175	P	2.52
2	SGIRL-MR-1	P	3.38
3	SC0423	P	2.13
4	AF-28 (derivative)	P	3.00
5	B Wheatland	P	8.76
6	B OK94	P	8.36
7	Caprock	P	9.00
8	B Wheatland x SGIRL-MR-1	F_1	9.00
9	B OK94 x SC0175	F_1	6.95
10	B Wheatland x SC0423	F_1	8.63
11	B OK94 x SC0423	F_2	6.61
12	B OK94 x SGIRL-MR-1	F_2	6.89
13	B Wheatland x SGIRL-MR-1	F_2	6.29
14	B Wheatland x AF-28 (der.)	F_2	6.39
15	Caprock x SC0175	F_2	7.09
16	SGIRL x (SGIRL x B Wheatland)	BC	5.68
17	Caprock x (Caprock x SGIRL)	BC	8.69
18	B OK94 x (B OK94 x SC0423)	BC	7.35
19	Caprock x (Caprock x SC0175)	BC	8.66
20	SC0175 x (Caprock x SC0175)	BC	4.94
21	B Wheatland x (B Wheatland x AF-28)	BC	8.33
22	AF-28 x (B Wheatland x AF-28)	BC	5.00

[1]Damage Rating Scale: 1 = 0-10 percent blasted seed to 9 = more than 80 percent blasted seed.

the cross B OK94 x SC0175 may have flowered earlier or later than other plants, thereby escaping the high population of midge. Nevertheless, the average damage ratings of all F_1 hybrids of B Wheatland x SGIRL-MR-1, B OK94 x SC0175, and B Wheatland x SC0423 were 9.00, 6.95, and 8.63, respectively (Table III). Therefore, all crosses in the F_1 generation were classified as susceptible. Thus, the results indicate that the resistance to sorghum midge in SC0175, SGIRL-MR-1, and SC0423 sorghum is controlled by recessive genes.

F_2 Populations

The F_2 populations from five crosses of susceptible x resistant varieties segregated into nine damage rating classes (Table II), and were arranged into resistant, moderately resistant, and susceptible categories. However, this segregation did not fit any well-defined genetic ratio. Therefore, resistant and moderately resistant plants were pooled in a "resistant" category. These F_2 data were summarized in Table IV.

The F_2 population of B OK94 x SC0423 was classified into 160 resistant and 153 susceptible plants (Table IV). These data showed a good fit to a 7:9 genetic ratio by the chi-square test with a probability of 0.30-0.50 (Table IV). Thus, the resistance of SC0423 to sorghum midge appears to be conditioned by two recessive gene pairs.

The digenic ratio 7:9 or 9:7 indicates complete dominance of both gene pairs, but either recessive homozygote is epistatic to the effects of the other gene (Strickberger, 1968). In this case, dominance controls susceptibility in sorghum to midge injury. Either pair of homozygous recessive alleles is epistatic to the other dominant gene pair which

TABLE IV

SORGHUM MIDGE REACTION OF SORGHUM PARENTS, F_1, F_2 GENERATIONS AND BACKCROSSES, COLLEGE STATION, TX

Entry	Identification	Generation	Number of Plants		Total	Ratio[1]	P Value
			Resistant	Susceptible			
1	SC0175	P	21	-	21	-	-
2	SGIRL-MR-1	P	12	1	13	-	-
3	SC0423	P	15	1	16	-	-
4	AF-28 (derivative)	P	32	-	32	-	-
5	B Wheatland	P	-	33	33	-	-
6	B OK94	P	-	28	28	-	-
7	Caprock	P	-	28	28	-	-
8	B Wheatland x SGIRL	F_1	-	27	27	-	-
9	B OK94 x SC0175	F_1	5	14	19	-	-
10	B Wheatland x SC0423	F_1	-	30	30	-	-
11	B OK94 x SC0423	F_2	106	153	259	7:9	0.30-0.50

TABLE IV (Continued)

Entry	Identification	Generation	Number of Plants		Total	Ratio[1]	P Value
			Resistant	Susceptible			
12	B OK94 x SGIRL-MR-1	F_2	28	46	74	7:9	0.30-0.50
13	B Wheatland x SGIRL-MR-1	F_2	17	21	38	7:9	0.90-0.95
14	B Wheatland x AF-28 (der.)	F_2	138	156	294	7:9	0.20-0.30
15	Caprock x SC0175	F_2	79	149	228	5:11	0.30
16	SGIRL x (SGIRL x B Wheatland)	BC	13	15	28	3:1	<0.01
17	Caprock x (Caprock x SGIRL)	BC	-	29	29	-	-
18	B OK94 x (B OK94 x SC0423)	BC	5	18	23	-	-
19	Caprock x (Caprock x SC0175)	BC	-	29	29	-	-
20	SC0175 x (Caprock x SC0175)	BC	11	5	16	3:1	0.70-0.90

TABLE IV (Continued)

			Number of Plants				
Entry	Identification	Generation	Resistant	Susceptible	Total	Ratio[1]	P Value
21	B Wheatland x (B Wheatland x AF-28)	BC	2	16	18	-	-
22	AF-28 x (B Wheatland x AF-28)	BC	16	8	24	3:1	0.30-0.50

[1]The ratio based on segregation of two gene pairs.

results in resistance. Susceptibility in sorghum, thus, arises as the complementary effect of dominant alleles at two different loci; e.g., AAbb, Aabb, aaBB, aaBb would be resistant, whereas, AABB, AaBb would be susceptible.

The F_2 populations of B OK94 x SGIRL-MR-1, B Wheatland x SGIRL-MR-1, and B Wheatland x AF-28 (derivative) all segregated into resistant and susceptible classes which fit a 7:9 genetic ratio with satisfactory probabilities (Table IV). Again, these results indicated that the resistance to sorghum midge in SGIRL-MR-1 and AF-28 (derivative) sorghum was probably controlled by two recessive gene pairs.

The F_2 population of Caprock x SC0175 segregated into 79 resistant to 149 susceptible plants. When evaluated by the chi-square goodness of fit test, these data fit a 5:11 ratio of resistant to susceptible plants with the probability of 0.30 (Table IV). It appears that resistance in SC0175 is also conditioned by two pairs of recessive alleles. The digenic ratio 5:11 or 11:5 indicated dominance of both gene pairs with each gene pair affecting the same character; i.e., susceptibility is dominant to resistance for both genes. Dominance occurs only if both kinds of dominant alleles are present in an individual and the susceptible reaction is produced. The absence of a dominant allele at one gene pair produces susceptible plants only when the dominant allele at the other gene pair is homozygous; i.e., aaBB, AAbb would be susceptible, whereas, aaBb, Aabb would be resistant.

Backcross Populations

The backcross populations of susceptible x F_1 (susceptible x susceptible) produced all susceptible plants, except some plants of the crosses B OK94 x (B OK94 x SC0423) and B Wheatland x (B Wheatland x AF-28) as shown in Table IV. Susceptible x F_1 (susceptible) would not be expected to segregate, but they did. The explanation may be a lack of uniform infestation by sorghum midge at flowering time. However, all backcrosses of susceptible x F_1 (susceptible) had average damage ratings in the susceptible categories (Table III).

The backcross populations of resistant x F_1, (resistant x susceptible) segregated from classes 1 through 9 (Table II). The backcross of resistant SC0423 x F_1 was not available in this test. The backcross populations, with resistant varieties SC0175 and AF-28 (derivative) as recurrent parents, were fitted to 3:1 digenic ratios of resistant to susceptible by the chi-square test with the probability 0.70 to 0.90 and 0.30 to 0.50, respectively (Table IV). This result appeared to confirm that resistance to sorghum midge in SC0175 and AF-28 (derivative) is controlled by two recessive gene pairs. The backcross population with resistant SGIRL-MR-1, did not fit a digenic ratio of 3:1 by the chi-square test. Therefore, the resistance to sorghum midge in SGIRL-MR-1 sorghum might not be controlled by two pairs of recessive genes.

Considering the average damage ratings of all backcrosses, backcrossing to the resistant parent decreased the extent of damage while backcrossing to the susceptible parent increased the damage (Table III).

F_3 Populations

Sorghum plants selected for resistance and good agronomic type from the F_2 generation were sown as the F_3 generation. Heads from F_2 plants that were used as F_3 lines were selected from the higher levels of resistance in damage classes 1 to 3. The reaction to sorghum midge of each line in the F_3 generation is shown in Table V. Every F_3 line from a resistant F_2 plant segregated into resistant and susceptible plants. Open-pollinated resistant F_2 plants might be expected to produce a few susceptible outcross plants in F_3. However, outcrossing did not explain the large number of susceptible plants in each and every F_3 line. One may need to consider that resistance to sorghum midge in sorghum may be conditioned by more than two pairs of recessive genes.

The assessment of midge damage in sorghum populations of segregating plants by natural infestation has inherent problems. The level of the midge population in nature fluctuated and flowering time of the sorghum plants occurred over a period of several weeks in segregating populations. The plants which were selected as resistant plants from the segregating F_2 generation might have been the result of a combination of intrinsic and environmental influences.

This study indicated that the resistance to sorghum midge in SC0423, SGIRL-MR-1, AF-28 (derivative), and SC0175 was controlled by recessive genes at more than one locus and the inheritance was not simple. It appears to be difficult to transfer genes for resistance into good agronomic sorghum by simple hybridization.

Glumes Observation

As indicated by Johnson (1974), the most obvious morphological difference between resistant and susceptible types was a difference in the size of the glumes. In this study, all resistant parents were observed to have small glumes, but susceptible parents had normal size glumes. Sorghum hybrid materials which were selected from both Stillwater and College Station were planted at College Station in the summer 1982.

TABLE V

SORGHUM MIDGE REACTION OF F_3 INDIVIDUAL SORGHUM LINES, COLLEGE STATION, TX

Entry	Identification	Number of Plants		
		Resistant	Susceptible	Total
1	B OK94 x SC0423 TR1	6	37	43
2	B OK94 x SC0423 TR2	16	43	59
3	B OK94 x SC0423 TR3	4	57	61
4	B OK94 x SC0423 TR4	4	33	37
5	B OK94 x SC0423 TR5	8	26	34
6	B OK94 x SC0423 TR6	13	44	57
7	B OK94 x SC0423 TR7	13	74	87
8	B Wheatland x SGIRL-MR-1 TR8	9	27	36
9	B Wheatland x AF-28 TR1	11	24	35
10	B Wheatland x AF-28 TR2	7	22	29
11	B Wheatland x AF-28 TR3	9	21	30
12	B Wheatland x AF-28 TR4	4	37	41

TABLE V (Continued)

Entry	Identification	Number of Plants Resistant	Susceptible	Total
13	B Wheatland x AF-28 TR5	9	36	45
14	B Wheatland x AF-28 TR6	6	39	45
15	B Wheatland x AF-28 TR7	6	35	41
16	Caprock x SC0175 TR1	13	47	60
17	Caprock x AC0175 TR2	7	36	43
18	Caprock x SC0175 TR3	5	41	46
19	Caprock x SC0175 TR4	9	40	49
20	Caprock x SC0175 TR5	6	21	27
21	Caprock x SC0175 TR6	11	22	33

At harvesting time, heads were selected based on a high level of resistance and good agronomic characteristics. It was observed that 39 of 50 resistant heads had small glumes (Table VI). In other words, 78 percent of the resistant plants had the small glume character. This character may be nonpreferred by the female midge, or it may interfere with the normal growth of midge larvae after oviposition. In breeding programs which are handicapped by a lack of natural sorghum midge infestation, this character could be used as the index to select sorghum in segregating generations.

TABLE VI

CHARACTERISTIC OF GLUMES ON PEDIGREE SORGHUM LINES
RATED FOR MIDGE RESISTANCE

Head	Pedigree	Generation	Damage Rating	Glume[1]
1	Caprock x SC0175 TR5-1	F_3	3	N
2	Caprock x SC0175 TM1-1	F_3	3	S
3	Caprock x SC0175 TM3-1	F_3	4	S
4	Caprock x SC0175 TM4-1	F_3	3	N
5	B OK94 x SC0175 BK1-1	F_4	4	S
6	B OK94 x SC0175 BK2-1	F_4	2	S
7	B Wheatland x SC0175 BK2-1	F_4	2	N
8	SC0175 x (Caprock x SC0175) TR1-1	F_2	3	N
9	B Wheatland x SGIRL BK2-1	F_4	3	S
10	B Wheatland x AF-28 TR3-1	F_3	3	S
11	B Wheatland x AF-28 TR4-1	F_3	4	N
12	B Wheatland x AF-28 TM1-1	F_3	3	S
13	B Wheatland x AF-28 TM2-1	F_3	4	S
14	B Wheatland x AF-28 TMS-1	F_3	3	S
15	B OK94 x AF-28 BK1-1	F_4	3	S
16	B OK94 x AF-28 BK2-1	F_2	2	S
17	AF-28 x (B Wheatland x AF-28) TR1-1	F_2	3	S
18	AF-28 x (B Wheatland x AF-28) TR2-1	F_2	4	S

TABLE VI (Continued)

Head	Pedigree	Generation	Damage Rating	Glume[1]
19	AF-28 x (B Wheatland x AF-28) TR4-1	F_2	2	S
20	(B Wheatland x SGIRL) x (B Wheatland x SC0423) OK6-1	F_2	2	S
21	B OK94 x SC0423 TR11-1	F_3	3	S
22	B OK94 x SC0423 TS1-1	F_3	2	S
23	B OK94 x SC0423 BK2-1	F_4	2	S
24	Caprock x SC0423 BK2-1	F_4	2	S
25	Caprock x SC0423 BK2-2	F_4	2	S
26	Caprock x SC0423 BK2-3	F_4	2	S
27	Caprock x SC0423 BK2-4	F_4	2	S
28	SC0423 x (Caprock x SC0423) OK1-1	F_2	3	N
29	SC0423 x (Caprock x SC0423) OK1-2	F_2	2	N
30	SC0423 x (Caprock x SC0423) OK1-3	F_2	3	N
31	SC0423 x (Caprock x SC0423) OK3-1	F_2	3	N
32	SC0423 x (Caprock x SC0423) OK3-2	F_2	3	N
33	SC0423 x (Caprock x SC0423) OK4-1	F_2	4	N
34	SC0423 x (Caprock x SC0423) OK4-2	F_2	2	S
35	SC0423 x (Caprock x SC0423) OK4-3	F_2	3	S
36	SC0423 x (Caprock x SC0423) OK4-4	F_2	3	S
37	SC0423 x (Caprock x SC0423) OK4-5	F_2	3	S

TABLE VI (Continued)

Head	Pedigree	Generation	Damage Rating	Glume[1]
38	B OK94 x (B OK94 x SC0423) TR1-1	F_2	2	S
39	AF-28 x SC0423 TR1	F_2	2	S
40	AF-28 x SC0423 TR2	F_2	2	S
41	AF-28 x SC0423 TR3	F_2	2	S
42	SGIRL x AF-28 TR1	F_2	2	S
43	SGIRL x AF-28 TR2	F_2	2	S
44	SGIRL x AF-28 TR3	F_2	2	S
45	SGIRL x AF-28 TR4	F_2	3	S
46	SGIRL x AF-28 OK1	F_3	2	S
47	SGIRL x SC0175 TR1	F_2	2	S
48	SC0423 x SGIRL OK1-1	F_3	2	S
49	SC0423 x SGIRL OK1-2	F_3	2	S
50	SC0423 x SGIRL PK1-3	F_3	2	S

[1]N = normal glume; S = small glume.

CHAPTER III

SORGHUM RESISTANCE TO THE GREENBUG

The greenbug, *Schizaphis graminum* (Rondani), is one of the most destructive pests of sorghum, small grains and many types of grasses in the Great Plains area of the United States. The outbreak of this insect on sorghum in the Midwest and Southwest area caused losses of grain valued in excess of $20 million (USDA, 1969). In 1976, damage and control costs exceeded $80 million in Oklahoma alone (Starks and Burton, 1977b).

Greenbugs and Biotypes

The greenbug was first described by Rondani (1852) in Italy. The greenbug is approximately 1.6-mm long and has light green coloration, with a darker green mid-dorsal abdominal stripe. The distal leg segments and the tips of the cornicles are black. Alate and apterous forms may be present in the same colony. Females produce young parthenogentically (Almand et al., 1969).

In regard to damage, the greenbug has piercing-sucking mouthparts. While feeding on the plant, it injects toxic substances. The leaves attacked by greenbugs first turn yellow or orange. In heavy infestations, the leaves soon turn brown and the plants die. The aphids then leave these plants and move to others. Greenbugs also have a high parthenogenetic reproductive rate, so in a short time huge populations result. Portions or whole fields may be severely damaged. Damage to sorghum by greenbug is usually worse on small plants where feeding causes discoloration of leaves. Maturing plants can have large populations of greenbugs in the sorghum heads (Starks and Burton, 1977b). In addition to the damage they cause, greenbugs also transmit maize dwarf mosaic virus (MDMV) and may predispose sorghum to charcoal rot (Daniels and Toler, 1971; Teetes et al., 1973).

A wide host range and a capability of rapid parthenogenetic reproduction may be the cause of genetic variation that has occurred in greenbug populations. Up to present, the greenbug in the Great Plains is recorded as having five major biotypes A, B, C, D, and E. For separating biotypes, morphological characteristics are generally not as reliable as physiological characteristics based on fecundity and survival on certain resistant and susceptible host plants (plant response) and to tolerance to specific insecticides (Starks and Burton, 1977a).

Biotype A, the "original" greenbug, is differentiated from the other four biotypes by the resistance of Dickinson Selection 28-A (DS 28-A) and CI 9058 wheats to only this biotype (Starks and Burton, 1977a).

Biotype B was discovered by Wood (1961b) in barley cultures maintained in the greenhouse and became the predominant biotype by replacing A in the field by 1965. Both DS 28-A and CI 9058 wheats are susceptible to biotype B. It is not morphologically and reproductively different from biotype A, but differs in feeding habits. Saxena and Chada (1971) found stylet penetration of biotype A to be intercellular in the plant tissues, and invariably feeds in the phloem tissues of the vascular bundles; whereas, biotype B stylets penetrate both intra- and intercellularly and preferentially feeds in the mesophyll parenchyma of the leaf.

Biotype C was discovered during the summer of 1968 when large numbers of greenbugs made an unprecedented and widespread attack on sorghum (Harvey and Hackerott, 1969). This biotype was able to better reproduce at constant extreme temperatures than A and B (Wood and Starks, 1972). It has apparently replaced the previous biotypes. It infests sorghums in the summer and injures small grains during the winter. Piper sudangrass (S. sudanese) and broomcorn (S. bicolor) 'Deer' are both resistant to biotype B but susceptible to C and thus cen be used to separate the two biotypes (Harvey and Hackerott, 1969; Starks et al., 1972b).

Biotype D was first reported on sorghum in West Texas in the summer of 1974, but it was probably present on wheat in New Mexico prior to this. In 1975, it was reported in Texas, Oklahoma, Kansas, Nebraska and South Dakota (Starks and Burton, 1977a). It was tested and confirmed by Peters et al. (1975) and Teetes et al. (1975) that the greenbug populations had become organophosphate-resistant and were designated as biotype D.

Greenbug biotype E was first collected by Daniels and Chedester (1980) from a field near Bushland, Texas, in November and December 1979. Then it was tested and reported by Porter et al. (1982) that a wheat germplasm line "Amigo" and Amigo derivatives, which were resistant to greenbug biotype C prior to 1980, failed to survive laboratory infestations of progeny from that collection. Largo, an amphiploid wheat of Triticum turgidum L. and T. tauschii was resistant to biotype E. In sorghum, Porter et al. (1982) found that sorghums with resistance to biotype C from tunis grass, PI38108 were susceptible to the new biotype

E. But sorghums, PI220248 and Capbam, were indicated to be resistant to greenbug biotype E.

Daniels and Chedester (1981) conducted a biological experiment concerning reproduction, longevity and temperature tolerance of greenbug biotypes C and E. They concluded that the higher the temperature, the lower the instar number in which biotype E greenbugs began reproduction. At the temperature range of 26 to 31^{o}C, biotype E began reproduction before reaching the fifth or adult instar. High temperatures did not effect biotype C reproduction. Under these same conditions, the life-span of biotype E was shortened. No morphological differences between biotypes C and E were found.

Sources of Resistance and Inheritance in Sorghums

Soon after the first biotype C outbreak, sorghums were screened for greenbug resistance. Wood et al. (1969) found that SA7536-1 or 'Shallu,' S. bicolor, had extremely high tolerance. In the same year, Hackerott et al. (1969) conducted greenhouse tests without controlled temperatures by mass infestation of seedlings. Surviving seedlings indicated that two S. virgatum sources (PI38108 and TS1636) and some of their derivatives, as well as sudangrass, were resistant to greenbug biotype C. Seedling survival of the resistant entries ranged from 50 to 100 percent. For the inheritance study, the seedling survival trial involved the parents, the F_1, and F_2 generations of a resistant x susceptible cross. The F_1 and the resistant parent exhibited 100 percent survival while the susceptible parent was killed. In the F_2 population, there was segregation into resistant and susceptible plants in the ratio of 9:7. This indicated resistance was controlled by dominant genes at more than one locus. The F_2 population of two resistant sources S. virgatum x Sudan-grain did not segregate for resistance. This meant that genes conditioning resistance in S. virgatum and Sudan-grain appeared to be at the same locus.

Weibel et al. (1972) determined the inheritance of greenbug resistant varieties, Shallu Grain (SA7536-1), IS 809 and PI264453. The resistant entries were crossed with greenbug susceptible parents being used in the Oklahoma Agricultural Experiment Station sorghum breeding program. By individually rating injured plants, F_1 hybrid reactions to greenbugs appeared intermediate between the parents, but closer to the resistant parents. Data from F_2 populations fitted a ratio of 1:2:1 for resistant, intermediate, and susceptible plants which indicated that the inheritance of resistance probably was controlled by a single incompletely dominant factor.

Buajarern (1972) conducted studies on sorghum hybrids, 21 F_1's, 12 F_2's, and 18 backcross populations. He indicated that greenbug resistance in sorghum appeared to be conferred by genes at one locus with an indication of an allelic series at that locus. Gene actions appeared to be additive and either partially or completely dominant depending on the parents and crosses involved.

Johnson et al. (1981) also evaluated sorghum cultivars with natural populations of greenbugs at Halfway, Texas, and found that several biotype C resistant lines, KS30, SA7536-1, PI302178, PI302231, PI226096, and PI308976 were susceptible to biotype E. Two cultivars, PI220248 and 'Capbam' exhibited high levels of resistance to the aphid at the boot stage and later. Their subsequent seedling evaluations, by using aphids collected from the field at Halfway, indicated that PI220248, Capbam, PI264453 and TAM Bk 42 (derivative of PI264453) possessed seedling resistance to the biotype. Seedling evaluations of F_1 hybrids indicated that the resistance of PI220248 and Capbam is dominant.

Mechanism of Greenbug Resistance

Wood et al. (1969) studied greenbug biotype C for nonpreference and antibiosis on resistant SA7536-1, or Shallu. Shallu was highly nonpreferred and the fecundity of C was greatly reduced. Greenbugs became stunted with weight losses up to 80 percent of normal when reared on this variety. The reproduction of the greenbug biotype C was decreased nearly 90 percent and longevity was decreased by 15 days. This indicated that SA7536-1 was a very poor greenbug host.

Hackerott et al. (1969) indicated that tolerance appeared to be the major component of resistance in *S. virgatum* to greenbug biotype C, although antibiosis and/or nonpreference were also suggested by confinement tests.

Wood (1971) determined the mechanism of six resistant selections from laboratory screening: PI264453, PI220248, PI308976, PI302178, PI302231, and SA7536-1. The result showed that these possessed a high degree of nonpreference relative to the susceptible check. Fecundity and longevity did not vary appreciably but antibiosis was demonstrated by comparing aphid weights.

Starks et al. (1972a) indicated that levels of resistance varied considerably among cultivars and that cultivars had different types of resistance. The variety IS 809 demonstrated high antibiosis. Shallu showed high tolerance, and 'Piper' demonstrated nonpreference mechanism to greenbug biotype C.

Schuster and Starks (1973) determined three components of resistance to biotype C greenbug in 11 sorghum selections including B OK8, the susceptible check. Some of the selections were highly nonpreferred by both apterate and alate forms. Antibiosis was also a resistant factor in some selections since there were fewer nymphs weighing less on some selections than others. The time required until reproduction began was lengthened. Plant-height difference between infested and uninfested plants of each entry and by plant-injury ratings indicated that tolerance may be the main component of resistance of PI264453. Five of the selections, PI229828, IS 809, Shallu grain, PI302178, and PI226096 indicated comparatively high degrees of all three resistance components.

Teetes et al. (1974) also studied mechanisms of resistance of four resistant sorghum cultivars. They concluded that SA7536-1, KS30, and IS 809 appeared to show equal degrees of nonpreference and antibiosis for biotype C. F_1 hybrids of susceptible x resistant lines also showed nonpreference but to a lesser degree. In antibiosis studies, stadia were lengthened; whereas, progency per adult, adult longevity, and length of reproductive period were decreased. The lines PI264453, in general was more preferred and showed less antibiosis than the other resistant cultivars.

Johnson et al. (1981) conducted nonpreference studies with biotype E on seedlings in the greenhouse. The result indicated that PI220248, Capbam, and TX2737 were less preferred than susceptible TX430.

Materials and Methods

Mechanisms of Resistance to Greenbug Biotype E

Sorghum varieties screened for greenbug resistance to biotype E by USDA, ARS and Oklahoma Agricultural Experiment Station research workers at Stillwater were selected to test mechanisms of resistance; e.g., nonpreference, tolerance and antibiosis. PI220248, PI264453, and J242 were resistant sorghums while B Wheatland was used as the susceptible check (Table VII). Three separate tests were performed during January and February, 1983. Progeny from the biotype E greenbug collection at Hays, KS, were used. The greenbugs were cultured on susceptible barley (Hordeum vulgare L.) grown in plastic pots and covered with cylindrical nitrocellulose plastic cages 30 cm in height to prevent contamination from other insects and to confine the greenbugs.

Nonpreference was tested by randomly planting eight plants of four cultivars (two plants per cultivar) in a circular pattern in 15-cm plastic pots. The plant spacing was approximately 1.5 to 2 cm apart. When the plants were 5-6 cm tall, 40 apterous adult greenbugs or late nymphs were released into the center of the pot and plants were covered with a plastic cage with cloth-covered ventilation holes. Pots were then placed in the growth chamber at 22.2 to 25.6°C and 14 h photoperiod. The randomized complete block design with seven replicates was used as analysis in this test. Greenbugs were allowed to select the plants of their choice. The number of adult greenbugs on each plant was counted daily after infestation from 1 to 7 days.

Antibiosis was evaluated by counting the number of parthenogenetically produced nymphs and by measuring the number of days females

TABLE VII

SORGHUM ENTRIES TESTED FOR NONPREFERENCE, ANTIBIOSIS, AND TOLERANCE TO BIOTYPE E GREENBUG

Variety	Species	Origin	Height[1] (cm)	Type
PI220248	*Sorghum sudanese* (Peper) Stapf.	Sicily	214.6	grass type
PI264453	*S. bicolor* (L.) Moench	Spain	268.0	forage type
J242	*S. bicolor* (L.) Moench	Africa	176.8	grain type
B Wheatland	*S. bicolor* (L.) Moench	Oklahoma	55.2	grain type

[1]Height measured from the base of the plant to the tip of the head.

reproduced. The four sorghum entries were planted individually in 7.6-cm pots in ten replicates. When the plants were about 5-6 cm, five apterous adults or late nymphs were put on each plant which was covered with a plastic cage and placed in the growth chamber under the conditions indicated above. Adult greenbugs were observed every day. When nymphs were produced, adults were removed and five nymphs were left on each plant. The nymphs were allowed to grow on the test plant until they matured and started to parthenogenetically reproduce. At this time, all aphids but one were removed from the plant. Daily counts of nymph production were made and all nymphs were removed at the same time. This was done until the greenbugs died or failed to produced nymphs on consecutive days. The randomized complete block design was used as statistical analysis.

Tolerance was evaluated by measuring the ability of plants to grow after greenbug infestation. Two identical sets of the four sorghum cultivars with five replicates were planted individually in 7.6-cm pots. On the fourth day after plants emerged, the height from the soil to the tip of the longest leaf was measured and only one set was infested with ten apterate adult greenbugs per plant. The other set of sorghum plants was left uninfested. All plants were covered with plastic cages and placed in the greenhouse where the temperature averaged approximately 24°C. Every two days, all nymphs were removed and the number of adults was maintained at ten per infested plant. After ten days, the height of all plants was again measured and the differences between beginning and ending measurements were calculated for both the infested and uninfested plants. Infested plants were also rated for greenbug injury on the basis of 1 for no greenbug damage up to 9 for plant death. The design of this experiment is a randomized complete block.

Inheritance of Resistance to Greenbug Biotype E

Cultivars that were resistant to greenbug biotype E, sudangrass PI220248, and sorghum PI264453, were used. Susceptible parents in this study were the sorghums resistant to the sorghum midge: AF-28 (derivative), SC0175, and SGIRL-MR-1.

All of the parental lines were planted in pots and crosses were made by hand emasculation in the greenhouse in 1981. The resulting seeds were planted as F_1 in the Plant Science Research Laboratory greenhouse in 1982, and plant types were checked to affirm that plants were not from selfed-seed. F_1 heads were used for making backcrosses and were bagged to prevent outcrossing and to produce seed for the F_2 generation.

Parental lines, F_1, F_2, and backcross generations as shown in Table VIII were used to test for resistance to greenbug biotype E in the seedling stage. Techniques for screening and evaluation were similar to those of Wood (1961), and Starks and Burton (1977a). Sorghum entries were grown in galvanized metal flats, 35.5 x 50.8 x 9.5 cm, containing a soil-peat mixture. Each flat had ten rows spaced approximately 5 cm apart with about 20 seeds per row. Seeds were covered with about 2 cm of sand. Each flat had one row of resistant and one row of susceptible parents randomly located as checks. Tests were conducted in the greenhouse and the temperature ranged around 22^{o}C.

All entries were infested when the plants were about 4-5 cm tall with biotype E of varying ages from the culture pots. Flats were lightly reinfested two or three times to obtain uniform and adequate greenbug

TABLE VIII

SORGHUM ENTRIES USED FOR TESTING FOR RESISTANCE TO BIOTYPE E GREENBUG

Entry	Identification	Generation	Description
1	PI220248	P	Resistant
2	PI264453	P	Resistant
3	AF-28 (der.)	P	Susceptible
4	SGIRL-MR-1	P	Susceptible
5	SC0175	P	Susceptible
6	AF-28 (der.) x PI220248	F_1	Susceptible x Resistant
7	SC0175 x PI220248	F_1	Susceptible x Resistant
8	SGIRL-MR-1 x PI220248	F_1	Susceptible x Resistant
9	AF-28 (der.) x PI264453	F_1	Susceptible x Resistant
10	SGIRL-MR-1 x PI264453	F_1	Susceptible x Resistant
11	AF-28 (der.) x PI220248	F_2	Segregating
12	SC0175 x PI220248	F_2	Segregating
13	SGIRL-MR-1 x PI220248	F_2	Segregating

TABLE VIII (Continued)

Entry	Identification	Generation	Description
14	AF-28 (der.) x PI264453	F_2	Segregating
15	SGIRL-MR-1 x PI264453	F_2	Segregating
16	AF-28 x (AF-28 x PI220248)	BC	Susceptible x F_1
17	PI220248 x (AF-28 x PI220248)	BC	Resistant x F_1
18	(SC0175 x PI220248) x SC0175	BC	F_1 x Susceptible
19	(SC0175 x PI220248) x PI220248	BC	F_1 x Resistant
20	(AF-28 x PI264453) x AF-28	BC	F_1 x Susceptible
21	(AF-28 x PI264453) x PI264453	BC	F_1 x Resistant
22	(SGIRL-MR-1 x PI264453) x PI264453	BC	F_1 x Resistant

levels. Most of the greenbugs were apterous viviparities. The greenbugs were allowed to feed and reproduce until all plants of the susceptible parent were killed and then data were taken. This usually took 10-14 days after infestation.

For measuring greenbug resistance, individual plants were rated visually by using a scale ranging from 1 for no damage to 9 for dead plants. The damage rating classes 1 to 6 were considered resistant, and 7 to 9 susceptible. The segregation of the F_2 generation and backcrosses were tested for goodness of fit to an expected ratio by chi-square.

The resistant parents PI220248 and PI264453 were uniform for general agronomic characters. However, when they were infested with greenbug biotype E, the frequency distribution showed mostly resistant but some susceptible plants. If the resistant hosts and insect cultures were purified, the cause of this segregation was probably the environmental effects. The partitioning method of genetic analysis by Powers (1963) could be applied to the data. In the chi-square test for goodness of fit, theoretical values are compared to the observed frequency distributions. The theoretical values were calculated on the basis of genetic model which assumes that the parents are differentiated by one major effective factor pair in respect to greenbug injury. The theoretical distribution frequency of F_2 is $\frac{1}{4}(P_1 + P_2) + \frac{1}{2}F_1$ of the observed values. The theoretical distribution frequency of the backcross would be equal to the average of the F_1 and parent to which backcrossing was done; e.g., $BC_1 = \frac{1}{2}(F_1 + P_1)$ and $BC_2 = \frac{1}{2}(F_1 + P_2)$.

Results and Discussion

Mechanisms of Resistance to Greenbug Biotype E

Preferential response of greenbug biotype E to the test varieties is shown in Table IX. PI220248 exhibited the highest degree of nonpreference from 1 through 7 days after infestation. PI264453 also showed high nonpreference by the aphid. There was no statistical difference at the 5% level between resistant varieties PI264453 and PI220248. Nonpreferential response by greenbug biotype E to both resistant varieties became more pronounced at subsequent observations. Considering the average number of greenbugs on host varieties over time, J242 appears to possess moderately nonpreferred by the greenbug. On the first day after infestation, PI220248, PI264453, and J242 were all significantly less preferred. But feeding behavior started to change on the second day following infestation. Nonpreference response by greenbugs to PI220248 and PI264453 increased; whereas, nonpreference response to J242 decreased in later days. Possibly, nonpreference might result from a deterrent existing in resistant varieties. On the other hand, J242 may have lacked sufficient deterrent to reduce feeding more than one day. The susceptible variety, B Wheatland, was the most preferred host for greenbug biotype E in this study. On B Wheatland, PI220248, and PI264453, the number of aphids decreased slightly over time. Perhaps, this was due to aphid relocation on J242. The decrease on B Wheatland may have been partly due to dying plant tissues.

Antibiosis of host varieties is shown in Table X. Based on duration of parthenogenetic reproduction, greenbugs reared on the three resistant varieties PI220248, PI264453, and J242 had significantly shorter

TABLE IX

NONPREFERENCE OF BIOTYPE E GREENBUG ON SORGHUMS[1]

Variety	Average No. of Greenbugs After Infestation by Days							Average No. of Greenbugs
	1	2	3	4	5	6	7	
PI220248	2.4a	1.8a	1.8a	1.7a	1.6a	1.0a	0.6a	1.6a
PI264453	4.4a	3.5ab	2.4a	2.7a	2.0a	1.6a	1.8a	2.7a
J242	4.0a	4.8b	5.1b	5.2b	5.5b	5.7b	5.6b	5.2b
B Wheatland	7.6b	7.5c	7.6c	6.7c	6.5b	6.7b	6.8b	7.1c

[1] Means with the same letter are not significantly different at the 5% level by Duncan's multiple range test.

TABLE X

ANTIBIOSIS OF SORGHUMS TO BIOTYPE E GREENBUG [1]

Variety	Nymphs/adult	Average Days Reproducing
PI220248	16.1a	18.5a
PI264453	20.9b	17.8a
J242	38.6c	18.2a
B Wheatland	55.4d	24.4b

[1] Means with the same letter are not significantly different at the 5% level by Duncan's multiple range test.

reproductive periods than the susceptible B Wheatland. However, there was no significant difference in reproductive periods among the three resistant varieties.

The average number of nymphs per female reared on susceptible B Wheatland was much higher than on any other variety. Significant differences in reproduction were obtained among the three resistant varieties, PI220248, PI264453, and J242. The resistant variety, PI220248, produced only about one-third as many nymphs as B Wheatland and less than one-half as many as J242. PI264453 ranked between PI220248 and J242; the same positioning found in the nonpreference test.

The results of the tolerance test are shown in Table XI. PI220248 and PI264453 had a low percentage of plant height difference between infested and uninfested plants. The average plant injury scores of these two resistant varieties were also low. Thus, PI220248 and PI264453 demonstrated high levels of tolerance when they were infested by biotype E. The average plant damage of B Wheatland was in the susceptible category and the difference in plant height due to greenbug injury was 70%. B Wheatland exhibited the lowest tolerance in this study. The plant height increase in the resistant variety, J242, was significantly different which related to moderate injury scores. However, significant differences were obtained between J242 and B Wheatland. So, J242 exhibited a moderate level of tolerance in this study.

The relative degrees of greenbug biotype E resistance components among sorghum entries are summarized in Table XII. PI220248 demonstrated the highest antibiosis and high levels of nonpreference and tolerance as well. The resistance in PI264453 was also high in all three components. The resistance in J242 was at the moderate level. By observation, this

TABLE XI

TOLERANCE OF SORGHUM ENTRIES TO BIOTYPE E GREENBUG

Variety	Average Plant Height Increase (cm)		Percent Difference[1]	Average Plant Injury Score[2]
	Uninfested	Infested		
PI220248	13.44	12.78	5	1.6a
PI264453	15.38	14.1	8	2.0a
J242	16.72	12.74	24*	3.8b
B Wheatland	12.82	3.84	70**	7.8c

[1] * is significantly different at the 5% level.
** is significantly different at the 1% level.

[2] Means with the same letter are not signficantly different at the 5% level by Duncan's multiple range test.

TABLE XII

RELATIVE DEGREES OF BIOTYPE E GREENBUG RESISTANCE COMPONENTS EXPRESSED IN SORGHUMS

Variety	Nonpreference	Antibiosis	Tolerance
PI220248	+++	++++	+++
PI264453	+++	+++	+++
J242	++	++	++
B Wheatland	+	+	+

+ denotes low or no component expression; ++ denotes intermediate, and +++ and ++++ denote high and very high component expression, respectively.

variety was still segregating in agronomic characters and it is suspected that the resistant factors are probably in a heterozygous condition. Perhaps selection could increase the level of resistance.

Inheritance of Resistance to Greenbug Biotype E

Frequency distributions of the greenbug damage rating classes of all entries are shown in Table XIII. All plants of PI220248 were distributed into classes 2 to 9 but most of the population was in the resistant class 3 (Table XIII). The average greenbug damage rating for PI220248 was 4.07 (Table XIV) and was lower than that of the resistant PI264453 sorghum. Thus, the sudangrass PI220248 exhibited a higher level of resistance to biotype E than the sorghum PI264453.

All plants of susceptible parents AF-28 (derivative), SGIRL-MR-1, and SC0175 were classified into damage rating susceptible classes 7 to 9. The percentages of dead plants were 94.74, 95.52, and 100, respectively (Table XIV).

The frequency distributions of F_1 hybrids in all crosses of susceptible x resistant are predominantly in classes 3 to 6. The average damage classes of all F_1 crosses were in the range between 5.12 to 5.67 (Table (XIV) which was closer to resistant parents PI220248 and PI264453 than to the susceptible parents. Therefore, all crosses in the F_1 generation were classified as resistant. Thus, the results indicated that resistance to greenbug biotype E in both PI220248 and PI264453 is dominant.

The F_2 populations of susceptible x resistant crosses segregated into all greenbug damage rating classes (1 to 9) (Table XIII). These data were summarized into resistant and susceptible classes (Table XV). The theoretical segregation of resistant and susceptible plants was

TABLE XIII

FREQUENCY DISTRIBUTIONS OF DAMAGE RESPONSES BY SORGHUM PLANTS TO BIOTYPE E GREENBUG

Entry	Identification	Generation	Damage Rating[1]								
			1	2	3	4	5	6	7	8	9
1	PI220248	P	-	11	38	15	17	6	1	-	7
2	PI264453	P	-	5	15	15	23	23	2	2	8
3	AF-28 (der.)	P	-	-	-	-	-	-	-	3	54
4	SGIRL-MR-1	P	-	-	-	-	-	-	1	2	64
5	SC0175	P	-	-	-	-	-	-	-	-	42
6	AF-28 (der.) x PI220248	F_1	-	-	2	6	4	3	-	3	3
7	SC0175 x PI220248	F_1	-	-	3	5	1	3	-	-	3
8	SGIRL-MR-1 x PI220248	F_1	-	-	1	6	4	4	-	1	1
9	AF-28 (der.) x PI264453	F_1	-	-	-	2	2	1	2	-	-
10	SGIRL-MR-1 x PI264453	F_1	-	-	2	6	6	-	-	-	3
11	AF-28 (der.) x PI220248	F_2	-	8	97	59	35	38	9	8	65
12	SC0175 x PI220248	F_2	-	15	74	82	35	14	11	2	62

TABLE XIII (Continued)

Entry	Identification	Generation	Damage Rating[1]								
			1	2	3	4	5	6	7	8	9
13	SGIRL-MR-1 x PI220248	F_2	-	6	55	54	25	31	12	-	55
14	AF-28 (der.) PI264453	F_2	2	11	45	104	76	64	21	14	139
15	SGIRL-MR-1 x PI264453	F_2	-	8	47	59	56	48	28	11	71
16	AF-28 x (AF-28 x PI220248)	BC	-	1	2	1	2	5	3	2	11
17	PI220248 x (AF-28 x PI220248)	BC	3	8	9	-	1	2	-	-	-
18	(SC0175 x PI220248) x SC0175	BC	-	2	5	7	2	1	4	2	16
19	(SC0175 x PI220248) x PI220248	BC	-	2	14	1	-	-	-	-	4
20	(AF-28 x PI264453) x AF-28	BC			1	5	5	10	9	6	22
21	(AF-28 x PI264453) x PI264453	BC		3	2	6	2	2	3	1	6
22	(SGIRL-MR-1 x PI264453) x PI264453	BC			1	7	4	1	-	1	5

[1]The damage rating scale ranged from 1 for an undamaged plant to 9 for a dead plant.

TABLE XIV

AVERAGE BIOTYPE E GREENBUG DAMAGE CLASS AND THE PERCENTAGE OF DEAD SORGHUM PLANTS

Entry	Identification	Generation	Average Damage[1] Class	Dead Plants (%)
1	PI220248	P	4.07	7.37
2	PI264453	P	5.05	8.60
3	AF-28 (der.)	P	8.95	94.74
4	SGIRL-MR-1	P	8.94	95.52
5	SC0175	P	9.00	100.00
6	AF-28 (der.) x PI220248	F_1	5.67	14.29
7	SC0175 x PI220248	F_1	5.27	20.00
8	SGIRL-MR-1 x PI220248	F_1	5.18	5.88
9	AF-28 (der.) x PI264453	F_1	5.43	-
10	SGIRL-MR-1 x PI264453	F_1	5.12	17.65
11	AF-28 (der.) x PI220248	F_2	5.20	20.38
12	SC0175 x PI220248	F_2	5.05	21.02
13	SGIRL-MR-1 x PI220248	F_2	5.39	23.11

TABLE XIV (Continued)

Entry	Identification	Generation	Average Damage Class[1]	Dead Plants (%)
14	AF-28 (der.) x PI264453	F_2	5.99	29.20
15	SGIRL-MR-1 x PI264453	F_2	5.74	21.65
16	AF-28 x (AF-28 x PI220248)	BC	6.96	40.74
17	PI220248 x (AF-28 x PI220248)	BC	2.74	-
18	(SC0175 x PI220248) x SC0175	BC	6.44	41.03
19	(SC0175 x PI220248) x PI220248	BC	4.00	19.05
20	(AF-28 x PI264453) x AF-28	BC	7.19	37.93
21	(AF-28 x PI264453) x PI264453	BC	5.64	24.00
22	(SGIRL-MR-1 x PI264453) x PI264453	BC	5.79	26.32

[1]The damage rating scale ranged from 1 for an undamaged plant to 9 for a dead plant.

TABLE XV

REACTION OF SORGHUM PARENTS, F_1, F_2, AND BACKCROSSES WHEN INFESTED WITH BIOTYPE E GREENBUGS

Entry	Identification	Generation	Observed		Theoretical[1]		P Value
			Res.	Susc.	Res.	Susc.	
1	PI220248	P	87	8	-	-	-
2	PI264453	P	81	12	-	-	-
3	AF-28 (der.)	P	-	57	-	-	-
4	SGIRL-MR-1	P	-	67	-	-	-
5	SC0175	P	-	42	-	-	-
6	AF-28 (der.) x PI220248	F_1	15	6	-	-	-
7	SC0175 x PI220248	F_1	12	3	-	-	-
8	SGIRL-MR-1 x PI220248	F_1	15	2	-	-	-
9	AF-28 (der.) x PI264453	F_1	5	2	-	-	-
10	SGIRL-MR-1 x PI264453	F_1	14	3	-	-	-
11	AF-28 (der.) x PI220248	F_2	237	82	187	132	<0.001
12	SC0175 x PI220248	F_2	220	75	186	109	<0.001
13	SGIRL-MR-1 x PI220248	F_2	171	67	159	79	0.02-0.10

TABLE XV (Continued)

Entry	Identification	Generation	Observed Res.	Observed Susc.	Theoretical[1] Res.	Theoretical[1] Susc.	P Value
14	AF-28 (der.) x PI264453	F_2	302	174	274	202	0.05-0.01
15	SGIRL-MR-1 x PI264453	F_2	218	110	207	121	0.30-0.20
16	AF-28 x (AF-28 x PI220248)	BC	11	16	10	17	0.90-0.70
17	PI220248 x (AF-28 x PI220248)	BC	23	-	19	4	0.10-0.05
18	(SC0175 x PI220248) x SC0175	BC	17	22	16	23	0.90-0.70
19	(SC0175 x PI220248) x PI220248	BC	17	4	18	3	0.90-0.70
20	(AF-28 x PI264453) x AF-28	BC	21	37	21	37	1.00
21	(AF-28 x PI264453) x PI264453	BC	15	10	20	5	0.05-0.01
22	(SGIRL-MR-1 x PI264453) x PI264453	BC	13	6	16	3	0.20-0.10

[1]Calculated from the observed plants of two parents and F_1 on the basis that the parents are differentiated by one major effective factor pair.

calculated from the observed data by the partitioning method. Each cross of the F_2 population was tested for goodness of fit by the chi-square. Two crosses, SGIRL-MR-1 x PI220248 and SGIRL-MR-1 x PI264453, fit the theoretical segregation (Table XV). Therefore, the resistance of PI220248 and PI264453 to greenbug biotype E appears to be conditioned by a single dominant gene pair. The average damage class and percent dead plants among F_2 populations involving both resistant PI220248 and PI264453 were only slightly different (Table XIV). Thus, resistant varieties PI220248 and PI264453 expressed almost the same level of resistance to biotype E in F_2 progenies.

The segregation of F_2 populations of the crosses, AF-28 (derivative) x PI220248 and SC0175 x PI220248 did not fit the theoretical segregations calculated by the partitioning method. Nevertheless, the segregation of 237 resistant to 82 susceptible plants of the cross AF-28 (derivative) x PI220248 (Table XV) expressed a very good fit to the 3:1 genetic ratio of resistant to susceptible plants by the common chi-square test. Likewise, the segregation of 220 resistant to 75 susceptible plants from the cross SC0175 x PI220248 fit a 3:1 monogenetic ratio by the common chi-square test. The number of plants in the crosses of susceptible categories was considerably less than would be expected in the F_2 generation. Probably, there was misclassification of some seedlings. In the F_2 generation of the cross AF-28 (derivative) x PI264453, the segregating population also did not fit the 3:1 genetic ratio. No other satisfactory common ratio would fit these data. The number of plants in the susceptible class was less than those in the theoretical one.

In the backcross populations of resistant parent x F_1 (resistant x resistant), theoretical populations were calculated from the observed frequencies of resistant parents and F_1 on the basis that the parents are differentiated by one major effective factor pair in respect to biotype E injury. The observed populations of all backcrosses of resistant parent x F_1 or F_1 x resistant parent fit the theoretical populations except the cross (AF-28 x PI264453) x PI264453 (Table XV). In the backcross populations of susceptible parent x F_1 (susceptible x resistant), theoretical frequencies were also calculated from observed data by the partitioning method on the basis of monogenic control. All backcross populations of F_1 x susceptible or susceptible x F_1 involving both resistant PI220248 and PI264453 including three crosses which did not fit in the F_2 generation fit the hypothesis (Table XV). Thus, backcross data substantiated the previous conclusion that resistance to greenbug biotype E of PI220248 and PI264453 is governed by a dominant gene pair at one locus. There should be little difficulty in developing sorghum varieties resistant to greenbug biotype E by using the resistant varieties in this study.

CHAPTER IV

SORGHUM RESISTANCE TO THE CHINCH BUG

Chinch Bug

The chinch bug, *Blissus leucopterus leucopterus* (Say), is an important pest of small grains, corn, and sorghums. It belongs to the Family Lygaeidae, Order Hemiptera and was originally described in 1831 (Say, 1831). The chinch bug probably originated in Panama or Southern Mexico, feeding on native grasses (Webster, 1907). It is thought to have spread northward along the shores of the Gulf of Mexico and the Atlantic Coast from which it gradually spread westward.

The chinch bug was first reported in the United States on wheat in North Carolina in 1783 (Fitch, 1856). Howard (1888) reported serious damaged in Illinois, Ohio, Indiana, Iowa, Nebraska, Kansas, Missouri, and Oklahoma. The first outbreak of chinch bugs in Oklahoma was in 1871 (Webster, 1907). Webster (1915) estimated a total damage in the United States in excess of $350,000,000 from 1850 to 1915.

The history of the chinch bug in the United States has been one of recurring outbreaks at intervals of from 5 to 10 years. During such periods, which usually coincide with times of drought, these insects are present in small grains in spring, and corn and sorghum in summer in great abundance. In wet years, the adults tend to seek the drier and sunner parts of the field where plants are spaced farther apart (Painter, 1951).

Most reports indicated that there are two generations a year; however, in Oklahoma, three complete generations of chinch bugs occur as reported by Dahms (1935) and Snelling (1936). The overwintering adults hibernate chiefly in bunch grass usually close to the place where they were feeding, definite preference for certain grass species such as little bluestem and Indian grass. During late March and early April, they fly to small grain crops, especially barley and winter wheat, where eggs for the first generation are deposited during late April. Young nymphs feed on barley or wheat until they have become adults. They usually reach this stage about the time the small grain crops mature, or early June. These adults are forced to seek other sources of food such as sorghum, corn and millet in summer (Snelling and Dahms, 1940).

Chinch bugs attack any part of the vegetative phase of sorghum. The injury caused by chinch bug is primarily the result of a mass attack. Young plants are sometimes covered with bugs, the sap is extracted, and the death of the plants may result. Even if plants are not killed, the growth may be stunted and the yield of grain or fodder reduced. Rates of plant mortality may be highly variable. Older plants are better able to withstand the attack. Even resistant plants can be killed if they are small enough when infested and if there are sufficiently large numbers of chinch bugs.

Prolonged sublethal attacks by the bugs tend to stunt growth in all varieties. This often results in the death of the central leaf curl and some of the older leaves. Decay begins at the growing point near the crown where the tissue is usually beyond the reach of the stylets of the bugs and therefore must be a secondary result of the feeding. The stunting of the growth and death of the central leaf curl are especially characteristic of milo and might represent a different type of susceptibility from that found in other varieties. Distinctive color reactions in the leaves of the plants attacked are characteristic of injury to sorghum by chinch bugs. The dark red or purple pigment at the site of the punctures is apparently the same as that occurring on many varieties at the place of other kinds of wounds. In addition to these blotches of red pigment, the leaves of many varieties turn a suffused yellow or reddish yellow as a result of severe chinch bug injury (Snelling et al., 1937).

A study of feeding methods of the chinch bug by Painter (1928) has shown that the objective of the stylets is usually the phloem tissue of the vascular bundles where a number of branches of the stylet sheaths usually extend to the various tubes. Sometimes the stylets pass through the heaviest part of the sclerenchyma. The food of the chinch bug comes primarily from the phloem tissue.

Experiments and observations indicated that injury may result from a combination of one or more of at least four factors: (1) The direct withdrawal of plant fluids from cells and especially from the xylem and phloem tubes by the chinch bugs. (2) The exudation of plant fluids from punctures left open after the feeding of the insects, with possible attendant interference with root pressure and translocation. (3) A clogging of the plant conductive tissue with stylet sheath material deposited by the bugs. (4) Openings in the plant tissues are provided through which fungi and bacteria can enter. Wound response involving pigments frequently takes place in the region of chinch bug punctures (Snelling et al., 1937).

Resistance in Sorghums

Hayes and Johnston (1925) observed an invasion of chinch bugs among nearly 100 species of native and introduced grasses at Manhattan, Kansas. They found that the different plant species showed different degrees of resistance to injury, and later some of them exhibited marked ability to recover from the attack. Native, perennial species with harsh tissues were able to survive chinch bug injury and showed the most marked ability to recover.

Hayes (1922) observed that young milo plants were more seriously injured by chinch bugs than any of the other sorghums. He also observed that milo crosses exhibiting hybrid vigor were not injured as severely by the chinch bugs. But, Daane and Klages (1928) reported that complete failures resulting from chinch bug damage had been the rule with milo and milo hybrids tested at Stillwater, Oklahoma. Kiltz et al. (1933) stated that because of chinch bug injuries the growing of milos and, to a lesser extent, of feteritas was not to be recommended for the chinch bug infested area of Oklahoma, while all true kafirs, Darso, and Schrock were fairly dependable. Although most of the sweet sorghums were fairly resistant, Honey sorgo was quite susceptible. Fargo or straightneck milo was not as susceptible to chinch bug injury as were most milos.

Martin (1933) reported that there were differences in chinch bug injury on grain sorghums. The milos were particularly susceptible, feterita and hegari somewhat susceptible, while the kafirs showed considerable resistance. Many hybrid sorghums had been tested for resistance to chinch bug injury. Few strains that possessed resistance greater than that of either parent had been found.

Snelling et al. (1937) studied resistance of sorghum to the chinch bug for a long period of time. They concluded that the milos were very susceptible, the feteritas susceptible, and the kafirs and sorgos rather resistant to chinch bug injury. Most of the sorgos were slightly more resistant than the kafirs, but others were susceptible. Atlas sorgo was highly resistant to chinch bugs. Hegari was more susceptible to chinch bugs than most of the kafirs.

From the work on resistance of sorghum to chinch bugs in cooperation between the Oklahoma Agricultural Experiment Station and the U.S. Department of Agriculture (Sieglinger, 1946), three varieties which were resistant to chinch bugs had been released: Combine Winter Kafir 44-14, selection from the cross of Sharon kafir x Dwarf Feterita-Kaoliang which was reported to be more resistant than Martin or Wheatland milo; Kaferita 811, a white seeded variety that appeared to be the most resistant of any variety so far tested at Stillwater, Oklahoma; and the third variety was a chinch bug resistant strain of Honey sorgo, which produced a good grade of syrup and forage in addition to being insect resistant (Salter, 1948; Blizzard, 1948).

Dahms and Sieglinger (1954) also tested sorghum varieties for chinch bug resistance in Oklahoma. The result indicated that Kaferita CI 811 had the lowest percentage of plants killed. Sharon kafir was more resistant than any of the other kafirs tested. Wilde and Morgan (1978) tested four sorghum lines at seedling stage (75 mm height) in the growth chamber. Ten field-collected adult chinch bugs were confined on a single plant for 5 days. The damage ratings indicated that Early Sumac was most resistant and the other three varieties, Honey, Redlan, and Spanish Broomcorn, were susceptible in the seedling stage.

The preference of chinch bugs for seedling sorghum varieties, and the tolerance of several varieties to a uniform chinch bug attack were studied by Dahms et al. (1936). The effect of different sorghum varieties on the oviposition and longevity of the adult chinch bug and the rate of development and mortality of chinch bug nymphs when confined to resistant and susceptible varieties were also determined. In a series of tests on the preference of the chinch bug to Dwarf Yellow Milo (susceptible) and Atlas Sorgo (resistant), 80 percent of the bugs were attracted to the susceptible variety. They also found that 10-inch plants of Atlas Sorgo lived longer than plants of the same size Dwarf Yellow Milo under the same chinch bug infestation. Chinch bug females lived longer and laid many more eggs on the susceptible variety of Dwarf Yellow Milo than on any of the other varieties tested, and nymphs reared on Dwarf Yellow Milo developed more rapidly and had lower mortality than those reared on Atlas Sorgo.

On the causes of resistance, Snelling et al. (1937) reported that some morphological characteristics of the varieties were found to be related with chinch bug resistance in particular varieties in their experiments. Apparently chinch bug resistance or susceptibility was not definitely determined by any one of the gross morphological characteristics studied. However, some evidence was found that there was an association between a few of the characteristics and chinch bug resistance.

Height of the plant showed some relationship with the degree of chinch bug injury. The tall types tended to be resistant, while the dwarf varieties tended to be susceptible. The dwarf varieties were largely milo and milo hybrids which were most susceptible to chinch bug injury. The sweet-stalk varieties tended to be resistant, while the nonsweet group showed a wide range in injury and included both resistant types such as kafir and the highly susceptible milos. Color of stigma was found to be slightly related to chinch bug reaction. The varieties with yellow stigma were generally more susceptible than the white stigma varieties, which were rather resistant.

The manner in which the leaf sheath fitted around the stalk might be closely related to chinch bug injury. The leaf sheath closely surrounded the stalk of a number of resistant varieties, while it fitted loosely around the stalk of certain susceptible varieties, especially milo. Chinch bugs were gregarious and fed in the protected location inside the sheath when possible, and this may have resulted in concentrated injury to the plants. This feeding habit was indicated by the greater number of punctures on the inside of the leaf sheath of varieties in which the sheath fitted loosely around the stalk.

In addition to morphological characters, the milo group of sorghum which exhibited very high susceptibility to chinch bugs was found to possess a relatively low silica content (Lanning and Linko, 1961).

Some inheritance studies were suggested by Snelling et al. (1973). Based on their hybrids studied, resistance of sorghum to chinch bug might be dominant or partially dominant. Although the continued manifestation of heterosis in the F_2 generation of those crosses might have increased the average resistance of the population, there was a close relationship between heterosis and chinch bug resistance of some F_1 sorghum hybrids. From the cross Sharon Kafir (resistant) x Dwarf Yellow Milo (susceptible), observed figures indicated that one main factor pair governed chinch bug reaction in this cross. However, they proposed that the inheritance of chinch bug resistance was more complex and was influenced not only by other genes directly affecting chinch bug reaction but by genetic factors controlling such plant characters as earliness, vigor of early growth, character of sheath, and others. So, the single factor hypothesis might not be the correct genetic interpretation.

Whether hybrid vigor or genetic factors controlled resistance in sorghum was determined by Dahms and Martin (1940). Eleven F_1 sorghum hybrids which exhibited resistance were determined by counting the number of eggs laid by chinch bugs when confined to the stems of the plants. In most of the crosses, resistance as measured by such counts was dominant to susceptibility. The extent of hybrid vigor as measured by height of plant, diameter of stalk, and number of tillers did not appear to be definitely associated with chinch bug resistance as measured by oviposition and longevity of the females.

Materials and Methods

Screening of Sorghum Cultivars for Chinch Bug Resistance

Sixty sorghum cultivars of various types were initially screened for chinch bug resistance by natural infestation at Stillwater in the summer of 1981. Chinch bug infestation in the field was encouraged by planting winter barley around the test area. The barley served as the host in the spring after chinch bugs emerged from hibernation. The test was planted in four randomized complete blocks on May 20, 1981. Individual plots consisted of single rows, 3 m long, and spaced 1 m apart. Forty-five days after planting, all entries were rated for chinch bug injury. Injury to the sorghum was measured by visually rating the entire row by using a scale ranging from 0 = no damage to 6 = dead or severely damaged plants. Days to fifty percent bloom, plant height, kernel color, and head type were later recorded.

Sorghum and Hybrids Tested for Chinch Bug Resistance at Manhattan, Kansas

Four resistant varieties from the field test were selected for the inheritance study. These were Sol Kafir, Wonder Kafir CI 872, Dwarf Ellis, and B KS5. Varieties in the milo group were used as suceptible parents and crosses were made. The crossed seeds were planted as F_1's in Puerto Rico in the winter of 1981-82. F_1 plants were bagged to insure selfing and used as the F_2 generation. Additional seeds were planted in the Plant Science Research Laboratory greenhouse and used for making backcrosses.

Parents, F_1's, F_2's and backcrosses were planted in the summer of 1982 at the experimental field at Lake Carl Blackwell, Stillwater, OK. Unfortunately, heavy rains in the early summer reduced the population of chinch bugs in the test area. Therefore, a part of these materials was sent to the Kansas Agricultural Experiment Station, Manhattan, Kansas, for testing. A naturally occurring chinch bug infestation was utilized to study the inheritance of chinch bug resistance (Table XVI). At Manhattan, the test was planted on July 5, 1982. Ten days after planting, the seedling plants of each entry were counted before chinch bug attack. All entries were assessed for resistance 41 days after planting by counting the number of plants surviving and the number of sorghum plants that could bear well-developed heads in each entry. Damage

TABLE XVI

SORGHUM ENTRIES USED FOR TESTING CHINCH BUG RESISTANCE, MANHATTAN, KS

Entry	Identification	Generation	Description	Mode of Height (cm)	Days to 50% Bloom
1	Double Dwarf Yellow Milo (Ea)	P	Susceptible	46	55
2	Sol Kafir	P	Resistant	89	58
3	Wonder Kafir CI 872	P	Resistant	86	56
4	Dwarf Ellis	P	Resistant	61	61
5	B KS5	P	Resistant	69	55
6	Double Dwarf Yellow Milo (Ea) x Double Dwarf Yellow Sooner Milo	F_1	Susceptible x Susceptible	53	52
7	Double Dwarf Yellow Milo (Ea) x Dwarf Ellis	F_1	Susceptible x Resistant	158	67
8	Double Dwarf Yellow Sooner Milo x Double Dwarf Yellow Milo (Ea)	F_2	Susceptible x Susceptible	66	51
9	Sol Kafir x Double Dwarf Yellow Milo (Ea)	F_2	Resistant x Susceptible	152	59
10	Wonder Kafir CI 872 x Double Dwarf Yellow Sooner Milo	F_2	Resistant x Susceptible	117	55

TABLE XVI (Continued)

Entry	Identification	Generation	Description	Mode of Height (cm)	Days to 50% Bloom
11	Dwarf Ellis x Double Dwarf Yello Milo (Ea)	F_2	Resistant x Susceptible	142	54
12	B KS5 x Double Dwarf Yellow Milo (Ea)	F_2	Resistant x Susceptible	152	52
13	Sol Kafir x Wonder Kafir CI 872	F_2	Resistant x Resistant	127	59
14	Sol Kafir x Dwarf Ellis	F_2	Resistant x Resistant	94	62
15	Sol Kafir x B KS5	F_2	Resistant x Resistant	97	59
16	Wonder Kafir CI 872 x Dwarf Ellis	F_2	Resistant x Resistant	104	56
17	Wonder Kafir CI 872 x B KS5	F_2	Resistant x Resistant	107	54
18	B KS5 x Dwarf Ellis	F_2	Resistant x Resistant	102	56
19	(Sol Kafir x Double Dwarf Yellow Milo) x Double Dwarf Yellow Milo	BC	F_1 x Suscep-tible	107	-
20	(Double Dwarf Yellow Milo x Sol Kafir) x Sol Kafir	BC	F_1 x Resistant	127	-

TABLE XVI (Continued)

Entry	Identification	Generation	Description	Mode of Height (cm)	Days to 50% Bloom
21	(Double Dwarf Yellow Milo x Wonder Kafir CI 872) x Double Dwarf Yellow Milo	BC	F_1 x Susceptible	117	-
22	Wonder Kafir CI 872 x (Double Dwarf Yellow Milo x Wonder Kafir)	BC	Resistant x F_1	127	-
23	(Double Dwarf Yellow Milo x Dwarf Ellis) x Double Dwarf Yellow Milo	BC	F_1 x Susceptible	117	-
24	(Dwarf Ellis x Double Dwarf Yellow Milo) x Dwarf Ellis	BC	F_1 x Resistant	127	-
25	(Double Dwarf Yellow Milo x B KS5) x Double Dwarf Yellow Milo	BC	F_1 x Susceptible	122	
26	(Double Dwarf Yellow Milo x B KS5) x B KS5	BC	F_1 x Resistant	127	-
27	(B KS5 x Double Dwarf Yellow Sooner Milo) x Double Dwarf Yellow Sooner Milo	BC	F_1 x Susceptible	119	-

ratings could not be made in this study. Plants in each entry that produced well-developed panicles were considered to be chinch bug resistant, and the number of plants killed or stunted with several tillers and small, late-developing heads were considered susceptible. The F_2 populations and backcrosses were tested for goodness of fit to an expected ratio by chi-square.

Chinch Bug Confinement Test on Selected Sorghums at the Seedling Stage

Nine selected sorghums from the field screening test, consisting of six resistant and three susceptible milo varieties were tested for resistance at the seedling stage. J242 which was moderately resistant to the greenbug biotype E, F_1 hybrids from the crosses between J242 and four resistant varieties, and F_2 plants from two crosses of susceptible x susceptible varieties were included in this test. All entries were planted individually in 7.6 cm pots in five replications. When plants were 7-8 cm in height, ten adult or nearly adult chinch bugs from the culture were confined on each plant with a cylindrical nitrocellulose plastic cage. This test was conducted from mid-February to March, 1983. The temperature was about 22°C. After ten days, all plants were rated visually for chinch bug injury by using a scale ranging from 0 = no damage to 6 = dead plant.

Chinch Bug Rearing in the Greenhouse

The technique of culturing greenbugs was modified for use in rearing chinch bugs in the greenhouse. Millet and corn were grown as culture plants in 19.5 cm pots. Each pot had 10-15 millet plants and two corn plants. Sorghum and barley could be used as culture plants when there was no problem of greenbug contamination from cultures in the same greenhouse. Chinch bugs were collected in the field from bunch grasses in the winter; small grains, especially barley, in the spring; and sorghum, millet, or corn in the summer. When the culture plants were 10-12 cm in height, 10 to 12 pairs of male and female chinch bugs were confined on the plants with cylindrical nitrocellulose plastic cages 45 cm in height and 18 cm in diameter. The plastic cages had ventilation holes covered with cheesecloth. The top of the cage was covered with a piece of cheesecloth with light wire so that the cage could be opened. The temperature in the greenhouse was approximately 26 to 29^{o}C, 70% RH, and well ventilated. The warm temperature, long photoperiod of 14 h daylight or fluorescent lights contributed to chinch bug mating and nymphal production.

During the culture, millet was preferred and was killed in about two weeks after infestation, while the corn plants could prolong the culture maintenance up to one month and allowed insect colonization. When the culture plants deteriorated, the chinch bug colony could be transferred by placing a small pot (7.6 cm diameter) of corn or other small grain plants in the cage. Chinch bugs readily infested the new plants, which were transferred to a new culture the next day. Also, sections of sorghum or corn stalks could be used on a small tray or petri dish of sand or other materials where chinch bugs might hide and this container could be transferred to the new culture. In this way, cultured chinch bugs could be used for testing plant resistance and other studies.

RESULTS AND DISCUSSION

Screening of Sorghum Cultivars for Chinch Bug Resistance

Days to 50% bloom ranged from 57 to 66% (Table XVII). None of the heavily damaged entries bloomed late but many of the early blooming ones appeared resistant. Thus, maturity did not seem to be a factor in resistance. Though the susceptible entries tended to be short, this was probably due to stunting by chinch bug injury instead of height control by dwarfing genes. However, some short entries were resistant. Therefore, the height of the plant probably did not relate to chinch bug resistance in this study.

Average damage ratings of all sorghum entries are shown in Table XVII. Most of the cultivars of the milo type were severely injured by chinch bug attack. Sooner Milo 917 was the least damaged among the milo cultivars. Average damage of the milo group was 4.6 (Table XVIII). Feterita and kaoliang groups were less susceptible than milo. Hegari and durra showed resistance in this study. Varieties of sorgo and kafir exhibited the highest resistance to chinch bug attack in the field. Average damage ratings were 1.0 and 1.2 , respectively (Table XVIII). The results of this study are similar to those obtained and reported by Hayes (1922), Daane and Klages (1928), Martin (1933), and Snelling et al. (1937). Thus, it appears that a new chinch bug biotype has not developed in regard to the relative injury to sorghum.

The high yielding cultivars developed from the crosses of milo x kafir or kafir x milo showed considerable resistance. All kafir hybrids

TABLE XVII

SORGHUM CULTIVARS RATED FOR RESISTANCE TO CHINCH BUG, STILLWATER, OK

Entry	Cultivar	Type of Sorghum	Kernel Color	Panicle Type	Days to 50% Bloom	Plant Height (cm)	Average Damage Rating[2]
1	Double Dwarf R-322	Milo	Red	Semicompact	–[1]	60	5.8
2	Double Dwarf Yellow Milo 868	Milo	Red	Compact	–[1]	75	5.3
3	Double Dwarf Yellow Milo (Ea)	Milo	Red	Compact	5959	60	5.8
4	Double Dwarf White Milo	Milo	White	Compact	–[1]	60	6.0
5	Sooner Milo 917	Milo	Red	Compact	59	120	2.8
6	Sooner Milo GC241	Milo	Red	Compact	59	140	3.0
7	Double Dwarf White Sooner Milo	Milo	White	Compact	59	45	4.5
8	Double Dwarf Yellow Sooner Milo	Milo	Red	Compact	59	45	5.5
9	Day Milo 959	Milo	Red	Compact	57	45	4.3
10	Bonar x Day-4	Milo	Red	Semicompact	59	60	3.5
11	Colby Milo CI 218	Milo	Red	Semicompact	59	75	3.8
12	Res. Colby	Milo	Red	Semicompact	58	45	4.5

TABLE XVII (Continued)

Entry	Cultivar	Type of Sorghum	Kernel Color	Panicle Type	Days to 50% Bloom	Plant Height (cm)	Average Damage Rating[2]
13	Ryer Milo	Milo	Red	Compact	59	45	6.0
14	Beaver Milo 871	Milo	Red	Semicompact	66	75	3.5
15	Res. Beaver Milo GC38776	Milo	Red	Compact	65	90	4.3
16	Wheatland GC38288	Milo x Kafir	Red	Semicompact	60	60	1.8
17	Martin	Milo x Kafir	Red	Semicompact	59	90	1.8
18	Westland	Milo x Kafir	Red	Semicompact	59	90	1.8
19	Midland	Milo x Kafir	Red	Compact	60	90	2.5
20	Plainsman	Milo x Kafir	Red	Semicompact	60	90	1.8
21	Caprock	Milo x Kafir	Red	Semicompact	61	90	2.0
22	Combine 7078	Milo	Red	Compact	60	60	5.0
23	Early Kalo CI 1009	Kafir x Milo	Red	Semiloose	59	75	1.5
24	Kalo CI 902	Kafir x Milo	Red	Compact	59	90	1.3
25	Standard Blackhull Kafir CI 71	Kafir	White	Compact	63	120	1.8
26	Blackhull Kafir CI 204	Kafir	White	Compact	59	105	1.3

TABLE XVII (Continued)

Entry	Cultivar	Type of Sorghum	Kernel Color	Panicle Type	Days to 50% Bloom	Plant Height (cm)	Average Damage Rating[2]
27	Lowe Blackhull Kafir	Kafir	White	Compact	64	135	1.0
28	Sol Kafir	Kafir	White	Semicompact	62	150	1.0
29	Pink Kafir	Kafir	White	Compact	59	150	1.3
30	White Kafir	Kafir	White	Compact	60	135	1.3
31	Eastern Blackhull Kafir 906	Kafir	White	Semicompact	63	165	1.0
32	Texas Blackhull Kafir 865	Kafir	White	Semicompact	62	120	1.0
33	Dwarf Bishop Kafir	Kafir	White	Semiloose	62	90	1.5
34	Rice Kafir	Kafir	White	Compact	63	150	1.0
35	Wonder Kafir CI 872	Kafir	White	Compact	59	135	1.0
36	Club Kafir CI 901	Kafir	White	Compact	61	120	1.5
37	Weskan Kafir CI 1017	Kafir	White	Compact	60	135	1.0
38	Coes	Kafir	White	Semiloose	58	120	1.3
39	Custer	Kafir	Red	Compact	66	90	1.3
40	Redland	Kafir	Red	Compact	63	90	1.3

TABLE XVII (Continued)

Entry	Cultivar	Type of Sorghum	Kernel Color	Panicle Type	Days to 50% Bloom	Plant Height (cm)	Average Damage Rating[2]
41	Combine Kafir-60	Kafir	White	Compact	61	110	1.0
42	Darso OK#1	Kafir	Brown	Semicompact	60	120	1.3
43	Feterita CI 745	Feterita	White	Compact	58	120	2.8
44	Dwarf Feterita	Feterita	White	Compact	58	75	3.3
45	Double Dwarf Feterita	Feterita	White	Semicompact	58	60	3.5
46	Cache Feterita	Feterita	White	Compact	59	90	3.0
47	Dwarf White Feterita	Feterita	White	Compact	58	90	3.0
48	White Durra CI 81	Durra	White	Compact	60	135	1.5
49	Early Hegari SF 281	Hegari	White	Compact	64	135	1.8
50	Dwarf Ellis	Kafir	White	Semicompact	60	120	1.0
51	Shantung Kaoliang CI 293	Kaoliang	Red	Semiloose	60	105	3.3
52	TX622	Kafir Hyb.	White	Semicompact	62	120	1.0
53	TX623	Kafir Hyb.	White	Compact	62	120	1.0
54	TX624	Kafir Hyb.	White	Semicompact	61	100	1.0

TABLE XVII (Continued)

Entry	Cultivar	Type of Sorghum	Kernel Color	Panicle Type	Days to 50% Bloom	Plant Height (cm)	Average Damage Rating[2]
55	B 813 x 1712-1	Sorgo	White	Compact	60	125	1.0
56	B KS5	Sorgo	Brown	Semicompact	59	160	1.0
57	B Sorgo x Collier	Sorgo	Red	Compact	63	90	1.0
58	B NB4692	Hybrid	White	Semiloose	61	100	1.3
59	B AR3008	Hybrid	Red	Semiloose	61	90	2.5
60	B AR3003	Hybrid	Brown	Semiloose	60	90	1.8
	LSD						1.05

[1]Damaged too badly to head normally.

[2]Chinch bug rating: 0 = no damage; 6 = dead plant; average of four replications.

TABLE XVIII

AVERAGE DAMAGE RATING TO CHINCH BUG INJURY
AMONG TYPES OF SORGHUMS, STILLWATER, OK

Type of Sorghum	Number of Variety	Average Damage Rating[1]
Milo	16	4.6
Kafir	19	1.2
Milo x Kafir	8	1.8
Kafir Hybrids	3	1.0
Feterita	5	3.1
Sorgo	3	1.0
Durra	1	1.5
Hegari	1	1.8
Kaoliang	1	3.3

[1]Chinch bug rating: 0 = no damage; 6 = dead plant.

in this test were also highly resistant. It appeared that the resistance to chinch bug in kafir types was inherited.

Sorghums and Hybrids Tested for Chinch Bug Resistance at Manhattan, Kansas

Individual plants in each entry were assessed for chinch bug injury as shown in Table XIX. Four resistant varieties from Stillwater were tested in Manhattan. All plants of Dwarf Ellis survived and produced well-developed heads. Wonder Kafir CI 872 was another resistant variety in which all plants survived (Table XIX) and 95.5 percent of the plants produced well-developed panicles (Table XX). Thus, Dwarf Ellis and Wonder Kafir CI 872 exhibited a high level of chinch bug resistance in the field at Manhattan. The other two resistant varieties appeared to have susceptible plants segregating within the varieties. All plants of Double Dwarf Yellow Milo (Ea) were severely damaged by chinch bugs, and only one plant produced a head (Table XIX). Therefore, Double Dwarf Yellow Milo (Ea) was very susceptible in this test.

F_1 hybrids of Double Dwarf Yellow Milo (Ea) x Double Dwarf Yellow Sooner Milo represented a cross of susceptible x susceptible milo. In this cross, 93.2% of the plants were killed or severely damaged by chinch bugs (Table XX). This result indicated that heterosis or hybrid vigor of a susceptible x susceptible cross did not produce resistance to chinch bug injury in the field test at Manhattan.

Double Dwarf Yellow Milo (Ea) x Dwarf Ellis represented an F_1 hybrid between susceptible and resistant varieties. All plants survived the chinch bug attack (Table XIX) and 75% of the plants produced well-developed heads (Table XX). Thus, most of the F_1 population of this

TABLE XIX

ASSESSMENT OF CHINCH BUG INJURY ON SORGHUM PLANTS, MANHATTAN, KS

Entry	Identification	Generation	Total	No. of Plants Surviving	No. of Plants Bearing Heads	No. of Tillers per Plant
1	Double Dwarf Yellow Milo (Ea)	P	19	14	1	2.21
2	Sol Kafir	P	15	10	8	1.3
3	Wonder Kafir CI 872	P	22	22	21	1.55
4	Dwarf Ellis	P	12	12	12	1.25
5	B KS5	P	29	21	18	1.52
6	Double Dwarf Yellow Milo (Ea) x Double Dwarf Yellow Sooner Milo	F_1	13	6	1	3.0
7	Double Dwarf Yellow Milo (Ea) x Dwarf Ellis	F_1	12	12	9	1.58
8	Double Dwarf Yellow Sooner Milo x Double Dwarf Yellow Milo (Ea)	F_2	24	16	9	3.38
9	Sol Kafir x Double Dwarf Yellow Milo (Ea)	F_2	232	160	152	2.13

TABLE XIX (Continued)

Entry	Identification	Generation	Total	No. of Plants Surviving	No. of Plants Bearing Heads	No. of Tillers per Plant
10	Wonder Kafir CI 872 x Double Dwarf Yellow Sooner Milo	F_2	287	211	200	2.11
11	Dwarf Ellis x Double Dwarf Yellow Milo (Ea)	F_2	273	203	195	2.21
12	B KS5 x Double Dwarf Yellow Milo (Ea)	F_2	283	213	203	2.57
13	Sol Kafir x Wonder Kafir CI 872	F_2	263	209	208	1.62
14	Sol Kafir x Dwarf Ellis	F_2	252	210	206	1.91
15	Sol Kafir x B KS5	F_2	256	187	182	2.11
16	Wonder Kafir CI 872 x Dwarf Ellis	F_2	232	159	154	2.13
17	Wonder Kafir CI 872 x B KS5	F_2	276	166	163	1.76
18	B KS5 x Dwarf Ellis	F_2	324	216	212	1.91
19	(Sol Kafir x Double Dwarf Yellow Milo) x Double Dwarf Yellow Milo	BC	15	11	9	4.18

TABLE XIX (Continued)

Entry	Identification	Generation	Total	No. of Plants Surviving	No. of Plants Bearing Heads	No. of Tillers per Plant
20	(Double Dwarf Yellow Milo x Sol Kafir) x Sol Kafir	BC	25	15	15	2.2
21	(Double Dwarf Yellow Milo x Wonder Kafir CI 872) x Double Dwarf Yellow Milo	BC	21	17	15	3.53
22	Wonder Kafir CI 872 x (Double Dwarf Yellow Milo x Wonder Kafir)	BC	20	14	14	2.86
23	(Double Dwarf Yellow Milo x Dwarf Ellis) x Double Dwarf Yellow Milo	BC	24	18	17	3.56
24	(Dwarf Ellis x Double Dwarf Yellow Milo) x Dwarf Ellis	BC	17	12	12	2.67
25	(Double Dwarf Yellow Milo x B KS5) x Double Dwarf Yellow Milo	BC	19	15	14	3.2
26	(Double Dwarf Yellow Milo x B KS5) x B KS5	BC	21	17	16	2.76
27	(B KS5 x Double Dwarf Yellow Sooner Milo) x Double Dwarf Yellow Sooner Milo	BC	18	16	16	2.81

TABLE XX

REACTION OF SORGHUM PARENTS, F_1, F_2, AND BACKCROSSES TO CHINCH BUG INJURY, MANHATTAN, KS

Entry	Identification	Generation	Resistant (%)	Susceptible (%)	Ratio	P Value
1	Double Dwarf Yellow Milo (Ea)	P	5.3	94.7	-	-
2	Sol Kafir	P	53.3	46.7	-	-
3	Wonder Kafir CI 872	P	95.5	4.5	-	-
4	Dwarf Ellis	P	100.0	0.0	-	-
5	B KS5	P	62.1	37.9	-	-
6	Double Dwarf Yellow Milo (Ea) x Double Dwarf Yellow Sooner Milo	F_1	7.7	92.3	-	-
7	Double Dwarf Yellow Milo (Ea) x Dwarf Ellis	F_1	75.0	25.0	-	-
8	Double Dwarf Yellow Sooner Milo x Double Dwarf Yellow Milo (Ea)	F_2	37.5	62.5	-	-
9	Sol Kafir x Double Dwarf Yellow Milo (Ea)	F_2	65.5	34.5	3:1	<0.01
10	Wonder Kafir CI 872 x Double Dwarf Yellow Sooner Milo	F_2	69.7	30.3	3:1	0.05-0.01
11	Dwarf Ellis x Double Dwarf Yellow Milo (Ea)	F_2	71.4	28.6	3:1	0.20-0.10

TABLE XX (Continued)

Entry	Identification	Generation	Resistant (%)	Susceptible (%)	Ratio	P Value
12	B KS5 x Double Dwarf Yellow Milo (Ea)	F_2	71.7	28.3	3:1	0.30-0.20
19	(Sol Kafir x Double Dwarf Yellow Milo) x Double Dwarf Yellow Milo	BC	60.0	40.0	1:1	0.70-0.50
20	(Double Dwarf Yellow Milo x Sol Kafir) x Sol Kafir	BC	60.0	40.0	-	-
21	(Double Dwarf Yellow Milo x Wonder Kafir CI 872) x Double Dwarf Yellow Milo	BC	71.4	28.6	1:1	0.10-0.05
22	Wonder Kafir CI 872 x (Double Dwarf Yellow Milo x Wonder Kafir)	BC	70.0	30.0	-	-
23	(Double Dwarf Yellow Milo x Dwarf Ellis) x Double Dwarf Yellow Milo	BC	70.8	29.2	1:1	0.10-0.05
24	(Dwarf Ellis x Double Dwarf Yellow Milo) x Dwarf Ellis	BC	70.6	29.4	-	-
25	(Double Dwarf Yellow Milo x B KS5) x Double Dwarf Yellow Milo	BC	73.7	26.3	1:1	0.10-0.05
26	(Double Dwarf Yellow Milo x B KS5) x B KS5	BC	76.2	23.8		
27	(B KS5 x Double Dwarf Yellow Sooner Milo) x Double Dwarf Yellow Sooner Milo	BC	88.8	11.2	1:1	$<$ 0.01

susceptible x resistant cross was in the resistant class. This result suggested that the resistance to chinch bugs in Dwarf Ellis appeared to be dominant.

F_2 populations of all crosses of resistant x susceptible sorghums segregated into more resistant than susceptible plants in each cross. Thus, this indicated that chinch bug resistance in Sol Kafir, Wonder Kafir CI 872, Dwarf Ellis, and B KS5 sorghum varieties was dominant. The segregation of F_2 generations was tested for goodness of fit to 3:1 genetic ratio of resistant to susceptible plants by the chi-square. Only two crosses of resistant x susceptible sorghums fit this hypothesis. These were Dwarf Ellis x Double Dwarf Yellow Milo (Ea) and B KS5 x Double Dwarf Yellow Milo (Ea). These fit a 3:1 monogenic ratio of resistant to susceptible with the probability of 0.20 to 0.10 and 0.30 to 0.20, respectively. This result suggested a single dominant gene pair controls chinch bug resistance in these two crosses. However, the crosses Sol Kafir x Double Dwarf Yellow Milo (Ea) and Wonder Kafir CI 872 x Double Dwarf Yellow Sooner Milo did not fit this hypothesis. It needs further study in the F_3 generation.

Double Dwarf Yellow Sooner Milo x Double Dwarf Yellow Milo (Ea) is the reciprocal cross of susceptible x susceptible varieties in the F_2 generation. Most of the population was susceptible to chinch bug damage even though hybrid vigor still continued in this generation.

In the backcrosses of F_1 x susceptible parent, only the population of the backcross (Sol Kafir x Double Dwarf Yellow Milo) x Double Dwarf Yellow Milo fit the ratio 1:1 of resistant to susceptible with the probability of 0.70 to 0.50. The other three backcrosses gave a poor fit and the last one did not fit the monogenic ratio 1:1. Among the backcrosses of F_1 x resistant or resistant x F_1, the populations of all backcrosses segregated into resistant and susceptible plants. If a single major dominant gene pair controlled chinch bug resistance, the population of F_1 x resistant backcross would not segregate. Therefore, it is suspected that the resistance to chinch bug in sorghum may not be monogenic.

If a single dominant gene controlled resistance to chinch bug injury in all resistant varieties and the resistant genes are located in the same locus, no recombinations would be expected in the F_2 generation of crosses between resistant entries. All plants in the F_2 generation should be in the resistant class. However, all populations of resistant x resistant crosses did segregate (Table XXI). These segregations were tested for goodness of fit to the genetic ratio 15:1 of resistant to susceptible plants, which would indicate two dominant major genes independently inherited. None of the crosses fit this genetic ratio by the chi-square test (Table XXI). It is unclear from these results whether or not chinch bug resistance is governed by a single dominant gene pair. The genes for resistance of four resistant varieties were nonallelic in this study. However, it needs further study in the F_3 generation.

The segregating populations tested by natural chinch bug infestations were a problem in genetic studies. Chinch bug populations fluctuate, and other insect pests or diseases may cause sorghum plants to die at an early stage.

Tiller numbers per plant in susceptible varieties, susceptible crosses, and backcrosses to susceptible parents were higher than those in resistant varieties, resistant crosses, or backcrosses to resistant parents (Table XIX). Apparently, susceptible plants attempted to recover from chinch bug injury by tillering as much as possible when the original

TABLE XXI

REACTION OF F_2 POPULATIONS FROM CROSSES BETWEEN RESISTANT VARIETIES TO CHINCH BUG INJURY, MANHATTAN, KS

Entry	Identification	Generation	Resistant (%)	Susceptible (%)	X^2 15:1	P Value
13	Sol Kafir x Wonder Kafir CI 872	F_2	79.1	20.9	93.99	<0.001
14	Sol Kafir x Dwarf Ellis	F_2	81.7	18.3	59.94	<0.001
15	Sol Kafir x B KS5	F_2	71.1	28.9	220.42	<0.001
16	Wonder Kafir CI 872 x Dwarf Ellis	F_2	66.4	33.6	291.97	<0.001
17	Wonder Kafir CI 872 x B KS5	F_2	62.5	37.5	561.01	<0.001
18	B KS5 x Dwarf Ellis	F_2	59.1	40.9	438.60	<0.001

or main stem was severely damaged. However, most the tillers produced poorly developed heads.

Chinch Bug Confinement Test on Selected Sorghums at the Seedling Stage

In the greenhouse, seedlings of all entries were rated for chinch bug injury ten days after infestation, and the average damage was recorded (Table XXII). Double Dwarf Yellow Milo (Ea), Double Dwarf Yellow Sooner Milo and Combine 7078, varieties in the milo group, were killed or severely injured. The level of resistance in the kafir type decreased when compared with those from the field test because chinch bugs had no choice. Combine Kafir-60 was resistant in the field but showed severe damage from chinch bug attack in the greenhouse. The average damage rating of Combine Kafir-60 was in the susceptible category 5.4, and 80% of the plants were killed. Wonder Kafir CI 872 had an average damage rating of 2.2 which was less damage than that of any other entry. Thus, Wonder Kafir CI 872 exhibited the most resistance at the seedling stage in this test. Other kafir varieties and the sorgo B KS5 showed moderate resistance. In this test, resistant varieties of sorghum were apparently heterozygous for resistance to chinch bugs when uniformly infested by the confinement test. However, their general agronomic characters were homozygous in the field. So, further selection for chinch bug resistance within cultivars needs to be done.

J242 which is moderately resistant to greenbug biotype E showed considerable resistance to the chinch bug as well. No plants were killed in the seedling stage by chinch bugs. The A-line of this cultivar was crossed with the resistant kafirs. F_1 plants of four crosses were rated

TABLE XXII

CHINCH BUG CONFINEMENT TEST IN THE GREENHOUSE ON SELECTED SORGHUMS AT SEEDLING STAGE

Entry	Identification	Generation	Average Damage Rating[1]	% Plant Killed
1	Double Dwarf Yellow Milo (Ea)	P	6.0	100
2	Double Dwarf Yellow Sooner Milo	P	5.8	80
3	Combine 7078	P	6.0	100
4	Sol Kafir	P	4.8	60
5	Wonder Kafir CI 872	P	2.2	20
6	Combine Kafir-60	P	5.4	80
7	Dwarf Ellis	P	4.8	60
8	TX623	P	4.6	60
9	B KS5	P	4.2	40
10	J242	P	3.4	-
11	A J242 x Sol Kafir	F_1	3.0	-
12	A J242 x Wonder Kafir CI 872	F_1	3.8	40
13	A J242 x Dwarf Ellis	F_1	3.6	40

TABLE XXII (Continued)

Entry	Identification	Generation	Average Damage Rating[1]	% Plant Killed
14	A J242 x B KS5	F_1	3.4	20
15	Double Dwarf Yellow Sooner Milo x Combine 7078	F_2	5.6	80
16	Double Dwarf Yellow Sooner Milo x Ryer Milo	F_2	5.6	80
	LSD		1.8	

[1]Chinch bug rating: 0 = no damage to 6 = dead plant.

for chinch bug damage. All were fairly resistant and the levels of resistance were not statistically different from each other. Most of them were damaged less than their kafir parents.

The F_2 generation of Double Dwarf Yellow Sooner Milo x Combine 7078 and Double Dwarf Yellow Sooner Milo x Ryer Milo were the crosses of susceptible milo x milo type. Heterosis or hybrid vigor still continued in this generation. However, the average damage rating of both crosses was in the susceptible category 5.6 and the plants were 80% killed. Thus, heterosis or hybrid vigor from susceptible x susceptible milo did not exhibit resistance to the chinch bug in this confinement test. Results indicated that chinch bug resistance in sorghum is controlled by genetic factors which can be transferred from generation to generation.

CHAPTER V

SUMMARY AND CONCLUSIONS

The research was conducted to study varietal resistance and inheritance of resistance in sorghums to the sorghum midge, the greenbug biotype E, and the chinch bug, to investigate the mechanisms of resistance in sorghums to greenbug biotype E, to determine the feasibility of transferring the resistance to three kinds of insect pests to high yielding varieties.

SC0175, SC0423, AF-28 (derivative) and SGIRL-MR-1 were sorghum midge resistant varieties. From the natural sorghum midge infestation, SC0423 and SC0175 exhibited the highest levels of resistance to injury. These resistant varieties were crossed with the susceptible B Wheatland, B OK94, and Caprock. All F_1 plants of susceptible x resistant parents were sus-susceptible to natural sorghum midge infestation. This result indicated that sorghum midge resistance was a recessive trait. The segregations of plants in F_2, F_3, and backcross populations suggested that the resistance to sorghum midge in SC0175, SC0423, AF-28 (derivative), and SGIRL-MR-1 was controlled by recessive genes at more than one locus and the inheritance was not simple. It appears to be difficult to transfer genes for resistance into good agronomic sorghum by simple hybridization. It was apparent that 78% of the selected resistant plants had the small glume character. In breeding programs which are handicapped by a lack of natural sorghum midge infestation, this character may be used as the index to select for resistance in segregating generations.

Three sorghum varieties resistant to the greenbug biotype E, PI220248, PI264453, and J242 were tested for mechanisms of resistance: nonpreference, antibiosis, and tolerance. PI220248 showed the highest degree of antibiosis and high levels of nonpreference and tolerance as well. The resistance in PI264453 was also high in all three components. J242 demonstrated a moderate level of the three components and suffered moderate injury. All three resistant varieties showed significantly higher levels of the three components than the susceptible variety B Wheatland.

PI220248 and PI264453 were tested for inheritance of resistance to greenbug biotype E. Susceptible parents in the study were the sorghums resistant to the sorghum midge: AF-28 (derivative), SC0175 and SGIRL-MR-1. Parental lines, F_1, F_2, and backcross generations were infested with greenbug biotype E at the seedling stage. Individual plants were rated visually when the susceptible parents were killed. PI220248 exhibited a higher level of resistance to biotype E than PI264453 in this study. Populations of F_1 plants in all crosses of susceptible x resistant parents were classified as resistant. This indicated that resistance in sorghum to biotype E was dominant. Results from F_2's and backcrosses suggested that the resistance to biotype E in PI220248 and PI264453 was probably controlled by a single dominant gene pair. There should be little difficulty in developing sorghum varieties resistant to biotype E by using the resistant varieties in this study.

On chinch bug resistance in sorghum, sixty sorghum varieties of various types were initially screened for chinch bug resistance by natural infestation. Milo types were the most susceptible. Sorgo and kafir exhibited higher resistance than any other types. All kafir hybrids were also highly resistant.

Resistant sorghums from the field test were selected to test chinch bug resistance at the seedling stage by confining the chinch bugs to individual plants. Three susceptible milo varieties and the F_2 of milo x milo parents were used in this test. J242 and its F_1 crosses with selected resistant sorghums were also included. Individual plants of each entry were rated after being confined ten days with ten chinch bugs. Wonder Kafir CI 872 exhibited the highest tolerance at the seedling stage. Combine Kafir-60 was susceptible at the seedling stage. All plants of J242 survived the chinch bug attack. Most of the plants of F_1 hybrids from the crosses J242 x resistant kafir were less damaged than their kafir parents. The plants in F_2 populations of milo x milo crosses were susceptible. This indicated hybrid vigor did not confer resistance to chinch bug attack. Only genetic factors which can be transferred from generation to generation control chinch bug resistance in sorghums.

Selected sorghums and hybrids were tested for chinch bug resistance in the field at Manhattan, Kansas. Dwarf Ellis and Wonder Kafir CI 872 exhibited high levels of chinch bug resistance. F_1 and F_2 hybrids between milo types were susceptible. This substantiated the conclusion that heterosis or hybrid vigor of susceptible x susceptible crosses did not produce resistance to chinch bug attack. The results of rating plants in F_1 and F_2 generations between susceptible and resistant varieties suggested that the resistance to chinch bug in sorghum appeared to be dominant. The segregations in F_2 and backcross generations between resistant and susceptible parents could not be interpreted to indicate that a single dominant gene pair controlled resistance to chinch bug in sorghum. Further study in the F_3 generation is needed. The ratings of F_2 populations from resistant x resistant parents showed both resistant and susceptible plants and indicated that the genes for resistance of these varieties were nonallelic. Although the inheritance of resistance to chinch bugs is not completely understood, it is evident that highly resistant plants can be identified in segregating populations. So, there should be no problem in transferring chinch bug resistance to high yielding varieties.

Although resistance to the greenbug and to the chinch bug can be more readily transferred to the progeny of a cross than resistance to sorghum midge, it should be possible to combine resistance to all three insect pests in superior lines through present breeding techniques.

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APPENDIX

TABLE XXIII

CHARACTERISTICS OF SORGHUM PARENTS AND F_1 HYBRIDS USED FOR MIDGE RESISTANCE STUDIES, STILLWATER, OK, 1980

Entry	Identification	Generation	Days to 50% Bloom	Plant Height[1] (cm)	Panicle Exertion[2] (cm)
1	SC0175	P	66.0	69.4	-2.2
2	SGIRL-MR-1	P	75.0	100.2	-5.9
3	SC0423	P	60.0	67.3	-8.5
4	AF-28 (der.)	P	62.5	70.5	+0.6
5	B Wheatland	P	64.5	82.7	+2.6
6	B OK94	P	61.0	91.6	+2.1
7	Caprock	P	63.0	92.5	+5.7
8	B Wheatland x SGIRL-MR-1	F_1	99.0	139.5	+1.7
9	SGIRL-MR-1 x B Wheatland	F_1	93.0	145.7	+0.7
10	B OK94 x SGIRL-MR-1	F_1	99.0	140.3	-1.7
11	Caprock x SGIRL-MR-1	F_1	96.5	159.4	+5.3

TABLE XXIII (Continued)

Entry	Identification	Generation	Days to 50% Bloom	Plant Height[1] (cm)	Panicle Exertion[2] (cm)
12	B Wheatland x SC0175	F_1	63.0	110.6	-0.4
13	B OK94 x SC0175	F_1	62.0	99.4	+1.0
14	Caprock x SC0175	F_1	62.5	108.7	+2.0
15	B Wheatland x AF-28 (der.)	F_1	61.5	83.6	+4.1
16	B OK94 x AF-28 (der.)	F_1	59.0	84.1	+4.0
17	Caprock x AF-28 (der.)	F_1	60.5	91.6	+6.6
18	B OK94 x SC0423	F_1	61.5	130.4	+1.0

[1]Height measured from the base of the plant to the tip of the flag leaf.

[2]Distance measured from the lowest florets to the collar of the flag leaf.

2

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