LABORATORY STUDIES OF LEVELS AND CAUSES OF INSECT RESISTANCE IN VARIETIES OF STORED SORGHUM

by

STEPHAN C. WHITE

B. S., Kansas State University, 1973

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Entomology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1975

Approved by:

Major Professor

TABLE OF CONTENTS

THIS BOOK CONTAINS SEVERAL DOCUMENTS THAT ARE OF POOR QUALITY DUE TO BEING A PHOTOCOPY OF A PHOTO.

THIS IS AS RECEIVED FROM CUSTOMER.

INTRODUCTION

In recent years there has been much emphasis placed on limiting application of chemicals used in controlling pests, especially where human foods might be contaminated. In some cases, legislation has outlawed the use of certain pesticides which had previously been commonly used. The recent concern about chemical pollutants has put grain producers and processors in a difficult position; they must grow and store more crops but they cannot protect them adequately from storage pests without chemicals. Insect pests annually destroy at least 10% of the cereals grown in the world. In an effort to control these losses and still protect human and domestic animal consumers and environmental elements, researchers in recent years have been attempting to control insects through the use of resistant plant varieties. Numerous studies, including some at Kansas State University, to find grains and grain products which are resistant to insect attack have shown that many factors may contribute to insect resistance in grain including hardness, thickness of corneous endosperm, texture, moisture content, and kernel size.

The purpose of this paper is to add to the information about the combination of factors responsible for resistance in sorghum and determine how these components operate to prevent or reduce attack by stored-product insects. The insects studied were the maize weevil, Sitophilus zeamaize Motsch., and the lesser grain borer, Rhyzopertha dominica (F.).

Maize Weevil and Lesser Grain Borer Oviposition

The maize weevil feeds on a variety of cereal grains. The adult female chews a small hole in the kernel, lays an egg inside and seals the hole with a gelatinous material called the eggplug. The larvae feed and complete development within the kernel. Weevil infested grain may appear sound because the infestation is hidden within the kernels until the mature insects chew their way free approximately 35 days later. Since the female weevil places the eggs within the kernels, resistance studies should be directed at reducing ovipositional and feeding preference of the grain to adult insects.

The lesser grain borer also infests cereal grains; however, the eggs are distributed among the grain. The 1st instar larvae chew their way into the kernels and complete development within. As with the maize weevil it takes a little over a month before the new adults emerge. Varieties should be selected which are resistant to first instar larvae and adult feeding.

Review of Literature

Samuel and Chatterji (1953) indicated that factors responsible for resistance in sorghum could include hardness, texture, moisture content, and presence or absence of a husk.

Ayerst (1965) and Davey (1965) in separate studies noted that the more vitreous kernels of sorghum equilibrated at a lower moisture content than kernels with mealy endosperm. Davey observed that more rice weevils died on the more vitreous grain, perhaps as a result of lower moisture content, and more rice weevil progeny emerged from mealy varieties.

Lieu (1950-52) observed that lesser grain borer, rice weevil, and granary weevil would not survive on Double Dwarf White Sooner and Double Dwarf Yellow Sooner at 12% moisture contents. She also noted that rice weevil could not survive on Kansas Sourless sorghum.

Sorghum with yellow endosperm tested by Hunkapillar (1970) was shown to be highly susceptible to lesser grain borers but only intermediate against Angoumois grain moths. He also said, in contrast to some investigators, that kernel size was not a factor in sorghum resistance against these insects.

Sorghum with thick corneous endosperm layers of 17 cultivars tested were shown to be less susceptible to rice weevil infestation by Doggett (1957).

Susceptibility to maize weevil of various particle sizes of Atlas sorghum was studied by Morrison (1964). He determined that coarse, ground sorghum was more resistant than either finely-ground or sound kernels. There is some question here because he made adult progeny counts only 35 days after oviposition which is probably too soon.

Rogers and Mills (1974) said that Double Dward Early Shallu had an antibiotic effect on maize weevils at 43% RH but not at higher RH.

The role of the pericarp of sorghum in resistance was studied by Rout (1973). He removed the pericarp after soaking the sorghum in water. Removal of the pericarp did not appear to alter resistance or susceptibility of sorghum to Angoumois grain moths. Resistance was destroyed, however, when he drilled small holes through the pericarp into the kernels. This permitted access to the kernels by the 1st instar larvae.

In resistance studies with rice weevil, Russell (1962) found lower ovipositional preference in harder kernels. Hardness was evaluated using a pearling machine. He also said that rice weevils preferred larger seeds for oviposition, and fewer eggs were laid when the RH dropped below 83%. In tests on 4 varieties of sorghum, ovipositional preferences of maize weevil corresponded with rice weevil experiments.

Hardness of kernels was shown to be an important factor in resistance by Dobie (1974). Kernel hardness was shown to correlate highly with the presence of amylose; however the amylose may not be the cause of the hardness. He suggested that susceptibility of sorghum varieties may be a result of factors operating after oviposition.

Dang (1965) tested susceptibility of sorghum flour to flour beetles. He said that chemical factors might be influencing the survival of the insects.

Lange (1973) tested susceptibility of sorghums to maize weevils in 50-gram bulk and 50-kernel tests and found relative resistance of cultivars as determined by small samples to be consistent with that determined by 50-g samples.

Stevens and Mills (1973) compared 100-kernel samples of sorghum in free-choice and no-choice tests and found a high correlation (.85) between results.

Host Resistance in Other Stored Grains

Eden (1952) found a high negative correlation between corn hardness and rice weevil (RW) damage, but no correlation between pericarp thickness and amount of damage. Corn varieties with harder kernels were

shown by Singh and McCain (1963) to produce fewer RW progeny than those with soft kernels. The progeny completing development on harder kernels were also smaller than those reared on soft varieties.

In a study of corn resistance to lesser grain borer (LGB), Hopkins (1970) found that drilling holes into corn kernels did not increase the susceptibility of the grain. He suggested that LGB resistance in corn was related to the proportion of hard endosperm within the seeds.

Dobie (1974), in studies with maize weevil (MW), found uniform oviposition among different varieties of corn which indicated that MW resistance factors operated after oviposition.

Kempton (1917) suggested that certain Bolivian corns evolved with a mottled color pattern because Angoumois grain moths (AGM) laid fewer eggs on those varieties (which resemble seeds already infested with AGM larvae). Eickmeier (1965) showed a high correlation between AGM resistance and high amylose content of corn. High amylose content was also positively correlated with hardness. In another study, Rhine and Staples (1968) found that LGB was unaffected by high amylose content but rice weevil survival was lower on the same varieties. Fewer granary weevil progeny emerged on 70% amylose corn and those insects were smaller than those produced on 60% amylose corn which did not appear to affect the weevils.

Lesser grain borer and rice weevil progeny produced on different wheats were correlated with Pelshenke values (hardness) of the individual varieties by Bhatia and Gupta (1969). Low Pelshenke values correlated with high susceptibility of the wheat to rice weevil,

however, there was no correlation between the Pelshenke value and susceptibility to LGB.

Ewer (1945) showed that granary weevils lay more eggs on larger kernels of wheat.

Wheat grown in areas of low nitrogen levels were shown to produce seed more susceptible to rice weevil infestation by Chakraborty and Mathew (1972).

In nutrition tests with various foods, Kapoor (1964) found that broken wheat and unhusked paddy were the most nutritious foods for LGB while polished rice and oilseeds failed to support the growth of this insect.

Andrewartha (1972) found that a few LGB on sound wheat did not survive; however populations did develop when a larger number was introduced. Apparently, feeding by adults damaged the grain sufficiently to allow first instar larvae to feed on flour then infest the kernels.

Sinha (1969) found that neither LGB nor granary weevil could multiply on unbroken hulled oats but were able to increase on hulless varieties.

In tests with 7 varieties of broad beans, Podoler and Applebaum (1968) found a positive correlation between increasing thickness of the seedcoat and decreasing percent of larval pulse beetle penetration. Rao and Majumder (1964) in tests with the pulse beetle, found increased infestation levels in stored beans where the beans were larger (due to larger inter-granular spaces).

Soybean saponin and its calcium salts were shown to be highly toxic to rice weevil by Su et al. (1972).

GENERAL MATERIALS AND METHODS

Insects used in tests were cultured in the rearing room (80°F, 67±3% RH) of the Kansas State University Stored-Product Insects Laboratory. The Arkansas strain of the maize weevil (MW) and the lesser grain borer (LGB) were used primarily; however, the rice weevil, Sitophilus oryzae (L.), was also used in one preliminary test. Weekly cultures were set up in quart jars, each containing approx. 1 pint of medium (either wheat or sorghum). All test materials, usually in small samples, were left in the rearing room at least 14 days to allow the grain to reach moisture equilibration.

Since large numbers of insects and samples were to be tested, a means was needed for reducing the time involved in counting kernels, insects, and progeny for each replication involved. The free-choice testing method (McCain et al. 1964) appeared to be desirable for evaluating resistance since there would be no need for the time consuming task of determination of sex of each insect. Also, when introducing a small number of sexed insects in each replication of a no-choice test there was a greater chance for errors due to the introduction of non-fertile females, or too few or too many females, due to mistakes in sexing. Introduction of a large number of insects into a free-choice chamber increases the odds in favor of a 1:1 sex ratio, and also each replication has the same opportunity to be selected for oviposition. A free-choice test was conducted to determine if progeny distribution

would be equal (resulting from equal distribution of female parents introduced) from samples of a single variety of sorghum.

All plantings of sorghum material for these studies were done by Professor Harold Hackerott of the Hays, Kansas Agricultural Experiment Station.

The term "cultivar," as used in this study, will designate a row of plants or a single sorghum plant. Genetic information about certain of these plants was not considered complete enough to accurately use the terms "variety" or "strain."

PRELIMINARY TESTS WITH MAIZE WEEVIL AND RICE WEEVIL

Free-choice Testing

The free-choice test allows the insects to select a sample of sorghum in which to oviposit. A number of samples of sorghum (usually different cultivars) are placed in a test chamber and the chosen number of randomly-selected insects introduced. After a short ovipositional period (usually 5 days) the adult insects are removed by aspiration, the individual samples covered with screened lids, and held in the rearing room for progeny development. Numbers of emerged progeny indicated the relative resistance of each sorghum cultivar.

Materials and Methods

In an initial test to determine the distribution of insects in a free-choice test on one sorghum cultivar, a quarter-inch plywood rectangular box, 54.5 x 27.5 x 11 cm, was used as a test chamber. Two 2.5-cm-diameter holes were drilled in each end and covered with

plastic screen to allow air circulation. Inside the test chamber, 20 lids of plastic boxes, 4.8 x 4.8 x 0.7 cm, were placed around the perimeter, filled with 100 kernels of culture sorghum (variety unknown). Only one variety was used to determine if the insects distributed themselves randomly in this type of test. The arrangement of replications within the chamber was oval and insects were released at 2 points within the oval so that sorghum samples were more nearly equidistant from a release point. Two hundred rice weevils (RW) were released at each end. They had been temporarily stunned with CO_2 to allow time to tape on a plywood lid. After 5 days the lid to the chamber was removed under red light. Each sample was covered by placing a plastic box (4.8 x 4.8 x 1.8 cm) on the matching lid containing the kernels. Adults from each sample were counted and removed. Weekly adult progeny counts were made as they emerged. A Chi-square test was used on both adult and progeny distributions.

Results

The Chi-square statistics for adult and progeny distribution (Table 1) were 24.91 and 9.98, respectively. At the .05 level, distribution of adult insects among the 20 samples in the test chamber after 5 days was found to be non-uniform, but progeny distribution was uniform. McCain et al. (1964) found distribution of both adult and progeny correlated among different samples of corn tested in this manner. Most subsequent resistance tests were done in circular test chambers (Plate 1) rather than rectangular, with insects released at the center, thus all samples were equidistant from the release point.

Table 1. Distribution of ovipositing rice weevils given free-choice among 20 samples of a sorghum variety, and the numbers of progeny produced. (200 insects; 5-day ovipos. period)

Sample replication	Parent adults*	Progeny
1	13	70
2	16	63
3	23	64
4	16	59
5	15	64
6	21	69
7	20	63
8	18	68
9	18	56
10	13	56
11	9	63
12	9	59
13	10	69
14	11	60
15	20	56
16	13	52
17	21	69
18	13	52
19	9	67
20	13	65
Chi square	24.91	9.98

* Sex was not determined.

EXPLANATION OF PLATE 1

Fig. 1. Free-choice test chamber used for maize weevil and lesser grain borer screening of sorghum cultivars. Representative samples are shown below the chamber.

Fig. 2. Free-choice chamber with lid taped in position prior to insect infestation.

Plate 1

Figure 1

Figure 2

It was assumed that progeny distribution would have been equal to or possibly better than that in the rectangular boxes, if a similar test were done.

Comparison of Weekly Progeny Counts and Radiographic Evaluation

Weekly progeny counts were so time consuming that X-ray radiographs were tested for determining numbers of insect progeny in each sample. This test was to determine if a single progeny count using a radiograph would serve as an accurate substitute for weekly counts.

Materials and Methods

Five sorghum cultivars, 2 resistant, 2 susceptible, and 1 intermediate, were selected for comparison. Each of nine 100-kernel samples of each cultivar were placed in each 21 x 21 x 18 mm plastic box. The samples were equilibrated in the rearing room then placed in a single circular test chamber. Two hundred seventy maize weevils were introduced into the test chamber for a 5-day ovipositional period. The insects were removed and the sample boxes covered with plastic lids containing screens. The 9 samples of each cultivar were then divided into groups of 3. One group was frozen at the appearance of the first adult progeny and then radiographed when convenient. The emerged progeny of the 2nd group were counted and removed weekly, and progeny of the third group were radiographed at the end of the progeny emergence period.

Results

The results are shown in Table 2. Analysis of variance (.05 level) indicated no difference between weekly progeny counts and radiographic counts at the beginning of the emergence period. Radiographic counts at the end of the emergence period did not differ significantly from other counts, but only adults were counted, because second generation larvae were developing inside kernels. Radiograph counts were much more rapid and as accurate as weekly counts. An additional benefit of radiograph counts was that samples could be left frozen indefinitely and radiographed at a convenient time. The radiographic technique may also be satisfactory for some of the external feeding insects.

Table 2. Average number of maize weevil progeny as determined by 3 methods of counting. Three reps of each of 5 cultivars/counting method. (270 MW/45 samples/test chamber; 5-day ovipos. period)

Cultivar	Radiograph count ca. 30 days after beginning of ovipos.	Weekly counts	Radiograph count ca. 60 days after beginning of ovipos.
96-34-5 R*	7.7	5.3	5.0
96-40-2 R	6.3	9.0	5.7
60-154-3 I*	8.3	12.6	7.3
96-13-3 S*	18.0	17.6	17.0
60-152-3 S	26.0	28.0	23.0
.05 LSD	2.8	3.7	5.7

* R = resistant, I = intermediate, S = susceptible.

Analysis of Variance

Source of variance	d.f.	s.s.	m.s.	F
Between methods	2	64.93	32.46	0.50
Within methods	42	2726.26	64.91	
Totals	44	2791.20		

RESISTANCE TESTS USING MAIZE WEEVIL AND LESSER GRAIN BORER

Evaluation of Resistance of Sorghum Cultivars to the Maize Weevil

Materials and Methods

Twenty-four cultivars of sorghum were evaluated for resistance to maize weevils in a free-choice test. Twenty samples of cultivars previously tested by Rogers (1970) and then increased in 1970, and 2 samples of Double Dwarf Early Shallu seed were increased in 1972 at the Kansas Agricultural Experiment Station, Hays. Samples of our culture sorghum (variety unknown) and another Double Dwarf Early Shallu (DDES-ck) were included as checks. Three replications of each cultivar were tested except for 1 replication of culture sorghum and DDES-ck. Replications consisted of 100-kernel samples in 4.8 x 4.8 x 0.7-cm plastic boxes. Seventeen samples were placed in each of 4 circular test chambers. After samples were equilibrated in the rearing room, 170 MW (10/sample) were introduced into each chamber for a 5-day ovipositional period. Adult insects were then removed and the samples were covered with screened lids. Emerged progeny were counted and removed from samples 3 times a week.

Results

MP-10 Shallu and the Double Dwarf Shallus appeared to be the most resistant of the cultivars tested (Table 3). In most cases, results were analogous to studies by Lange (1973) with MW and Rout (1973) who

Table 3. Mean number of maize weevil progeny produced in 24 cultivars (170 MW/17 samples/test chamber; 5-day free-choice oviposition period, 3 replications, 100 kernel samples).

Cultivar (1972 Hays row No.)	Abbreviated pedigree	Mean progeny/rep[1]
72-20028	MP-10 Shallu	8*
72-20025	DDES	11**
72-20053	DDES	11**
72-20043	CM795 Kangarchari	12***
72-20054	DDES	13***
72-20036	CM65 Bajri Duhrar, Bauhara	13***
72-20040	CM172 Dwarf Shallu	14***
72-20035	CM38 Muttin Guti Jola	15***
72-20041	CM180	15***
72-20022	CM173 Dwarf Shallu	16****
72-20033	CM15 Disease resistant	17*****
72-20034	CM29 Silka Junnalo	17*****
72-20039	CM2123 Beid/el-Kebish	18*****
72-20037	CM95 Konda Jonna	19*****
72-20045	CM1225 DD schrock	23 *****
72-20019	CM1285 6327 Nebraska	24 *****
72-20042	CM280 DDET 6660	25 ****
72-20044	CM1115 Bodadille	29 ***
72-20038	CM111 Somba cholam	30 **
72-20047	CM2520 6358 Nebraska	33 *
72-20016	CM1726 Idutubia	47
72-20048	CM2791 Mungari Jola	67

[1] LSD .05 = 13.96 Means connected with vertical columns of * did not differ significantly.

Checks	Mean progeny/rep
DDES-ck	11
Culture sorghum	38

Analysis of Variance

Source of variance	d.f.	s.s.	m.s.	F
Between cultivars	21	11360.86	540.99	7.55 significant at .05 level
Within cultivars	44	3152.66	71.65	
	65	14513.53		

used Angoumois grain moths. Exceptions include 72-20035 (CM 38) which was intermediate in this test but was 25th for resistance of 26 cultivars Lange tested. Cultivar 72-20019 (CM 1285) was the 3rd most resistant of the cultivars Lange studied but was 16th in this test. Cultivar 72-20047 (CM 2520) was among the 3 most susceptible of the 24 cultivars tested but was 1st in resistance against AGM in Rout's experiments and 4th in Lange's tests with maize weevil.

Evaluation of Resistance of Sorghum Cultivars to the Lesser Grain Borer

Circular test chambers were used in a free-choice test to determine relative resistance among 12 sorghum cultivars to LGB. Sorghum samples were produced from seeds surviving LGB, MW, Indian meal moth, or red flour beetle pressure (seeds exposed to insects, surviving sound kernels planted for increase) on original random-mated material grown in 1970. The seed (samples from 2 lots, 1 population, labeled HKSP1BR(M)C_2 alal and HKSP1BR(M) Al-) represent the second cycle of a random-mated population. The alal series seed was harvested from male-sterile plants and the Al- series from male-fertile plants. Both the fertile and male-sterile plants carry greenbug resistance. The history of individual samples is given following Table 4.

Materials and Methods

Ninety-nine heads from the 12 cultivars were selected for testing. Three replicate samples of each head consisting of 100 kernels each were evaluated along with 2 replicates each of Culture Sorghum and

Double Dwarf Early Shallu (ck) and 1 replicate of MP-10 Shallu (ck). Twenty samples each in a 48 x 48 x 7 mm box were placed in each of 5 test chambers. After samples were equilibrated in the rearing room, 200 LGB were introduced into each chamber for a 10-day ovipositional period then removed. Samples were covered with screened lids. Progeny counts were made 3 times a week.

Results

The 2 cultivars previously determined to be susceptible in MS-RM tests, 72-20013 and 72-20006, ranked lowest in resistance to LGB in this test (Table 4). The average progeny produced per replicate for these 2 susceptible cultivars was 40.9 insects while the 10 remaining cultivars (resistant) averaged 11.9 insects per replicate. Culture sorghum, the susceptible check, did not appear susceptible in this test (average 4.0 insects/rep). DDES produced an average of 11.5 LGB progeny in 2 reps and on one rep of MP-10 Shallu no insects developed. Some samples were selected for further increase in 1973 for additional testing against MW and LGB.

Table 4. Range and mean lesser grain borer progeny/rep produced on individual heads of 12 sorghum cultivars (20 samples/chamber 10 LGB/sample; 3 reps; 10-day free-choice oviposition).

Cultivar**	Head number	Range	Mean progeny/rep
72-20010	5	0-2	1.0
	7	0-5	2.3
	8	2-5	3.0
	10	0-12	4.0
	2	0-9	5.3*
	3	0-10	5.3
	11	0-10	6.0*
	9	4-10	6.3
	6	0-18	7.3
	1	5-13	7.7
	4	2-18	10.0
	all heads	0-18	5.3
72-20015	6	0-0	0.0
	4	0-1	0.3*
	3	0-3	1.0
	9	0-7	3.7
	8	0-10	4.0
	5	0-13	4.3
	1	0-19	8.7
	7	1-20	12.3
	2	5-24	14.7
	all heads	0-24	5.5
72-20014	1	0-2	1.0
	5	0-10	4.0
	2	2-8	4.0
	8	0-7	4.3
	4	0-16	7.0
	6	0-28	10.0
	7	2-15	10.3
	9	0-24	12.7
	10	5-26	15.0
	3	1-27	18.0
	all heads	0-28	8.7
72-20008	5	0-2	0.7*
	3	1-4	3.0
	1	0-6	3.7*
	4	0-12	4.0*
	11	0-9	4.3
	6	0-13	5.0
	8	0-23	9.0*

Table 4 (cont'd).

Cultivar	Head number	Range	Mean progeny/rep
72-20008	10	0-18	9.7
	14	0-29	9.7*
	9	4-15	10.0
	15	0-31	10.7
	7	5-26	13.7
	12	0-33	15.3
	2	13-20	15.7
	13	0-29	18.7
	all heads	0-33	8.9
72-20004	2	1-10	4.6
	3	0-11	5.3
	1	1-24	10.0
	5	0-27	13.6
	4	10-21	14.7
	6	9-23	16.0
	all heads	0-27	10.7
72-20011	9	0-18	8.0
	4	0-25	8.3
	10	0-22	12.0
	7	0-24	12.3
	1	8-19	13.0
	8	1-23	13.3
	2	9-26	14.7
	3	11-30	17.7
	5	9-24	18.0
	6	0-39	18.7
	all heads	0-39	13.6
72-20007	5	0-5	2.0
	10	2-9	6.3
	9	2-23	9.3
	2	0-20	11.3
	3	9-16	13.3
	4	2-25	16.7
	1	13-26	18.7
	6	18-21	20.0
	8	9-28	21.6
	7	13-36	24.0
	all heads	0-36	14.3

Table 4 (cont'd).

Cultivar	Head number	Range	Mean progeny/rep
72-20005	5	0-12	7.3
	1	0-24	9.7
	7	0-37	13.3
	6	5-20	13.6
	8	11-29	18.7
	4	6-36	23.4
	2	13-62	37.6 (2 reps)
	3	31-47	39.0 (2 reps)
	all heads	0-47	20.3
72-20012	5	2-24	13.7
	4	1-21	14.0
	3	29-38	34.7
	1	-	47.0 (1 rep)
	2	-	59.0 (1 rep)
	all heads	1-59	33.7
72-20013	7	3-38	16.7
	6	1-70	27.0
	4	12-42	31.0
	5	13-49	35.0
	1	18-51	35.3
	8	33-48	38.7
	9	-	40.0 (1 rep)
	2	-	44.0 (1 rep)
	3	-	59.0 (1 rep)
	all heads	1-70	36.3
72-20006	2	28-56	39.6
	6	30-50	40.0
	5	32-57	47.0
	3	-	51.0 (1 rep)
	1	-	53.0 (1 rep)
	4	-	57.0 (1 rep)
	all heads	28-57	47.9
Checks			
Culture sorghum	-	0-8	4.0 (2 reps)
DDES	-	0-23	11.5 (2 reps)
MP-10 (ck)	-	0	0.0 (1 rep)

* Seed sent to Kansas Agricultural Experiment Station, Hays, for increase in 1973.

** See footnote on following page for cultivar description.

Table 4 (cont'd footnotes)

** Description and History of Cultivars

HKSP1BR(M)C_2 a1a1

(1970 random-mated, male sterile plants)

1972 row number

72-20001 Plants grown from 1970 seed (mixture of several heads) which had been "pressured" (infested to destroy the more susceptible seed) by Indian meal moth and then maize weevil. IMM survival was low so the MW were added to destroy more of the susceptible seeds.

72-20004 to 72-20010 1970 seed was pressured with LGB and the surviving seed increased in 1971 (1971 row number 15,005); 33 plants grew from the surviving seeds. Heads from these plants (labeled MS-1 to MS-33) were screened for resistance against LGB. From the screening test some seed was selected for increase in 1972:

1971 head number	1972 row number (several heads each)
MS-2-R***	72-20004
MS-3-R	72-20005
MS-6-S***	72-20006
MS-7-R	72-20007
MS-8-R	72-20008
MS-10-R	72-20010

72-20052 Plants grown from 1970 seed (representing several heads) surviving red flour beetle pressure.

HKSP1BR(M) A1-

(1970 random-mated seed, male-fertile plants)

1972 row number

72-20003 Plants grown from the 1970 random-mated seed (mixture of many heads) which had survived pressure by IMM and MW. IMM survival was low so the moths were replaced with MW.

72-20011 to 72-20015 Plants grown from 1970 seed that survived pressure of LGB and was increased in 1971 (1971 row number 15,009); 52 plants grew from the pressured material. Heads from these plants (labeled RM-1 to RM-52) were evaluated in a screening test for resistance against LGB. Seed from both susceptible and resistant heads was increased in 1972:

Table 4 (concluded footnotes)

72-20011 to
72-20015 (cont'd)

1971 head number	1972 row number (several heads each)
RM-4-R	72-20011
RM-7-R	72-20012
RM-12-S	72-20013
RM-14-R	72-20014
RM-15-R	72-20015

72-20051 Plants grown from a mixture of 1970 random-mated seed from several heads. The seed was pressured with ref flour beetles and surviving kernels increased in 1972.

*** R = resistant, S = susceptible; from RM-MS tests.

Relative Resistance of Selected Cultivars to Maize Weevil

Materials and Methods

One hundred twenty sorghum samples (described in Table 6) representing individual heads of 26 cultivars were evaluated for MW resistance using the free-choice method. The cultivars were grown in 1973 at Hays Kansas Agricultural Experiment Station from material previously screened for resistance against MW and LGB. Four 50-kernel replicate samples of each cultivar head in 21 x 21 x 7 mm boxes were tested in the circular chambers, 48 samples/chamber. After sample equilibration, 288 (6/sample) randomly-selected MW were placed in each chamber for a 5-day ovipositional period. At the end of 5 days adults were removed and the samples covered with screened lids. At emergence of first progeny, all samples were frozen, then radiographed. Progeny counts were made from radiographs.

Results

The 31 most resistant samples of the 120 tested (Table 5), with one exception, were Double Dwarf Early Shallus or MP-10 Shallu. The cultivar 96-33-1 was from 1971-grown material which had been pressured by rice weevils. Cultivar 60-152 (CM 1726) was the most susceptible of all cultivars tested. This cultivar was rated the most susceptible of 27 sorghums evaluated for resistance against Angoumois grain moth by Rout (1973), 490th of 497 cultivars screened for maize weevil resistance by Rogers (1970) and 24th of 26 sorghums tested by Lange (1973) against MW. Cultivar 60-154 (CM 2520) was rated most resistant to AGM by Rout but was not resistant to MW as shown in this paper. It was relatively resistant among the cultivars evaluated by Rogers against MW.

Table 5. Maize weevil progeny produced in a free-choice test comparing resistance of 26 cultivars, 120 heads (50 kernels/rep, 48 reps/chamber, 6 MW/rep, 4 reps, 5-day oviposition).

1973 cultivar* and Head No.	Mean MW progeny/rep	1973 cultivar and Head No.	Mean MW progeny/rep
1. 96-41-4[a]	7.75	23. 96-39-21[b]	12.75
2. 96-40-6[a]	9.25	24. 96-39-10[b]	13.00
3. 96-40-2[a]	9.75	25. 96-39-12[b]	13.25
4. 96-34-5[a]	9.75	26. 96-39-1[b]	13.75
5. 96-34-3[a]	10.25	27. 96-39-8[b]	14.00
6. 96-34-2[a]	10.50	28. 96-39-ck[b]	14.00
7. 96-39-7[b]	10.75	29. 96-41-7[a]	14.25
8. 96-39-16[b]	11.00	30. 96-39-2[b]	14.25
9. 96-39-15[b]	11.25	31. 96-39-11[b]	14.25
10. 96-40-10[a]	11.25	32. 60-155-3	14.25
11. 96-41-8[a]	11.25	33. 96-24-2	14.25
12. 96-40-4[a]	11.50	34. 96-39-14[b]	14.50
13. 96-41-1[a]	12.00	35. 96-37-1[b]	14.50
14. 96-39-4[b]	12.00	36. 96-34-6[a]	14.50
15. 96-39-19[b]	12.00	37. 96-41-2[a]	14.50
16. 96-34-4[a]	12.00	38. 96-1-1	14.50
17. 96-41-10[a]	12.25	39. 96-36-1	14.75
18. 96-40-9[a]	12.25	40. 96-24-1	14.75
19. 96-39-9[b]	12.50	41. 96-1-3	15.00
20. 96-37-5[b]	12.50	42. 60-151-2	15.25
21. 96-33-1	12.50	43. 96-40-1[a]	15.50
22. 96-41-3[a]	12.75	44. 96-40-3[a]	15.50

Table 5 (cont'd)

1973 cultivar and Head No.	Mean MW progeny/rep	1973 cultivar and Head No.	Mean MW progeny/rep
45. 96-39-18[b]	15.50	68. 96-31-1	17.75
46. 96-28-4	15.50	69. 96-13-4	18.25
47. 96-3-2	15.50	70. 96-5-2	18.50
48. 96-1-2	15.50	71. 60-156-3	19.00
49. 96-40-5[a]	15.75	72. 60-156-1	19.25
50. 96-39-20[b]	15.75	73. 60-155-1	19.25
51. 96-41-9[a]	16.00	74. 96-13-1	19.33
52. 96-40-7[a]	16.00	75. 96-36-3	19.50
53. 96-39-3[b]	16.00	76. 96-5-1	19.50
54. 96-39-17[b]	16.00	77. 60-154-1	19.50
55. 96-37-3[b]	16.00	78. 96-28-1	20.00
56. 96-37-4[b]	16.00	79. 96-41-5[a]	20.25
57. 96-34-1[a]	16.00	80. 96-31-2	20.25
58. 96-1-4	16.00	81. 60-156-4	20.50
59. 60-155-4	16.00	82. 96-39-6[b]	21.00
60. 96-39-13[b]	16.25	83. 96-23-1	21.25
61. 60-155-2	16.50	84. 96-23-2	21.50
62. 60-154-3	16.50	85. 61-56-1	21.75
63. 96-37-2[b]	16.75	86. 96-36-2	22.00
64. 96-5-4	17.00	87. 96-15-4	22.00
65. 96-40-8[a]	17.25	88. 96-9-3	22.50
66. 96-39-5[b]	17.25	89. 96-5-3	22.50
67. 96-41-6[a]	17.75	90. 96-13-2	22.67

Table 5 (concluded).

1973 cultivar and Head No.	Mean MW progeny/rep	1973 cultivar and Head No.	Mean MW progeny/rep
91. 96-28-3	22.75	106. 96-38-2	25.25
92. 96-31-4	22.75	107. 60-151-1	25.50
93. 60-156-2	23.00	108. 96-31-3	25.75
94. 96-38-1	23.25	109. 96-9-4	25.75
95. 96-38-3	23.25	110. 96-31-1	26.25
96. 96-15-1	23.25	111. 96-15-3	26.25
97. 96-3-3	24.00	112. 96-9-1	27.00
98. 96-36-4	24.50	113. 96-28-2	27.50
99. 96-9-2	24.50	114. 60-153-1	27.50
100. 60-154-2	24.50	115. 60-153-2	27.50
101. 60-154-4	24.75	116. 60-153-4	27.75
102. 96-15-2	24.75	117. 96-13-3	29.50
103. 60-151-3	25.00	118. 60-152-1	31.25
104. 60-151-4	25.00	119. 60-152-3	32.25
105. 60-153-3	25.00	120. 60-152-2	35.00

[a] Double Dwarf Early Shallu.

[b] MP-10 Shallu.

* See Table 6.

Table 6. 1972 and 1973 Hays Kansas Agricultural Experiment Station row and head numbers and cultivar origins for sorghums used in maize weevil and lesser grain borer experiments.

1973 row no.	1972 row no.	Head no.	Cultivar origin
96-1 96-2	72-20004	2	MS-2-R
96-3 96-4	72-20008	1	MS-8-R
96-5 96-6	72-20008	4	MS-8-R
96-7 96-8	72-20008	5	MS-8-R
96-9 96-10	72-20008	8	MS-8-R
96-11 96-12	72-20008	14	MS-8-R
96-13 96-14	72-20010	2	MS-10-R
96-15 96-16	72-20010	11	MS-10-R
96-17 96-18	72-20015	4	RM-15-R
96-19	-	-	AGM-Rog*
96-20 96-21	-	-	GW-Rog*
96-22 96-23	-	-	RW-Rog*
96-24 96-25	-	-	LGB-Rog*
96-26	-	-	MW-Rog*
96-27	-	-	MS-71 (1971 seed of remaining heads mixed, RW pressured)

Table 6 (concluded).

1973 row no.	1972 row no.	Head no.	Cultivar origin
96-28 96-29	-	-	MS-71, LGB pressured
96-30	-	-	RM-71, RW pressured
96-31 96-32	-	-	LGB pressured, RM-71
96-33	-	-	RW sel. RM
96-34 96-35	-	-	DDES MW-sel
96-36	-	-	CK A x MP-10 f_1
96-37	-	-	MP-10 x
96-38	-	-	CK B x
96-39	72-20028	-	MP-10
96-40	72-20053	-	DDES
96-41	72-20054	-	DDES
60-151	-	-	CI 1115
60-152	-	-	CI 1726
60-153	-	-*	CI 2116
60-154	-	-	CI 2520
60-155	-	-	CI 2791
60-156	-	-	CK 60
61-56	-	-	Unknown

* Rogers remnant seed pressured by stored grain insects.

Relative Resistance of Selected Cultivars to Lesser Grain Borer

Materials and Methods

Samples from the same 120 heads of the 26 cultivars tested in the preceding test using MW were tested using the lesser grain borer (LGB). The same methods were used.

Results

Results (Table 7) were similar to those in the MW test. DDES and MP-10 Shallu again ranked among the most resistant. Many cultivars which had previously been pressured by LGB (96-24, 96-13 and 60-154) were also among the more resistant cultivars. Apparently, some LGB resistance had been selected in the cultivars by pressuring.

Table 7. Lesser grain borer progeny produced in a free-choice test comparing resistance of 26 cultivars, 120 heads (50 kernels/rep, 48 reps/chamber, 6 LGB/rep. 5-day oviposition).

1973 cultivar and Head No.	Mean LGB progeny/rep	1973 cultivar and Head No.	Mean LGB progeny/rep
1. 96-24-1	3.25	11. 96-39-21[b]	7.50
2. 96-39-9[b]	4.00	12. 96-39-15[b]	7.50
3. 96-39-3[b]	5.00	13. 96-1-4	7.50
4. 96-39-5[b]	5.50	14. 96-39-8[b]	7.75
5. 96-39-13[b]	6.00	15. 96-39-18[b]	8.00
6. 96-34-1[a]	6.75	16. 96-13-4	9.00
7. 96-39-4[b]	7.00	17. 96-36-3	9.50
8. 96-39-10[b]	7.00	18. 60-154-1	9.50
9. 96-39-16[b]	7.25	19. 96-34-3[a]	9.50
10. 96-39-2[b]	7.25	20. 96-39-11[b]	9.75

Table 7 (cont'd).

1973 cultivar and Head No.	Mean LGB progeny/rep	1973 cultivar and Head No.	Mean LGB progeny/rep
21. 96-39-12[b]	10.25	53. 96-1-3	16.50
22. 96-41-10[a]	10.25	54. 96-41-4[a]	16.75
23. 96-39-7[b]	10.25	55. 60-155-4	16.75
24. 96-39-1[b]	10.50	56. 96-34-2[a]	16.75
25. 60-155-1	10.75	57. 60-151-1	16.75
26. 96-24-2	10.75	58. 96-36-2	17.00
27. 96-9-4	11.25	59. 60-156-3	17.25
28. 96-41-1[a]	11.75	60. 60-153-3	17.25
29. 96-39-ck[b]	12.00	61. 96-31-4	17.75
30. 96-41-5[a]	12.00	62. 60-153-4	17.75
31. 96-28-3	12.25	63. 96-40-10[a]	17.75
32. 96-34-4[a]	12.25	64. 96-31-1	18.50
33. 96-34-5[a]	12.75	65. 96-9-2	18.50
34. 60-153-2	13.25	66. 96-40-2[a]	18.75
35. 60-155-2	13.75	67. 96-40-7[a]	18.75
36. 96-34-6[a]	14.00	68. 96-39-20[b]	19.00
37. 96-9-1	14.25	69. 60-156-4	19.00
38. 96-39-17[b]	14.25	70. 96-3-3	19.50
39. 60-155-3	14.50	71. 96-37-4[b]	19.50
40. 96-3-2	14.50	72. 96-13-3	19.50
41. 96-1-2	14.50	73. 96-23-2	19.75
42. 60-154-2	14.75	74. 96-15-1	20.00
43. 96-40-5[a]	14.75	75. 96-41-9[a]	20.00
44. 96-39-14[b]	15.00	76. 96-41-2[a]	20.00
45. 96-15-3	15.00	77. 96-5-2	20.50
46. 96-5-1	15.50	78. 96-39-6[b]	20.75
47. 96-40-4[a]	15.75	79. 96-3-1	20.75
48. 96-28-4	16.00	80. 96-40-3[a]	21.00
49. 96-37-1[b]	16.00	81. 96-13-1	21.00
50. 96-41-3[a]	16.00	82. 96-37-3[b]	21.00
51. 60-156-1	16.00	83. 96-1-1	21.25
52. 96-40-6[a]	16.50	84. 60-154-4	21.25

Table 7 (concluded).

1973 cultivar and Head No.		Mean LGB progeny/rep	1973 cultivar and Head No.		Mean LGB progeny/rep
85.	60-154-3	21.25	103.	96-23-1	24.00
86.	96-9-3	21.50	104.	60-151-4	24.25
87.	96-15-2	21.75	105.	96-28-2	24.75
88.	96-40-9[a]	21.75	106.	96-33-1	24.75
89.	96-15-4	22.00	107.	96-38-1	25.75
90.	96-37-2[b]	22.25	108.	60-156-2	25.75
91.	96-36-1	22.25	109.	96-38-1	25.75
92.	96-40-8[a]	22.50	110.	96-5-4	26.00
93.	96-13-2	22.50	111.	96-41-6	26.75
94.	96-38-3	23.00	112.	60-152-3	27.25
95.	96-31-3	23.25	113.	96-28-1	28.50
96.	96-41-8[a]	23.25	114.	61-56-1	30.00
97.	96-40-1[a]	23.25	115.	96-31-2	30.25
98.	96-37-5[b]	23.50	116.	60-151-2	32.25
99.	96-5-3	23.50	117.	60-152-2	34.25
100.	96-39-19[b]	23.75	118.	96-38-2	34.75
101.	60-153-1	24.00	119.	60-152-1	34.75
102.	96-36-4	24.00	120.	60-151-3	40.50

[a] Double Dwarf Early Shallu.

[b] MP-10 Shallu.

* See Table 5.

Maize Weevil Resistance in Combine Kafir 60 x Double Dwarf Early Shallu

A cross between Combine Kafir 60 and Double Dwarf Early Shallu (from Rogers 1970) was made to study the inheritance of resistance to stored grain insects. In previous laboratory studies, DDES has been shown to be highly resistant to stored-grain insects, while Combine Kafir 60 (CK-60) has shown moderate to low resistance. The seed tested from this cross was from F_2 plants (F_3 embryos).

Materials and Methods

Ninety-six heads of CK-60 x DDES F_2 plants grown at the Hays Kansas Agricultural Experiment Station in 1971 in rows labeled 71-11001 to 71-11096 were evaluated in 2 reps for MW resistance. Replicate 50-kernel samples in 21 x 21 x 7 mm plastic boxes were distributed among 4 circular test chambers (48 samples in each) and allowed to equilibrate, then 288 MW were released into each chamber and left for a 5-day ovipositional period. The adult insects were removed and the samples covered with screened lids and held in the rearing room for MW progeny emergence. At the appearance of the first progeny all samples were frozen and radiographed. Progeny counts were made from radiographs.

Results

The CK-60 x DDES F_2 seed was highly resistant to MW (Table 8). MW progeny produced on the samples ranged from 0 to 16 insects with a mean in all samples of ca. 3 insects/rep. This is greater resistance than

that usually seen in either CK-60 or DDES. Analysis of variance shows no difference in resistance among the 96 cultivars even though physical differences in the seed (pericarp color, size, and presence of hulls) were quite conspicuous. This suggests that the resistance is derived from factors operating in the endosperm. Further study of this seed could be useful in future resistance tests.

Table 8. Maize weevil progeny produced on 96 samples (individual heads) of Combine Kafir 60 x Double Dwarf Early Shallu (2 reps, 50 kernels/rep, 48 samples/test chamber, 288 MW/chamber, 5-day free-choice ovipos.).

1971 Plant No.	Progeny Rep 1	Rep 2	Mean	1971 Plant No.	Progeny Rep 1	Rep 2	Mean
10001	2	1	1.5	10021	2	4	3.0
02	3	5	4.0	22	3	6	4.5
03	5	0	2.5	23	1	4	2.5
04	11	4	7.5	24	5	13	9.0
05	0	2	1.0	25	3	5	4.0
06	2	4	3.0	26	10	4	7.0
07	6	9	7.5	27	2	0	1.0
08	5	12	8.5	28	2	2	2.0
09	0	5	2.5	29	5	15	10.0
10	2	4	3.0	30	0	4	2.0
10011	0	6	3.0	10031	2	3	2.5
12	8	4	6.0	32	5	3	4.0
13	4	12	8.0	33	3	3	3.0
14	1	3	2.0	34	3	6	4.5
15	0	2	1.0	35	5	5	5.0
16	9	3	6.0	36	1	4	2.5
17	7	4	5.5	37	5	1	3.0
18	1	1	1.0	38	2	3	2.5
19	0	2	1.0	39	2	6	4.0
20	3	3	3.0	40	1	1	1.0

Table 8

Plant No.	Progeny Rep 1	Rep 2	Mean	Plant No.	Progeny Rep 1	Rep 2	Mean
10041	1	6	3.5	10071	7	7	7.0
42	5	6	5.5	72	0	0	0.0
43	2	6	4.0	73	3	3	3.0
44	3	6	4.5	74	5	14	9.5
45	0	1	0.5	75	2	3	2.5
46	5	4	4.5	76	1	4	2.5
47	1	1	1.0	77	1	0	0.5
48	0	1	0.5	78	4	4	4.0
49	9	3	6.0	79	5	6	5.5
50	1	2	1.5	80	2	6	4.0
10051	1	2	1.5	10081	5	6	5.5
52	2	0	1.0	82	2	4	3.0
53	3	3	3.0	83	5	2	3.5
54	5	3	4.0	84	0	4	2.0
55	1	2	1.5	85	0	16	8.0
56	5	1	3.0	86	3	3	3.0
57	2	4	3.0	87	1	2	1.5
58	5	0	2.5	88	0	0	0.0
59	0	6	3.0	89	4	10	7.0
60	3	1	2.0	90	1	1	1.0
10061	1	2	1.5	10091	3	5	4.0
62	0	1	0.5	92	7	0	3.5
63	3	3	3.0	93	0	1	0.5
64	2	4	3.0	94	2	4	3.0
65	4	5	4.5	95	3	10	6.5
66	6	5	5.5	96	0	0	0.0
67	1	3	2.0				
68	2	5	3.5				
69	5	3	4.0				
70	4	4	4.0				

Analysis of Variance

Source of Variance	d.f.	s.s.	m.s.	F
Between cultivars	95	978.24	10.29	1.41 (significant at .05)
Within cultivars	96	699.50	7.28	
Totals	191	1677.74		

Maize Weevil Population Growth Rate in Sorghum Samples at Different Volumes

Resistance tests are customarily performed with small samples consisting of 50 to 100 kernels each, especially when many cultivars are tested; however, this does not simulate the storage conditions of a grain bin. Lange (1973) compared resistance of 5 sorghums to MW in 50-kernel and 50-gram samples and found a correlation in resistance rankings of the sorghums in the 2 different sample sizes. In this test, growth of MW populations was compared in 4 different sizes of bulk samples of MP-10 Shallu and culture sorghum (variety unknown).

Materials and Methods

Maize weevil population growth rate and progeny numbers were compared in 50, 75, 200, and 400-ml bulk samples of MP-10 Shallu (96-39-ck) and culture sorghum. Three replicates of each sample size and cultivar were used. The samples were not cleaned of any dockage (debris other than sound kernels) but were allowed to equilibrate in the rearing room before infestation. The 50- and 75-ml samples were held in small baby food jars, the 200-ml samples in pint canning jars, and the 400-ml samples in quart canning jars. The 50-ml samples were each infested with 3 female and 2 male MW, and the 75-ml samples each with 5 and 3, respectively. The 200- and 400-ml samples were infested with 10 and 20 randomly-selected MW, respectively. The adult insects were not removed from the samples. After 32 days, progeny and parent insects were counted weekly and returned to the samples. At the end of 2 months,

most insects were dying, probably due to lack of food. Progeny numbers were so great that insect numbers were estimated on the basis of volume, after determination of the ca. number/volume. After separation from dust and kernels, the insects were temporarily stunned with CO_2 to make volume measurements more uniform.

Results

Numbers of adults from each of the samples may be seen in Table 9. Data were converted to the log of actual numbers so that linear regression lines could be calculated for the rate of population growth for each sample. The surprising result of this test was that no differences were evident between MP-10 Shallu and culture sorghum in any of the samples. This may be partially explained by the difference in the numbers of kernels of each cultivar that can be placed in the same volume. As shown by regression equations, the rate of population growth (slope of regression line) was similar for both cultivars in all sample sizes.

Table 9. Numbers of maize weevil adults (and logs of numbers) from infestation of 2 sorghum cultivars in 50-, 75-, 200-, and 400-ml samples (correlation coefficients and regression line equations included).

Rep		Days after infestation 32	35	40	46	53	60	67	74	81	88
						Culture sorghum - 50 ml sample					
1.	No. adults	10	26	41	77	124	140	202	481	651	837
	Log	0.000	0.414	0.612	0.886	1.093	1.146	1.305	1.682	1.813	1.922
2.	No. adults	11	48	102	217	233	264	44	279	527	589
	Log	0.041	0.681	1.008	1.336	1.367	1.421	0.643	1.445	1.721	1.770
3.	No. adults	19	68	138	264	279	70	140	248	481	620
	Log	0.278	0.832	1.139	1.421	1.445	0.845	1.146	1.394	1.682	1.793
		1. r = .976		y = .0311x - .7072							
		2. r = .739		y = .0205x - .0404							
		3. r = .754		y = .0174x + .1943							
						MP-10 Shallu - 50 ml sample					
1.	No. adults	35	77	137	233	512	744	1054	1178	1271	1287
	Log	0.544	0.886	1.136	1.367	1.709	1.871	2.022	2.071	2.104	2.109
2.	No. adults	20	38	75	140	295	171	248	527	744	868
	Log	0.301	0.579	0.875	1.146	1.469	1.232	1.394	1.721	1.871	1.938
3.	No. adults	23	45	108	171	233	264	327	620	837	1054
	Log	0.361	0.653	1.033	1.232	1.367	1.421	1.514	1.792	1.922	2.022
		1. r = .931		y = .0268 + .0344							
		2. r = .946		y = .0261 - .2550							
		3. r = .959		y = .0261 - .1753							

Table 9 (cont'd).

Rep		Days after infestation 32	35	40	46	53	60	67	74	81	88
						Culture sorghum - 75 ml sample					
1.	No. adults	38	156	267	387	543	713	899	1147	1426	1426
	Log	0.579	1.193	1.426	1.587	1.734	1.853	1.953	2.059	2.154	2.154
2.	No. adults	56	154	303	512	588	744	898	1085	1209	1581
	Log	0.748	1.187	1.481	1.709	1.769	1.871	1.953	2.035	2.082	2.198
3.	No. adults	47	146	341	512	620	805	868	1178	1333	1271
	Log	0.672	1.164	1.532	1.709	1.792	1.905	1.938	2.071	2.124	2.104
		1. r = .902 y = .0228x + .3541									
		2. r = .903 y = .0207x + .5110									
		3. r = .871 y = .0207x + .5072									
						MP-10 Shallu - 75 ml sample					
1.	No. adults	71	151	279	418	155	186	620	1178	1302	1457
	Log	0.851	1.178	1.445	1.621	1.190	1.269	1.792	2.071	2.114	2.163
2.	No. adults	58	151	248	683	758	217	526	945	1364	1364
	Log	0.7634	1.178	1.394	1.834	1.879	1.336	1.720	1.975	2.134	2.134
3.	No. adults	54	107	217	372	1116	1240	1302	1519	1798	1829
	Log	0.732	1.029	1.336	1.514	2.047	2.093	2.114	2.181	2.254	2.262
		1. r = .881 y = .0204x + .3908									
		2. r = .827 y = .0190x + .5389									
		3. r = .906 y = .0258x + .2663									

Table 9 (cont'd).

Rep		Days after infestation 32	35	40	46	53	60	67	74	81	88
					Culture sorghum - 200 ml sample						
1.	No. adults	32	107	310	481	589	775	961	1705	2635	3255
	Log	0.505	1.029	1.491	1.682	1.770	1.889	1.982	2.231	2.420	2.512
2.	No. adults	14	46	109	186	155	186	186	775	1798	2635
	Log	0.146	0.662	1.037	1.269	1.190	1.269	1.269	1.889	2.254	2.420
3.	No. adults	36	153	372	605	682	946	1256	2232	2759	3069
	Log	0.556	1.184	1.570	1.781	1.833	1.975	2.098	2.348	2.440	2.486
		1. r = .935		y = .0296x + .0449							
		2. r = .941		y = .0332x - .5722							
		3. r = .919		y = .0282x + .2002							
					MP-10 Shallu - 200 ml sample						
1.	No. adults	102	243	481	667	930	1116	1581	2728	3116	3875
	Log	1.008	1.385	1.682	1.824	1.968	2.047	2.198	2.435	2.493	2.588
2.	No. adults	24	53	140	202	310	388	605	1411	2341	3410
	Log	0.380	0.724	1.146	1.305	1.491	1.588	1.781	2.149	2.369	2.532
3.	No. adults	36	83	171	295	357	527	775	186	2728	3487
	Log	0.556	0.919	1.232	1.469	1.552	1.721	1.889	1.269	2.435	2.542
		1. r = .959		y = .0246x + .5407							
		2. r = .979		y = .0346x - .4466							
		3. r = .874		y = .0277x - .0378							

Table 9 (concluded).

Rep		Days after infestation 32	35	40	46	53	60	67	74	81	88
					Culture sorghum - 400 ml sample						
1.	No. adults	69	214	588	868	1147	1488	1922	3441	5115	5735
	Log	0.838	1.330	1.769	1.938	2.059	2.172	2.283	2.536	2.708	2.758
2.	No. adults	70	201	557	790	1147	1519	1984	3720	5115	5890
	Log	0.845	1.303	1.745	1.897	2.059	2.181	2.297	2.570	2.708	2.770
		1. r = .941 y = .0291x + .3633									
		2. r = .948 y = .0297x + .3216									
					MP-10 Shallu - 400 ml sample						
1.	No. adults	61	189	450	682	945	1333	1705	3348	4185	4960
	Log	0.785	1.276	1.653	1.833	1.975	2.124	2.231	2.524	2.621	2.695
2.	No. adults	54	112	294	449	589	744	1085	2294	4340	5580
	Log	0.732	1.049	1.468	1.652	1.770	1.871	2.035	2.360	2.637	2.746
		1. r = .949 y = .0295x + .2712									
		2. r = .976 y = .0322x - .0276									

Maize Weevil Population Growth in Cleaned or Uncleaned Bulk Sorghum

Materials and Methods

This experiment was to compare population growth of MW in cleaned or uncleaned bulk samples of 3 cultivars of sorghum. The cultivars selected were MP-10 Shallu, culture sorghum, and 73-60-152 (most susceptible of LGB and MW resistance tests). Six 50-ml replicate samples each were used for MP-10 and culture sorghum; 3 of these were cleaned by hand prior to measuring. The remaining 3 were measured uncleaned. Only one cleaned sample of 73-60-152 was tested due to lack of material. Each sample was placed in a baby food jar and allowed to equilibrate in the rearing room, then 20 unsexed adult MW were placed in each sample and left for the duration of the test. Samples were frozen after 65 days, then radiographed and MW progeny counted.

Results

Progeny numbers recorded from each sample are listed in Table 10. It would appear from these data that the resistant cultivar, MP-10, has suddenly become more susceptible than either of the other 2 cultivars. The analysis of variance (Table 10) confirms that distinct differences do exist between MP-10 and culture sorghum. Analysis of variance also shows that no differences exist in progeny numbers on 50-ml samples with and without prior cleaning. This suggests that in bulk tests, samples do not need to be cleaned prior to testing.

Table 10. Maize weevil progeny produced on 3 sorghum cultivars in cleaned and uncleaned 50-ml samples (20 randomly-selected MW/sample, 3 reps, 65-day infestation).

Variety	Rep	Progeny	Mean
Culture sorghum, uncleaned	1	885	869
	2	853	
	3	869	
Culture sorghum, cleaned	1	824	862
	2	918	
	3	844	
MP-10, uncleaned	1	1254	1220.7
	2	1186	
	3	1222	
MP-10, cleaned	1	1214	1211.3
	2	1259	
	3	1161	
73-60-152, uncleaned	1	655	655

Table 10 (concluded).

Analysis of Variance

Source of variance	d.f.	s.s.	m.s.	F
Clean culture sorghum and clean MP-10 Shallu				
Between cultivars	1	185,504	185,504	262.5 (not significant at .05 level)
Within cultivars	4	2,826	706	
Totals	5	188,330		
Culture sorghum, clean and unclean samples				
Between cultivars	1	73.5	73.5	.05 (significant at .05 level)
Within cultivars	4	5416.0	1354.0	
Totals	5	5489.5		
MP-10 Shallu, clean and unclean samples				
Between cultivars	1	130.6	130.6	.07 (significant at .05 level)
Within cultivars	4	7127.3	1781.8	
Totals	5	7257.9		

Since the resistant sorghum supported more progeny than the culture sorghum and twice as many as the most susceptible 73-60-152, I decided to check the number of kernels in 50-ml of each cultivar. MP-10 Shallu had 1875 kernels in 50-ml; culture sorghum, 1410 kernels; and 60-152, 795 kernels.

MP-10 had (1875 - 1410) ÷ 1410, or 33% more kernels in 50 ml than culture sorghum. MP-10 had (1875 - 795) ÷ 795, or 136% more kernels than 50 ml of 60-152. By adding 33% of the observed progeny in each sample of culture sorghum to the observed progeny in each sample and 136% to the progeny observed in each sample of 73-60-152, an adjusted progeny count was determined showing the number of progeny that would be expected if equal numbers of kernels had been used (Table 11).

Analysis of variance at the 5% level showed no statistical differences between samples of culture sorghum (clean and not cleaned) and MP-10 Shallu when progeny counts of culture sorghum were adjusted for differences in number of kernels/sample. The mean numbers of progeny (adjusted) emerged from samples of 73-60-152 differed significantly at the 5% level from numbers emerged from MP-10 Shallu. It is possible that 60-152 is exceptionally susceptible to maize weevil infestation or two weevils/kernel may have developed in some cases, as these kernels were exceptionally large.

Table 11. Adjusted MW progeny numbers on 3 sorghum cultivars in cleaned and uncleaned samples.

Variety	Rep	Observed progeny	Mean	Adjusted progeny	Adjusted mean
Culture sorghum, uncleaned	1	885	869	1180	1158.6
	2	853		1137	
	3	869		1159	
Culture sorghum, cleaned	1	824	862	1099	
	2	918		1224	
	3	844		1125	
MP-10, uncleaned	1	1254	1220.7	1254	1220.7
	2	1186		1186	
	3	1222		1222	
MP-10, cleaned	1	1214	1211.3	1214	1211.3
	2	1259		1259	
	3	1161		1161	
60-152, uncleaned	1	655	655	1545	1545

Analysis of Variance

Source of variance	d.f.	s.s.	m.s.	F
Culture sorghum (clean and unclean) vs. MP-10 Shallu (clean and unclean) with maize weevil progeny numbers adjusted				
Between cultivars	3	11,793.33	3931.11	1.87 (significant at .05 level)
Within cultivars	8	16,752.66	2094.08	
Totals	11	28,546.00		
Uncleaned MP-10 and uncleaned 60-152 (progeny adjusted)				
Between cultivars	1	78,894.08	78,894.08	68.16 (not significant at .05 level)
Within cultivars	2	2,314.66	1,157.33	
Totals	3	81,208.75		

Hardness of Sorghum Kernels as a Factor in Maize Weevil and Lesser Grain Borer Resistance

Materials and Methods

Twenty-four of the 26 cultivars previously evaluated for MW and LGB resistance were selected to test kernel hardness and correlate it with progeny emergence in previous LGB and MW resistance tests. Hardness was tested by measuring the longest diagonal of the impression made on a sorghum kernel (middle of kernel opposite germ) by a weighted tetrahedral-cut diamond. A 1 kg weight was placed directly above the diamond, and the diamond was allowed to rest on each kernel for ca. 5 sec (see Plate 2). Five to 8 kernels of each variety were tested and the mean hardness was recorded. The impression in the kernel was wider in softer kernels because the diamond penetrated deeper.

Results

A correlation analysis between MW and LGB progeny (Tables 5 and 7) and kernel hardness (Table 12) shows a correlation of .65 and .61, respectively. These correlation coefficients indicate that kernel hardness was associated with insect resistance. Other factors probably are involved which individually contribute to resistance or combine with hardness in a synergistic effect to reduce insect attack. The correlations in this test were higher than those observed by Lange (1973); however, he used the pearling method to estimate kernel hardness, in which hardness was determined by the percentage weight lost during a standard period of pearling.

EXPLANATION OF PLATE 2

Fig. 1. Mechanism used for testing hardness of sorghum kernels and samples of seed.

Fig. 2. Kernel hardness mechanism in operation.

Plate 2

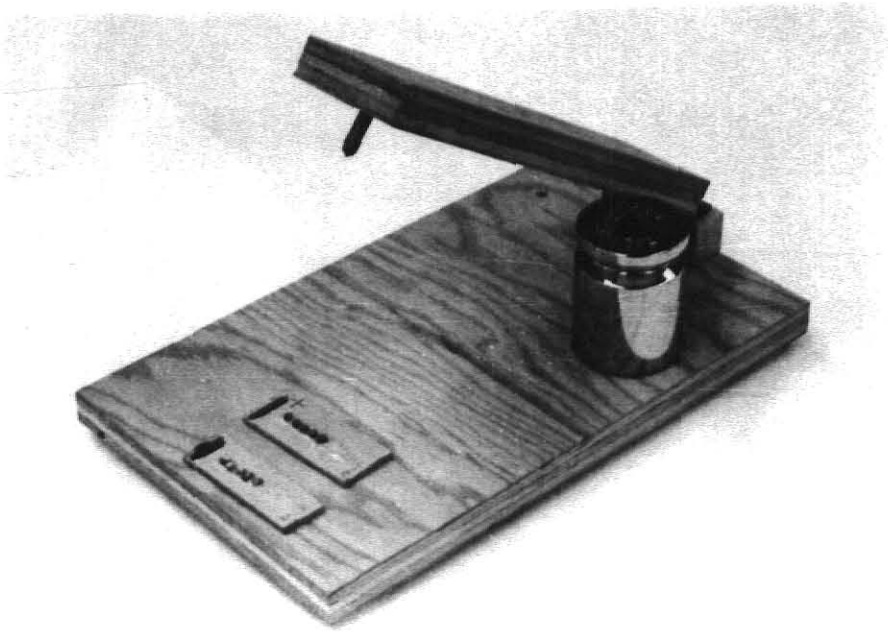

Figure 1

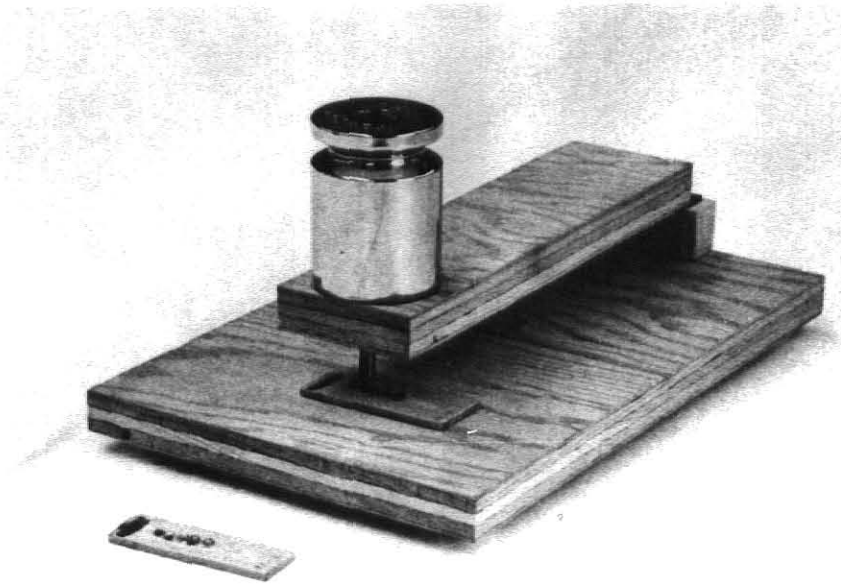

Figure 2

Table 12. Relative hardness of 24 sorghum cultivars compared with maize weevil and lesser grain borer progeny (recorded from resistance tests). Hardness recorded as width of diamond impression.

Sorghum cultivar (1973 Hays number)	Hardness (microns)	MW progeny (Table 5)	LGB progeny (Table 7)
96-36-3	390	19.50	9.50
96-39-21	403	12.75	7.50
96-39-11	409	14.25	9.75
96-23-2	413	21.50	19.75
96-40-2	416	9.75	18.75
96-39-9	430	12.50	4.00
96-34-5	440	9.75	12.75
96-40-10	442	11.25	17.75
96-34-6	444	14.50	14.00
96-37-3	445	16.00	21.00
96-40-1	452	15.50	23.25
96-34-2	463	10.50	16.75
60-153-2	466	27.50	13.25
96-24-2	471	14.25	10.75
96-34-4	475	12.00	12.25
60-151-1	476	25.50	16.75
96-24-1	478	14.75	3.25
96-13-3	481	29.50	19.50
96-28-1	504	20.00	28.50
96-1-1	548	14.50	21.25
61-56-1	553	21.75	30.00
96-9-4	577	25.75	11.25
96-28-2	642	27.50	24.75
60-152-2	967	35.00	34.25
	Correlation coefficient	.65	.61

Single vs Multiple Kernel Layers in Relation to Resistance to Maize Weevils

Materials and Methods

Previous tests indicated that there were statistical differences in MW resistance between cultivars when tested in 50- or 100-kernel samples, while some of the same cultivars were not significantly different in bulks as small as 50 ml. This led to tests comparing progeny counts on identical amounts of sorghum but in a single layer vs several layers of kernels.

Forty-five ml of culture sorghum or MP-10 Shallu were used in each of 4 replications. Each of 4 samples of each cultivar was poured into a 15.5-cm-diam plastic petri dish, so that the grain was only 1 kernel layer in depth. The kernels of 2 of the 4 samples were glued to the bottom of the dish with white glue. The kernels in the other 2 samples remained free to roll if moved by weevils. Four more samples of each variety (2, hand-cleaned) were placed in baby food jars. These samples were several kernels deep. All samples were placed in the rearing room and left to equilibrate. Each sample was infested with 20 randomly-selected adult MW which were left for the duration of the experiment. After 57 days the samples were frozen. Progeny counts (all insect stages) were made from radiographs.

Results

Maize weevil progeny numbers from the different samples (Table 13) did not differ significantly; however, it appeared that numbers of kernels involved for each cultivar influenced the number of progeny

emerging from the samples. Although no differences appeared between single and multiple layer samples, this needs further investigation.

Table 13. Maize weevil progeny from single or multiple layers of kernels of 2 cultivars of sorghum in clean and uncleaned samples (20 MW/sample left for 57 days).

Cultivar	Kernel depth	Loose/dockage	MW progeny	
			Rep 1	Rep 2
MP-10-ck	single layer	loose	998	1025
	single layer	glued	910	1085
	multi-layer	uncleaned	1001	1186
	multi-layer	cleaned	1148	706
Culture sorghum	single layer	loose	850	822
	single layer	glued	1193	367*
	multi-layer	uncleaned	1030	796
	multi-layer	cleaned	583	843

* Insects lost through hole in screen lid.

Maize Weevil Progeny in Free-Choice vs No-Choice Tests

Materials and Methods

No-choice and free-choice tests were used to compare resistance of 18 sorghum cultivars in 15-ml samples. Previous studies of this nature have compared sorghums in 50- or 100-kernel samples. The no-choice test involved confining a specified number of insects on each sample. This type of test more nearly approaches the situation in a grain bin where only one variety is stored. The 18 cultivars used were selected. Samples were from bulk lots, each containing

several heads of a single cultivar, or from individual heads where bulk samples were not available. Three replicates (15-ml samples in 4.8 x 4.8 x 1.8-cm boxes) of each cultivar were used in both the free-choice and no-choice tests. The free-choice test was carried out in the circular test chambers with 18 samples and 180 insects in each chamber. The no-choice replicates were infested with 10 randomly-selected maize weevils each. Adult insects were removed from all samples after a 5-day ovipositional period and the individual samples covered with screened lids. The replicates were held in the rearing room for 1 month then frozen. Progeny counts were made from radiographs.

Results

The correlation between the ranking of the MW progeny by the 2 test methods was .14 (Table 14). This is a rather low correlation and indicates there is no similarity between the results of the two test methods. Lange (1973) and Stevens and Mills (1973) conducted similar tests with MW and rice weevil, respectively, and found a high degree of correlation so some other factor may have been responsible for the differences in this test. It is possible that the 10 randomly-selected weevils placed on each sample of the no-choice tests were not enough insects to insure a 1:1 ratio of males to females. Either more insects should be used, or the insects should be sexed to provide greater probability of equal numbers of ovipositing females on each sample.

Table 14. Maize weevil progeny number and cultivar resistance rank of 18 cultivars compared in free-choice (10 MW/sample, 18 samples/chamber) and no-choice tests (10 MW/sample, 5-day oviposition).

Cultivar	Free-choice		No-choice	
	Mean progeny/rep	Rank	Mean progeny/rep	Rank
96-9-3	35.3	6	75.7	17
60-151-4	116.3	18	47.3	5
96-28-3	51.3	11	51.7	6
96-15-1	52.0	12	73.7	16
96-3-3	35.3	7	79.3	18
96-31-2	58.3	13	54.7	12
96-39-ck	26.0	3	52.0	8
96-1-3	49.3	9	65.3	15
60-156-3	33.0	4	44.7	4
60-153-4	79.7	15	64.0	14
Culture sorghum	115.0	17	53.0	10
96-38-Bulk	49.7	10	30.7	2
60-155-Bulk	34.3	5	59.0	13
96-37-Bulk	18.3	1	44.3	3
61-56-Bulk	58.3	14	53.7	11
96-36-Bulk	42.3	8	22.3	1
60-152-Bulk	87.0	16	52.7	9
96-40-Bulk	22.0	2	51.7	7

A correlation analysis between the ranks gave a correlation coefficient of .14.

Relation of Pericarp-Seedcoat Thickness to Maize Weevil and Lesser Grain Borer Resistance

In an effort to determine the role of the pericarp and seedcoat in insect resistance, cross sections (cut with a razor through middle of kernel perpendicular to long axis) of test sorghum kernels were photographed using a scanning electron microscope in the Kansas State University Entomology Department. Measurements of the pericarp and seedcoat were made from the photographs (Plate 3). Much variation was indicated in thickness and amount of starch granules in the pericarp layers. Seed coats of some cultivars included a thick testa layer; however, this did not appear to influence insect resistance.

A correlation analysis between maize weevil progeny produced in the cultivars and combined thickness of the seed coat and pericarp showed a positive correlation of .68, thus in general, the thicker the pericarp-seedcoat the more susceptible to maize weevils (Table 15). The resistant Shallus had very thin pericarp-seedcoats with little or no starch in the mesocarp layers while the large susceptible kernels had thick pericarp-seedcoats with conspicuous quantities of starch granules in the mesocarp. Correlation between LGB resistance and thickness of pericarp and seedcoat was .26. This is not enough to be considered significant; therefore, some other factor(s) is probably involved in LGB resistance in sorghum.

Correlation Analysis of Data from Previous Lesser Grain Borer and Maize Weevil Resistance Tests

Mean numbers of progeny from samples of 120 heads of 26 cultivars of sorghum in previous tests for resistance to MW (Table 5) and LGB (Table 7) were ranked from highest to lowest resistance for each

EXPLANATION OF PLATE 3

Fig. 1. Scanning electron micrograph (600X) of MP-10 Shallu cross-section, a resistant cultivar.

Fig. 2. Scanning electron micrograph (600X) of 73-60-152 (CI 1726) cross-section, a susceptible cultivar.

Plate 3

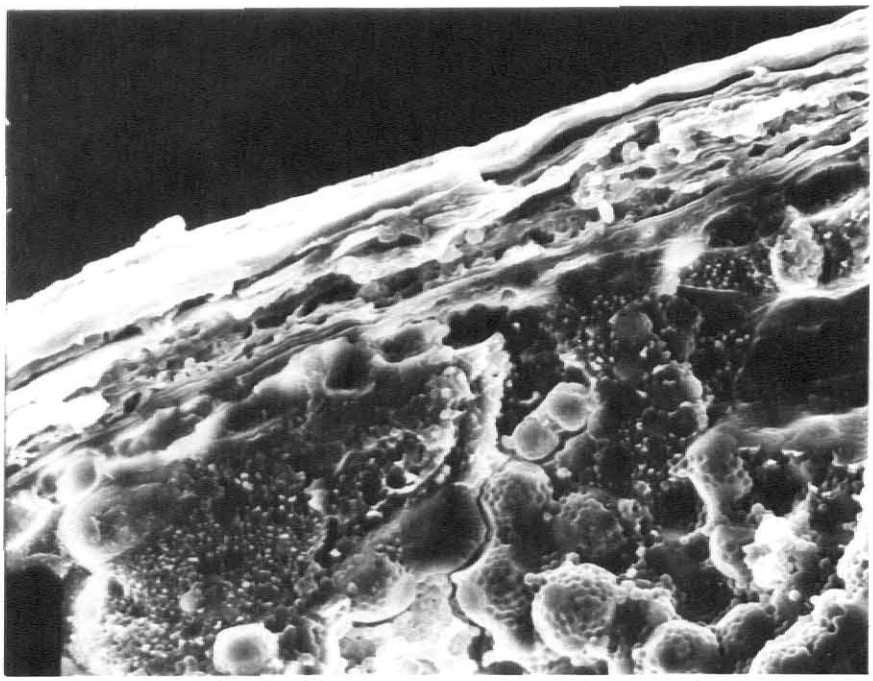

Figure 1

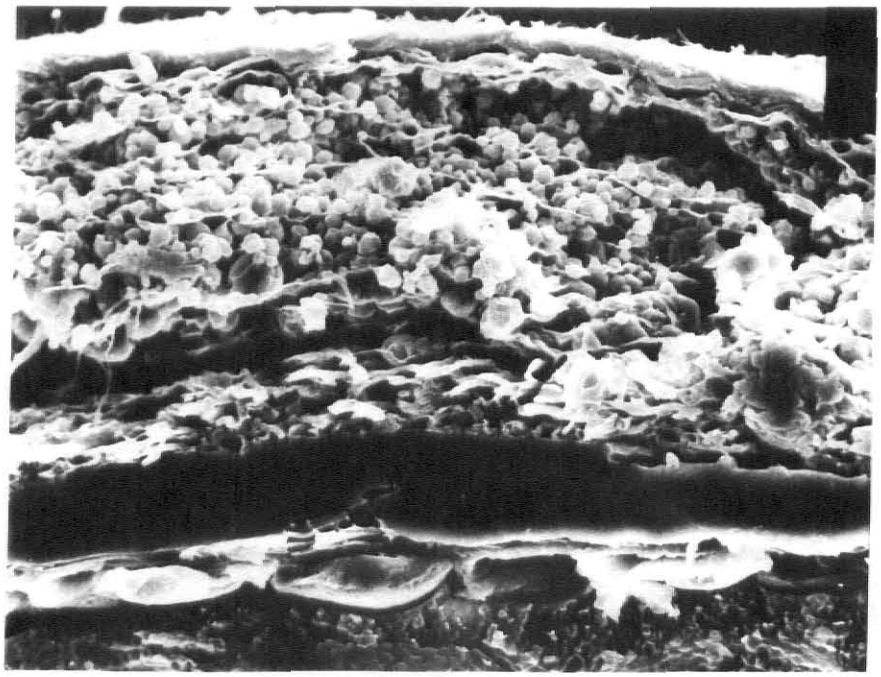

Figure 2

Table 15. Maize weevil and lesser grain borer progeny produced on 15 sorghum cultivars compared with thickness of each cultivar's pericarp-seed coat layers (measured from scanning electron micrographs, enlarged 600X).

Cultivar	Pericarp-seedcoat thickness (mm)	MW progeny (Table 5)	LGB progeny (Table 7)
96-40-bulk	12	13.4	19.08
96-37-bulk	14	18.9	20.45
60-155-bulk	20	16.6	13.94
96-9-3	22	22.5	21.50
96-38-bulk	26	24.1	27.31
96-1-3	26	15.0	16.50
61-56-bulk	26	21.7	30.00
96-36-bulk	27	20.2	18.19
96-3-3	31	24	19.50
60-153-bulk	34	26.9	18.06
60-156-bulk	34	20.4	19.50
96-15-1	38	23.3	20.00
60-151-4	38	25.0	24.25
96-28-3	42	22.7	12.25
60-152-bulk	53	32.6	32.08
	Correlation coefficient	.68	.26

insect. A correlation analysis of the ranks was done to determine how nearly alike the cultivars corresponded in resistance to the two insect species. The results indicated a positive .41 correlation. Although this correlation was not high, there probably are numerous factors involved in resistance to each insect species, some of which they may not have in common.

DISCUSSION

Resistance Testing Techniques

Techniques involved in evaluating sorghum resistance can influence both the speed with which experiments can be performed and the results. To test the various cultivars of sorghum, specific methods were used for economizing time and still achieve valid results.

In many previous studies, adult insects used to infest test material have been individually sexed and a specific ratio of male to female insects placed on test material. In some cases sexing the insects can be performed rather easily; however, for many species it is difficult and time-consuming. Mistakes in sex determination can influence the number of progeny from grain samples, especially if small numbers of insects are used. Even where sex differences are distinct, the small stored-product insects must be viewed individually under a microscope. To avoid this, larger samples may be used and infested with a larger number of randomly-selected unsexed insects. As shown by the low correlation between free-choice and no-choice tests, 10 randomly-selected insects per sample is probably too few to

obtain valid results in no-choice tests. Twenty or more insects would be more likely to have a 1:1 ratio of males to females. The 1:1 ratio in all samples is necessary to keep the results between replications statistically alike. When larger numbers of samples are infested simultaneously in the same chamber as in a free-choice test, as few as 6 insects per sample probably can be used and still have a ratio approaching 1:1.

Sorghum samples to be evaluated can be measured by volume or by counting actual numbers of kernels. Numerous tests in the past involved 50- or 100-kernel samples. The grain was cleaned and kernels counted individually which was time consuming, especially when numbers of damaged kernels were large; however, these tests did indicate distinct differences in resistance between cultivars. In the free-choice vs no-choice test, grain samples were measured by volume; 15-ml uncleaned samples were used. The ranking of these cultivars was similar to that in tests where grain was cleaned and kernels individually counted. Samples measured by volume could be prepared quickly. In larger bulk tests (50-ml samples), the presence of dockage (material other than sound grain) did not change the resultant numbers of progeny collected; however, the size of the kernels appeared to be important. In bulk tests the previously designated resistant variety produced larger numbers of insects than the susceptible varieties. However, a much larger number of the small resistant kernels occupied the same volume than of larger kernels. This allowed more insects to emerge from the same volume since there are more kernels to infest.

Progeny numbers should be mathematically adjusted to show the true relative resistance of the sorghums. Bulk tests should be used to evaluate potentially resistant cultivars, since they more closely resemble the grain bin situation.

progeny counts have been performed in the past by counting and removing insects 1 to 3 times a week for 4 to 5 weeks during the emergence period. A single progeny count of 200 to 300 samples could take a full day and tests had to be scheduled so count days did not coincide. In this study, radiographing samples once at the beginning of the emergence period was shown to provide an accurate count of the progeny expected to emerge from the grain. Since samples are frozen as soon as progeny begin to emerge they can be held indefinitely and radiographed when convenient. All stages of the insect are counted from the radiographs. This reduces from an average of 10 days to one day the time required to make complete progeny counts. Also, complete results of these tests are available 30 days after infestation instead of the 60-70 days previously required. Developmental rate of insects on the various sorghum cultivars can be estimated by the proportion of adults, pupae, and larvae visible in radiographs. The disadvantage of radiographing is that insects must be frozen to prevent movement of larvae within kernels and emergence of adults during the X-ray process. Also, it is not certain how effective this technique would be for externally feeding insects.

To determine population growth rates, volume measurement of insects becomes more practical. The insects can be separated from dust and kernels and measured quite accurately in a graduated cylinder after a determination of the number of insects/volume. The insects should be anesthesized with CO_2 so that the measurements will be uniform.

The free-choice testing method as used in this study was a quick and effective means of evaluating relative sorghum resistance. Although the correlation of results was low between the free-choice and no-choice tests, it has proved a reliable means of evaluation of resistance in other studies (McCain et al. 1964; Stevens 1973). With only 3 test chambers, as many as 3 replicates of 48 sorghum varieties can be tested and evaluated in 30 days, or 144 if screened in only one replicate. The sorghum samples can be measured by volume and the infesting adults counted randomly which also adds to the efficiency of this test procedure. Where 50 or 100 kernel replicates are used, a single 14 x 17-inch radiograph is large enough for determination of progeny numbers in all samples from one test chamber. This test method would be excellent for screening large numbers of sorghum cultivars.

Resistance Tests

Initial screening tests, using the free-choice method, to determine the relative resistance of cultivars (LGB "pressured" material and remnant seed from Rogers (1970) (see Tables 3, 4, 5, 6, and 7), have shown that the Shallus, particularly MP-10 and Double Dward Early Shallu, to be the most resistant of the cultivar examined. These tests proved to be useful in quickly evaluating sorghums for insect resistance prior to more extensive tests in bulk samples. Material previously "pressured" (samples of seed exposed to insect feeding; surviving sound kernels planted for increase) by LGB has produced samples of seed which are relatively resistant to this

insect. A cultivar found to be susceptible to both MW and LGB by the screening process was 73-60-152 (CM 1726). This cultivar has large, soft kernels. The results of the screening tests were similar to those found by other investigators.

A cross was made between CK-60 and DDES to study the inheritance of resistance to stored grain insects. Seeds from 96 F_2 plants were evaluated for MW resistance in a free-choice test. The results indicated that the seed resulting from the cross appears to be significantly more resistant than either the CK-60 or DDES parents were in previous tests. Even though various conspicuous differences existed in the appearance of the pericarps of seeds from different plants, the resistance was nearly uniform, which seemed to indicate that the MW resistance factors were operating after oviposition. The seed of this particular cross needs further investigation including tests using larger samples, tests with other stored-product insects, and physical tests such as hardness and measurement of pericarp-seedcoat thickness, and chemical analysis.

The population growth rate of MW was observed in 50-, 75-, 200-, and 400-ml samples of culture sorghum and MP-10 Shallu (ck). The results indicated no significant differences between sample sizes or cultivars on the basis of numbers of progeny recorded from each sample once a week. These samples had not been cleaned of dockage (debris other than sound kernels) so further tests were done to compare the same 2 cultivars in cleaned and uncleaned 50-ml samples. A 50-ml sample of an uncleaned highly susceptible cultivars (73-60-152) was also included in this test. No differences were observed between

cleaned and uncleaned samples of the same cultivar; however, the expected ranking of resistance to MW of the cultivars was reversed, i.e., the most susceptible cultivar produced fewer progeny than the resistant check. No differences in progeny numbers on the 3 cultivars were expected on the basis of the previous population growth test results; however, 3 female and 2 male MW were used to infest the 50-ml samples in the population growth test and 20 unsexed, randomly-selected MW were used to infest the cleaned-uncleaned samples test. Perhaps sex ratios of other than 1:1 accounted for the different mean numbers of progeny on the samples but they do not explain the reversal of the expected resistance ranking.

Further investigation of the samples showed that the different sizes of the kernels of each cultivar resulted in different numbers of kernels in the 50-ml samples. The resistant MP-10 Shallu had more kernels in the same volume than either culture sorghum or the susceptible 73-60-152. Since there were more kernels of the resistant cultivar, more progeny were produced. When progeny counts were mathematically adjusted to allow equal numbers of kernels for each cultivar in 50-ml samples no differences were observed between MP-10 and culture sorghum; however, the susceptible cultivar, 73-60-152, did produce significantly more progeny. This particular cultivar had very large kernels so higher progeny numbers may be a result of 2 weevils occupying the same kernel or the variety may simply be more susceptible with a higher percent of the kernels being infested (perhaps as a result of larger inter-granular spaces).

Kernel hardness of 24 sorghum cultivars was correlated with average numbers of MW and LGB progeny produced on each cultivar in previous resistance screening tests. Hardness was calculated by measuring the longest diagonal of the impression made on a kernel by a weighted tetrahedral-cut diamond. A correlation between hardness and insect progeny gave coefficients of .65 for MW and .61 for LGB. The correlations indicate kernel hardness is associated with MW and LGB resistance; however, other factors are undoubtedly involved including kernel size, nature of the pericarp, and chemical factors.

A test was done comparing the effect of single kernel layer vs. multiple kernel layers, but same volume, on MW progeny production in 2 sorghum cultivars. Results were rather inconclusive, possibly because 20 unsexed randomly-selected insects were used to infest the 45-ml samples. Too much variation in the number of female insects selected may have caused results (2 replicates) to be useless for drawing conclusions. This test should be repeated incorporating 20 individually sexed MW/sample and more replications. Numbers of kernels occupying the same volume for each cultivar involved should also be made a resistance factor in the test.

Eighteen cultivars were compared in free-choice and no-choice tests. No correlation between the two tests was found, possibly because of high variability involved by infesting no-choice samples with 10 unsexed randomly-selected MW per sample. Previous experimenters, Lange (1973) and Stevens and Mills (1973), have found a high degree of correlation between the two testing methods.

Thickness of the pericarp-seedcoat layers of 15 cultivars was compared with corresponding MW-LGB progeny emergence. Susceptible cultivars had thick pericarps with conspicuous quantities of starch granules present in the mesocarp layers while the resistant varieties generally had fewer starch granules in the mesocarp and thinner pericarp-seedcoats. The correlation between pericarp-seedcoat thickness and MW and LGB progeny was .68 and .26, respectively. MW resistance in sorghum may result from a combination of thin pericarp-seedcoats (with low numbers of starch granules) and hardness of the kernels. Both MP-10 and Double Dwarf Early Shallus which are MW resistant in most laboratory tests have these characteristics. Pericarp-seedcoat thickness did not appear to influence resistance to LGB, so in this study, only kernel hardness was linked with LGB resistance in sorghum.

Mean numbers of MW and LGB progeny from samples of 120 heads of 26 sorghum cultivars were compared by correlation analysis. The correlation between the ranks for each insect was .41. This suggests that similar factors are responsible for both MW and LGB resistance; however, investigators should look for causes of resistance which operate on the specific insect.

ACKNOWLEDGMENTS

I would like to express sincere appreciation to my major professor, Dr. Robert B. Mills, for his guidance and counseling during my stay at Kansas State. I would also like to thank the members of my supervisory committee, Dr. T. L. Hopkins, and my good friend, Dr. Gregory J. Partida.

Sincere appreciation is extended to the many people who have contributed their time and talents to help with my research including Richard Biege, Sandy White, Ted Granovsky, Harlan Feese, Steven Lange, and Loretta Charlton.

I also want to express my gratitude to Professor Harold Hackerott who increased cultivars and provided new material for me to study.

I would especially like to thank my bride-to-be, Cheryl Drummond, for her moral support during the course of this study.

LITERATURE CITED

Andrewartha, H. G. 1972. Introduction to the Study of Animal Populations. University of Chicago Press, Chicago. 283p.

Ayerst, G. 1965. The determination of water activity of some hygroscopic food materials by a dew point method. J. Sci. of Food and Agric. 16(2):71-78.

Bhatia, S. K. and M. Gupta. 1969. Resistance to stored grain pests in world collection of wheat--Relative susceptibility of nine high yielding dwarf varieties to the rice weevil and the lesser grain borer. Bull. Grain Technol. 7(4):199-204.

Chakraborty, D. P. and G. Mathew. 1972. The effect of host plant nutrition on the susceptibility of the seeds of several exotic wheat varieties to Sitophilus oryzae (L.). Bull. Grain Technol. 10(2):116-119.

Dang, K. and N. C. Pant. 1965. Relative resistance or susceptibility of several varieties of sorghum to Tribolium castaneum. Indian J. Entomol. 27:245-248.

Davey, Pauline M. 1965. The susceptibility of sorghum to attack by the weevil Sitophilus oryzae (L.). Bull. Entomol. Res. 56(2):287-297.

Dobie, P. 1974. The laboratory assessment of the inherent susceptibility of maize varieties to post-harvest infestation by Sitophilus zeamais Motsch. (Coleoptera, Curculionidae). J. Stored Prod. Res. 10(3-4):183-197.

Doggett, H. 1957. The breeding of sorghum in East Africa. I. Weevil resistance in sorghum grains. Empire J. Exp. Agric. 25(97):1-9.

Eden, W. G. 1952. Effect of kernel characteristics and components of husk cover on rice weevil damage to corn. J. Econ. Entomol. 45:1084-1085.

Eickmeier, Marcia. 1965. Use of Angoumois grain moth in corn breeding. Crops and Soils 18(3):8-9.

Ewer, R. F. 1945. The effect of the grain size on the oviposition of Calandra granarium L. Proc. Roy. Entomol. Soc. Lond. 20:57-63.

Hopkins, H. Glynn. 1970. A search for resistance to the lesser grain borer among 314 genetic sources of corn. Ph.D. Dissertation. Kansas State University, Manhattan.

Hunkapillar, Paul D. 1970. A search for resistance to the maize weevil, the lesser grain borer, and the Angoumois grain moth among 269 cultivars of sorghum. Ph.D. Dissertation. Kansas State University, Manhattan.

Kapoor, Santosh. 1964. Nutritional studies on Rhyzopertha dominica F. (Bostrychidae: Coleoptera) I. Effects of various natural foods on larval development. The Indian J. of Entomol. XXVI(part 3):289-295.

Kempton, J. H. 1917. Protective coloration in seeds of Bolivian maize. J. of Hered. 8(5):200-202.

Lange, Steven K. 1973. Laboratory studies of varietal sorghum grain resistance to the maize weevil, Sitophilus zeamais Motsch. (Coleoptera, Curculionidae). Ph.D. Dissertation. Kansas State University, Manhattan.

Lieu, Victoria. 1950-52. Unpublished report. Kansas State University, Manhattan.

McCain, F. S., W. G. Eden, and D. N. Singh. 1964. A technique for selection of rice weevil resistance in corn in the laboratory. Crop Sci. 4(1):109-110.

Morrison, E. O. 1964. The effect of particle size on sorghum grain on development of the weevil, Sitophilus zeamais. J. Econ. Entomol. 57(3):390-391.

Podoler, H. and S. W. Applebaum. 1968. Physiological aspects of host specificity in the Bruchidae-I. Varietal differences in the resistance of Vicia faba L. to Callosobruchus chinensis L. J. Stored Prod. Res. 4(1):9-11.

Rao, Gundu H. R., and S. K. Majumder. 1964. Inter-granular space as a limiting factor for the growth of pulse beetles. J. Econ. Entomol. 57(6):1013-1014.

Rhine, Jon J. and Robert Staples. 1968. Effect of high-amylose field corn on larval growth and survival of five species of stored grain insects. J. Econ. Entomol. 61(1):280-282.

Rogers, Rodney R. 1970. Sources of resistance to the maize weevil, Sitophilus zeamais Mots., in 1511 cultivars of sorghum. Master's Thesis. Kansas State University, Manhattan.

Rogers, Rodney R. and Robert B. Mills. 1974. Reactions of sorghum varieties to maize weevil infestation under three relative humidities. J. Econ. Entomol. 67(5):692.

Rout, Giridhari. 1973. Studies of resistance of sorghums to Angoumois grain moths, Sitotroga cerealella (Olivier) and red flour beetles, Tribolium castaneum (Herbst.). Ph.D. Dissertation. Kansas State University, Manhattan.

Russell, Mercer P. 1962. Effect of sorghum varieties on the lesser rice weevil, Sitophilus oryzae (L.) I. Oviposition, immature mortality, and size of adults. Ann. Entomol. Soc. Amer. 55(6):678-685.

Samuel, C. K. and S. Chatterji. 1953. Studies on the varietal resistance and susceptibility of jowar (Andropogon sorghum) to storage pests of India. Indian J. Entomol. 15:225-239.

Singh, D. N. and F. S. McCain. 1963. Relationship of some nutritional properties of the corn kernel to weevil infestation. Crop Sci. 3(3):259-261.

Sinha, R. N. 1969. Reproduction of stored-grain insects on varieties of wheat, oats, and barley. Ann. Entomol. Soc. Amer. 62(5): 1011-1015.

Stevens, Rodney A. and Robert B. Mills. 1973. Comparison of techniques for screening sorghum grain varieties for resistance to rice weevil. J. Econ. Entomol. 66(5):1222-1223.

Su, Hellen C. F., R. D. Speirs, and P. G. Mahany. 1972. Toxic effects of soybean saponins and its calcium salt on the rice weevil. J. Econ. Entomol. 65(3):844-847.

LABORATORY STUDIES OF LEVELS AND CAUSES OF INSECT RESISTANCE IN VARIETIES OF STORED SORGHUM

by

STEPHAN C. WHITE

B. S., Kansas State University, 1973

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Entomology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1975

The object of this study was to determine the relative resistance among selected sorghum cultivars to maize weevil, Sitophilus zeamais Motsch., and lesser grain borer, Rhyzopertha dominica (F.), and investigate factors which may cause resistance. Specific techniques were devised to minimize time required to count kernels and insect progeny. Potential factors of resistance examined included hardness, kernel size, pericarp-seedcoat thickness, presence of debris other than sound kernels, and single vs. multiple layers of kernels.

Screening tests, for evaluating relative resistance of the cultivars, were done in circular free-choice test chambers. Fifty- or 100-kernel samples were replicated 2 to 4 times. Depending upon the test, 17 to 48 samples were placed in each chamber and infested with 6 to 10 randomly-selected insects per sample. Usually the adult insects were removed after 5 days oviposition. Most progeny counts were made from X-ray radiographs 30 days after infestation.

Samples of different sizes (45-, 50-, 75-, 200-, or 400-ml) were tested. Number of insects placed on each sample varied with sample size, and remained on the samples for the duration of the tests.

Selected cultivars were tested for hardness (based on width of the impression on kernels made by a weighted diamond point) and correlated with numbers of progeny from screening tests. Correlation analysis was done of pericarp-seedcoat thickness vs. MW and LGB progeny recorded for each cultivar. In a final test, ranked MW and LGB progeny numbers were compared in 120 sorghum samples representing 26 cultivars.

Specific techniques used to reduce time involved in performing tests included free-choice tests that could be completed and evaluated in 30 days, use of randomly-selected insects to infest test chambers rather than individually sexed insects as should be used in a no-choice test, and a single progeny count from radiographs which were accurate and required much less time than daily counts of emerging progeny. In no-choice tests with 15-ml samples, 10 randomly-selected unsexed MW were too few to insure a close approximation of a 1:1 ratio of males to females. In a maize weevil population growth test, progeny numbers were estimated weekly by volume measurement after determination of the number of insects/volume. In some cases, kernels were measured by volume; however, this presented a question of the effect of the size of the kernels on the number of kernels/volume.

MP-10 Shallu and Double Dwarf Early Shallu (DDES) were found to be the most resistant to both MW and LGB by the free-choice testing method. Seed which was previously selected by LGB, produced samples of seed relatively resistant to this insect.

Ninety-six F_2 heads of CK-60 x DDES were screened for MW resistance. The seed of this cross appears to be more resistant than either the CK-60 or DDES parents. The pronounced variability in the pericarps of these seeds seemed to indicate that MW resistance factors are operating after oviposition.

An investigation of MW population growth rates on culture sorghum and MP-10 Shallu in 50-, 75-, 200-, and 400-ml uncleaned samples (contained dockage) showed no significant differences between sample sizes or between cultivars. Further tests in 50-ml cleaned or uncleaned

samples revealed that the presence of dockage had no effect on population build-up. Number of kernels/volume affected the number of insects that could be produced on different cultivars when infestation was severe. Such tests, where kernels are measured by volume, need to have progeny numbers mathematically adjusted according to numbers of kernels, before comparing resistance.

Kernel hardness was shown to have a .65 and .61 correlation with MW and LGB resistance.

Results of tests with single layer vs. multiple layers of kernels in free-choice or no-choice tests were inconclusive probably because too few randomly-selected MW were used to infest these tests.

Pericarp-seedcoat thickness correlated significantly with MW resistance, but not LGB resistance.

A correlation between resistance rankings (based on numbers of MW and LGB progeny) of 120 heads of sorghum in screening tests gave a correlation of .41, which suggested that similar factors are responsible for resistance.